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Eye Movements while Ascending and Descending Staircases in Koshien Hotel: Comparison with Architecture Studio

Toshitomo Suzuki[1] and Shigeyuki Okazaki[1]

[1] *Department of Architecture, Mukogawa Women's University, Nishinomiya, Japan*

Corresponding author: Toshitomo Suzuki, Department of Architecture, Mukogawa Women's University, 1-13 Tozaki-cho, Nishinomiya, Hyogo, 663-8121, Japan, E-mail: ttsuzuki@mukogawa-u.ac.jp

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Abstract: We conducted experiments in which participants wearing an eye camera ascended and descended two staircases in the former Koshien Hotel designed by Arata Endo and one staircase in the Architecture Studio, a contemporary university building. Analyses and discussion, which concentrated on the relationship among footings, visible occluding edges, distributions of eye movement direction, and total fixation time by fixation spot, found similarities and differences of eye movement directions and fixation spots among the staircases. The staircases in the Koshien Hotel were probably designed for rich spatial experiences while ascending them due to great changes of eye movements. However, they were also designed for changes of eye movements while descending them.

1. Introduction

We grasp such living spaces as architectural and urban spaces and gardens through visual perception and ambulation. We cannot walk without visual perception, and we cannot grasp intricately shaped spaces without ambulation. Visual perception and ambulation share a coordinative relationship.

Our ability to discriminate fine details drops markedly outside of a central area within two or three visual degrees of the retina. Eve movements are therefore essential for human visual perception. We previously conducted experiments with an eye camera and studied eye movements while walking in a maze (Kitahama et al., 1999; Okazaki, Kitahama et al., 2000; Suzuki, Sugai et al., 2002), subway stations (Suzuki, Okazaki and Tokunaga, 2001; Suzuki and Okazaki, 2002a, 2002b), a garden of a tea ceremony room (Nakamura et al., 2002), and urban streets around a train station (Suzuki, Okazaki and Ikeou, 2004; Ikeou et al., 2004). We found discriminative eye movements including fixations on the edges called the "occluding edges" by Gibson (1979), changes of the movements before and after path-learning, and differences of spatial characteristics. In recent years, other researchers have also studied and reported eye movements in living spaces including train stations (Yamamoto et al., 2003; Kido et al., 2006), underground shopping malls (Takenouchi et al., 2004; Hikosaka et al., 2006), public libraries (Fujiki et al., 2006), streets (Chibata, 1999; Watanabe et al., 2003; Miura et al., 2005; Kawamura et al., 2007; Kagami et al,, 2007; Miura, 2010), gardens (Sakai et al., 2004; Kinoshita et al., 2007), and landscape areas (Sugano et al., 2007; Yokoyama et al., 2007, 2009).

In this paper1, we conducted experiments in which participants wearing an eye camera ascended and descended the staircases in two buildings on the Kami-koshien Campus of Mukogawa Women's University. The results showed the similarities and differences between the eye movements on the staircases in the former Koshien Hotel, a modern Japanese architectural masterpiece, and the staircase in the Architecture Studio, a contemporary university building completed in 2007.

The Koshien Hotel was designed by Arata Endo and completed in 1930. Endo studied architectural design from Frank Lloyd Wright, and together they designed the Imperial Hotel and the Yamamura House. Wright considered and designed modern architecture based on the relationship between nature and humans. Many researchers (Manson, 1958; Stewart, 1987; Nute, 1993; Meech, 2001; Aguar et al., 2002) have noted that Japanese ukiyo-e prints, gardens, and architecture strongly influenced Wright's thoughts and works. Endo inherited Wright's thoughts and also considered and designed modern architecture in Japan.

The staircases of the Koshien Hotel have expressive interiors that progressively unfold while ascending or descending them. These spatial structures have similarities to many of Wright's works and are in contrast to the western traditional box-buildings he tried to destruct (Wright, 1955). They also have similarities to Japanese shoin-style architecture and gardens, including the Katsura Imperial Villa and the Ninomaru Palace at Nijo Castle and the approaches to Japanese temples and shrines, including Shisen-do and Daitoku-ji Koto-in Temples reported by Kinoshita et al. (2007). Therefore, this study approaches not only the spatial characteristics of the Koshien Hotel but also Japanese traditional spatial structure that progressively unfolds during walking.

2. Methods

2.1. EXPERIMENT

2.1.1. Experimental routes

The experiments were conducted on the routes in the former Koshien Hotel and the Architecture Studio on the Kami-koshien

Campus of Mukogawa Women's University (Fig. 1).

The route in the Koshien Hotel has a quarter-turn staircase from the first to the second floor and a straight-flight staircase from the second to the third floor (Fig. 2). Both staircases are 3.18 m high with low ceilings and are positioned between walls. The scenery in both staircases darts in and out of pedestrian's vision. The bottom corners of the walls in the staircases have ornamental baseboards.

