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Detection of warning surfaces in pedestrian environments: The importance for blind people of kerbs, depth, and structure of tactile surfaces

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Abstract

Purpose. The overall purpose was to study whether and how persons with blindness detect warning surfaces with a long white cane in a real pedestrian environment after following a natural guidance surface to the warning surfaces. Of particular interest was the importance of kerb, depth, and structure of the warning surfaces.

Method. A concurrently mixed methods approach, with a combination of observation using a structured form together with 'think aloud' and a structured interview, was used. It was done with well-defined samples and study sites in an inter-disciplinary research context.

Results. The results show that the most important design characteristic for detection of the warning surfaces with a white cane is the structure of the surface, while the depth of the surface and availability of a kerb do not have any impact on the detection. A precondition was that there is a distinct natural guidance surface leading up to the warning surface.

Conclusions. The probability among pedestrians with blindness to detect a tactile surface is not higher if the design solution has a kerb. This study also confirms the complexity of being a blind pedestrian in the traffic environment. The results can be used for evidence-based physical planning. The study also has implications for development of more efficient vision rehabilitation.

Keywords: *Blindness, kerb, crossroad design, pedestrian environment*

Introduction

Crossing a street or a cycle path can be a difficult and risky task, especially for blind persons [1–3]. In many situations in everyday life, a blind pedestrian has to know exactly where he is, where his destination is located, and how to get there [4,5]. Advances in crossroads design have resulted in more complex traffic environments and new types of information for pedestrians who are blind to handle [2,3], even though some design measures make it easier for them to accomplish certain tasks [6–8]. Still, Barlow et al. [3] recently showed that pedestrians who are blind have considerable difficulty locating crosswalks at complex signalized intersections. Further, blind persons have location problems in traffic environments where there are no kerbs [1,3,6,8]. Consequently, it is of crucial importance to acquire better knowledge of how various details in the pedestrian environment should be designed to meet the needs for people who are blind, and the same goes for environments where pedestrians meet other road users [1].

The challenges just introduced are part of the complex discourse of person–environment interactions, involving practical as well as conceptual and theoretical considerations. For a long time, according to Swedish legislation and international policy [9], public spaces must be designed so that they are accessible and usable for people with mobility or

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orientation disabilities [10,11]. The definition of accessibility involves the relationship between functional capacity and environmental demands, i.e. the relationship between a personal and an environmental component [12,13]. In the environmental component, environmental barriers are described in relation to official norms and guidelines, while the personal component is described in terms of functional limitations and dependence on mobility devices. Accessibility is objective in character and should be professionally assessed. The definition of the word usability is that a person should be able to move around in the environment on equal terms with other citizens. Moving around refers to being in and using environments for different activities. Thus, usability includes both the personal and environmental components, as well as an activity component. Most important, usability is based on user perceptions, i.e. it is subjective in character [13].

Turning back to the specific topic of this study, persons who are blind must rely on specific types of information gathering. That is, unlike individuals with normal or reduced sight, they must rely solely on sounds and sensory information, i.e. tactile information and clues, combined with *a priori* knowledge of what to expect and what is common [5,14], involving both perceptual and cognitive processes [14]. Therefore, although this study also focuses on some fundamental issues of potential relevance for a broader group of people with visual impairments, to really capture the issue of tactile detection, it is necessary to study people who are totally blind, i.e. those who do not have any light perception. Pedestrians who are blind use different aids [5,15] for kerb detection such as a white cane or their feet [16] as a warning indication of where a street or a cycle path crossing starts [3,7,17]. The kerb also has an important function in guiding for the direction to cross the street; blind people and people with low vision are often trained to take out the direction by their feet from the kerb, and then to walk perpendicular to the line of the kerb. The long white cane and the various techniques for its use are designed and developed to provide the pedestrian with awareness of detectable changes, such as alteration in surface texture [15] and obstacles such as bikes and poles. Earlier studies [15] have shown that when a correct touch technique (i.e. constant contact) is being used, information about the surface texture can be detected. The pendle technique (i.e. two point touch) is, however, more often used in situations where the person is very well acquainted with the environment. It should also be noted that the two techniques often are used in combination. People who are blind have also learned to effectively discriminate among sounds [5,14]. The process of becoming and being orientated is complex, but it is important to understand the process by which pedestrians who are blind engage to orientate safely. It is a learning skill, but also dependent on how various details in the environment are designed [1,4,14,18].

Commonly in many countries, on sidewalks and at kerb ramps, artificial surfaces with flat-topped or rounded domes are installed as detectable warnings. Likewise, rib texture and sinusoidal textures are installed as guidance surfaces [7]. These artificial surfaces are intended to help people with visual impairments or blindness to orientate in the pedestrian environment, and are supposed to increase the possibility for societal participation [7,17,19]. However, scarce research-based evidence is available for how to design detectable warnings to achieve the best possible effects. One important issue that warrants study is whether it is possible to use tactile warning surfaces instead of kerbs to caution for traffic at raised intersections. The results of such research could give implications calling for alternative means of directional guidance. As there is a great diversity of such artificial surfaces available on the market, and because there are different approaches to arranging them in the traffic environment, the knowledge about their usability for persons who are blind is insufficient [18,20]. Even though some studies on detectable warning surfaces have been carried out [7,8,17–19,21], the quality and interpretation of the results vary across studies.

