Gazing behavior exhibited by people with low vision while navigating streets

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ABSTRACT

“Low vision” is defined as uncorrectable vision loss that interferes with daily activities. The gazing behavior exhibited by people with low vision as they walk is particularly important because it illustrates how they utilize information in various environments. In this study, eight participants with low vision and eight fully sighted participants were asked to navigate a roadway and a sidewalk wearing a mobile eye-tracking device. Their gazing behavior and walking behavior were recorded and analyzed. As a result, on the roadway, participants with low vision walked while fixing their gazes mainly on the road surface and white traffic lines around 10 meters ahead, as well as on the buildings around 39 meters ahead. On the sidewalk, on the other hand, they walked while fixing their gaze mainly on the road surface and tactile paving seven to eight meters ahead, as well as on the buildings around 24 meters ahead. These findings suggest that people with low vision use not only nearby objects but also distant objects as visual cues. In addition, the importance of using continuous road surface markers, such as white traffic lines and tactile paving, to enable people with low vision to walk outdoors safely is suggested.

1. Introduction

1.1. Background

In 2010, the WHO estimated that 285 million people were visually disabled, 246 million of whom had low vision (WHO 2013). Low vision is defined as uncorrectable vision loss that interferes with daily activities (Massof and Lidoff 2001). Low vision can be attributed to a variety of diseases, such as glaucoma, age-related macular degeneration, retinitis pigmentosa, and diabetic retinopathy. Because many of these diseases are caused by aging, it is predicted...
that the number of people with low vision will significantly increase with the aging of society (Eye Diseases Prevalence Research Group 2004).

Low vision is known to have a negative impact on behavioral abilities, especially mobility (Burmedi et al. 2003). This is because, during travel, most environmental information is received through the visual sensory system. In order to maintain the independence of people with low vision, several orientation and mobility training programs have been developed in the field of low vision rehabilitation (Ivanov et al. 2016; Zijlstra, Ballemans, and Kempen 2012). However, few studies have examined how people with low vision use the information present in existing street environments.

1.2. Previous studies

Many existing studies suggest that vision plays a significant role in mobility performance. Burmedi et al. (2003) reviewed research on the behavioral competence of those with age-related low vision and concluded that age-related low vision was highly detrimental to mobility. Haymes et al. (1996) investigated the mobility performance of people with low vision and concluded that there was a highly significant correlation between clinical measures of residual vision and mobility. Bibby et al. (2007) also investigated the self-reported mobility performance of people with low vision. They found that vision was significantly correlated with self-reported mobility performance, pointing out that the visual field is the most efficient predictor of it. Regarding the hazards that people with low vision encounter, Goodrich and Ludt (2003) investigated the ability of people with low vision to visually detect hazards (drop-offs, obstacles on the travel surface, and head-height obstacles). They concluded that many study participants with low vision could not visually detect some hazards at a safe distance.

On the relationship between mobility performance and visual function, many studies have been conducted in an experimental indoor setting. For example, Black et al. (1997) compared the walking speed and number of errors between participants with low vision and fully sighted participants in indoor courses, and reported that people with low vision showed significantly lower walking speed and greater numbers of errors than fully sighted participants. On the other hand, several studies have been conducted in outdoor or real-world settings. Marron and Bailey (1982) investigated the relationship between mobility performance and visual acuity, visual fields, and contrast sensitivity of 19 participants with low vision walking on an outdoor mobility course and an indoor corridor. They reported that the visual field and contrast sensitivity were highly correlated with mobility performance. Leat and Lovie-Kitchin (2008) also analyzed the correlation between walking speed and visual acuity, visual field, and contrast sensitivities with mobility performance by having 35 participants with low vision walk a partially indoor and partially outdoor route. The results showed that loss of visual field reduced walking speed, while reduced visual acuity and contrast sensitivity affected distance and depth perception.

The gazing behavior of people with low vision, when they are walking, is particularly important because it illustrates which environmental features are needed for safe navigation and which information is missed. Previous studies on the gazing behavior of people with low vision are roughly divided into two groups: those done in indoor settings and those done in outdoor settings. In an example of a study conducted in an indoor setting, Turano et al. (2001) compared the gazing behavior of people with low vision and fully sighted people wearing an eye-tracking device while they were walking along an indoor corridor. Based on this study, they reported that, while fully sighted people directed their gaze primarily ahead or at the goal, people with low vision directed their gaze at objects on the walls, downward, or at the edges or boundaries between walls. Marigold and Patla (2007) created an indoor walkway with varying types of ground terrain and asked participants with and without visual disabilities to traverse the walkway while their gaze fixation was monitored. They found that the gaze fixation of participants with low vision was frequently located in a transitional region between various surfaces in addition to an actual surface. Similarly, Timmis et al. (2017) compared the gazing behavior of people with low vision and that of fully sighted people navigating an indoor walkway with obstacles on the surface. They reported that people with low vision demonstrated a more active visual search pattern, looking at more areas on the ground than fully sighted people. In addition, Matsuda et al. (2019) compared the gazing behavior of people with low vision and that of fully sighted people when they walked into a small clinic. They concluded that people with low vision tended to fixate on closer points more frequently than fully sighted people.

Although there are several studies on the gazing behavior of people with low vision in indoor environments, few studies have focused on the gazing behavior of people with low vision in outdoor environments. One of the few existing studies is that of Vargas-Martín and Peli (2006). In this study, the researchers recorded the eye movements of people with low vision when they walked in outdoor environments wearing an eye-tracking device and concluded that people with low vision exhibited narrower horizontal eye-position dispersions than fully sighted people. Another example of such a study is that of Geruschat et al. (2006). They investigated the gazing behavior of people with low vision as they crossed unfamiliar intersections and reported that participants with low vision due to age-related macular degeneration fixated less on vehicles and traffic controls
and more on crossing elements (curbs, bollards, and crosswalk lines) than fully sighted participants or participants who had a low vision due to glaucoma.

As we have shown so far, much of the research on mobility performance and visual function of people with low vision has been conducted in indoor, laboratory settings, and few studies have been conducted in outdoor settings. This is mainly because in outdoor settings there are far more complex variables such as the changes in illumination and road conditions which are difficult to control compared to the indoor and experimental settings. In order to solve this problem, Kuyk, Elliott, and Fuhr (1998) compared the walking performance (time to complete routes and the number of errors) measured in both indoor and outdoor settings. The results showed that walking performance between both settings was highly correlated, suggesting that experiments in outdoor settings could produce similar results to those in indoor settings.

1.3. Purpose of the study

Previous studies have suggested that visual information plays an important role in the mobility of people with low vision. However, most of the existing studies have been conducted in indoor experimental settings, with few studies conducted in real outdoor environments. In addition, the environmental features that people with low vision use when they navigate streets have not been investigated. The purpose of conducting this study is to clarify which types of visual information are used by people with low vision when they navigate streets quantitatively by analyzing gazing behavior using an eye-tracking device. This study was also conducted to clarify the characteristics of the gazing behavior of people with low vision by comparing it to that of fully sighted people.