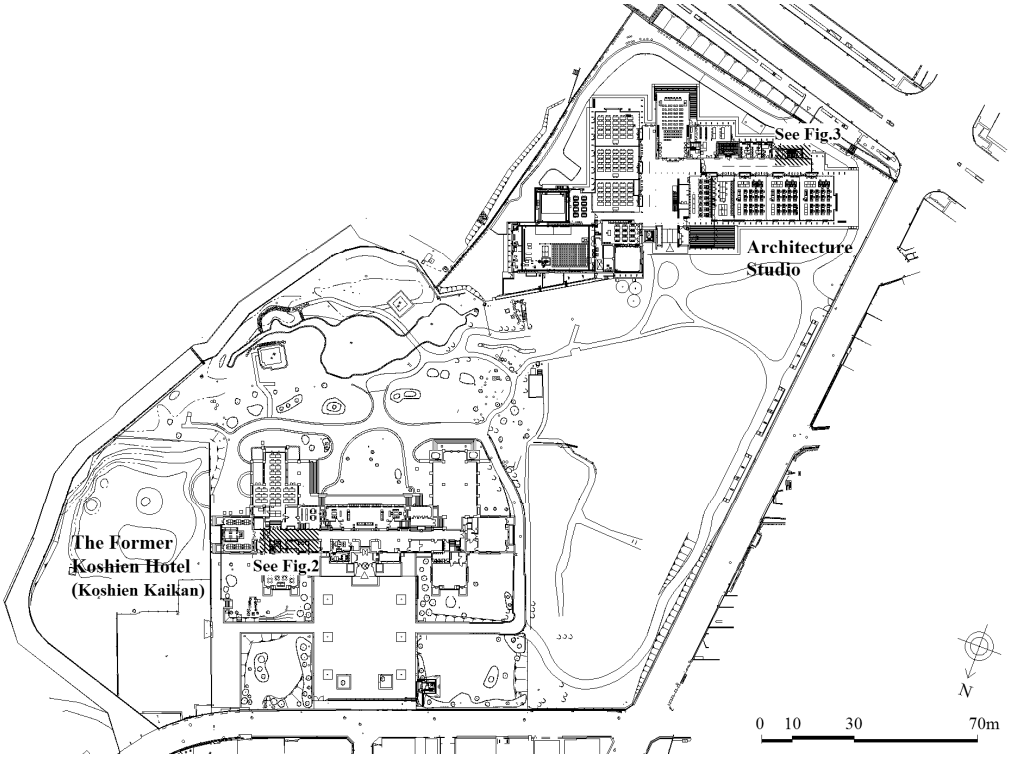


Fig. 1 Kami-koshien Campus of Mukogawa Women's University

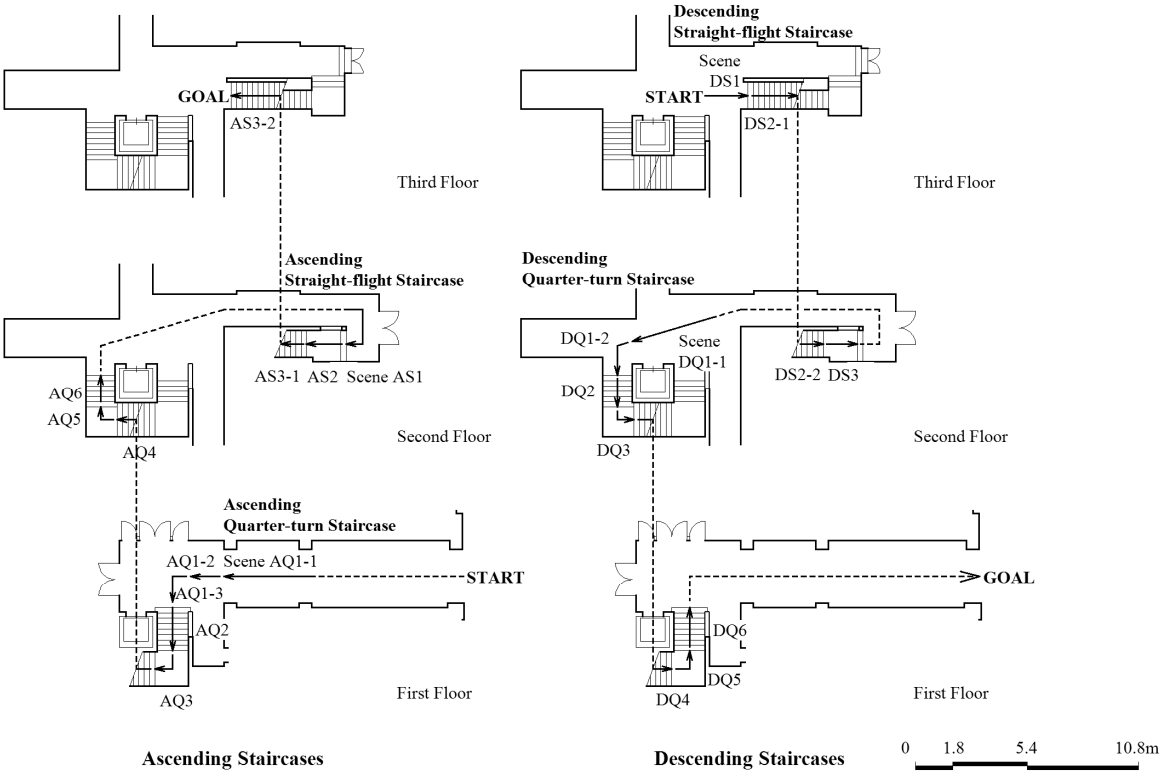


Fig. 2 Experimental route and scenes in ascending and descending staircases in former Koshien Hotel

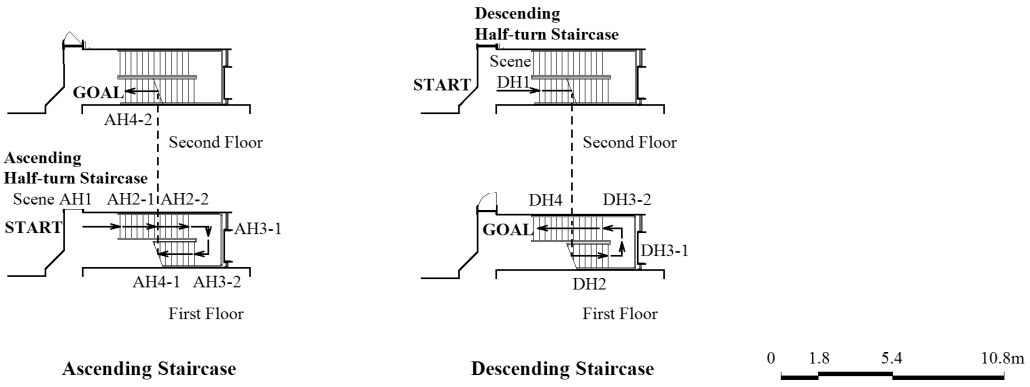


Fig. 3 Experimental route and scenes in ascending and descending staircase in Architecture Studio

The route in the Architecture Studio has a half-turn staircase from the first to the second floor (Fig. 3). It is 4.5 m high with higher ceilings than in the Koshien Hotel and walls outside but not inside it. Unlike in the Koshien Hotel, since there is no ceiling hiding ahead, pedestrians can see the scenery over the banisters on the route in the Architecture Studio.

2.1.2. Participants

Participants AK, EH, KA, KM, MH, and MN were students and staff of the Department of Architecture at Mukogawa Women's University and usually use both buildings.

2.1.3. Procedure

In a room at the Architecture Studio, the participants wore an NAC EMR-8B eye camera (with a 115º lens) and a backpack with the controller, battery, and Panasonic NV-GS100K-S video camera to record the data of the eye camera. After the eye camera was calibrated in the room, they ascended and descended the staircase in the Architecture Studio (Fig. 3). After walking to the Koshien Hotel, they ascended and descended its staircases (Fig. 2).

Before ascending and descending the staircases, they were indicated to walk step by step. While ascending and descending them, the experimenter shot them from behind on a Panasonic NV-G300-S video camera. At the end of the experiment, the experimenter checked the eye mark on the eye camera to correspond with the eye movements.

2.2. ANALYSIS

2.2.1. Fixation

The data of the eye camera recorded by the video camera were loaded into NAC EMR-dFactory Ver 1.2 analysis software. Eye movements were comprised of fixation and saccade. While ascending and descending the staircases, eye marks oscillated not only in saccade but also in fixation. In this analysis, we considered eye mark movements within 3.0 visual degrees per fixation and input the criterion into the software.

2.2.2. Eye Movement Direction

Eye movement directions were calculated from the vectors expressing the movements of the fixation points on the eye camera and sorted into eight classes: up, upper-right, right, lower-right, down, lower-left, left and upper-right.

2.2.3. Fixation Spot

We watched video footage of the eye camera and defined the location of all fixation points in the staircases as fixation spots and categorized them into the previously reported 14 classes (Suzuki and Okazaki, 2002b). We also added another class called "Banisters" for the half-turn staircase in the Architecture Studio (Tables 1 and 2). The occluding edge (Gibson, 1979) is the edge whose one side can be seen but not the other side. As previously reported (Suzuki, Okazaki and Tokunaga, 2001; Suzuki and Okazaki, 2002b), we observed not only the edges of the walls but also those of the landing and the stairs, and those of the ceilings.

2.2.4. Scene

As previously reported (Suzuki and Okazaki, 2002b), we divided the scenes while ascending and descending the staircases based on their footing and visible occluding edges (Figs. 2 and 3 and Tables 3-8). The footing was divided into landing and stairs. We only analyzed the occluding edges related to the path selections of the participants. The edges were selected by the pedestrians in the Simulation Model for Pedestrian Movement (Okazaki and Matsushita, 1981, 1993). Close relationships were previously found among the path-selections, path-learning, and fixations on the occluding edges of walls (Kitahama et al., 1999). However, the occluding edges in this analysis include not only those of the walls but also those of the landing and the stairs under the route and those of the ceilings over the route (Suzuki, Okazaki and Tokunaga, 2001; Suzuki and Okazaki, 2002b).

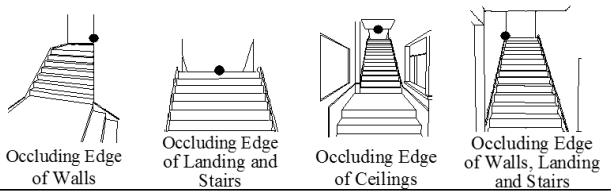
In experiments at a subway station (Suzuki and Okazaki, 2002b), all visible occluding edges were analyzed because the route was unbranched and unknown by the participants. In these experiments, on the other hand, the participants had already learned the routes, and the route in the Koshien Hotel was branched. We ignored the edges unrelated to the path selections, with the exception of the scenes at the end of the routes.

3. Results

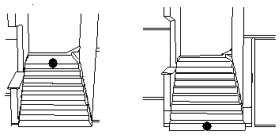
The distributions of the eye movement directions and the total fixation time by fixation spot in every scene are shown in Tables 3-8. If more than one fixation spot of the same class is visible in the scene, it is distinguished as Notes 2, 6, 7, 9, 10, 13 of Tables 3-8.

