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Experimental observations on the optimal layout of orientation blocks for safe road crossing by the visually impaired

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ABSTRACT

For people with visual impairments who face difficulties when crossing the road, in urban areas of Japan the infrastructure designed to provide an indication of crossing direction and the curbstones at sidewalk-roadway boundaries often varies in reliability from one crossing to another. If anything, this promotes stress for users and is an issue for which improvement is urgently needed. The authors have proposed new orientation blocks to be installed at crosswalk entrances as a means of more accurately indicating to people with visual impairments the trajectory to follow when crossing the road, and in prior research have derived desirable specifications for the profile of these blocks and their position relative to tactile walking surface indicators (TWSI).

For this paper, in order to examine in greater detail the desirable position of orientation blocks relative to TWSI, the authors conducted an experiment using totally blind subjects to evaluate conditions on a 10 m walk that simulated an actual crossing. The results, based on observations of the trajectories walked by participants in the experiment and interviews eliciting their subjective evaluations, showed that separating orientation blocks and blister tactile blocks by about 8–12 cm is effective in constraining lateral deviation at a point 5 m from the start of crossing and that an 8 cm separation was desirable in order to maintain an effective reduction of mental stress while crossing.

1. Introduction

In Japan, to ensure that people with visual impairments can move around outside safely and securely, guidance systems such as tactile walking surface indicators (TWSI), acoustic traffic signals, and tactile maps and information boards are widespread throughout the country. In the half-century since TWSI were invented in Japan in 1965, they have spread to countries around the world as a way to support independent walking by people with visual impairments, and Japan has taken the lead in developing guiding principles and guidelines with respect to methods for installing them.

Crossing at intersections is one of the situations frequently cited as problematic for the visually impaired when moving around in urban areas; there are even reports that one in five people with visual impairments have experienced an accident in a crosswalk [1]. Specifications and installation methods for tools such as acoustic traffic signals and "escort zones" to assist people with visual impairments when crossing the road have been discussed from various approaches, with a great deal of research conducted and numerous examples of application in the real world [2,3]. Nevertheless, as in situations where installation is problematic for various reasons or the protrusions in escort zones have worn over time to the point that they provide greatly reduced support [4], there are many cases in which crossing support infrastructure is inadequate or inappropriate and the continuity of support has not been maintained because TWSI at sidewalk-roadway boundaries have not been properly installed [5,6]. Because TWSI spread without sufficient consideration of installation methods or clearly determined guidelines after they were first installed in Japan in 1967, they can be found around the world in many forms and using many installation methods that were developed independently, resulting in numerous variations from country to country. Today, progress has been made in creating standards and guidelines for installing TWSI and other tactile guidance methods and there is great significance in finding in Japan, where efforts are being made to lead the way in reviewing more correct methods, a model case for solving problems that occur when crossing the road.

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At the same time, people with visual impairments often "square off," a basic technique for determining direction of movement [7], using curbs at the sidewalk-roadway boundary [8]. This involves detecting the difference in level at the curb with the underside of the foot and determining the crossing direction to be perpendicular to the line along which the curb is aligned. However, this often leads them to head in the wrong direction since the curb is not necessarily perpendicular to the proper crossing direction [5], and there are also cases where this technique cannot be used due to the elimination of the difference in level at the sidewalk-roadway boundary. There have been efforts to balance the needs of the visually impaired with the demands of wheelchair users by making the surface of the curb bumpy or making the crossings slope multistepped [9], but the question of how to resolve the issue of the difference in the relationship between the curb alignment and the crossing direction for people with visual impairments has not yet been considered.

Although there are multiple clues at crosswalk entrances to assist the visually impaired in identifying the direction in which they should cross, their reliability often varies by crossing situation along the walking route, a situation that, if anything, promotes stress for those involved, can inadvertently induce mistaken crossing behavior, and is an issue for which improvement is urgently needed. While it would be desirable to actively confirm and correct inappropriate installations of TWSI based on accessibility guidelines such as *Doro no ido to enkatsuka seibi gaidorain* [Guidelines for Improvements to Facilitate Roadway Mobility] [10], there may be cases in which such repositioning unavoidably requires numerous drastic, large-scale measures. If, in such cases, the addition to existing infrastructure of equipment dedicated to orienting users to the crosswalk direction would more easily create a highly reliable support environment, then the need to develop such a tool would be high.