2. Methods

2.1. Participants

At the beginning of this study, 11 people with low vision and eight fully sighted people participated in the study. However, three participants with low vision were excluded from the study because they were unable to complete the calibration process of the eye-tracking device, which is discussed below. Therefore, the final number of participants with low vision in this study was eight. Tables 1 and 2 show overviews of the fully sighted participants and those with low vision, respectively. All fully sighted participants were adults in their 20s and had a visual acuity of 20/20 or more. All the participants with low vision were adults in their 20s to 60s who had a visual acuity of 20/30 or under; six had visual field loss. Three of them used white canes when they walked outside, and all of them went out almost every day. None of the participants had previously visited the study site.

2.2. Experimental environment

Because we focused on analyzing which types of visual information people with low vision used in their daily environments, two types of streets on an existing block were selected as the experimental sites for this study (Figure 1). One was a roadway without sidewalks (hereinafter referred to as “the Roadway”), and the other was a relatively wide sidewalk (hereinafter referred to as “the Sidewalk”). These were both approximately 100 meters long, and each is described below.

The Roadway was located on the north side of the surveyed block and was approximately 6 meters wide. The surface of the Roadway was paved with black asphalt and had white traffic lines at approximately 0.8

| Participant ID | Gender | Age | Acuity (Right) | Acuity (Left) |
|----------------|--------|-----|----------------|---------------|
| FS 1           | Female | 20s | Greater than 20/20 | Greater than 20/20 |
| FS 2           | Female | 20s | Greater than 20/20 | Greater than 20/20 |
| FS 3           | Female | 20s | Greater than 20/20 | Greater than 20/20 |
| FS 4           | Female | 20s | 20/20           | 20/20          |
| FS 5           | Male   | 20s | 20/16           | 20/16          |
| FS 6           | Male   | 20s | 20/20           | 20/20          |
| FS 7           | Female | 20s | 20/13           | 20/13          |
| FS 8           | Female | 20s | 20/16           | 20/16          |

| Participant ID | Gender | Age | Diagnosis | Visual Acuity (Right) | Visual Acuity (Left) | Visual Field Loss (Right) | Visual Field Loss (Left) | Use of White cane | Frequency of going out alone |
|----------------|--------|-----|-----------|-----------------------|----------------------|--------------------------|--------------------------|------------------|-----------------------------|
| LV1            | Female | 20s | Retinitis pigmentosa | 20/30                | 20/40                | Peripheral               | Peripheral              | Yes              | Every day                   |
| LV2            | Male   | 50s | Retinitis pigmentosa | 20/30                | 20/40                | Peripheral               | Peripheral              | No               | Every day                   |
| LV3            | Female | 30s | Retinitis pigmentosa | 20/50                | 20/50                | Peripheral               | Peripheral              | Yes              | Every day                   |
| LV4            | Male   | 30s | Retinal detachment  | 20/70                | 0.0                  | Peripheral               | Peripheral              | Yes              | Every day                   |
| LV5            | Male   | 60s | Cataract, Microphthalmia | 0.0                  | 20/70                | -                        | -                        | No               | Every day                   |
| LV6            | Male   | 40s | Excessive myopia, Age-related macular degeneration | Hand motion | 20/200               | Central                  | -                        | No               | 5 days a week               |
| LV7            | Male   | 40s | Monochromatism      | 20/1000              | 20/1000              | Central                  | -                        | No               | Every day                   |
| LV8            | Female | 50s | Central serous choriodetinopathy | 20/2000 – 20/1000 | 20/2000 – 20/1000 | Central                  | -                        | No               | Every day                   |
meters from both sides of the road to indicate the walking zone for pedestrians. Regarding the traffic volume, there was little traffic by cars, bicycles, or pedestrians at the time of the survey.

The Sidewalk was located on the south side of the surveyed block and had a bus stop along the way. The width of the Sidewalk was approximately 5.2 meters, and the part that included the bus stop was narrower; the narrowest point was approximately 3.2 meters wide. The surface of the Sidewalk was paved with gray interlocking pavement tiles, and yellow tactile paving had been installed. Regarding the traffic volume, because there was an entrance to a subway station on the opposite side of the pedestrian crossing, there was a relatively large amount of pedestrian and bicycle traffic.

**2.3. Eye-tracking and definition of gaze fixation**

In this study, a mobile eye-tracking device, the EMR-9 developed by NAC Image Technology, was used. This device consists of two eye cameras fixed to the left and right sides of a participant’s face and a camera fixed to the top of his or her forehead. The two eye cameras record the gaze movements of the participants and the top camera records the surrounding environment. With these three cameras, this eye-tracking device can record participants’ gaze points with a 60 Hz recording frequency.

“Gaze fixation” occurs when a participant’s gaze remains fixed on an area for a specific amount of time. The use of these two parameters (i.e., fixation area and duration) to define gaze fixation has yet to be established (Kiefer, Giannopoulos, and Raubal 2014). As for the fixation area, Adachi and Akagi (1998) conducted an experiment in which a subject wearing an eye-tracking device walked while gazing at a red, circular target placed 16 meters away. They reported that the subject’s gaze points were located in an area within 5° of the visual angle. Based on this result, the area within 5° of the visual angle was adopted as the fixation area for this study. As for fixation duration, there have been various definitions proposed in previous research, ranging from 0.25 to 0 seconds. In this study, following Maltz and Shinar (1999) suggestion that a gaze duration of under 0.1 seconds should not be considered gaze fixation, a duration of 0.1 seconds or more has been adopted as the minimum threshold for gaze fixation duration.

**2.4. Procedure**

The experiments were conducted between 12:00 and 16:00. After explaining the research purpose and providing an outline of the experiment, the participants walked around the surveyed block once with the researchers to grasp the route and surrounding environments. Then, the participants wore an eye-tracking device, and perform a calibration process to match the location the participants were looking at to the gaze points recorded on the device. In this calibration process, the participants were asked to gaze the nine targets in sequence, about four meters ahead. At this point, three participants with low vision who could not finish the calibration process were excluded from this study. After the calibration, the participants walked clockwise around the surveyed block. Their walking behavior was recorded from behind using a digital video recorder. From the gaze data obtained from this one-round walk, the data on the Roadway and Sidewalk were extracted for the analysis. For each experiment, the illuminance on the Roadway and the Sidewalk were measured in the middle of the route, and the number of pedestrians (number of people passing or overtaking the participant), bicyclists, and cars were counted, which are shown in Table 3. Since the experimental site was surrounded by tall buildings and not exposed to direct sunlight, there was no significant difference in the illumination condition of the experimental site. There was also no significant difference in the number of pedestrians, bicyclists or cars.
Table 3. Conditions of the Roadway and the Sidewalk for each experiment.