Table 1 Classification of fixation spots while ascending staircases

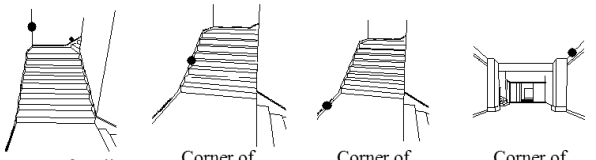
(a) Occluding Edges



(b) Top or Bottom Stair



(c) Corners



(d) Wall, Banisters, Stairs, Landing or Ceiling

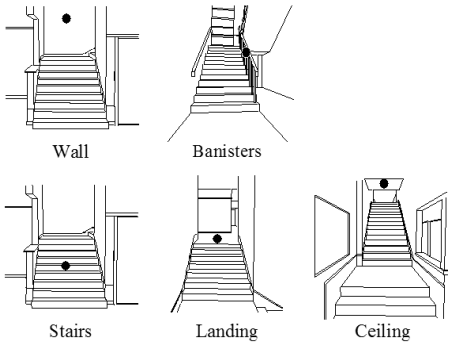
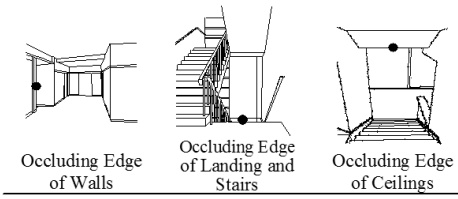
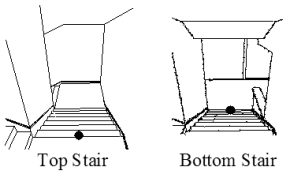


Table 2 Classification of fixation spots while descending staircases

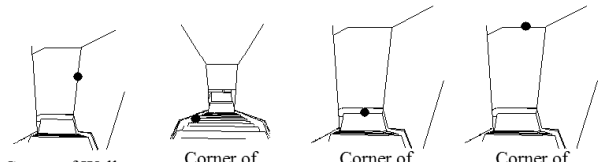
(a) Occluding Edges [1)]



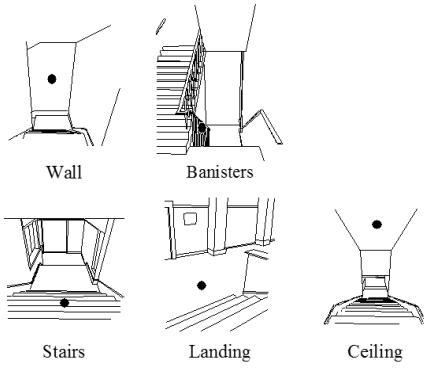
(b) Top or Bottom Stair



(c) Corners



(d) Wall, Banisters, Stairs, Landing or Ceiling



Note

1) As previously reported (Suzuki and Okazaki, 2002b), fixation on the "Occluding Edge of Walls, Landing and Stairs" was not found while descending the staircases.

3.1. ASCENDING

3.1.1. Ascending Quarter-turn Staircase in Koshien Hotel (Table 3)

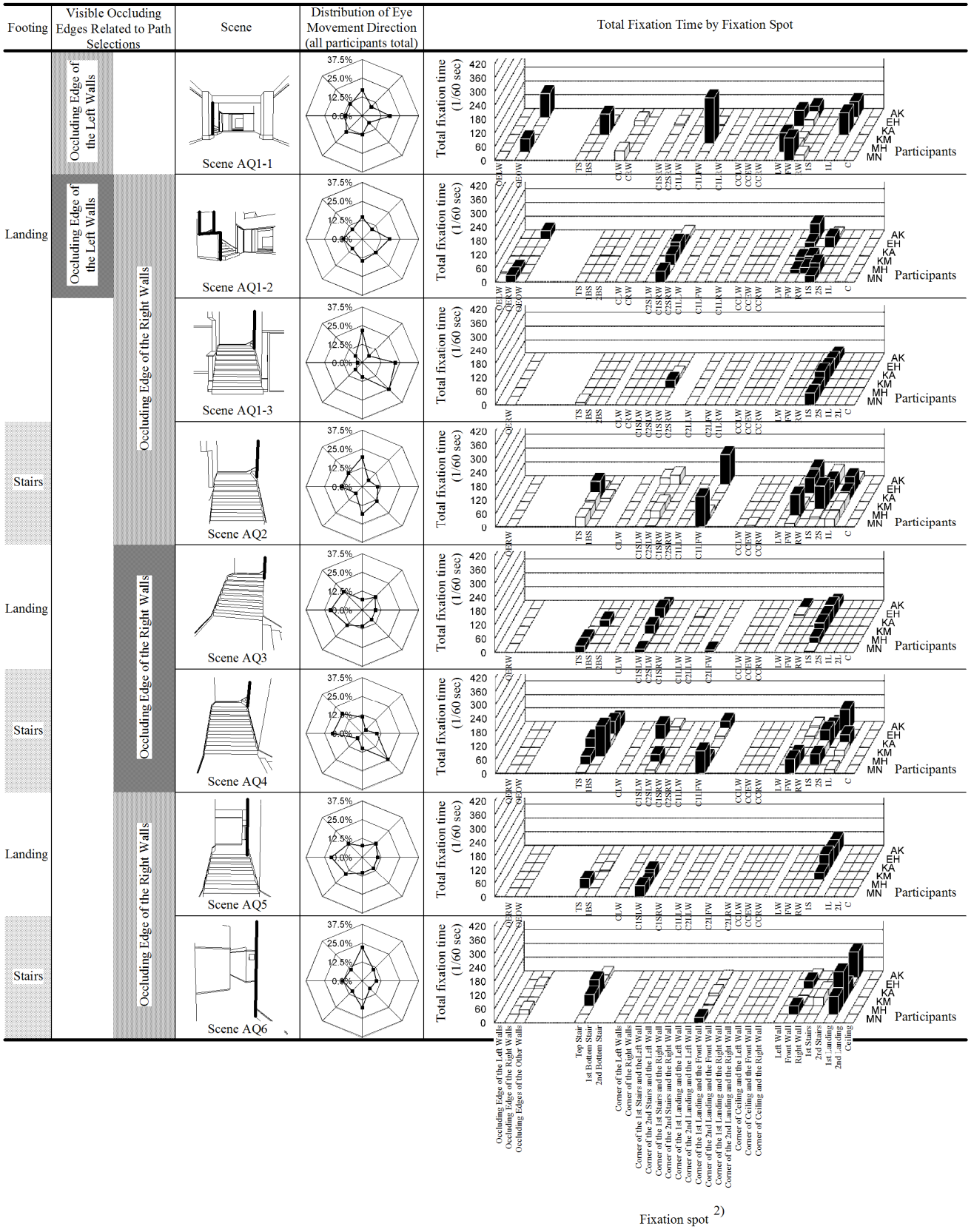
On the stairs, many up-and-down eye movements occurred such as Scenes AQ2 and AQ6. Many movements to the lower-right and upper-left occurred, exceptionally in Scene AQ4, where the stairs were ascending had been covered by the previous occluding edge of walls, and the following stairs were still covered by the present edge. The lower-right was the direction to the following stairs, and the upper-left was the opposite direction from them. Many movements in the directions were not found in Scene AQ2 on the stairs uncovered by the previous edge and Scene AQ6 on the last stairs of the staircase.

There were great differences in the fixation spots among the participants and in Scenes AQ2 and AQ4. However, some fixations occurred on the "Top Stair," the "Bottom Stair," the "Corner of Stairs and the Left Wall," the "Corner of Landing and the Front Wall," the "Front Wall," the "1st Stairs," the "2nd Stairs," and the "Landing." In Scene AQ6 on the last stairs of the staircase, fixations tended to focus on the "Landing," which was the next floor.

On the landing, many eye movements opposite the participant turns occurred in Scenes AQ1-2, AQ1-3, AQ3, and AQ5 during and just before the quarter-turn. These denote right turns in Scenes AQ1-2 and AQ1-3 and left turns in Scenes AQ3 and AQ5. In addition, many upward movements and those to the lower-right occurred in Scene AQ1-3 just before ascending the first stairs. It was difficult to identify a trend for them in Scene AQ1-1.

There were some differences in fixation spots among the participants in Scene AQ1-2 just before approaching the first stairs. However, many fixations occurred on the "Corner of the 1st Stairs and the Right Wall," the "Front Wall," and the "1st Stairs." From Scene AQ1-3, they tended to focus on the "1st Stair" in the scenes on the landing. They also focused on the "Corner of the 1st Stairs and the Left Wall" in Scenes AQ3 and AQ5 on the landing between the two stairs.