The authors, seeking to develop methods to increase safety for the visual impaired when crossing the road, have previously proposed a new type of block to be installed at crosswalk entrances that is dedicated to indicating direction ("orientation blocks") [11] and, through walking experiments conducted with totally blind subjects in a test space, have derived desirable specifications for the profile of these blocks and their positioning relative to TWSI. This paper seeks to evaluate longer-distance walking conditions that approximate actual crossing distance and to examine, in more detail than the experiments done during prior research, how to install orientation blocks to ensure optimal positioning that provides effective guidance.

2. Overview of orientation blocks that support road crossing

The safety of people with visual impairments when crossing has dramatically improved due to the installation of acoustic traffic signals and, in recent years, the proliferation of escort zones, but in addition to such improvements not being available at many crosswalks there are also examples, such as in Fig. 1, where vehicular traffic has eroded the

Fig. 1. Example of erosion of protrusions on crosswalk.

Fig. 2. Example of tactile blocks not perpendicular to the crossing direction.

protrusions to the point where they no longer provide support. In addition, although the *Doro no ido to enkatsuka seibi gaidorain* [Guidelines for Improvements to Facilitate Roadway Mobility] [10] establish the principle that lines of linear blocks (TWSI) at crosswalk approaches are to be positioned such that they indicate the crossing direction, in many cases they are not aligned in the crossing direction or do not connect to the escort zone, breaking the continuity of support (Fig. 2). Furthermore, many people with visual impairments use the difference in level at the curb as a clue to orient themselves at intersection crossing entrances. At intersections where the curb is not aligned perpendicular to the crossing direction, as in Fig. 3, this may not support crossing because people with visual impairments who use the basic "squaring off" technique to orient themselves with the alignment of the curb may veer off in a different direction.

To solve such problems, the authors have proposed, as a tool dedicated to assisting with orientation to the crossing direction at crosswalk entrances, a method of installing linear protrusions oriented perpendicularly to the crossing direction. As illustrated in Fig. 4, the linear protrusions (orientation blocks) are installed behind the blister blocks and enable users to more accurately cross the road by stepping on them

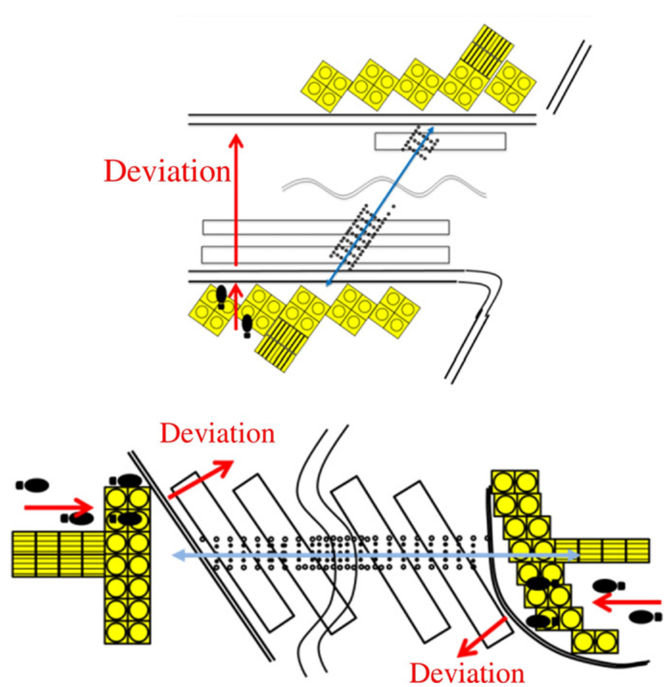

Fig. 3. Examples of curbs not perpendicular to the crossing direction.

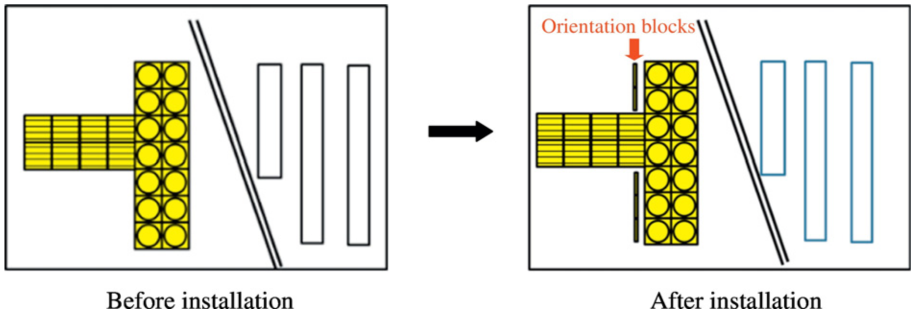

Fig. 4. Illustration of orientation blocks as installed.

with both feet to orient their bodies perpendicular to the direction of the protrusions.