| Participant ID | Weather | Illuminance (lx) | Number of pedestrians | Number of bicyclists | Number of cars | The Roadway | The Sidewalk |
|---------------|---------|-----------------|-----------------------|----------------------|---------------|-------------|-------------|
| FS 1          | Clear   | 2550            | 6                     | 1                    | 0             | 1890        | 20          |
| FS 2          | Clear   | 2440            | 1                     | 2                    | 3             | 2480        | 24          |
| FS 3          | Clear   | 2900            | 0                     | 0                    | 0             | 4360        | 27          |
| FS 4          | Cloudy  | 4510            | 3                     | 5                    | 0             | 5740        | 51          |
| FS 5          | Cloudy  | 3627            | 3                     | 1                    | 9             | 4690        | 30          |
| FS 6          | Cloudy  | 1091            | 2                     | 2                    | 1             | 1477        | 26          |
| FS 7          | Cloudy  | 2130            | 2                     | 1                    | 1             | 2230        | 28          |
| FS 8          | Cloudy  | 1670            | 8                     | 3                    | 2             | 2170        | 36          |
| LV 1          | Cloudy  | 5080            | 3                     | 0                    | 0             | 6760        | 21          |
| LV 2          | Cloudy  | 2530            | 0                     | 0                    | 0             | 2230        | 12          |
| LV 3          | Cloudy  | 2994            | 3                     | 0                    | 0             | 3372        | 25          |
| LV 4          | Cloudy  | 1783            | 2                     | 0                    | 0             | 2150        | 17          |
| LV 5          | Cloudy  | 2150            | 3                     | 2                    | 0             | 2120        | 22          |
| LV 6          | Cloudy  | 2190            | 1                     | 1                    | 1             | 2480        | 28          |
| LV 7          | Cloudy  | 4307            | 3                     | 1                    | 0             | 4848        | 24          |
| LV 8          | Cloudy  | 6650            | 2                     | 2                    | 1             | 6700        | 53          |
| SD:           |         | 3037.6          | 2.7                   | 1.3                  | 1.1           | 3486.7      | 27.8        |

After walking, the participants were asked to evaluate the walkability of the Roadway and Sidewalk on a five-point scale (5: very easy to navigate, 1: very difficult to navigate). The researchers asked the participants to provide reasons for their evaluations and recorded them. In addition, the researchers measured the luminance of the surface of the Roadway, Sidewalk, white lines, and tactile paving.

3. Results

3.1. Walking speed and gazing behavior

The walking speed of each participant was calculated on both the Roadway and the Sidewalk, and a Mann–Whitney U-test was conducted to assess differences between the participants with low vision and fully sighted participants. No significant difference was found (Table 4). Then, total fixation counts, the average fixation duration, the average distance to the objects of fixation, and the average distance from the ground of fixation were compared between participants with low vision and fully sighted participants using a Mann–Whitney U-test on data from both the Roadway and the Sidewalk. This time, there were significant differences in the average height of fixation on both the Roadway and the Sidewalk, indicating that the participants with low vision had gazed at lower points than the fully sighted participants (Tables 5 and 6).

Table 4. Comparison of walking speed.

|                  | Roadway                          | Sidewalk                        |
|------------------|----------------------------------|---------------------------------|
|                  | Mean (m/s)                      | SD                              | U     | p-value | Mean (m/s) | SD | U     | p-value |
| Fully sighted participants | 1.20                           | 0.15                            | 30.5  | 0.878   | 1.22       | 0.08 | 23.5 | 0.382  |
| Participants with low vision    | 1.17                           | 0.17                            |       |         |            |      |      |        |

Table 5. Comparison of gazing behavior on the Roadway.

|                           | Fully sighted participants | Participants with low vision |
|---------------------------|----------------------------|-----------------------------|
|                           | Mean                       | SD                          | U     | p-value |
| Total fixation count (times) | 147.5                     | 70.2                        |       |         |
| Average fixation duration (s) | 0.27                      | 0.07                        |       |         |
| Average fixation distance (m) | 23.14                     | 12.34                       |       |         |
| Average fixation height (m)  | 3.52                      | 1.58                        |       |         |
|                           | Mean                       | SD                          | U     | p-value |
| Total fixation count (times) | 155.9                     | 50.5                        | 35.0  | 0.798   |
| Average fixation duration (s) | 0.30                      | 0.08                        | 37.0  | 0.645   |
| Average fixation distance (m) | 17.81                     | 10.22                       | 22.0  | 0.328   |
| Average fixation height (m)  | 1.02                      | 0.89                        | 3.0   | 0.001** |

**p < .01

Table 6. Comparison of gazing behavior on the Sidewalk.

|                           | Fully sighted participants | Participants with low vision |
|---------------------------|----------------------------|-----------------------------|
|                           | Mean                       | SD                          | U     | p-value |
| Total fixation count (times) | 160.0                     | 81.8                        |       |         |
| Average fixation duration (s) | 0.24                      | 0.06                        |       |         |
| Average fixation distance (m) | 19.93                     | 9.64                        |       |         |
| Average fixation height (m)  | 2.83                      | 1.16                        |       |         |
|                           | Mean                       | SD                          | U     | p-value |
| Total fixation count (times) | 187.3                     | 73.9                        | 38.0  | 0.574   |
| Average fixation duration (s) | 0.26                      | 0.04                        | 44.0  | 0.234   |
| Average fixation distance (m) | 12.84                     | 10.82                       | 15.0  | 0.083   |
| Average fixation height (m)  | 0.86                      | 0.72                        | 4.0   | 0.002** |

**p < .01
3.2. Classification of gaze fixation targets

From the data, the elements that were subject to gazing for longer than 0.1 seconds within 5° of the visual angles were extracted as gaze fixation targets. Then, these gaze fixation targets were classified into five categories: fixed objects, semi-fixed objects, non-fixed objects, objects on the ground, and the sky. The fixed objects consisted of buildings, utility poles, road fixtures (road signs, streetlamps, guardrails, traffic mirrors, signals, utility pole guywires, roadside trees, vending machines, bus stops, and bulletin boards), fixed signboards, and objects on private land (parked cars in parking lots, fences, and trees). The semi-fixed objects consisted of sidewalk signs, temporarily parked vehicles (cars, bicycles, and motorcycles), and other movable objects such as traffic cones, flags and banners, and garbage cans. The non-fixed objects consisted of people, cars, bicycles, and motorcycles. The objects on the ground consisted of the road surface, white traffic lines, tactile paving, and objects on the road surface such as manhole covers, gutters, and curbs (Table 7).