A Swedish interview study [22] conducted in the 1970s showed that the kerb is important for the detection of a street or a passage. Later on, Acking [22] also concluded that different textures like edges and deepening at walking areas can be used as information indications, but the dimensions are very important. Two research projects conducted in the 1990s studied detection of the street [8,18]. Bentzen and coworkers [3] studied the blind pedestrians crossing the street at kerb ramps without detectable warning. The result showed that the participants were unable to detect the street. Hauger et al. studied the detectable warnings at kerb ramps of different slopes. The result showed that failing to detect the streets was highly correlated to the slope of the kerb ramp. Hauger et al. also found that detectable warning surfaces decreased the number of unsuccessful crossings in some way. However, he also concluded that the result did not provide clear answers regarding the effectiveness of detectable warning surfaces at kerb ramps. Instead, he concluded that other aspects such as the design of intersections, social factors, traffic density and the skills of travellers might be of importance for detection [18]. Later on, Benzen et al. (2000) conducted a study of persons with visual impairments or blindness who travelled up and down a laboratory ramp with different warning surfaces. The result showed that use of warning surfaces on kerb ramps would increase their safety [17]. Moreover, an experimental Swedish study [21] showed that it is very difficult for a person with blindness to identify a warning surface at the end of an artificial tactile guidance route. Schroeder et al. (2006) performed a study involving blind and sighted pedestrians crossing streets with no artificial surfaces, showing that blind pedestrians make more decisions than sighted pedestrians. He concluded that the results depended on many factors not studied, calling for more complex study designs. Very few studies have been performed in real traffic environments; thus it is important to carry out structured research in real environments [1,18].

Summing up, we did not find any study investigating detection of warning surfaces in pedestrian environments for people with blindness focusing on the availability of kerbs, and on the depth and structure of the tactile surfaces. Therefore, structured studies in real traffic environments, with well-defined samples and study sites are called for. Even if passages without kerbs are more common nowadays, people with blindness are trained to search for the kerb with a long white cane as a warning indicator prior to a street or a passage [14,17,21]. Thus, one important issue is whether it is possible to use tactile warning surfaces instead of kerbs at raised intersections. Therefore, the overall purpose of this study was to study whether and how persons with blindness detect warning surfaces in the pedestrian environment with a long white cane. The study was delimited to the detection of warning surfaces when following a natural guidance surface before the passage of a potential danger, and only in bare ground conditions. The four specific aims were:

- To study whether and how warning surfaces were detected.
- To study what impact kerb, depth, and structure had on the detection.
- To study whether there were differences in the detection with and without kerb, depending on structure and depth.
- To study if and what impact the surrounding material and natural guidance surface had on the detection.

Method and material

A study with a concurrently mixed methods approach [23–25] was carried out in a real pedestrian environment. A combination of quantitative and qualitative data sources was used to elucidate both how the participants acted, and how the participants experienced the spots as well as additional features affecting the detection [24,25].

The test route

The test route was laid out in a pedestrian environment in a Swedish medium-sized town with 48,000 inhabitants. The test route passed through an area with a college, a large shopping centre, and the head office of the National Swedish Road Administration. The area had a constant flow of traffic, although not as much as in the town centre. The test route was 1.5 km long and contained 14 passages, designed with different warning surfaces at each side of the path/street to be passed (Figure 1). The 14 passages were laid out in the already existing pedestrian environment. Thus, the warning surfaces were surrounded by different materials that were categorized into two groups: (1) smooth (asphalt) or (2) rough (cobblestones, concrete slabs). Likewise, the natural guidance surfaces leading up to the warning surfaces were categorized into two groups according to the combination of materials at the specific spot: (1) distinct, (grass to asphalt; gravel to asphalt; edge to asphalt; edge to concrete slabs) or (2) indistinct (cobblestones to asphalt; cobblestones mixed with concrete slabs to soil).

This study only included testing of the warning surface prior to a passage, not after (Figure 2). Further on in this article, the 14 passages are referred to as ‘spots’. The 14 spots were implemented during the summer and fall of 2005.

Initially, the intention was that the 14 spots should represent all possible combinations of three variables important for tactile detection: kerb (yes/no), depth (1000 mm/1500 mm) and type of structure (four different types of concrete slabs). The three variables were chosen based on knowledge from earlier research [21] and ISO standardization work [26].

The chosen slabs were manufactured in (1) Denmark, (2) the United Kingdom (UK), (3) Japan, or (4) Sweden. All four structures were 5 mm high; structures 1 and 2 can be classified as having rounded domes, whilst the structures 3 and 4 had flat-topped domes; structure 2 had diagonal alignment domes whilst structures 1, 3, and 4 had domes aligned in parallel (Figure 3). The test route consisted of seven spots with kerb and seven without kerb. Likewise, seven spots had a depth of 1000 mm and seven 1500 mm. The number of spots was, however, not the same for all four structures. The test site did not include any warning surface of structure 3 without kerb. The test route thus contained four spots with structures 1, 2, and 4, respectively, whilst only two spots had structure 3.

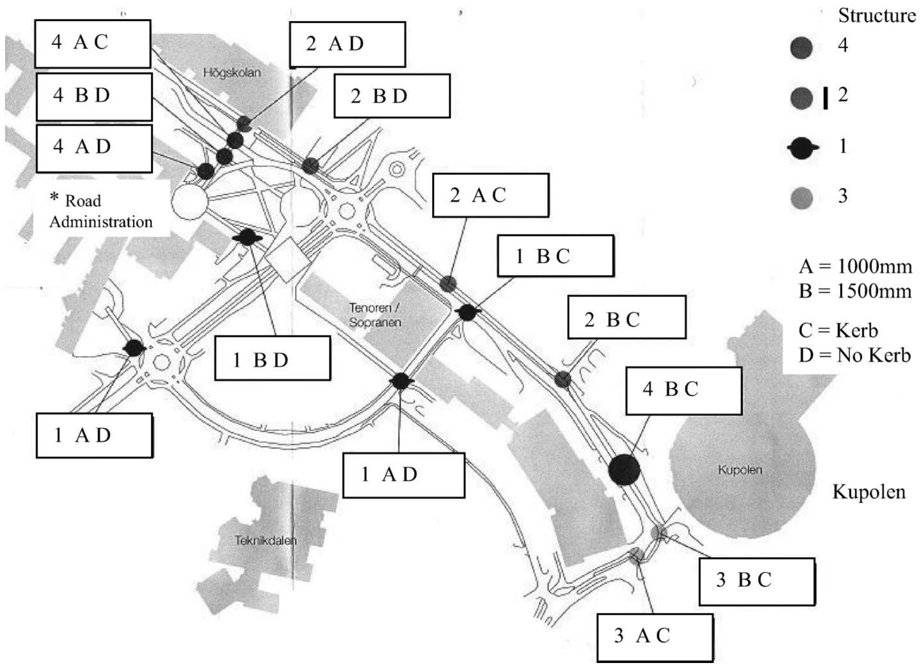


Figure 1. Map showing the test route and the 14 spots. *Note: The Swedish Road Administration's head office, at the top on the left side in the figure and the shopping centre down in the right corner, Kupolen.