Table 3 Relationship among scenes defined by footing and visible occluding edges, distributions of eye movement direction and total fixation time by fixation spot while ascending the quarter-turn staircase in Koshien Hotel



Notes

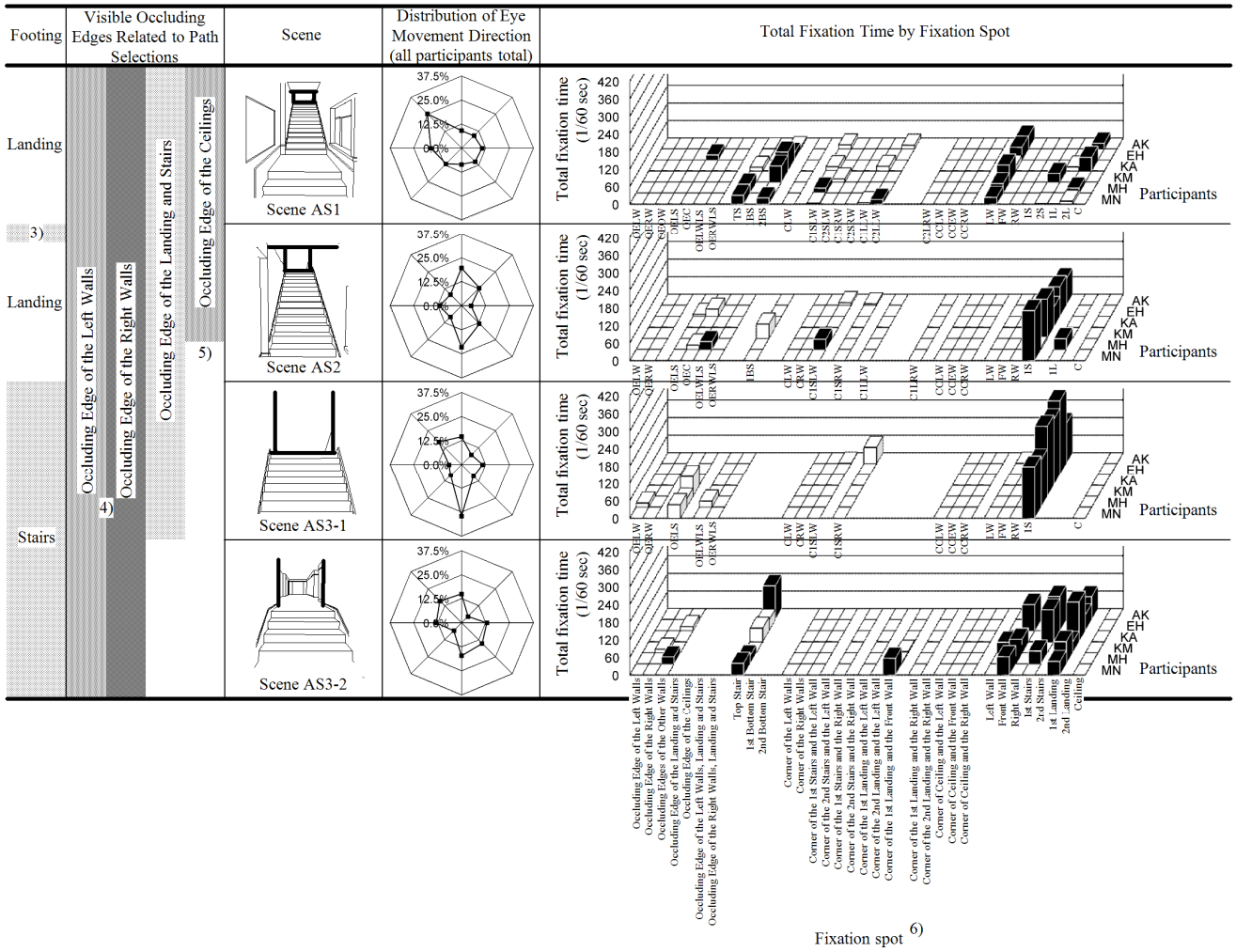
2) Black bars indicate the fixation spots on which the participants fixated longer than the white bars in the scene. The spots were selected by Otsu's method (Otsu, 1979), which is an unsupervised discriminant analysis. No bar indicates that the spot is invisible in the scene.

If more than one fixation spot (Table 1) of the same class is visible in the scene, it is distinguished as below:

(a) Occluding Edges: The "Occluding Edge of Walls" relating to the path selections is defined as the "Occluding Edge of the Right Walls" or the "Occluding Edge of the Left Walls." The other edges are defined as the "Occluding Edges of the Other Walls."

(b) Top or Bottom Stairs: The front top stair is defined as the "1st Top Stair" and the second as the "2nd Top Stair." The same applies for the bottom stairs.
(c) Corners: The "Corner of Walls" bordering the "Right Wall" described in (d) is defined as the "Corner of the Right Walls" and bordering the "Left Wall" as the "Corner of the Left Walls." The "Corner of Stairs and Wall," the "Corner of Landing and Wall" and the "Corner of Ceiling and Wall" are defined in terms of "Wall," "Stairs," "Landing," and "Ceiling," as described in (d). The corner bordering the following stairs and the wall on their right side is exceptionally defined as the "Corner of the 1st Stairs and the Right Wall" in Scenes AQ1-1 and AQ1-2, unlike the definition of the walls in (d).
(d) Walls: On the stairs, the wall in front of the stairs is defined as the "Front Wall," and the wall orthogonal to them defined as the "Right Wall" or the "Left Wall." The other wall in the distance is included in the "Front Wall." On the landing, the wall in the scene preceding on the stairs is defined in the same way as on the stairs. In Scenes AQ1-1 and AQ1-2, the wall bordering the "Occluding Edge of the Left Walls" is defined as the "Left Wall," the wall side of the following stairs as the "Front Wall," and the wall on the right side of the "Front Wall" as the "Right Wall" based on the next path selection.
Stairs and Landings: The front stairs are defined as the "1st Stairs," and the second stairs are defined as the "2nd Stairs." The same applies for the landings.

Table 4 Relationship among scenes defined by footing and visible occluding edges, distributions of eye movement direction and total fixation time by fixation spot while ascending the straight-flight staircase in Koshien Hotel



Notes
3) Scene AS2 could not be divided into two scenes based on the footing because the time on the stairs with only two steps was too short to determine between on them and on the landing.
4) Because the staircase was ascended just before the arrival at the GOAL, we couldn't determine which occluding edges of walls were related to the path selection. Therefore, both edges are shown in the Table.
5) Scene AS2 could not be divided into two scenes based on the "Occluding Edge of the Ceilings" because the edge gets out of the range of the eye camera in the scene.
6) For the meanings of the black, white, and no bars, see Note 2 of Table 3.
If more than one fixation spot (Table 1) of the same class is visible in the scene, it is distinguished as below:
(a) Occluding Edges: For the "Occluding Edge of Walls", see Note 2. The same applies for the "Occluding Edge of Walls, Landing and Stairs."
(b) Bottom Stairs: See Note 2.
(c) Corners: See Note 2.
(d) Walls: In Scene AS1, the walls are defined in the same way as in Scene AS2. In the other scenes, see Note 2.
Stairs and Landings: See Note 2.

3.1.2. Ascending Straight-flight Staircase in Koshien Hotel (Table 4)

On the stairs in Scenes AS3-1 and AS3-2, many up-and-down eye movements occurred. In Scene AS3-1 while ascending to the occluding edge of the landing and the stairs, fixation spots tended to focus on the "Stairs." In Scene AS3-2 after the next floor appeared, there were some differences among the participants. However, they tended to focus on the "Landing," which was the next floor. In addition, many fixations occurred, including on the "Top Stair," the "Front Wall," and the "Stairs."