| CATEGORY | ELEMENTS |
|----------|----------|
| FIXED OBJECTS | Buildings, Utility Poles, Road fixtures (road signs, streetlamps, guardrails, traffic mirrors, signals, utility pole guywires, roadside trees, vending machines, bus stops, bulletin boards), Fixed signboards, and Objects on private land (parked cars in parking lots, fences, trees) |
| SEMI-FIXED OBJECTS | Sidewalk signs, Temporarily parked vehicles (cars, bicycles, motorcycles), Other movable objects (traffic cones, flags and banners, garbage cans) |
| NON-FIXED OBJECTS | People, Cars, Bicycles, motorcycles |
| OBJECTS ON THE GROUND | Road surface, White traffic lines, Tactile paving, Objects on the road surface (traffic paints, manhole covers, gutters, curbs), Private land |
| SKY | |

3.3. Gaze fixation patterns on the roadway

For the Roadway, the ratio of the fixation count of each element to the total fixation count (hereafter referred to as the “fixation ratio”) was calculated. Then, the fixation ratio, the average fixation distance, and the average fixation height were calculated and compared between participants with low vision and fully sighted participants using a Mann–Whitney U-test (Tables 8–10). Regarding the fixation ratio, participants with low vision directed a significantly higher proportion of their gaze fixations at the road surface, white traffic lines, and the objects on the road surface compared to fully sighted participants. On the other hand, fully sighted participants directed a significantly higher proportion of their gaze fixations at buildings compared to participants with low vision. Regarding the average fixation distance, participants with low vision tended to fix their gaze on the objects present on the road surface at a significantly shorter distance than fully sighted participants. In addition, concerning the average fixation height, there was a significant difference only regarding utility poles, and the participants with low vision tended to fix their gaze on

| Table 8. Comparison of the fixation ratio on the Roadway. |
|-----------------|-----------------|-----------------|-----------------|
|                  | Fully sighted people | People with low vision | p-value |
|                  | Mean | SD   | Mean | SD   |               |
| Objects on the ground | 3.5  | 3.1  | 26.7 | 19.0 | 0.000**        |
| White traffic lines | 1.0  | 0.9  | 17.1 | 10.1 | 0.000**        |
| Tactile paving    | 0.1  | 0.2  | 0.8  | 1.0  | 0.083          |
| Objects on the road surface | 1.3  | 1.5  | 6.2  | 2.7  | 0.000**        |
| Private land      | 0.8  | 0.9  | 2.0  | 1.6  | 0.161          |
| Fixed objects     | 65.4 | 12.2 | 24.2 | 18.5 | 0.001**        |
| Utility poles     | 11.5 | 7.4  | 11.1 | 7.8  | 0.959          |
| Road fixtures     | 2.3  | 4.2  | 1.9  | 3.5  | 0.959          |
| Fixed signboards  | 0.6  | 0.9  | 0.5  | 0.6  | 1.000          |
| Objects on private land | 2.7  | 2.3  | 1.9  | 2.2  | 0.382          |
| Semi-fixed objects | 2.0  | 3.1  | 0.7  | 0.8  | 0.721          |
| Temporarily parked vehicles | 1.7  | 3.0  | 3.2  | 2.4  | 0.234          |
| Other movable objects | 0.0  | 0.0  | 0.3  | 0.6  | 0.442          |
| Non-fixed objects | 2.0  | 2.4  | 2.8  | 3.2  | 0.574          |
| People            | 2.9  | 6.1  | 0.4  | 1.0  | 0.645          |
| Cars              | 1.4  | 2.8  | 0.3  | 0.5  | 1.000          |
| Bicycles and motorcycles | 0.9  | 1.2  | 0.0  | 0.0  | 0.234          |

**p < .01


### Table 9. Comparison of the average fixation distance on the Roadway.

|                                | Fully sighted people Mean | Fully sighted people SD | People with low vision Mean | People with low vision SD | p-value |
|--------------------------------|---------------------------|-------------------------|----------------------------|---------------------------|---------|
| **Objects on the ground**      |                           |                         |                            |                           |         |
| Road surface                   | 18.9                      | 17.1                    | 10.6                       | 6.9                       | 0.382   |
| White traffic lines            | 15.1                      | 19.7                    | 11.3                       | 7.9                       | 1.000   |
| Tactile paving                 | 2.0                       | 3.7                     | 3.6                        | 3.0                       | 0.382   |
| Objects on the road surface    | 3.7                       | 4.6                     | 8.8                        | 2.2                       | 0.050*  |
| Private land                   | 10.2                      | 19.0                    | 7.8                        | 9.5                       | 0.721   |
| **Fixed objects**              |                           |                         |                            |                           |         |
| Buildings                      | 27.0                      | 13.5                    | 38.9                       | 20.4                      | 0.161   |
| Utility poles                  | 12.2                      | 5.7                     | 10.4                       | 5.7                       | 0.798   |
| Road fixtures                  | 10.0                      | 14.0                    | 3.0                        | 3.6                       | 0.442   |
| Fixed signboards               | 2.7                       | 4.5                     | 7.3                        | 12.3                      | 0.798   |
| Objects on private land        | 22.5                      | 15.5                    | 15.3                       | 16.8                      | 0.442   |
| **Semi-fixed objects**         |                           |                         |                            |                           |         |
| Sidewalk signs                 | 7.0                       | 12.0                    | 2.6                        | 3.2                       | 0.721   |
| Temporarily parked vehicles    | 2.5                       | 4.0                     | 5.7                        | 6.9                       | 0.279   |
| Other movable objects          | 0.0                       | 0.0                     | 1.2                        | 2.6                       | 0.442   |
| **Non-fixed objects**          |                           |                         |                            |                           |         |
| People                         | 7.6                       | 11.2                    | 16.8                       | 17.8                      | 0.234   |
| Cars                           | 3.0                       | 6.4                     | 0.8                        | 2.3                       | 0.721   |
| Bicycles and motorcycles       | 2.5                       | 5.1                     | 5.2                        | 7.8                       | 0.574   |

*p < .05

### Table 10. Comparison of the average fixation height on the Roadway.

|                                | Fully sighted people Mean | Fully sighted people SD | People with low vision Mean | People with low vision SD | p-value |
|--------------------------------|---------------------------|-------------------------|----------------------------|---------------------------|---------|
| Fixed objects                  |                           |                         |                            |                           |         |
| Buildings                      | 4.3                       | 1.8                     | 2.7                        | 1.8                       | 0.065   |
| Utility poles                  | 2.9                       | 1.1                     | 1.0                        | 0.8                       | 0.003** |
| Road fixtures                  | 2.2                       | 3.0                     | 0.7                        | 0.6                       | 0.234   |
| Fixed signboards               | 0.8                       | 1.2                     | 0.8                        | 0.8                       | 0.105   |
| Objects on private land        | 1.5                       | 1.0                     | 0.8                        | 0.8                       | 0.105   |
| Sidewalk signs                 | 0.5                       | 0.6                     | 0.3                        | 0.4                       | 0.721   |
| Temporarily parked vehicles    | 0.7                       | 1.1                     | 0.5                        | 0.4                       | 0.505   |
| Other movable objects          | 0.0                       | 0.0                     | 0.1                        | 0.2                       | 0.442   |
| Non-fixed objects              |                           |                         |                            |                           |         |
| People                         | 0.7                       | 0.8                     | 0.9                        | 0.6                       | 0.878   |
| Cars                           | 0.3                       | 0.6                     | 0.1                        | 0.2                       | 0.645   |
| Bicycles and motorcycles       | 0.3                       | 0.6                     | 0.6                        | 0.8                       | 0.505   |

**p < .01

**p < .05

a significantly lower part of them compared to fully sighted participants.