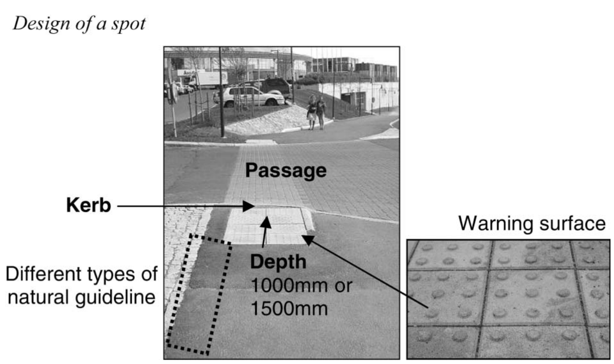


Figure 2. Design of a spot.

Likewise, there was no warning surface of structure 1 with 1000 mm and kerb. Instead, there were two structures without kerb. The reasons were a shortage of the material ordered for structure 3 and structural mistakes regarding structure 1.

Participants and sampling procedure

The participants were selected from a directory maintained by the Low Vision Centre in the region. The directory covered all residents with visual impairments who had been in contact with the Centre. To ensure that it was the tactility of the warning surfaces that was to be tested, an important inclusion criterion for the test was that the participants were totally blind, i.e. the person must have no light perception [27,28]. Another inclusion criterion was that the participant should be used to orientate in pedestrian environments with the long white cane. During the test, the participant used the long white cane he/she usually orientated with. The target population was defined by an occupational therapist working as a rehabilitation instructor at the centre. In all, 10 persons fulfilled the inclusion criteria.

To recruit the study sample, the instructor at the Low Vision Centre called the identified persons to give brief information about the study and ask for their participation. The 10 persons all expressed their voluntary interest and were sent more information. A researcher (second author) called them again to give more detailed information before they gave their final agreement to participate; eight accepted. One drop-out stated that he/she felt too old and lived too far away, while the other was not interested. The final sample represented both sexes and different ages (age range = 19–59 years; mean age = 43 years) (Table I).

Data collection

Methods. The methodology used was a mixed methods approach to data collection, i.e. observation using a structured form together with 'think aloud' and a structured interview [30]. Mixed methods were chosen to capture many aspects of the detection of the warning surfaces and to fully understand the phenomenon of interest, i.e. how a person with

Description of the four structures

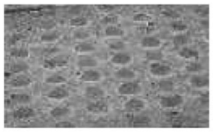
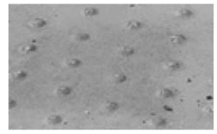
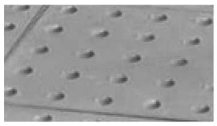
Nr 1 Danish surface 300x300	**Diameter dome**	**mm**	**Nr 2 English surfaces 400x400**	**Diameter dome**	**mm**
	Bottom Top c/c	33 10 47		Bottom Top c/c	23 20 65
Nr 3 Japanese surface 300x300	**Diameter dome**	**mm**	**Nr 4 Swedish surfaces 210x210**	**Diameter dome**	**mm**
	Bottom Top c/c	22 12 60		Bottom Top c/c	30 25 70

Figure 3. Description of the four structures.

Table I. Description of the person components, assessed by means of housing enabler and a study-specific interview.

Participant	1	2	3	4	5	6	7	8
Sex	F	F	F	F	F	M	F	M
Age	44	48	36	55	31	19	59	56
Duration of blindness	15	37	4	12–15	14	10	30	30
Practised, outdoor rehabilitation		X	X	X	X	X		X
Commonly used cane technique	P	PT	PT	P	P	P	P	P
Dog guide user	X	X	X	X	X		X	X
Diabetic high blood pressure	X		X	X			X	
Self perceived reduced tactile sensation				X				
Other functional limitations*	4		3	3–5	1		2,4,5	

T, touch technique; P, pendle technique; PT, pendle and touch technique (generally).
*Assessed by means of housing enabler [29].
1, difficulty interpreting information; 2, severe loss of hearing; 3, limitations of stamina; 4, difficulty in reaching with arms; 5, difficulty bending, kneeling.

blindness attains all the information needed during a walk, followed by decision-making [5,23,25,31]. Observation integrated with the think-aloud method was used to study the participants' actions [32,33]. The observation concentrated on the detection of the warning surfaces as such, whilst the think-aloud method strove to capture the thinking process and the inside perspectives of how the participant used sounds, slopes, etc. as aids in the detection of the warning surfaces [5,34–36]. The surrounding sounds and everything the person commented on were tape-recorded and constituted complementary information in the analyses. The structured interview was used to get the subjective view of the detection immediately as well as the participant's own experience of the warning surface [30,32].

The mixed methods of quantitative and qualitative approach were recorded concurrently, i.e. the data was collected at the same time and brought together in the results to confirm, cross-validate, or corroborate findings from one method with those from another [23,24].