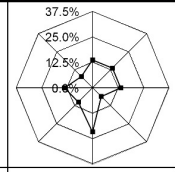
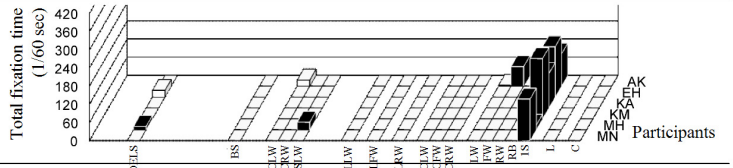
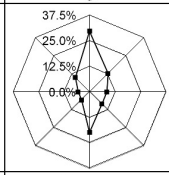
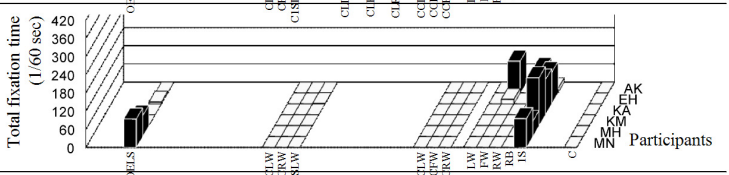
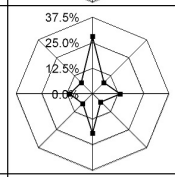
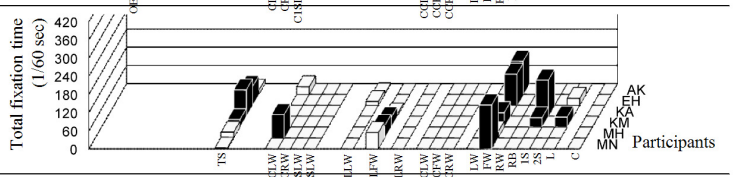
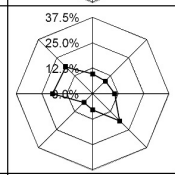
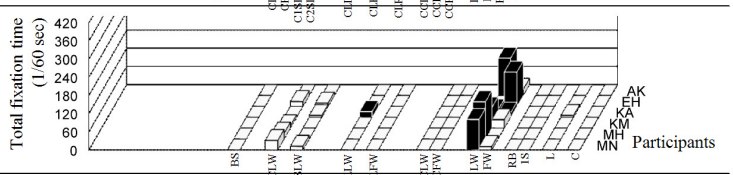
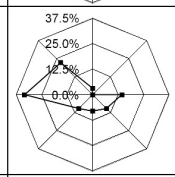
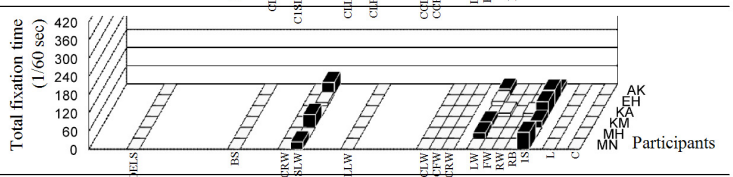
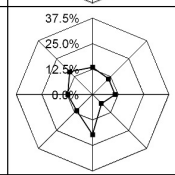
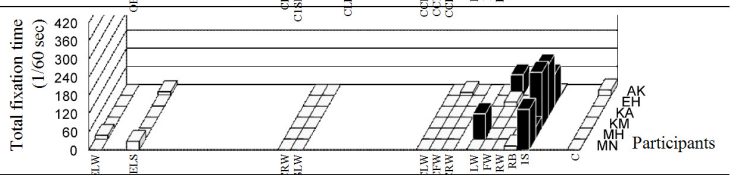
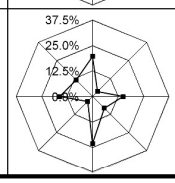
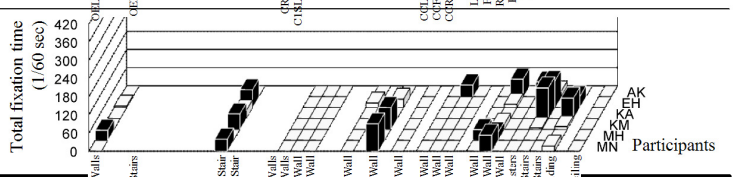
On the landing, many movements to the upper-left, which was the opposite direction from the next stairs, occurred in Scene AS1 during 180° turns and while approaching stairs. In this

scene, there were some differences in the fixation spots among the participants, although they tended to focus on the "2nd Bottom Stairs" and the "Left Wall." In Scene AS2 just before ascending the long stairs, many up-and-down movements occurred, just as in Scenes AS3-1 and AS3-2 on the stairs. The participants were seemingly affected by the stairs with only two steps in the scene. In this scene, the spots tended to focus on the "Stairs."

3.1.3. Ascending Half-turn Staircase in Architecture Studio (Table 5)

On the stairs, many up-and-down eye movements occurred in Scene AH2-1 at the beginning of the ascent of the first stairs. In Scenes AH2-2 and AH4-2 after the landing appeared, many right-and-left movements also occurred. In Scene AH4-1, their directions were between Scene AH3-2 described below and Scene AH4-2.

Table 5 Relationship among scenes defined by footing and visible occluding edges, distributions of eye movement direction and total fixation time by fixation spot while ascending the half-turn staircase in Architecture Studio

Footing	Visible Occluding Edges Related to Path Selections	Scene	Distribution of Eye Movement Direction (all participants total)	Total Fixation Time by Fixation Spot
Landing	Occluding Edge of the Landing and Stairs	Scene AH1		
Stairs	Occluding Edge of the Landing and Stairs	Scene AH2-1		
Stairs	Occluding Edge of the Landing and Stairs	Scene AH2-2		
Landing	Occluding Edge of the Landing and Stairs	Scene AH3-1		
Landing	Occluding Edge of the Landing and Stairs	Scene AH3-2		
Stairs	Occluding Edge of the Left Walls	Scene AH4-1		
Stairs	Occluding Edge of the Left Walls	Scene AH4-2		

Notes

7) For the meanings of the black, white, and no bars, see Note 2 of Table 3.
If more than one fixation spot (Table 1) of the same class is visible in the scene, it is distinguished as below:
(c) Corners: See Note 2. The corner bordering the following stairs and the wall on their left side is exceptionally defined as the "Corner of the 1st Stairs and the Left Wall" in Scene AH3-1, unlike the definition of the walls in (d).
(d) Walls: In Scene AH3-1, the wall ahead of the following stairs is defined as the "Right Wall," the wall side of the stairs as the "Front Wall," and the wall on their left side of the "Front Wall" as the "Left Wall." In the other scenes, see Note 2.
Stairs: See Note 2.

The fixation spots tended to focus on the "Stairs" in Scenes AH2-1 and AH4-1 when the top stair was the occluding edge. In Scenes AH2-2 and AH4-2 after the landing appeared, there were great differences among the participants and scenes. They occurred on the "Top Stair" and the "Front Wall."

On the landing, many right-and-left eye movements and those to the upper-left occurred in Scenes AH3-1 and AH3-2 during half-turns. In Scene AH3-1 during the first quarter of the turn, many movements to lower-right and upper-left also occurred. The lower-right was the direction to the following stairs, and the upper-left was the opposite direction from them. The fixation spots tended to focus on the "Left Wall" in Scene AH3-1. In Scene AH3-2 during the last quarter of the turn and just before ascending the stairs, there were some differences among the participants. However, they tended to focus on the "Stairs."

In Scene AH1 at the beginning of the ascent, downward eye movements were slightly more common than the other directions, and fixation spots tend to focus on the "Stairs."

3.2. DESCENDING

3.2.1. Descending Quarter-turn Staircase in Koshien Hotel (Table 6)

In Scene DQ1-1, identifying a trend of eye movement directions was difficult. In Scene DQ1-2 just before descending the first stairs, many movements occurred to the right, which was the opposite direction from the staircase.

From Scenes DQ2 at the beginning of the descent to DQ4 before the next floor appeared, many right-and-left movements occurred whether on the stairs or the landing. In addition, their directions in Scene DQ4 were between Scenes DQ3 and DQ5 described below.

In Scenes DQ5 and DQ6 after the next floor appeared, movements occurred to the right and lower-right, which were the direction of the GOAL in Fig. 2. In Scene DQ5, those to the upper-left, which was the opposite direction of the GOAL, also occurred.

The fixation spots tended to focus on the walls by Scene DQ5 before descending the last stairs. In Scenes DQ2 and DQ4 on the stairs, many fixations occurred on the "Front Wall." On the landing, they occurred on the "Right Wall" in Scenes DQ1-2 and DQ3 before the next floor appeared. In Scene DQ5 after the next floor appeared, they occurred on both walls.