With respect to the effectiveness of providing orientation support through the use of linear blocks, research on walking experiments conducted with the visually impaired [11] showed that aligning the linear projections perpendicular to the direction of travel led to a more stable walking trajectory in test subjects after they moved away from the projections. In the experiments, two linear blocks (TWSI) were lined up side-to-side and oriented perpendicular to the direction of travel, although for application on actual roads it would be effective to replace the two central, roadway-side blister blocks installed along the crosswalk entrance with linear blocks. This would not resolve situations such as illustrated in Fig. 2, however, where the blister blocks are not aligned perpendicularly to the crossing direction in the first place. Tokuda [12] has classified obstacles to movement by wheelchair users and people with visual impairments in the road environment, noting that TWSI are frequently installed inconsistently and inappropriately. This includes, for example, cases where TWSI are installed at a crosswalk but disappear midway and create a very dangerous situation for users that he argues need to be dealt with swiftly. In addition, Mizuno et al. [13] researched examples of TWSI installation in countries in Europe, the Americas, Oceania, and Asia and, noting that there are many cases of inappropriate installation that provide low levels of guidance or warning or induce dangerous situations, raised the need for common global standards for the installation of TWSI. Such research takes the approach of securing guidance by correcting the way that TWSI are installed, but our proposed orientation blocks, which adopt the approach of adding small, independent linear projections near blister blocks at crosswalk entrances, can be installed in the necessary orientation irrespective of the alignment of the blister blocks, giving them the major advantage of easily providing highly accurate orientation support.

Fig. 5. Mounted test samples.

The authors considered, based on walking experiments conducted with totally blind subjects during prior research, how to derive specifications for the profile of such high-guidance blocks and their positioning. Ease of finding samples, ease of orientation to the crossing direction, and sense of security while crossing were chosen for analysis as subjective indices on which participants in the experiment would provide user evaluations, while the time required to find the sample and get oriented, the time required from orientation to walk 3 m, and deviation from crossing direction were chosen for analysis as objective indices. As a result, the authors determined that to achieve highly reliable orientation support it would be optimal to install two orientation blocks, trapezoidal in profile, from 8 to 12 cm behind (that is, on the sidewalk side of) the blister blocks.

3. Overview of the evaluation experiment

3.1. Experimental environment

In order to analyze in greater detail post-orientation walking performance when using the proposed orientation blocks, for this paper an evaluation experiment was conducted, with the objective of considering optimal positioning, that established a longer walking distance for crossing than the experiment conducted during prior research. The experiment was conducted on 8 days in March 2014 with 21 totally blind test subjects, none of whom had any hearing issues. Blister blocks consistent with JIS standards and sample orientation blocks for evaluation were installed on an exterior road on a university campus (Fig. 5), which participants in the experiment were asked to walk and evaluate as if approaching a crosswalk entrance on a sidewalk. Two trapezoidal linear protrusions (height of protrusions: 5 mm, length: 280 mm, width: 18 mm, center-to-center distance between the two: 56 mm) derived from prior research were used for evaluation (Fig. 6) and installed in three patterns: at distances of 8 cm, 12 cm, and 16 cm behind the blister blocks (Fig. 7).[1] When presuming installation of orientation blocks on real public roads, the strong space restrictions near crosswalk entrances mean that it is important to consider how changes in distance influence walking performance and subjective evaluation.

Prior to being led to the test space, participants in the experiment received an explanation of research objectives and an overview of the experiment using tactile diagrams, with sufficient time provided. They were informed that they could drop out of the experiment freely at any time without any adverse consequences, and provided their consent to taking part in the experiment. They then moved to the test space and became sufficiently familiar with the walking space and the installed blister blocks and samples for evaluation through detection with the undersides of their feet or a white cane.

[1] The distance between the samples and the blister blocks is defined as the distance between the edge of the sample closest to the blister block and the edge of the blister block protrusion closest to the sample.