### 3.4. Gaze fixation patterns on the sidewalk

For the Sidewalk, as for the Roadway, the fixation ratio, the average fixation distance, and the average fixation height were compared between the participants with low vision and fully sighted participants using a Mann–Whitney U-test (Tables 11–13). As a result, regarding the fixation ratio, participants with low vision directed a significantly higher proportion of their gaze fixations at the road surface, tactile paving, objects on the road surface, and objects on private land than fully sighted participants. On the other hand, fully sighted participants directed a significantly higher proportion of their gaze fixations at buildings, fixed signboards, and

### Table 11. Comparison of the fixation ratio on the Sidewalk.

|                                | Fully sighted people Mean | Fully sighted people SD | People with low vision Mean | People with low vision SD | p-value |
|--------------------------------|---------------------------|-------------------------|----------------------------|---------------------------|---------|
| Fixed objects                  |                           |                         |                            |                           |         |
| Buildings                      | 45.7                      | 19.9                    | 17.5                       | 9.8                       | 0.007** |
| Utility poles                  | 2.5                       | 2.4                     | 0.9                        | 1.8                       | 0.105   |
| Road fixtures                  | 6.2                       | 4.5                     | 5.1                        | 7.5                       | 0.382   |
| Fixed signboards               | 7.1                       | 7.4                     | 0.7                        | 1.2                       | 0.003** |
| Objects on private land        | 0.9                       | 1.4                     | 1.8                        | 2.4                       | 0.234   |
| Semi-fixed objects             |                           |                         |                            |                           |         |
| Sidewalk signs                 | 2.9                       | 3.1                     | 3.4                        | 3.0                       | 0.721   |
| Temporarily parked vehicles    | 1.4                       | 1.4                     | 4.3                        | 4.4                       | 0.105   |
| Other movable objects          | 1.7                       | 3.1                     | 1.7                        | 1.5                       | 0.574   |
| Non-fixed objects              |                           |                         |                            |                           |         |
| People                         | 12.9                      | 6.8                     | 21.4                       | 9.6                       | 0.130   |
| Cars                           | 1.3                       | 2.4                     | 0.7                        | 1.0                       | 0.959   |
| Bicycles and motorcycles       | 0.1                       | 0.2                     | 1.5                        | 1.8                       | 0.050   |
| **Sky**                        | 13.7                      | 14.7                    | 1.2                        | 1.8                       | 0.002** |

**p < .01
the sky than participants with low vision. Regarding the average fixation distance, participants with low vision tended to fix their gaze on fixed signboards at significantly closer points than fully sighted participants. Concerning the average fixation height, participants with low vision tended to fix their gaze at significantly lower parts of buildings, fixed signboards, and people than fully sighted participants.

### 3.5. Comparison of the fixation ratio between the roadway and the sidewalk

In order to evaluate the effect of differences in environmental components on the fixation ratio, the fixation ratio between the Roadway and the Sidewalk of both the participants with low vision and fully sighted participants was compared using Mann–Whitney U-test. The results of fully sighted participants (Table 14) indicate that they directed

| Table 12. Comparison of the average fixation distance on the Sidewalk. | Fully sighted people | People with low vision | p-value |
|---|---|---|---|
| Objects on the ground | | | |
| Road surface | 7.2 | 5.8 | 8.0 | 3.8 | 1.000 |
| White traffic lines | 6.3 | 2.0 | 6.8 | 3.0 | 0.798 |
| Tactile paving | 7.0 | 6.5 | 2.9 | 4.9 | 0.028 |
| Objects on the road surface | 1.9 | 4.9 | 1.7 | 3.7 | 0.195 |
| Private land | 14.9 | 9.1 | 20.3 | 7.7 | 0.038* |
| Fixed objects | | | |
| Buildings | 29.9 | 23.1 | 24.0 | 22.2 | 0.328 |
| Utility poles | 16.5 | 16.4 | 8.1 | 16.3 | 0.161 |
| Road fixtures | 14.9 | 9.1 | 12.7 | 14.6 | 0.442 |
| Fixed signboards | 20.3 | 7.7 | 7.7 | 11.7 | 0.038* |
| Objects on private land | 2.9 | 5.1 | 5.0 | 4.7 | 0.234 |
| Semi-fixed objects | | | |
| Sidewalk signs | 5.0 | 3.9 | 8.4 | 4.1 | 0.161 |
| Temporarily parked vehicles | 7.1 | 6.7 | 8.6 | 2.4 | 0.382 |
| Other movable objects | 5.0 | 5.9 | 6.6 | 5.8 | 0.645 |
| Non-fixed objects | | | |
| People | 9.5 | 5.6 | 9.8 | 4.7 | 0.721 |
| Cars | 9.8 | 14.2 | 8.2 | 11.8 | 0.878 |
| Bicycles and motorcycles | 0.6 | 1.6 | 4.8 | 5.5 | 0.083 |

*p < .05

| Table 13. Comparison of the average fixation height on the Sidewalk. | Fully sighted people | People with low vision | p-value |
|---|---|---|---|
| Fixed objects | | | |
| Buildings | 3.7 | 1.4 | 2.1 | 1.6 | 0.050 |
| Utility poles | 1.9 | 1.5 | 0.8 | 1.5 | 0.161 |
| Road fixtures | 1.9 | 0.9 | 1.2 | 1.0 | 0.161 |
| Fixed signboards | 3.7 | 1.1 | 1.2 | 1.8 | 0.005** |
| Objects on private land | 0.4 | 0.6 | 0.6 | 0.5 | 0.328 |
| Semi-fixed objects | | | |
| Sidewalk signs | 1.0 | 0.7 | 0.8 | 0.4 | 0.442 |
| Temporarily parked vehicles | 0.9 | 0.6 | 0.8 | 0.3 | 0.328 |
| Other movable objects | 0.9 | 0.9 | 0.5 | 0.7 | 0.645 |
| Non-fixed objects | | | |
| People | 1.2 | 0.5 | 1.0 | 0.3 | 0.038* |
| Cars | 0.7 | 1.0 | 0.5 | 0.7 | 0.645 |
| Bicycles and motorcycles | 0.2 | 0.5 | 0.6 | 0.6 | 0.161 |