Instruments. The observer (second author) used a structured form, designed to record details about the walk where the participant followed a natural guidance surface up to a warning surface (the spot), and the detection of the warning surface with the white cane. At each spot, the observer recorded, by watching and listening, details such as whether the participant could follow the natural guidance surface and whether and how he/she identified the warning surface and stopped prior to crossing the street. The criterion for detecting a warning surface was thus that the participant would stop or say that he/she detected the surface before stepping out in street. The observer also recorded which cane technique was used, whether the participant got stuck in the surfaces with the white cane, if there were any disturbances along the walk and if help was needed during the walk (Appendix).

In the structured interview, the questions were about whether and how easy the participant detected the warning surface of each spot, and if it was with the white cane, by foot or by both cane and foot; if the participant was able to feel the surface by cane/foot; whether the depth was sufficient to enable adequate reaction and what it really was that warned the participant at the spot. The interview also contained questions about the participants' feeling of safety, security and usability at each spot. The questions had scaled response alternatives [30]; very easy – quite easy – neither/nor – quite difficult – very difficult, (secure/clear/sufficient depth). Some of the questions were dichotomous (yes/no). (Appendix)

Both instruments were developed from a previous Swedish study [21], involving reliability tests showing a high level of agreement between the two independent observers conducting the observation.

For assessment of functional limitations (13 dichotomous items; present/not present), the standardized Housing Enabler instrument was used [29], and to get a picture of each participant an interview about different personal components was also conducted (Table I).

Procedure. The participant was informed about the study and how the test day was laid out. Thereafter, the participant took a first walk along the test route, accompanied by the observer (second author). This introductory walk lasted for around 30 min and incorporated both an orientation and a training component. During this walk, the participant learned about the principle design of each spot and was able to ask questions. None of the participants was familiar with the route. During a second walk (the test walk), the spots were tested one by one. At each spot, the participant started 7–12 m prior to the spot, unaware of its design. During this walk, the participant was asked to think aloud. The participant was informed to follow the natural guidance route up to the warning surface, to report when finding it, and to continue to cross the street and stop after having crossed it. The observer filled in an observation form for each spot. After each spot the observer conducted an interview. The participant did not know the observers purpose.

To get a variation in the order of spots, the participants did not start at the same spot of the test route. One test lasted for about 3 h. The tests were conducted during one week in July and one week in August 2006. One participant did the test in the morning and one in the afternoon. The weather was a little bit windy some of the days, but the sun shone on all days and the temperature was between 20 and 30°C.

In close connection to the test, either before or after the test day, each participant was interviewed by an occupational therapist about different personal component data, including an assessment of functional limitations [29].

Material. The data collected during the tests contained eight observations and eight interviews of each spot; in all, the study contains 112 observations and 112 interviews (eight participants $\times$ 14 spots), henceforth called cases (totally 112). Accordingly, the consists of

> 56 observations/interviews, cases, at kerb and 56 observations/interviews, cases, without kerb; 56 observations/interviews, cases, at a depth 1000 mm and 56 observations/interviews, cases, at a depth 1500 mm; 32 observations/interviews, cases, for structures 1, 2 and 4 and 16 for structure 3.

Finally, the combined record also includes data collected with the think-aloud method, i.e. 5.40 h of tape-recorded comments and surrounding sounds.

Data analysis

All data collected from the observations, interviews and think-aloud method, were analyzed separately and brought together in the results [23,24].

The procedure of the analysis of data from observations and interviews was divided in three steps. First, all observation and interview data were analyzed according to whether or not the participant detected the warning surface. In the second step, the detection was analyzed according to spots; with/without kerb the two depths and the four structures. In the third step, the data were divided in two groups based on the variable kerb/no kerb. In all three steps, the data were analyzed by means of descriptive statistics, through cross-tabulation and likelihood-ratio chi-square, or Fisher's Exact Test.

The qualitative data were analyzed as follows: The think-aloud data were transcribed by the second author, including surrounding sounds like cars, lorries, fans near the shopping centre, cyclists, and sounds generated from the white cane. The text was then repeatedly read and sorted according to whether the data contributed information about things that could especially affect the detection.

Ethical considerations

During the preparation of this study, an ethical application was submitted to the regional ethical review board in Lund. Their opinion was that the study did not fall under the law of ethical considerations of research that refer to people. Even so, we put the regulation into practice during the study.

Results

All data are brought together in the results and stepwise presented according to the specific aims. Firstly, Detection of warning surfaces with all 112 cases are presented, answering whether and how warning surfaces were detected. Secondly, the results are presented according to what impact kerb, depth, and structure had on the detection. Thirdly, the results are presented according whether there were differences in the detection with and without kerb, depending on structure and depth. At the end, the results are answering if and what impact the surrounding material and natural guidance surface had on the detection.

It should be kept in mind that the unit of analysis was observation, not persons. To check this approach in the very first phase of data analyses, all participants were analyzed separately according to if they detected the surfaces or not, inquired whether there were any systematic differences between the participants; it could have been any of the participants who distinguished from the others depending on personal characteristics. However, there were no systematic differences in the detection of warning surfaces between the participants.

Detection of warning surfaces

The observation showed that the warning surfaces were detected in 86% of the cases (96 of 112) ($p=0.03$) while according to the interviews, the warning surfaces were identified in 91% of the cases (102 of 112). When it comes to how the participants detected the warning surfaces, the white cane was reported in 61% of the cases, feet in 18% and sound in 8% (remaining proportion = other/don't know). In most cases (84%; 94 of 112), the touch technique (i.e. constant–contact) was used, while in 13% (15 of 112) of the cases the two-point touch technique (i.e. including touch in two points) was used. According to the comments from the participants, habits and training improve the skills to detect the warning surfaces. One participant said; 'yes, I felt it all right, clear and with sufficient depth'. Another who used a guide dog daily and thereby was not equally familiar with using the white cane said, 'Rough, but I do not really know, do not fully dare to rely on it . . . but here it is, I feel it with the cane.' Later on, during the walk the same person said; 'Feel soil and something under my feet. Now I know what I should search for, this is like rehabilitation for me (. . .) here it is something I feel it with the cane, oh cool I have never done that before'.