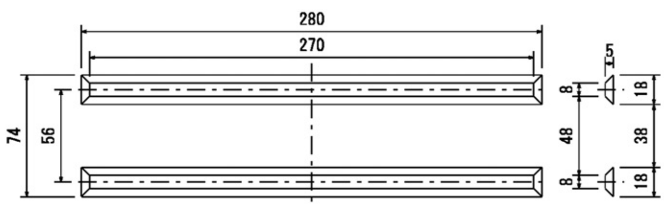

Fig. 6. Orientation blocks sample shape (twin trapezoids).

3.2. Experimental procedure

Test procedures for each trial are indicated in Fig. 8. When directed to by test staff, participants in the experiment began walking from a point 2–3 m from the samples for evaluation. When they found the blister blocks and samples for evaluation and had oriented themselves in the crossing direction, they stopped and signaled to test staff. At this point, participants in the experiment were asked to evaluate, on a 7-point scale (1: Very Bad–7: Very Good), 1) the ease of finding the samples and 2) the ease of orienting themselves in the crossing direction. Then, participants in the experiment began walking as if crossing the road, stopping at a signal from test staff when they had advanced at least 10 m. Each trial ended with participants in the experiment evaluating, on the same 7-point scale, their 3) degree of confidence in crossing and 4) degree of peace of mind in crossing. To provide some diversity in approach to the blister blocks, three angles of approach were established: 90°, 45° from the left, and 45° from the right. Three trials were conducted from each angle of approach for each distance from the blister blocks (9 trials). Since there were three distances (8 cm, 12 cm, 16 cm), each participant in the experiment performed 27 trials. In order to offset the influence of the training effect caused by becoming accustomed to the test, the order of the 27 trials was randomized.

This continuous flow was recorded using a video camera installed behind participants in the experiment. Walking trajectories were derived from these recordings using DIPP-Motion Pro 2D (DITECT Co. Ltd.) to acquire the coordinates of each point of contact of the heels while walking and finding the midpoints of lines joining adjacent points of contact. Note that the margin of error for two-dimensional projective transformation was ±0.05 m, the temporal resolution for the images was 29.97 fps, and spatial resolution was 1 pixel ≒ 2–36 mm.

4. Evaluation of location for installation for orientation blocks

4.1. Evaluation based on walking trajectory

Fig. 9 indicates—for all trials, by distance between orientation blocks and blister blocks—the crossing trajectories of participants in the experiment in the form of their coordinates relative to the point where crossing began at the blister blocks, and shows that in all cases the degree of lateral deviation increased with distance from blister blocks. Here, with respect to lateral deviation (the absolute value of the degree of lateral change in coordinates relative to the crossing direction) at the point 5 m from the start of crossing, a two-factor analysis of variance using distance from blister blocks and angle of approach as factors showed the main effect to be distance from blister blocks at a significance level of 5% (Table 1). A multiple comparison using Fisher's least significant difference method also found a significant difference in the mean deviation between 8 cm and 16 cm ($p < 0.01$) and between 12 cm and 16 cm ($p < 0.05$) (Fig. 10). The mean lateral deviation for 8 cm was 0.33 m and for 12 cm was 0.31 m, but because the lateral deviation at a point 5 m from the start of walking when providing support using the perpendicularly aligned linear blocks shown to be effective in previous research [14] was 30–40 cm, the orientation blocks proposed here can be said to have shown a comparable level of effectiveness in preventing veering from the crossing trajectory.

At the same time, an analysis of variance conducted in the same way for lateral deviation at the point 10 m from the start of crossing found no significant main effect or interaction effects (Table 2). A comparison of difference in mean deviation showed the same level as the 5 m point, confirming that distance of separation from the blister blocks had little impact on the degree of difference in trajectory deviation over a longer walking distance (Fig. 11).

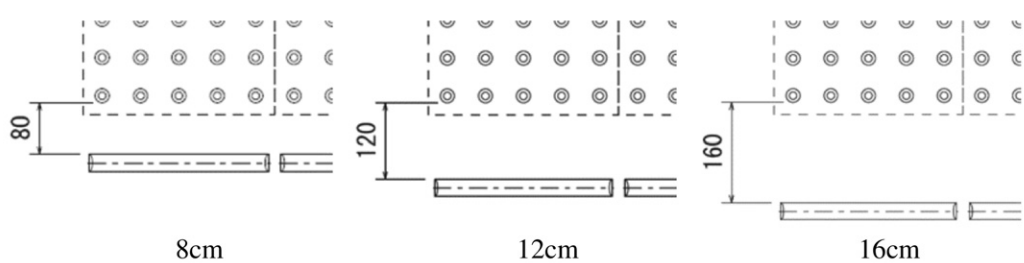

Fig. 7. Distances between orientation blocks sample and blister blocks.