*p < .05, ** p < .01

| Table 14. Comparison of the fixation ratio of fully sighted participants. | Roadway | Sidewalk | p-value |
|---|---|---|---|
| Objects on the ground | | | |
| Road surface | 3.5 | 3.1 | 2 | 2.1 | 0.279 |
| White traffic lines | 1 | 0.9 | 0 | 0 | 0.010* |
| Tactile paving | 0.1 | 0.2 | 1 | 0.7 | 0.021* |
| Objects on the road surface | 1.3 | 1.5 | 0.2 | 0.3 | 0.328 |
| Private land | 0.8 | 0.9 | 0.3 | 0.8 | 0.442 |
| Fixed objects | | | |
| Buildings | 65.4 | 12.2 | 45.7 | 19.9 | 0.038* |
| Utility poles | 11.5 | 7.4 | 2.5 | 2.4 | 0.015* |
| Road fixtures | 2.3 | 4.2 | 6.2 | 4.5 | 0.083 |
| Fixed signboards | 0.6 | 0.9 | 7.1 | 7.4 | 0.001** |
| Objects on private land | 1.7 | 2.3 | 0.9 | 1.4 | 0.002* |
| Semi-fixed objects | | | |
| Sidewalk signs | 2 | 3.1 | 2.9 | 3.1 | 0.382 |
| Temporarily parked vehicles | 1.7 | 3 | 1.4 | 1.4 | 0.505 |
| Other movable objects | 0 | 0 | 1.9 | 3.1 | 0.038* |
| Non-fixed objects | | | |
| People | 2 | 2.4 | 12.9 | 6.8 | 0.005** |
| Cars | 2.9 | 6.1 | 1.3 | 2.4 | 0.878 |
| Bicycles and motorcycles | 1.4 | 2.8 | 0.1 | 0.2 | 0.645 |
| Sky | 0.9 | 1.2 | 13.7 | 14.7 | 0.234 |

*p < .05, ** p < .01
a significantly higher proportion of gaze fixation at the white traffic lines on the Roadway, and a significantly lower proportion of gaze fixation at the tactile paving and people on the Sidewalk. This is mainly because of the differences in the environmental components, such as the lack of the white traffic lines on the Sidewalk, as well as the differences in the number of pedestrians. In addition, the fully sighted participants directed a significantly higher proportion of gaze fixation at buildings compared to the Sidewalk. This result indicates that in an environment with many elements such as the Sidewalk, fully sighted participants are more likely to disperse their gaze.

As for the participants with low vision, while the results (Figure 2) show a similar trend overall, there is no significant difference in the proportion of gaze fixation at the buildings. This fact suggests that the gaze fixation pattern does not change with environmental changes in participants with low vision as much as it does in fully sighted participants.

### 3.6. Evaluation of roadway and sidewalk walkability

The evaluations of the walkability of the Roadway and the Sidewalk by participants with low vision and fully sighted participants were aggregated (Figure 2). Participants with low vision tended to evaluate the walkability of both the Roadway and the Sidewalk more highly than fully sighted participants. In addition, both participants with low vision and those without visual disabilities evaluated the walkability of the Roadway more highly than that of the Sidewalk. However, no significant difference between evaluations of the walkability of the Roadway and the Sidewalk by the two groups was found using the Mann-Whitney U test.

| Table 15. Comparison of the fixation ratio of participants with low vision. | Roadway | Sidewalk | p-value |
|---|---|---|---|
| **Objects on the ground** | **Mean** | **SD** | **Mean** | **SD** | **p-value** |
| Road surface | 26.7 | 19 | 21.8 | 15.2 | 0.798 |
| White traffic lines | 17.1 | 10.1 | 0.1 | 0.1 | 0.000** |
| Tactile paving | 0.8 | 1 | 9 | 5.6 | 0.000** |
| Objects on the road surface | 6.2 | 2.7 | 7.1 | 10.3 | 0.161 |
| Private land | 2 | 1.6 | 1.9 | 1.8 | 1.000 |
| **Fixed objects** | | | | | |
| Buildings | 24.2 | 18.5 | 17.5 | 9.8 | 0.721 |
| Utility poles | 11.1 | 7.8 | 0.9 | 1.8 | 0.007** |
| Road fixtures | 1.9 | 3.5 | 5.1 | 7.5 | 0.328 |
| Fixed signboards | 0.5 | 0.9 | 0.7 | 1.2 | 0.645 |
| Objects on private land | 1.9 | 2.2 | 1.8 | 2.4 | 1.000 |
| **Semi-fixed objects** | | | | | |
| Sidewalk signs | 0.7 | 0.8 | 3.4 | 3 | 0.038* |
| Temporarily parked vehicles | 3.2 | 2.4 | 4.3 | 4.4 | 0.878 |
| Other movable objects | 0.3 | 0.6 | 1.7 | 1.5 | 0.050* |
| **Non-fixed objects** | | | | | |
| People | 2.8 | 3.2 | 21.4 | 9.6 | 0.000** |
| Cars | 0.4 | 1 | 0.7 | 1 | 0.505 |
| Bicycles and motorcycles | 0.3 | 0.5 | 1.5 | 1.8 | 0.195 |
| Sky | 0 | 0 | 1.2 | 1.8 | 0.105 |

*p < 0.05, **p < 0.01
The results of the interviews regarding the reasons given for the evaluations were summarized for each group of participants (Tables 16 and 17). Regarding the reasons given for the evaluations of the Roadway, fully sighted participants evaluated it poorly due to the presence of utility poles and traffic on the road, whereas participants with low vision evaluated it highly due to the presence of white traffic lines on the road and the absence of traffic. On the other hand, regarding the Sidewalk, both participants with low vision and participants without visual disabilities stated that it was difficult to walk because there were many pedestrians and bicycles. Participants with low vision also stated that they were worried that there were many obstacles on the road, such as sidewalk signs and temporarily parked bicycles.

4. Discussion

4.1. Characteristics of the gazing behavior of participants with low vision on the roadway

Participants with low vision and fully sighted participants evaluated the Roadway as an environment that was easy to navigate while walking. When providing reasons for their evaluations, both groups of participants pointed out that there were few obstacles and little traffic from cars or pedestrians (Table 17).