The impact of kerb, depth, and structure on detection

The observation showed that there was no difference between detecting the warning surface depending on whether there was a kerb at the spot or not. In 86% of the cases (48 of 56), the warning surface was identified both with kerb and without kerb. According to the interview, it was mainly the warning surface itself that was the reason for the detection (78% of the cases), while the kerb was mentioned in 2% of the cases. Regarding the feeling of safety/security experienced, the interviews showed no differences between kerb/no kerb (Figure 4). The comments from the participants supported these findings, one person saying: 'I'm sliding the cane . . . and there it is (the tactile surface), is there any kerb?' Another person who identified the structure said: 'This was wide, well it's all right then to go straight ahead over the street . . . ohh there was a kerb . . .'. The same person commented later on: 'Here I found the next surfaces, I will see whether it is a kerb and things'.

Turning to the depth of the warning surfaces, the observations showed that there was no difference regarding the detection between the two depths tested. At the depth 1000 mm, 87% (49 of 56) of the cases were detected, and at the depth 1500 mm 84% (47 of 56). Likewise, the interviews showed that the warning surfaces were detected in 91% (51 of 56) of the cases at both depths. According to the interviews, the 1000 mm depth was judged as sufficient or completely sufficient in 57% (32 of 56) of the cases, while this response was stated in 68% (38 of 56) of the cases at the 1500 mm depth. Both depths were experienced as much or quite safe/secure in a majority of the cases (63% at 1000 mm; 52% at 1500 mm).

The observation data showed a difference regarding detection depending on the structure of the

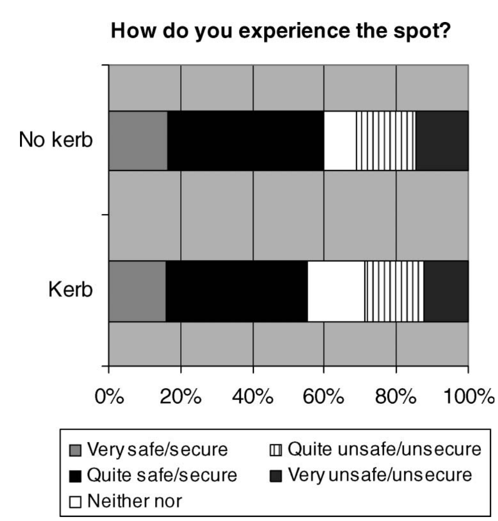


Figure 4. Experienced safety/security with kerb or no kerb according to interview data.

warning surfaces ($p = 0.003$) (Likelihood ratio = LR). Structure 1 was detected in 72% of the cases (23 of 32), structure 2 in 84% (27 of 32), structure 3 in 88% (14 of 16), and structure 4 in 100% of the cases (32 of 32). Also according to the participants' subjective statements, structure 4 was detected in all cases, while structures 1–3 were detected in 88% of the cases. Structure 4 was also judged as the easiest to detect as well as the most safe/secure. It was also felt most clearly with the white cane (Figure 5). The four different surfaces were primarily felt by cane or foot (Figure 6). For structure 2, according to the interviews, the sound when the white cane touched the surface also had an impact, further supported by the tape recordings, both by the sounds on the tape and the comments from the participants: 'Here is something, but I rely more on the sound'. With structure 4, according to the comments made by the participants, the white cane got stuck at all spots but one.

Detection of warning surfaces with/without kerb

When analyzing the observed data separately for spots with/without kerb, no differences were found regarding the two depths of the warning surfaces with kerb ($p = 0,258$) and without kerb ($p = 0.740$). At spots with no kerb, the surfaces were detected in 84% of the cases at the 1000 mm depth and in 88% at the 1500 mm depth. The corresponding figures for kerb were 92% and 81%, respectively.

According to the observations, the structure had an impact on the detection without kerb ($p = 0.00$) as well as with kerb ($p = 0.047$) (Figure 7). Structure 4 was the structure detected best overall. At spots with no kerb, the surface was detected in 100% of the cases for structures 2 and 4, and in 67% of the cases for structure 1 (No data from structure 3). At spots with kerb, again structure 4 was detected in 100% of the cases, structure 2 was detected in 69% and structures 1 and 3 were detected in 88% of the cases.

Impact of the surrounding material and the natural guidance surface on detection

The observation indicated that the material of the natural guidance surface had an impact on the detection of the warning surfaces, while the surrounding material in terms of smooth or rough did