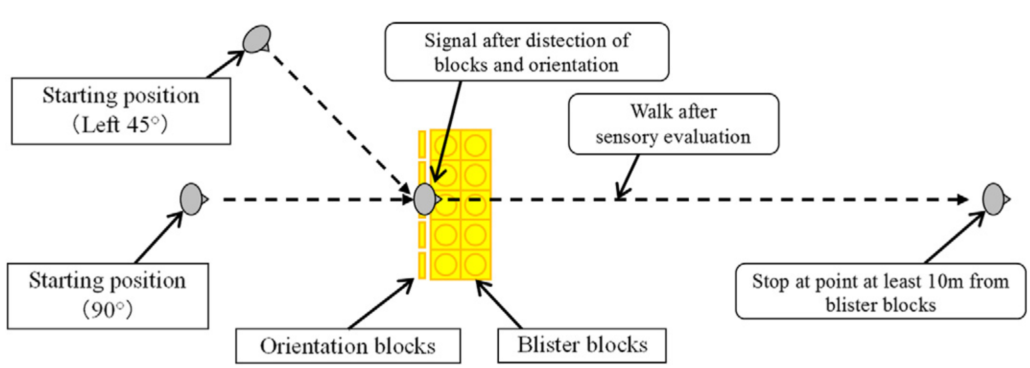

Fig. 8. Procedure for each experimental trial.

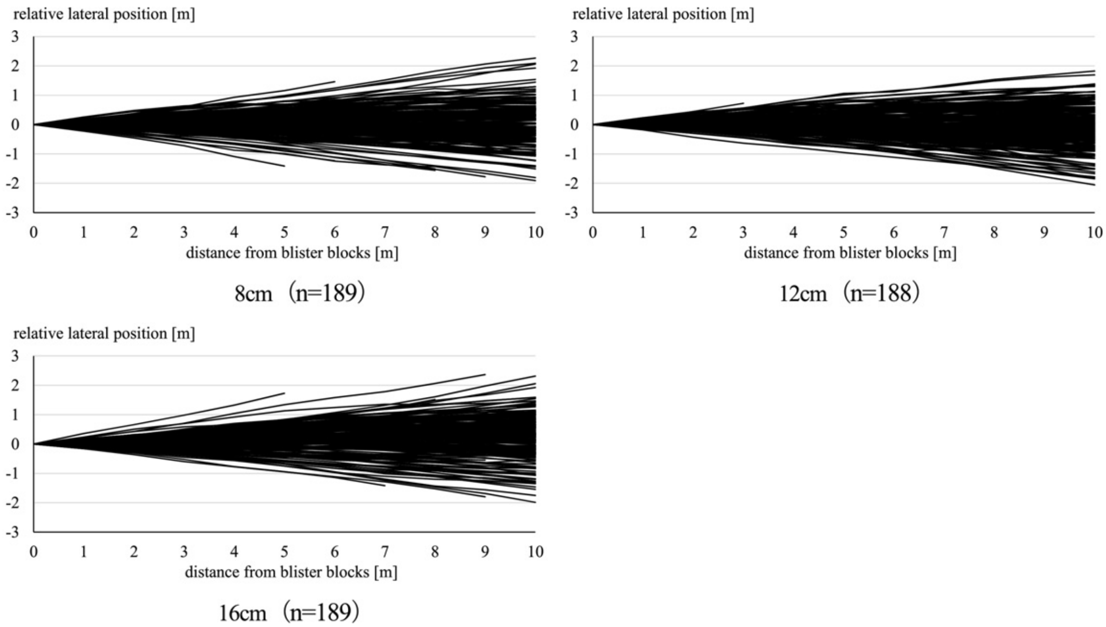

Fig. 9. Walking trajectories by participants in the experiment.