The analysis of gaze fixation patterns indicates that fully sighted participants walked while fixing their gaze mainly on buildings and that they seldom fixed their gaze on other objects. On the other hand, the participants with low vision tended to walk while fixing their gaze on the road surface and white traffic lines on the road (Table 8). In order to show the overall gaze

| Table 16. Reasons given for evaluations of the walkability of the Roadway. |
|---------------------------------------------------------------|
| **Type of participant** | **Evaluation** | **Reason** |
|------------------------|---------------|------------|
| Fully sighted participants | 5             | It is easy to navigate it because there are few pedestrians or cars and it is wide. It is easy to navigate it because of the good view and absence of cars. |
|                         | 4             | It is easy to navigate it because there are no obstacles other than a few utility poles. I felt a little anxious because of the cars passing through. It is easy to navigate it because there are few cars or pedestrians, but I needed to avoid the utility poles. |
|                         | 2             | It is difficult to navigate it because there are utility poles in the walking zone. I feel uneasy because the speed of the cars is high. There is no sidewalk, so you must be careful to avoid the cars. I’m worried about the sound of the cars coming from ahead and behind. It is difficult to know where to walk. |
| Participants with low vision | 5           | It is easy to navigate it because the road is flat, there are white traffic lines, and there are few cars. The contrast between the asphalt and the white traffic lines is so strong that it is easy to find the white traffic lines. |
|                         | 4             | It is easy to navigate it because the white traffic lines are uninterrupted. The utility poles are annoying. It is easy to navigate it because there are few pedestrians and the white traffic lines can be used as a clue. It is easy to navigate it because there are few cars or pedestrians, but I was surprised when people suddenly emerged at the corner. I feel comfortable navigating it because there are few cars. While walking, I can look at the white traffic lines, but sometimes the utility poles get in the way. It is easy to navigate it because there are white traffic lines, but I am worried about the obstacles on the right side of the road. |
|                         | 2             | I am worried because I must avoid cars while also avoiding utility poles. |

5: Easy to navigate, 4: Relatively easy to navigate, 3: Neutral, 2: Relatively hard to navigate, 1: Hard to navigate.

| Table 17. Reasons given for evaluations of the walkability of the Sidewalk. |
|---------------------------------------------------------------|
| **Type of participant** | **Evaluation** | **Reason** |
|------------------------|---------------|------------|
| Fully sighted participants | 5             | There are many pedestrians, but I don't care much. |
|                         | 4             | It is wide and easy to navigate, but I must be careful to avoid pedestrians and bicycles. |
|                         | 3             | There are too many pedestrians, but the road is wide. |
|                         | 1             | There is too much bicycle and pedestrian traffic. There are too many pedestrians. There are too many pedestrians. The tactile paving is also in the way. There are too many pedestrians and bicycles. I'm scared of a bicycle coming up from behind. There are too many pedestrians and bicycles. The bicycles coming from ahead and behind are dangerous. |
| Participants with low vision | 4             | The road is wide and easy to navigate, but I am worried about the pedestrians and parked bicycles. It is difficult to navigate because there are so many pedestrians and parked bicycles. There are many pedestrians and it is difficult to navigate it. I felt that I was about to hit a store sign. The tactile paving can be used as a clue. I must watch out for people exiting stores. |
|                         | 2             | I am anxious about the presence of so many pedestrians. There are so many objects as well. I'm scared that a bicycle may suddenly appear. I don't know which way to go to avoid them. Because there are so many objects, I become tired when deciding what to focus on. |
|                         | 1             | There are many pedestrians and bicycles, which makes me very worried. |

5: Easy to navigate, 4: Relatively easy to navigate, 3: Neutral, 2: Relatively hard to navigate, 1: Hard to navigate.

| Table 18. Summary of gazing behavior of fully sighted participants on the Roadway. |
|----------------------------------|----------------|----------------|
|                                  | **Fixation ratio (%)** | **Average fixation distance (m)** | **Average fixation height (m)** |
| Buildings                        | 65.4**          | 27.1           | 4.3           |
| Utility poles                    | 11.5            | 12.2           | 2.9**         |
| Road surface                     | 3.5             | 18.9           | 0.0           |

**p < .01**
tendencies of the participants, the fixed elements with a high fixation ratio were aggregated until the total fixation ratio exceeded 80%. The average distances and fixation heights for each element are summarized in Tables 18 and 19. Asterisks indicate items for which there were significant differences between participants with low vision and fully sighted participants. In addition, the fixation ratio, average fixation distance, and average fixation height for these elements are illustrated in Figure 3. The diameter of the circle in the figure is proportional to the fixation ratio.

These results show that, on the Roadway, fully sighted participants walked while fixing their gaze on mainly the high parts of distant buildings, whereas participants with low vision walked while fixing their gaze on the road surface and white traffic lines on the road about 10 meters ahead. Participants with low vision also fixed their gaze on distant buildings to some extent. To summarize the characteristics of the gaze fixation pattern of participants with low vision, the road surface and white traffic lines on the road approximately 10 meters ahead were used as the main clues to determine their direction, and distant buildings were used as clues to ensure that the direction was correct. While a previous study analyzing the gazing behavior of people with low vision in an indoor setting (Matsuda et al. 2019) reported that people with low vision tended to fixate on closer points, this result indicates that the people with low vision walk on the Roadway using distant information for some extent as well.

### 4.2. Characteristics of the gazing behavior of participants with low vision on the sidewalk

Both the participants with low vision and fully sighted participants evaluated the Roadway as an environment that was relatively difficult to navigate while walking. Thus, fully sighted participants pointed out that there were too many people and bicycles, and participants with low vision pointed out that there were many additional obstacles, such as sidewalk signs (Table 17). Based on the analysis of gaze fixation patterns, it is suggested that the fixation ratio of fully sighted participants decreased by 20% for buildings compared to the Roadway, and the fixation ratios for people and signboards increased accordingly (Table 11). On the other hand, the participants with low vision tended to walk while fixing their gaze on the road surface, as they did on the Roadway, but the average fixation distance to the road surface was 6.8 to 8.5 meters, which is shorter than that for the Roadway. In addition, 21.4% of total gaze fixation was directed at people who were 9.5 meters away, on average. As in the previous section, the elements with high fixation ratios were aggregated until the total fixation ratio exceeded 80%. The average distances and fixation heights for each element are summarized in Tables 20 and 21. In addition, the fixation ratio, average fixation distance, and average fixation height for these elements are illustrated in Figure 4.

These results indicate that, on the Sidewalk, fully sighted participants, while fixing their gaze on mainly

### Table 19. Summary of gazing behavior of participants with low vision on the Roadway.

| Element                          | Fixation ratio (%) | Average fixation distance (m) | Average fixation height (m) |
|----------------------------------|--------------------|-------------------------------|----------------------------|
| Road surface                     | 26.7**             | 10.6                          | 0.0                        |
| Buildings                        | 24.2               | 38.9                          | 2.7                        |
| White traffic lines              | 17.1**             | 11.3                          | 0.0                        |
| Utility poles                    | 11.3               | 10.4                          | 1.0                        |
| Objects on the road surface      | 6.2**              | 8.8                           | 0.0                        |

**: p < .01

![Figure 3](image-url). Diagram of gazing behavior on the Roadway.
Table 20. Summary of the gazing behavior of fully sighted participants on the Sidewalk.

|                  | Fixation ratio (%) | Average fixation distance (m) | Average fixation height (m) |
|------------------|--------------------|-------------------------------|----------------------------|
| Buildings        | 45.7***            | 29.9                          | 3.7*                       |
| People           | 12.9               | 9.5                           | 1.2*                       |
| Fixed signboards | 7.1**              | 20.3**                        | 3.7**                      |
| Sky              | 3.7**              | -                             | -                          |