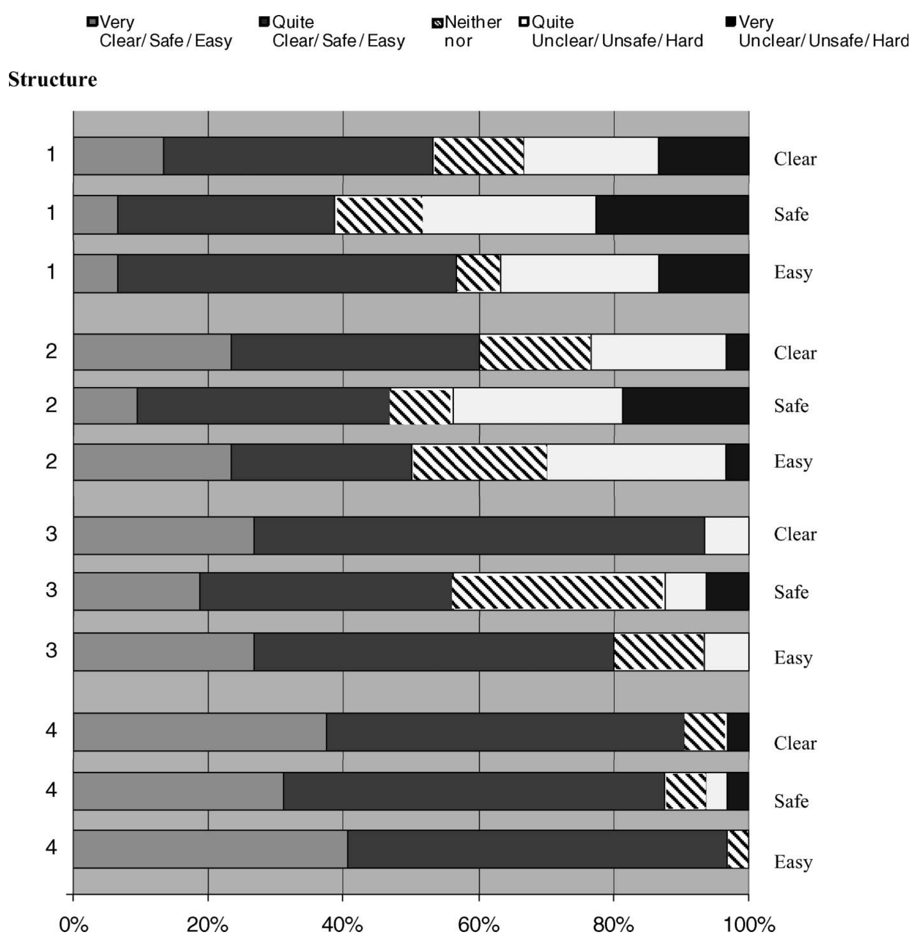


Figure 5. Experience (clearness, safety, easiness) when detecting the four structures according to interview data.

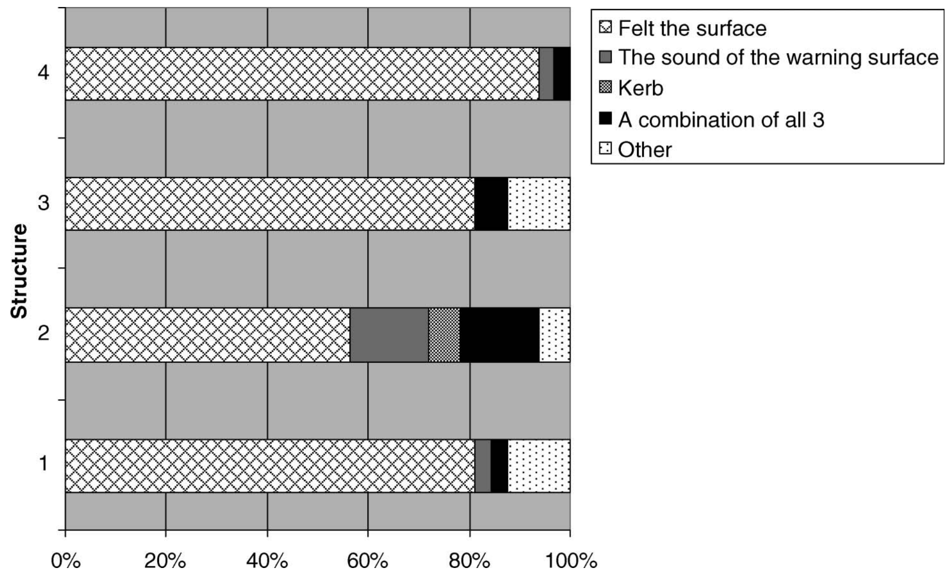


Figure 6. Reported reasons for detection at the four structures according to interview data.