4.2. Subjective evaluation by participants in the experiment

A conjoint analysis was conducted of the evaluations elicited after each trial from participants in the experiment for ease of finding the samples, ease of orienting themselves (both prior to start of crossing), degree of confidence in crossing, and degree of peace of mind in crossing (both after walking 10 m). The subjective evaluations of participants in the experiment are presumably formed through the influence of multiple factors that interrelate in complex ways, but conjoint analysis makes it possible to analyze the relative importance and influence of each factor and level. Analytical results by item for evaluation are indicated in Table 3. For each item, there are 567 data points analyzed. The Pearson's R (correlation coefficient of the observed values and the values estimated by the model), which indicates the goodness of fit of the model, for each evaluated item was high at 0.952, 0.977, 0.854, and 0.992. Note that utility values in the table are estimated using the least squares method based on the scores given by participants in the experiment for each evaluated item. This incorporates the constraint that the total of the utility values estimated for each level within an attribute should equal zero, more highly positive values indicate more highly positive evaluations. Relative importance is the variance of utility values for each attribute divided by the variance of utility values for the whole, so that the larger a range of utility values, the larger relative importance. This enables comparison of the strength of influence on the evaluation of each attribute.

First, for all evaluated items, relative importance was highest for distance from blister blocks, a trend that was particularly strong for ease of orienting. The importance of angle of approach was higher for ease of finding than for other items, suggesting a tendency to have an influence. Next, looking at utility value for each level of distance from the blister blocks shows that, for all evaluated items, the evaluation for 16 cm was markedly low. A positive effect was seen for both 8 cm and 12 cm, but although the difference between the two was negligible for ease of finding and ease of orientation, for confidence in crossing and peace of mind in crossing the 8 cm distance was evaluated more highly. No such clear difference was found in prior research, but as a result of the establishment of a longer walking distance for this experiment

Table 1
ANOVA on the Degree of Deviation at the 5 m point.

Variable	Sum of squares	df	Mean square	F ratio	Sig.
Distance from blister blocks	0.572	2	0.286	4.364	0.013
Approach angle	0.213	2	0.106	1.622	0.198
Distance from blister blocks * approach angle	0.091	4	0.023	0.347	0.846
Error	36.413	556	0.066		
Total	37.286	564			

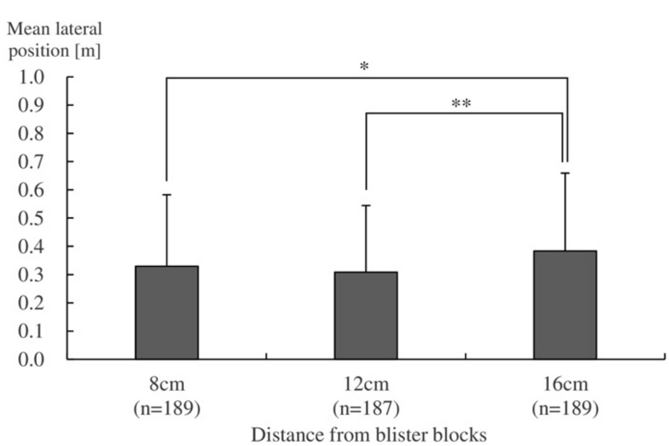

Fig. 10. Comparison of mean lateral position 5 m from starting point (*$p < 0.01$, **$p < 0.05$).

Table 2
ANOVA on the Degree of Deviation at the 10 m point.

Variable	Sum of squares	df	Mean square	F ratio	Sig.
Distance from blister blocks	0.498	2	0.249	1.160	0.312
Approach angle	0.781	2	0.391	1.820	0.163
Distance from blister blocks * approach angle	0.578	4	0.145	0.674	0.610
Error	113.073	527	0.215		
Total	114.903	535			

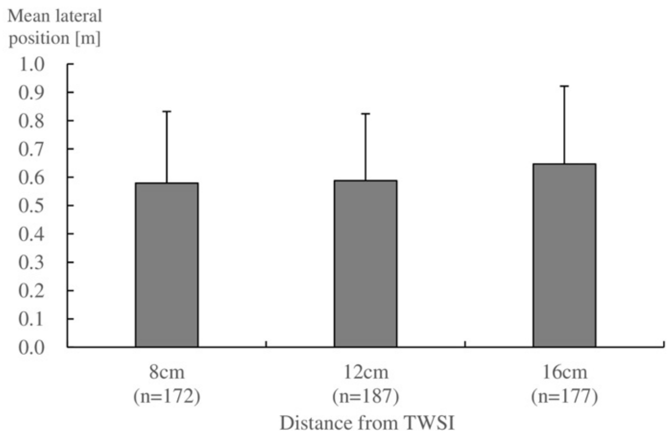

Fig. 11. Comparison of mean lateral position 10 m from starting point.