*: p < .05, **: p < .01

Table 21. Summary of the gazing behavior of participants with low vision on the Sidewalk.

|                  | Fixation ratio (%) | Average fixation distance (m) | Average fixation height (m) |
|------------------|--------------------|-------------------------------|----------------------------|
| Road surface     | 21.8**             | 8.0                           | 0.0                        |
| People           | 21.4               | 9.8                           | 1.0*                       |
| Buildings        | 17.5**             | 24.0                          | 2.1*                       |
| Tactile paving   | 9.0***             | 6.8                           | 0.0                        |
| Objects on the road surface | 7.1**      | 8.5                           | 0.0                        |
| Road fixtures    | 5.1                | 12.7                          | 1.2                        |

*: p < .05, **: p < .01

Figure 4. Diagram of gazing behavior on the Sidewalk.

distant buildings, fixed their gaze partially on people at a short distance. Participants with low vision fixed their gaze not only on distant buildings and nearby road surfaces but also on nearby people. This relatively complicated gazing pattern, which requires one to gaze at both distant and nearby objects and people, is believed to contribute to a decreased evaluation of an area’s walkability.

4.3. Elements that support walking safety for participants with low vision

The results of this study revealed that, when walking along streets, participants with low vision used the white traffic lines on the Roadway and tactile paving on the Sidewalk as a guide. For the white traffic lines and tactile paving to be used efficiently, they must be perceived clearly visually. Based on the data gathered in this survey, the contrast ratio\(^1\) between the road surface and white traffic lines on the Roadway and that of the road surface and tactile paving on the Sidewalk has been calculated and summarized in Table 22. Yokoyama and Kido (1998) reported that when the contrast ratio exceeds 43%, tactile paving is easily recognized by people with low vision. In addition, according to the ISO 23599:2012, which determines the requirements for Tactile Walking Surface Indicators (TWSIs) for blind or vision-impaired persons, the contrast ratio of tactile paving must be 30% or more. ISO 23599:2012 also states that, if tactile paving is to be used to warn a walker of the presence of danger, the contrast ratio must be at least 50%. In the experimental environment, the contrast ratio of both the white traffic lines and tactile paving exceeded these figures, which is believed to be the reason for the frequent use of both elements by participants with low vision.

Table 22. Contrast ratio of white traffic lines and tactile paving.

|                  | White traffic lines | Tactile paving |
|------------------|--------------------|---------------|
| Mean (%)         | 73.6               | 40.7          |
| SD               | 5.8                | 22.2          |

\(^1\)Here, we used the Michelson definition of luminance contrast: \(C = 100 \times \frac{L_{max} - L_{min}}{L_{max} + L_{min}}\) (\(L_{max}\) and \(L_{min}\) are the maximum and minimum luminances, respectively.)
In a comparison between the contrast ratio of the white traffic lines and tactile paving assessed in this survey, the former had a higher contrast ratio than the latter. Originally, the white traffic lines were installed not to facilitate the walking safety of people with low vision but to indicate the walking zones for pedestrians. However, it possessed higher visual discriminability than tactile paving in this instance. Installing tactile paving is costly. There is also a longstanding controversy over whether tactile paving is a barrier for wheelchair users. In this context, utilizing white traffic lines does not seem costly, nor is there any possibility of such traffic lines becoming a barrier. Based on the results of this survey, it is suggested that the effectiveness of white traffic lines as a visual support element to help people with low vision walk along streets safely is considerably high.

4.4. Street environments that support the walking safety of people with low vision

Regarding the gazing behavior of people with low vision, it was reported that, in a small indoor environment, people with low vision tended to walk while gazing at a closer point than fully sighted people (Matsuda et al. 2019). In contrast, the results of this survey show no significant difference in fixation distance between participants with low vision and fully sighted participants. At the same time, the discussions on the gazing behavior exhibited on the Roadway and Sidewalk in this chapter show that people with low vision tend to fix their gaze not only on nearby road surfaces but also on distant buildings. In addition, the results of the interview with participants with low vision (Tables 13 and 14) indicate that they feel that it is easier to walk along the Roadway, which has fewer obstacles than the Sidewalk. Based on these results, it is suggested that the outdoor street environments that support independent walking by people with low vision include not only easily perceived road surface markers, such as white traffic lines and tactile paving, but they also include few obstacles, allowing walkers to discern the direction in which they must travel from a distance.

5. Conclusions

By analyzing the gazing behavior of people with low vision using an eye-tracking device, we attempted to clarify which types of visual information they used while navigating streets as well as the characteristics of their gazing behavior. As a result, the following points are suggested. First, the information used by participants with low vision was different when walking along the Roadway and the Sidewalk. On the Roadway, participants with low vision walked while fixing their gaze on mainly the road surface and white traffic lines around 10 meters ahead. On the Sidewalk, on the other hand, they walked while fixing their gaze mainly on the road surface and tactile paving seven to eight meters ahead. In addition, the road surface, white traffic lines, and tactile paving were not the only elements that participants with low vision used as a guide while they walked. On both the Roadway and the Sidewalk, they walked while fixing their gaze on distant buildings at a specific rate. These findings support the importance of using continuous road surface signs, such as white traffic lines and tactile paving, to indicate the direction that walkers should follow as well as the importance of ensuring good visibility and making sure there are no obstacles on the road to help people with low vision walk outdoors independently.

Until now, the laying of tactile paving has been almost the only option to assist people with visual disabilities to walk outdoors. However, due to the high cost of installing, the extent to which tactile paving can be laid is limited. It has also been pointed out that tactile paving may act as a barrier to wheelchair users. The results of this study show that white traffic lines, which do not cost much to install and do not create barriers, can be very effective in assisting people with visual disabilities to walk, especially on roadways where enough safety is required. Furthermore, it could be suggested that the white traffic lines can be further utilized by removing obstacles such as utility poles and sidewalk signs from the pedestrian zone created by the white traffic lines. From the results of this study, it is indicated that it is possible to create a relatively simple and inexpensive environment for people with visual disabilities to walk safely by using the existing environmental components such as white traffic lines.

Finally, we must discuss the limitations of this study and future tasks. First, because of the small number of participants with low vision, it was impossible to categorize or analyze their gazing behavior in terms of age or type of disease. In future studies, we must clarify differences in gazing behavior due to age and disease. Second, the experimental sites were both straight routes with relatively few obstacles. In a real-life situation, walking routes are generally more complex and include more obstacles. In the future, it will be necessary to conduct surveys in an environment that is more similar to the walking routes that are used by pedestrians regularly. Third, the experimental site was surrounded by tall buildings. It is possible that the scale of the building affected the gazing behavior of the participants, but this could not be verified by the current study alone. In the future, similar studies should be conducted in environments created by smaller buildings, such as residential areas.

Disclosure statement

No potential conflict of interest was reported by the authors.
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