In Scene DQ6 on the last stairs of the staircase, fixations tended to focus on the "Landing," which was the next floor.

3.2.2. Descending Straight-flight Staircase in Koshien Hotel (Table 7)

In Scene DS1 at the beginning of the descent, many upward eye movements occurred. In Scene DS2-1 on the stairs before the occluding edge of the ceiling disappeared, in Scene DS3 on the landing between the long and short stairs with only two steps, many up-and-down movements and those to the upper-left and lower-right occurred. Upper-left was the intermediate direction between upward and to the next staircase, and lower-right was the opposite from the direction. Although Scene DS2-2, which was on the stairs and after the occluding edge of the ceiling disappeared, was between Scenes DS2-1 and DS3, it was difficult to identify a trend of their directions.

There were great differences in fixation spots among the participants by Scene DS2-2 late in their descent of the long stairs. However, some fixations occurred in Scene DS1 on the "Occluding Edge of the Left Walls," the "1st Bottom Stair," the "Corner of the 1st Stairs and the Left Wall," the "Corner of the 3rd Landing and the Right Wall," the "Corner of Ceiling and the Right Wall," the "Left Wall," the "Right Wall," and the "2nd Stairs." In Scene DS2-1, they occurred on the "Occluding Edge of the Front Ceilings," the "1st Bottom Stair," the "Left Wall," the "Right Wall," the "1st Stairs," the "2nd Stairs," and the "1st Landing." In Scene DS2-2, they occurred on the "Occluding Edge of the Left Walls," the "Occluding Edge of the Other Walls," the "Corner of the 2nd Landing and the Right Wall," the "2nd Stairs," the "2nd Floor," and the "Ceilings.".

In Scene DS3 on the landing between the long and short stairs, fixations tended to focus on the "2nd Landing," which was the next floor.

3.2.3. Descending Half-turn Staircase in Architecture Studio (Table 8)

In each scene, many right-left eye movements occurred whether on the stairs or the landing. In addition, many up-down movements occurred in Scenes DH2 and DH4 on the stairs, and many upward movements occurred in Scene DH3-1 during the first quarter of the half-turn.

Fixation spots tended to focus on the walls in each scene. In Scene DH1, many fixations occurred on the "Front Wall," the "Right Wall," and the "Corner of the Right Walls" bordering the two walls. In Scenes DH2 and DH4 on the stairs, they occurred on the "Front Wall." In addition, some fixations occurred on the "Corner of the 1st Landing and the Front Wall" and the "Right Wall" in Scene DH4 on the last stairs of the staircase. In Scenes DH3-1 and DH3-2 during half-turns on the landing, many fixations on the "Right Wall" occurred.

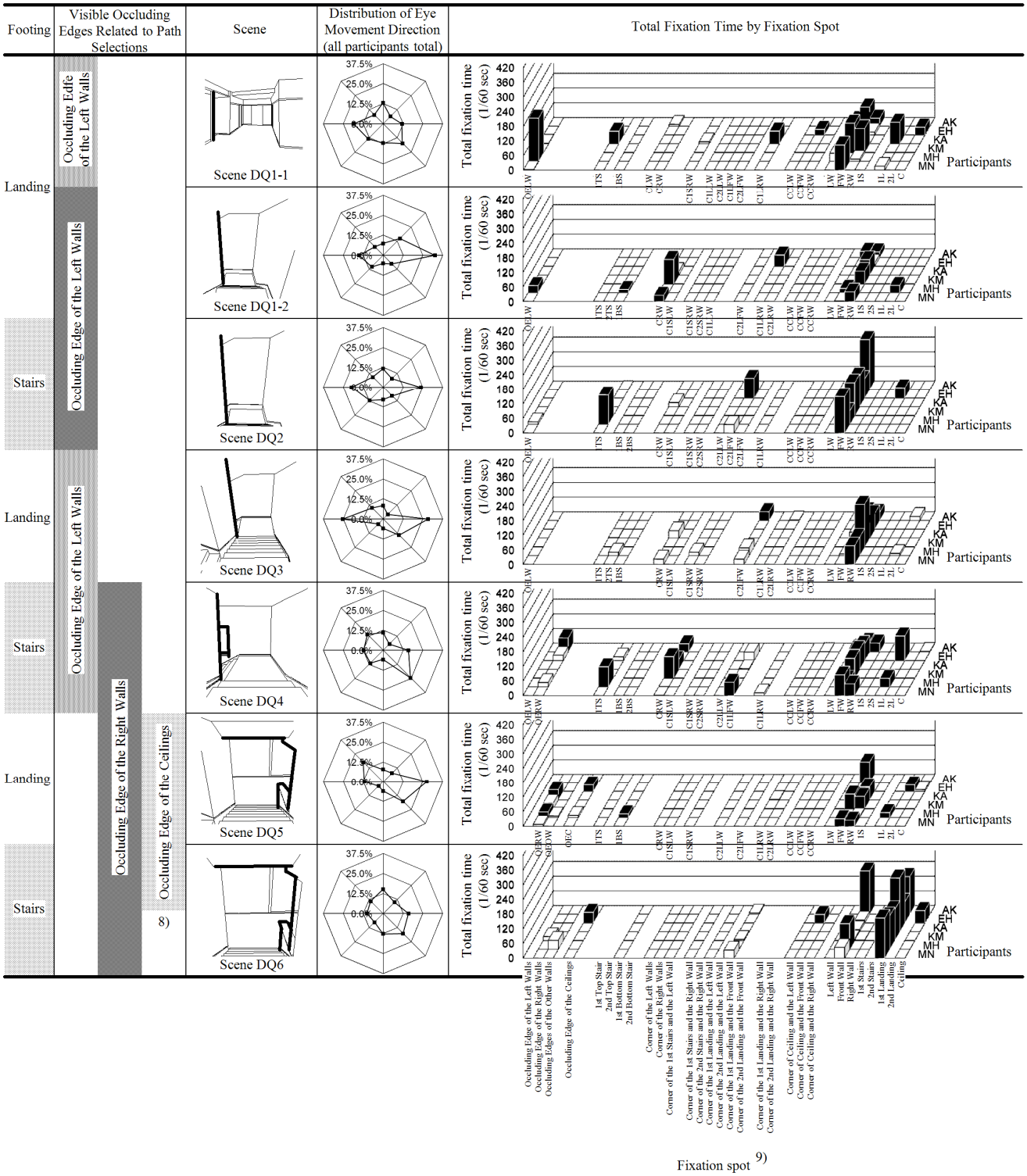
4. Discussion

4.1. ASCENDING STAIRCASES

The results showed that whether the following landing appeared, on the stairs or the landing, straight or turn ambulation influenced the eye movement direction and the fixation spots of the participants while ascending the staircases.

On the quarter-turn staircase in the Koshien Hotel, the directions changed widely among the scenes. Many up-and-down movements occurred in Scenes AQ2 and AQ6 on the stairs, those to the right in Scenes AQ1-2 and AQ1-3 during left turns, and those to the left in Scenes AQ3 and AQ5 during right turns. On the straight-flight staircase, many up-and-down movements occurred in all scenes after AS2 because of ambulation without any turns.

Table 6 Relationship among scenes defined by footing and visible occluding edges, distributions of eye movement direction and total fixation time by fixation spot while descending the quarter-turn staircase in Koshien Hotel



Notes

8) Scene DQ6 could not be divided into two scenes based on the "Occluding Edge of the Ceilings" because the edge gets out of the range of the eye camera in the scene.

9) For the meanings of the black, white, and no bars, see Note 2 of Table 3.

If more than one fixation spot (Table 2) of the same class is visible in the scene, it is distinguished as below:

(a) Occluding Edges: See Note 2.