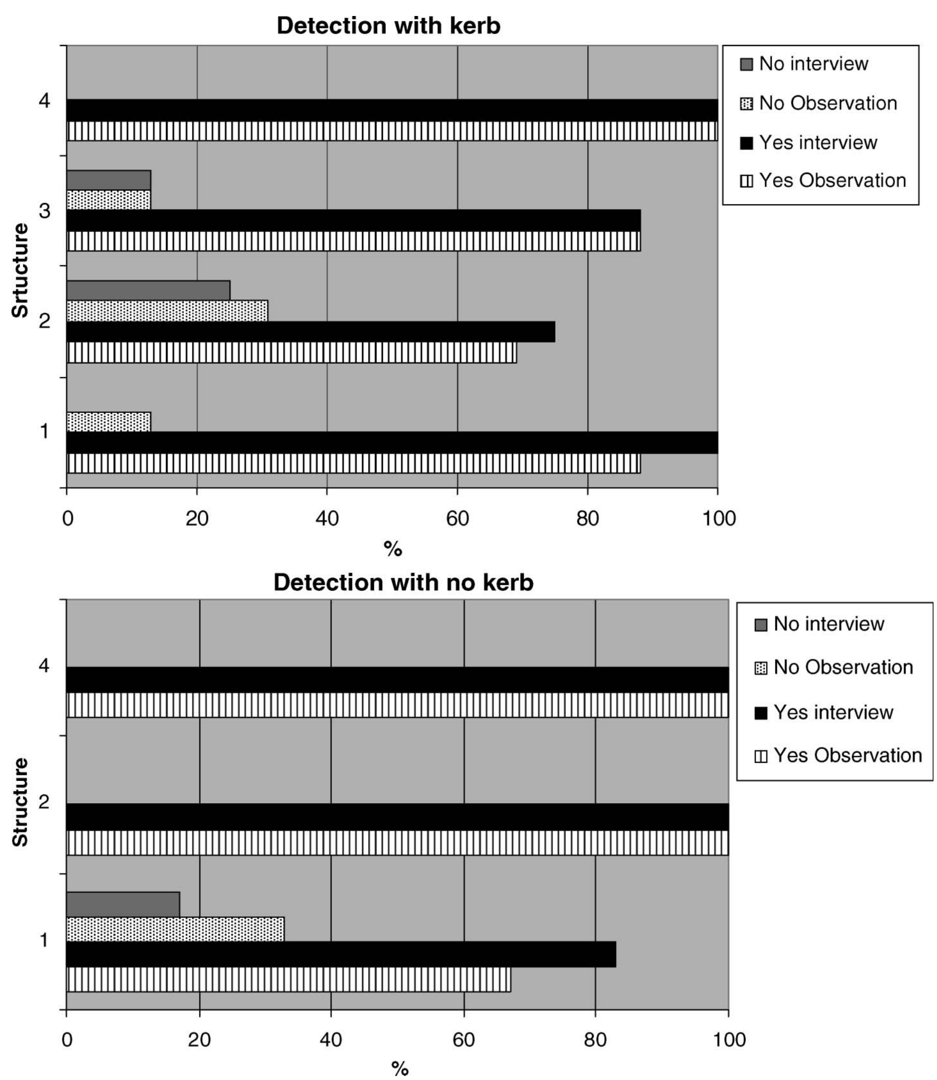


Figure 7. Detection of the warning surfaces at kerb/no kerb at the four structures according to data from interviews and observations.

not (Table II). In more detail, a natural guidance surface involving cobblestones made the detection more difficult at all structures but number 4. Think-aloud comments supported these findings. That is, the 'material leading up to the spot' was often mentioned as an important factor for the detection of the warning surface. One participant commented: 'Ohh it's difficult, cobblestone concrete slabs and some other things to the left, it's very difficult to walk here, barely will I find any slabs at all'. Another participant said: 'I feel something here, no it is tricky with cobblestones . . . I don't really know.'

Discussion

To the best of our knowledge, this study is the first systematic research study focusing on how persons with blindness detect warning surfaces in the pedestrian environment, using a long white cane. The study was delimited to the detection of warning surfaces prior to crossing a street when following a natural guidance surface, and somewhat unexpectedly the results show that the probability to detect a tactile surface is not higher if the design solution has a kerb or not, or if the depth is 1000 mm or 1500 mm. Instead, the most important design characteristic for detection is the structure of the surface, with a distinct natural guidance surface prior to the warning surface. As concerns the different structures, the Japanese and Swedish slabs proved to be the best. Both have surfaces with flat-topped domes, and in accordance with Ståhl et al.'s (2004) earlier study in an experimental environment, this design of these slabs causes the cane to get stuck in the surfaces. Primarily, persons with blindness detect warning surfaces with their white cane. Because this is the technique that most persons with blindness are trained to use [14,15], in Sweden as well as in many other countries, this finding was less surprising. The overall results confirm the complexity of being a blind pedestrian in the real traffic environment, with many factors influencing the ability to detect warning surfaces [1,5,18]. Already in 1996, Hauger et al. concluded that detectable warning surfaces function as part of a larger, interactive system that includes elements of the built environment as well as of the social environment, including the density of traffic and the skills of the blind travellers. Thus, our results should be interpreted and understood on the basis of this complexity, while the detailed results are of course important and much in demand from a physical planning perspective.

Table II. Detection of the warning surface according to type of natural guidance surface and structure of surrounding material.

	Identification					
	Yes		No		Total	
	%	Count	%	Count	%	Count
Natural guidance surface						
Distinct	93	(67)	7	(5)	100	(72)
Indistinct	72	(29)	28	(11)	100	40)
Surrounding material						
Smooth	86	(48)	14	(8)	100	(56)
Rough	86	(48)	14	(8)	100	(56)

Data from observation.

To prepare the test site in a real environment, we made a strategic choice of three different design characteristics (structure, depth, with and without kerb). According to Schroeder et al. (2006), it is important to choose test sites that are similar in all but one or two dimensions, aiming to isolate effects of the site characteristics. Despite our efforts in this respect there are many potentially disturbing factors, impossible to control for, in a real traffic environment. To record such factors, we tried to capture the complexity by means of the mixed-methods approach applied. In several ways, the mixed-methods approach applied made it possible to detect aspects of the results otherwise impossible to identify. By integrated analysis, utilizing different kinds of data, we arrived at results strengthening the main conclusions. Another advantage of using mixed methods is the validation obtained, because of different type of information about same item. The more complex the situation and environment, the more important it is to design studies carefully, preferably by use of several data collection methods. If the multiple sources had not been used, it would have been hard to capture the complexity of how people with blindness detect warning surfaces. Most important, the fact that we managed to design 14 different spots with different characteristics gave a more differentiated result with very relevant findings.

Our results contradict those from earlier studies that demonstrated that kerb is the most important aspect for successful detection of warning [8,22]. Our results actually show that the probability to detect a tactile surface is not higher depending on whether the design solution has a kerb or not. This could be considered as surprising, but might be because in earlier studies, no other aspects than the kerb were considered. It should be noted that in Sweden and some other countries, people with blindness are trained to locate a kerb prior to crossing a street. This was mirrored by the comments from the participants that they found the tactile surface while searching for the kerb; they also stressed that habits and training improve the skills to detect warning surfaces. Here, it should be kept in mind that the participants went through the test site encountering the spots in different order.

This study shows that it is important to use materials for natural guidance surfaces that provide well-defined detection with a white cane. But, in contrast to earlier studies [21], our study did not show any clear impact on detection depending on the surrounding material. There might be different explanations for this finding. One might be that it is difficult to distinguish between the natural guidance route and surrounding material. Another might be that when the natural guidance route provides well-defined detection by the white cane, the material of the surrounding material is of less importance – the reason being that less concentration is needed to orientate.

When it comes to the results on depths, the integrated results show that 1500 mm is not necessary, whether with kerbs or without. The subjective experiences of the 1500 mm depth as such were somewhat more positive, while the 1000 mm depth was more positively experienced when the question posed concerned the overall impression. These variations might indicate that the structure impacts on the results in different ways.