8 cm can be said to be advantageous in terms of sustaining a reduced psychological load after the start of crossing. With respect to the utility value of angle of approach participants tended to have greater difficulty in detecting when approaching at an angle than when approaching at 90°, but because the t-values were small for items other than ease of finding it would be difficult to conclude that there was any significant influence on behavior subsequent to orientation.

5. Conclusions and future issues

This paper examined optimal installation methods for newly proposed blocks to support the orientation of people with visual impairments when crossing the road using walking experiments over a longer distance than used in the past and conducted with subjects who were totally blind. While an evaluation of walking trajectories showed that the utilization of orientation blocks did constrain lateral deviation when crossing, it was shown that when the distance between blister blocks and orientation blocks was extended to 16 cm there was a significant increase in lateral deviation at the point 5 m from the start of crossing. Although this difference did not tend to grow larger at the 10 m mark, in terms of constraining deviation there is a need to install orientation blocks 8–12 cm from blister blocks.

In subjective evaluations elicited from participants in the experiment, for ease of finding orientation blocks and ease of orienting themselves, both the 8 cm and 12 cm distances from blister blocks were evaluated positively at comparable levels, but for confidence and peace of mind after the start of crossing the 8 cm distance was evaluated superior. While there was no clear difference in walking trajectory between 8 cm and 12 cm, there were different trends when looking at

Table 3
Result of conjoint analyses on subjective evaluations by participants in the experiment.

Evaluation item	Attribute	Relative importance	Level	Utility value	t-ratio
Discoverability	Distance from TWSI	55.9	8 cm	0.107	2.617
			12 cm	0.095	2.321
			16 cm	-0.202	-4.939
	Approach angle	44.1	90°	0.131	3.210
			Left 45°	-0.135	-3.309
			Right 45°	0.004	0.099
Ease of orientation	Distance from TWSI	62.0	8 cm	0.212	5.446
			12 cm	0.141	3.614
			16 cm	-0.353	-9.060
	Approach angle	38.0	90°	0.034	0.865
			Left 45°	-0.044	-1.120
			Right 45°	0.010	0.254
Confidence in crossing	Distance from TWSI	53.1	8 cm	0.181	2.552
			12 cm	0.018	0.255
			16 cm	-0.200	-2.807
	Approach angle	46.9	90°	-0.057	-0.797
			Left 45°	-0.016	-0.223
			Right 45°	0.073	1.021
Peace of mind in crossing	Distance from TWSI	59.2	8 cm	0.294	11.382
			12 cm	0.101	3.920
			16 cm	-0.396	-15.302
	Approach angle	39.0	90°	-0.016	-0.603
			Left 45°	-0.057	-2.186
			Right 45°	0.072	2.789

the mental state of participants in the experiment while crossing. Therefore, when seeking to reduce the psychological stress on users of crossing alone in addition to the characteristics of walking trajectory mentioned above, it is desirable to position the orientation blocks as close to 8 cm from the blister blocks as possible. Given the spatial restrictions when adding orientation blocks to crosswalk entrances where TWSI have already been installed, narrower gaps between orientation blocks and blister blocks are preferable; taken together with the conclusions mentioned above, this suggests high feasibility for installation on actual roads.

In addition, because angle of approach to the blister blocks was shown to have a significant influence on ease of finding the orientation blocks, in terms of the smoothness and efficiency of providing guidance, it is desirable wherever possible to enable approaching the crosswalk entrance from the perpendicular direction.

This paper reached certain conclusions through observations of walking trajectory and subjective evaluation based on a walking experiment over a 10 m section in a test space. Going forward, based on the results of the experiment, the authors will attempt a demonstration and evaluation in a real road space to confirm the potential for crossing support in actual road traffic environments. In addition, the authors will analyze the relationship of various individual characteristics such as walking skill, walking style, frequency of walking alone, and form of block use with walking performance and preference in considering in further detail what specifications offer even higher usability. Furthermore, there is a need to address guidance support for people with low vision and the elderly who are not totally blind, to incorporate input from local residents and road users other than those with visual impairments, to consider concrete specifications and positioning methods that are compatible with installation on public roads.

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