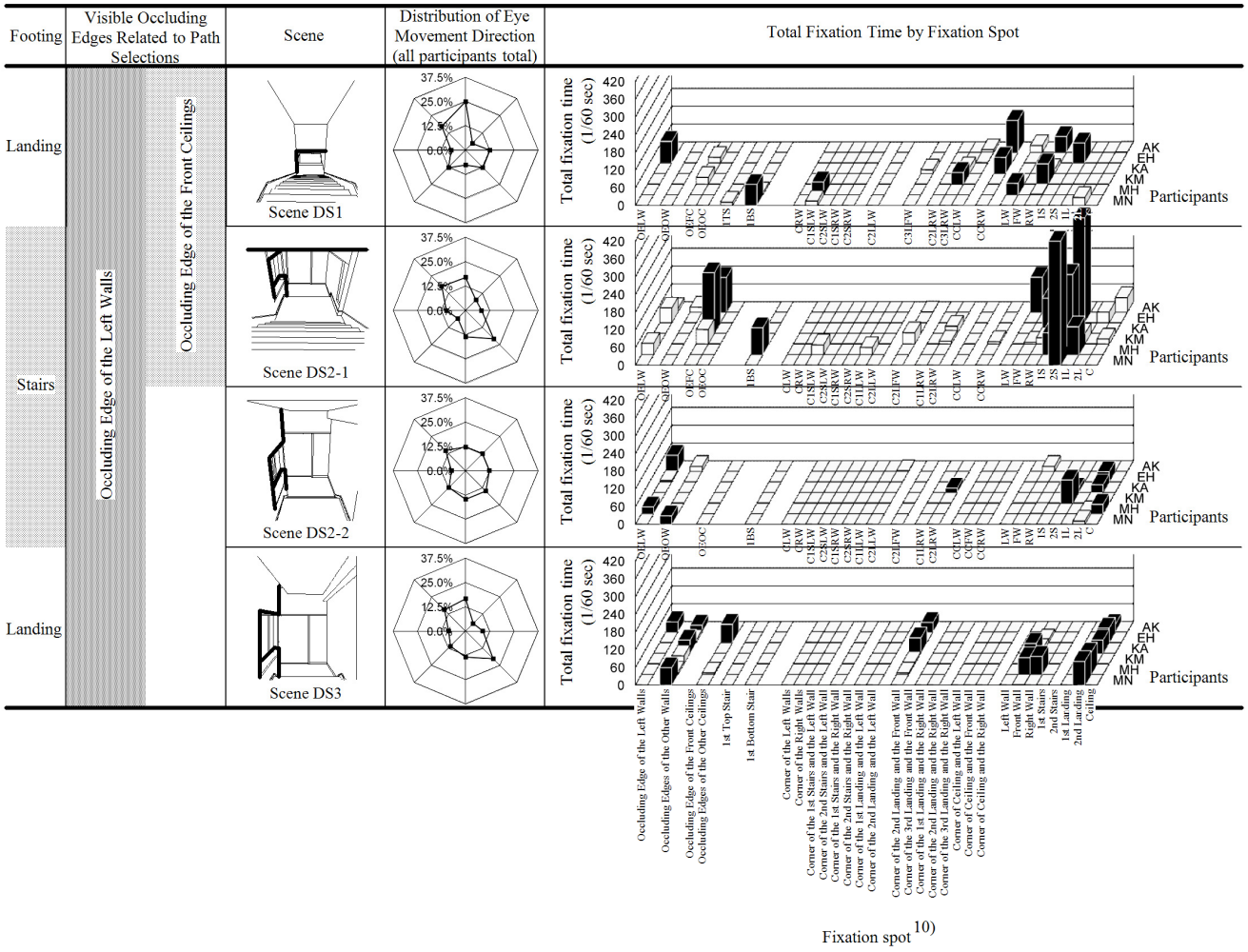
(b) Top or Bottom Stairs: See Note 2.

(c) Corners: See Note 2. The corner bordering the following stairs and the wall on their right side is exceptionally defined as the "Corner of the 1st Stairs and the Right Wall" in Scene DQ1-1, unlike the definition of the walls in (d).

(d) Walls: In Scene DQ1-1, the wall bordering the "Occluding Edge of the Left Walls" is defined as the "Left Wall," the wall side of the following stairs as the "Front Wall," and the wall on the right side of the "Front Wall" as the "Right Wall" based on the next path selection. For the other scenes, see Note 2.

Stairs and Landings: See Note 2.

Table 7 Relationship among scenes defined by footing and visible occluding edges, distributions of eye movement direction and total fixation time by fixation spot while descending the straight-flight staircase in Koshien Hotel



Notes

10) For the meanings of the black, white and no bars, see Note 2 of Table 3.

If more than one fixation spot (Table 2) of the same class is visible in the scene, it is distinguished as below:

(a) Occluding Edges: For the "Occluding Edge of Walls," see Note 2. The "Occluding Edge of Ceilings" related to the path selections is defined as the "Occluding Edge of the Front Ceilings." The other edges are defined as the "Occluding Edges of the Other Ceilings."

(b) Top or Bottom Stairs: See Note 2. However, the "2nd Top Stair" and "2nd Bottom Stair" are included as "2nd Stairs" described in Note 2 because there are only two stairs, which see too small to determine the fixation spots of the top and bottom of the stairs in Scenes DS1 to DS2-2.

(c) Corners: See Note 2.

(d) Walls: In Scene DS3, the wall is defined in the same way as in Scene DS2. In the other scenes, see Note 2.

Stairs and Landings: See Note 2. In Scene DS1, the "3rd Landing" is also defined. However, it is included as the "Corner of the 3rd Landing and the Front Wall," the "Corner of the 3rd Landing and the Right Wall," or the "2nd Stairs" because the landing among the corners and stairs see too small to determine the fixation spots of the landing in the scene.

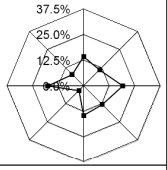
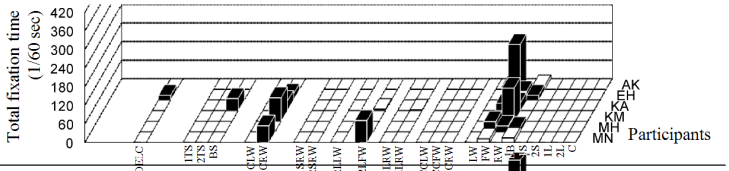
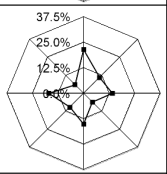
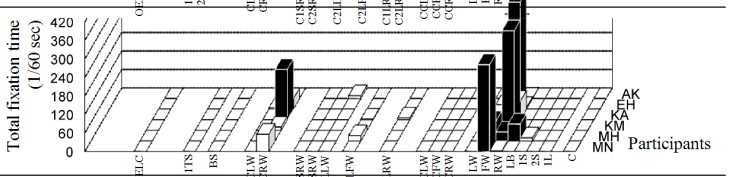
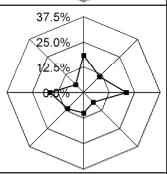
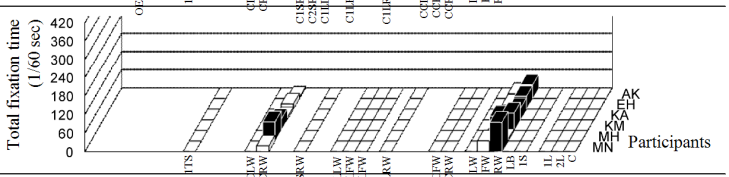
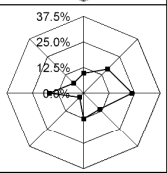
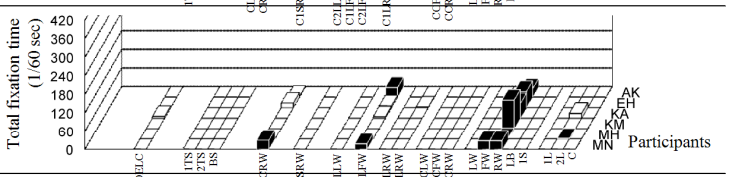
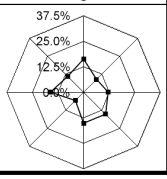
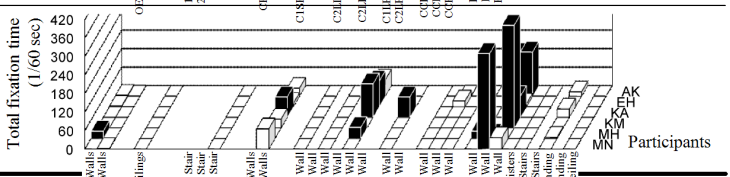
On the half-turn staircase in the Architecture Studio, many up-and-down movements also occurred in Scenes AH2-1, AH2-2, and AH4-2 on the stairs, and those to the left in Scenes AH3-1 and AH3-2 during right turns, as in the Koshien Hotel. However, many right-and-left movements also occurred in Scenes AH2-2 and AH4-2, and their intermediate distribution appeared in Scene AH4-1. The differences among the scenes were clearer while ascending the staircases in the Koshien Hotel than in the Architecture Studio.