Another important strength of the current study, distinguishing it from several others, is that it was accomplished in an inter-disciplinary research context. In many studies about different design solutions, based on a purely technical perspective, valid and reliable information about the participants and their functional limitations is often lacking. In the current study, the participants were carefully assessed for personal characteristics, using valid methodology and professional expertise. To interpret results from data collected in complex contexts [1,18], and to be able to nurture the understanding of the interplay of the components interacting in accessibility and usability problems, the personal component as well as the environmental component have to be explicitly defined [13].

Drawing upon experiences from vision rehabilitation, because of different needs and prerequisites low vision and blindness should be treated as separate fields [14]. Still, in many studies participants with visual impairments of different kinds have been treated as one group without specific description of individual characteristics [1,3,22,37,38,39], resulting in findings difficult to interpret. This suggests the importance of interdisciplinary collaboration [3,4,40], as demonstrated by the current study. More requirements to the design of warning surfaces, to function well for a broader user group is needed because this study focusing on people who are Blind, some questions are left open by this study.

Turning to possible weaknesses with this study, it is worth mentioning that it was sometimes difficult to get the participants to think out loud, probably because it was not a natural situation for them. Still, this information gave an additional perspective and captured the participant's immediate feeling. According to Van den Haak et al. this method is highly valid, as the data obtained reflect the actual use of the design and not the participant's judgement about its usability [35].

Methodologically, we would like to draw attention to the uneven distribution of the variables under study. As mentioned above, the intention was to test all possible combinations of the three variables kerb, depth, and structure, but structure 3 was only tested at two spots with kerb and not at any without. Likewise, structure 1 was not tested with a kerb at 1000 mm depth. Since the results are very uniform and clear, showing that it is the structure that is the only variable that has importance for detection, these two deviations are not likely to have had any significant influence on the results.

We would also like to discuss the fact that this study only surveyed the detection of warning surface prior to a passage, not after, and only in bare ground condition. Moreover, even though the study strove to capture very realistic traffic situations, because it was not possible to arrive at a continued walking direction when crossing the passage, it was necessary to delimit the data collection to detection of warning surfaces in one direction. Thus, even more complexity remains to be studied.

In conclusion, the most important finding of this study is that a kerb does not make a difference for the detection of warning surfaces among pedestrians with blindness. The result shows that tactile warning surfaces with flat-topped domes with a minimum depth of 1000 mm can be detected with a white cane. In connection to the warning surface, there should be a smooth surface, preferably with a natural guidance. The results can be used for evidence-based physical planning, but also have implications for development of more efficient vision rehabilitation.

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Appendix

OBSERVATION GUIDE – WITH KERB

Participant Code:________________ Date:________________ ☐ Wind ☐ Overcast ☐ Sun ☐ Rain
Type of shoe:________________________ Which hand holds the cane? L ☐ R ☐

Guidance – distance until the warning surface

Cane technique ☐ Touch technique ☐ Pendle technique ☐ Both
Does the person lose guidance? ☐ Yes ☐ No External influence
☐ Cyclist ☐ Pedestrian
☐ Noise ☐ The cane gets stuck ☐ Other____
Observer comments ____

Warning – detection of the warning surface

Detection of . . . Warning surface ☐ Yes ☐ No
Kerb ☐ Yes ☐ No
'Side' kerb ☐ Yes ☐ No (curb ramp)
Disturbing factors ☐ Cyclist
☐ Pedestrian
☐ Noise
☐ Others______________________________
Cane technique ☐ Touch technique ☐ Pendle technique
Gets stuck in the surface ☐ Yes ☐ No
Slows down ☐ Yes ☐ No
Stops ☐ Yes ☐ No If yes, where?
☐ Prior to street
☐ In the street

General observations

Needs help ☐ Yes ☐ No
Loses guidance ☐ Yes ☐ No
Walking speed ☐ Normal Fast ☐ Insecure/Irregular

I have observed and answered all sections of the questionnaire ☐ Yes ☐ No

INTERVIEW GUIDE – WITH KERB

1. Did you detect when the natural guidance changed to warning surface? ☐ Yes ☐ No
2. Did you detect the warning surface through . . . Sound ☐
   Tactile with cane ☐
   Tactile with feet ☐
3. What warned you?
   Felt the warning surface ☐
   Sound of the warning surface ☐
   Kerb ☐
   Neither ☐
   Other ☐
4. How was it to find the warning surface by tactile means?
   1. Very easy
   2. Quite easy
   3. Neither easy nor difficult
   4. Quite difficult
   5. Very difficult
5. How well was the warning surface felt with the cane?
   1. Very clearly
   2. Quite clearly
   3. Neither clearly nor unclearly
   4. Quite unclearly
   5. Very unclearly
6. How well was the warning surface felt with your feet?
   1. Very clearly
   2. Quite clearly
   3. Neither clearly nor unclearly
   4. Quite unclearly
   5. Very unclearly
7. How did you feel about this design?

1. Very safe		1. Very secure
2. Quite safe		2. Quite secure
3. Neither safe nor unsafe		3. Neither secure nor insecure
4. Quite unsafe		4. Quite insecure
5. Very unsafe	ALT	5. Very insecure

8. In your opinion, do you think there were any disturbing factors during the promenade?
   ☐ Yes ☐ No
   If yes ☐ Sounds ☐ Other pedestrians or moving vehicles
   ☐ Other________________________
9. How did you feel about the depth of the warning surface?
   1. Completely sufficient
   2. Sufficient
   3. neither . . . nor
   4. Short
   5. Too short
10. How useful do you think the design is on a scale from 1 to 10?
    (1 = not useful at all, 10 = very useful)

    ____
    1 2 3 4 5 6 7 8 9 10