The fixation spots in the Koshien Hotel tended to focus on the following stairs in Scenes AQ1-3, AQ3, AQ5, and AS2 just before ascending the stairs, the stairs in Scene AS3-1 while ascending to the occluding edge of the landing and the stairs, and the next floor in Scene AQ6 after they appeared as a result of turn ambulation. In the other scenes, there were great variations in the spots among the participants, and the variations created differences among the scenes.

In the Architecture Studio, they also tended to focus on the following stairs in Scene AH1 just before ascending the stairs, and the stairs ascended to the occluding edge of the landing and the stairs in Scenes AH2-1 and AH4-1. In Scenes AH2-2 and AH4-2, the landing appeared after the occluding edge of the landing and the stairs disappeared, and in Scene AH3-2 the following stairs appeared as a result of turn ambulation; there were such great variations as the Koshien Hotel. However, those focused on the wall in Scene AH3-1 were not found in the Koshien Hotel.

The clear differences of eye movement directions among scenes in the Koshien Hotel were influenced by the stairs positioned between walls, and the paucity of fixation focused on wall was influenced by the low height of the stairs in the quarter-turn staircase.

Table 8 Relationship among scenes defined by footing and visible occluding edges, distributions of eye movement direction and total fixation time by fixation spot while descending the half-turn staircase in Architecture Studio

Footing	Visible Occluding Edges Related to Path Selections	Scene	Distribution of Eye Movement Direction (all participants total)	Total Fixation Time by Fixation Spot
Landing	Occluding Edge of the Left Ceilings 12)	Scene DH1		
Stairs	Occluding Edge of the Left Ceilings 12)	Scene DH2		
Landing	11)	Scene DH3-1		
Stairs	Occluding Edge of the Left Walls / Occluding Edge of the Front Walls; Occluding Edge of the Left Ceilings 12)	Scene DH3-2		
		Scene DH4		

Fixation spot 13)

Notes

11) Because Scene DH4 was just before the arrival at the GOAL, we couldn't determine which occluding edges of walls were related to the path selection. Therefore, both edges are shown in the Table.

12) In Scenes DH2 and DH4, "Occluding Edge of the Ceilings" related to the path selections is visible on the left side. Therefore, the edge is shown as "Occluding Edge of the Left Ceilings" in the Table. However, the scenes could not be divided into two scenes based on the edge because it gets out of the range of the eye camera in the scene.

13) For the meanings of the black, white, and no bars, see Note 2 of Table 3.
If more than one fixation spot (Table 2) of the same class is visible in the scene, it is distinguished as below:
(a) Occluding Edges: The "Occluding Edge of Walls" relating to the path selections is defined as the "Occluding Edge of the Left Walls" or the "Occluding Edge of the Front Walls." The "Occluding Edge of Ceilings" is defined as the "Occluding Edge of the Left Ceilings."
(b) Top Stairs: See Note 2.
(c) Corners: See Note 2. The corner bordering the following stairs and the wall on their right side is exceptionally defined as the "Corner of the 1st Stairs and the Right Wall" in Scene DH3-1, unlike the definition of the walls in (d).
(d) Walls: In Scene DH3-1, the wall ahead of the following stairs is defined as the "Left Wall," the wall side of the stairs as the "Front Wall," and the wall on the right side of the "Front Wall" as the "Right Wall." In the other scenes, see Note 2.
Stairs and Landings: See Note 2.

4.2. DESCENDING STAIRCASES

The results showed that regardless whether the next floor appeared, straight or turn ambulation influenced the eye movement directions and the fixation spots of the participants while descending the staircases. In contrast to ascending them, the differences of the directions and spots between the stairs and the landing were not clear while descending them.

On the quarter-turn staircase in the Koshien Hotel, many eye movements occurred to the right in Scene DQ1-2 during left turns, many right-and-left movements occurred in Scenes DQ2 and DQ3, and to the lower-right in Scene DQ6 after the next floor appeared and the start of descending the last stairs. Their intermediate distribution occurred in Scenes DQ4 and DQ5. The differences of eye movement directions among scenes were clearer while ascending the staircases than descending them. On the straight-flight staircase, low right-and-left movements occurred in every scene, and the differences of their directions

among scenes were not so clear while descending it.

On the half-turn staircase in the Architecture Studio, many right-left movements appeared in every scene. Although there were a few differences among such scenes as additional up-and-down movements in Scenes DH2 and DH3-1, they were not clearer than ascending it.

The fixation spots in the Koshien Hotel tend to focus on the walls ahead or the right side, opposite the direction of ambulation while descending the quarter-turn staircase. On the straight-flight staircase, there were great differences among the participants. They tended to focus on the next floor in the last scene of both staircases in Scenes DQ6 and DS3.

In the Architecture Studio, the fixation spots tended to focus on the walls ahead or the right side while descending the half-turn staircase, as in the quarter-turn staircase in the Koshien Hotel. They tended to focus on the walls not only in or before Scene DS3-2, but also in the last scene, Scene DH4.

In both the Koshien Hotel and the Architecture Studio, the differences of eye movement directions and fixation spots among scenes were not so clear while descending. The spots tended to focus on the next floor in the last scenes of both staircases in the Koshien Hotel. Because these phenomena were not found in the Architecture Studio, they might be influenced by the shortness of the last stairs in both staircases in the Koshien Hotel.

The staircases in the Koshien Hotel were mainly designed for rich spatial experiences while ascending them due to great changes of eye movements. However, they were also designed for changes of eye movements while descending them, such as concentrated fixations on the next floor. The approaches to Japanese temples and shrines, including the Shisen-do Temple and Fushimi Inari Taisha Shrine, share similar characteristics.

5. Conclusions

We conducted experiments in which participants wearing an eye camera ascended and descended the quarter-turn and straight-flight staircases in the former Koshien Hotel and the half-turn staircases in the Architecture Studio. We clarifird the following:

1) While ascending the staircases, whether the following landing appeared, on the stairs or the landing, straight or turn ambulation influenced the eye movement direction and the fixation spots of the participants.

2) The differences of eye movement directions and fixation spots among scenes were clearer while ascending the staircases in the Koshien Hotel than in the Architecture Studio. The differences might be influenced by the stairs positioned between walls in the Koshien Hotel.

3) While ascending the half-turn staircases, the fixation spots tended to focus on the wall during the first quarter of the half-turn on the landing in Scene AH3-1. However, these phenomena were not found in the quarter-turn staircase. They might be influenced by the higher stairs in the Architecture Studio than in the Koshien Hotel.

4) While descending the staircases, whether the next floor appeared, straight or turn ambulation influenced the eye movement direction and the fixation spots of the participants. In contrast to ascending them, the differences of the directions and spots between the stairs and the landing were not clear while descending them.

5) The differences of eye movement directions and fixation spots among scenes were clearer while ascending the staircases than descending them, especially in the Koshien Hotel.

6) In the last scenes while descending both staircases in the Koshien Hotel, fixation spots tended to focus on the next floor in the last scenes. However, since these phenomena were not found in the Architecture Studio, they might be influenced by the shortness of the last stairs in both staircases in the Koshien Hotel.

The staircases in the Koshien Hotel were apparently mainly designed for rich spatial experiences while ascending them due to the great changes of eye movements. However, they were also designed for some changes of eye movements while descending them, such as the concentrated fixations on the next floor in the last scenes. The approaches to much Japanese traditional architecture such as temples and shrines share similar characteristics.

Acknowledgements

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Endnotes

1. This paper contains the drastically-revised contents of our previous papers (Suzuki, Uemura et al., 2008a, 2008b, 2009a, 2009b, 2010; Hirano et al., 2010; Suzuki, Okazaki and Uemura, 2011).

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