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Original article

Visual Recognition of the Elderly Concerning Risks of Falling or Stumbling Indoors in the Home

—Comparison of Visual Attention Points Among Elderly, Middle Aged and Young Individuals—

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Abstract

Objective: The objective of this study was to verify the recognition of dangers and obstacles within a house in the elderly when walking based on analyses of gaze point fixation.
Materials and Methods: The rate of recognizing indoor dangers was compared among 30 elderly, 14 middle-aged and 11 young individuals using the Eye Mark Recorder.
Results: 1) All of the elderly, middle-aged and young individuals showed a high recognition rate of 100% or near 100% when ascending outdoor steps but a low rate of recognizing obstacles placed on the steps. They showed a recognition rate of about 60% when descending steps from residential premises to the street. The rate of recognizing middle steps in the elderly was significantly lower than that in younger and middle-aged individuals. Regarding recognition indoors, when ascending stairs, all of the elderly, middle-aged and young individuals showed a high recognition rate of nearly 100%. When descending stairs, they showed a recognition rate of 70-90%. However, although the recognition rate in the elderly was lower than in younger and middle-aged individuals, no significant difference was observed. 2) When moving indoors, all of the elderly, middle-aged and young individuals showed a recognition rate of 70%-80%. The recognition rate was high regarding obstacles such as floors, televisions and chests of drawers but low for obstacles in the bathroom and steps on the path. The rate of recognizing steps of doorsills forming the division between a Japanese-style room and corridor as well as obstacles in a Japanese-style room was low, and the rate in the elderly was low, being 40% or less.
Conclusion: The rate of recognizing steps of doorsills as well as obstacles in a Japanese-style room was lower in the elderly in comparison with middle-aged or young individuals.

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Key words: visual recognition, visual attention, elderly, falling, stumbling

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Introduction

Fall-related accidents in elderly individuals frequently occur in their daily lives. It has been reported that fractures caused by falls frequently occur in healthy and community-dwelling elderly, as well as facility-residing elderly[1)]. A study in Japan[2)] reported that the annual fall incidence in community-dwelling elderly aged 65 years or over is about 20%, increases with aging and is higher in females than in males. Regarding places where falls occur, they frequently take place indoors, in the home, as well as outside on streets and steps[2)]. Indoor falls are caused by various environmental factors such as steps of doorsills, tatami mat borders, rugs, stairs, poor lighting, and presence of slippery surfaces[1)].

Fall-induced fractures occur in 5 to 10% of those who fall. Bed rest following fractures is one of the main causes of a bedridden state[2)]. In addition, the above study also reported problems in community-dwelling elderly in which their fall experiences made them even more scared of falling, leading to withdrawal, which decreases daily life activities and IADL, thereby decreasing quality of life[2)].

Reportedly, the main factors, excluding environmental factors, associated with elderly falls include reductions of regulatory, motoric and sensory functions owing to aging[1)]. When visual function decreases, elderly individuals become less aware of steps, leading to an increased risk of falls and stumbling. Vision helps us perceive dangers such as steps and structures in our living environment, helping us to avoid dangers such as stumbling over steps, as well as control the center of gravity and balance recovery when the body sways[3]. Various vision-assisted information processings are basic functions supporting the behavior of the elderly[4], but the relationship between vision-assisted information processing of the elderly and falls has not been clarified.

Measures to prevent falls and fall-induced fractures in a community are important to maintain a healthy and independent life without being bedridden for as long as possible and extend the healthy life expectancy even when reaching an advanced age. Falls and fractures are often followed by conditions in which caregiving is required; thus, it may be necessary to examine vision-assisted recognition of dangers in the living environment from the perspective of long-term care prevention. Therefore, the purpose of this study was to investigate how many fall-related dangers there are for community-dwelling elderly.

In this present study, we performed empirical analyses in a typical house to examine whether or not the elderly walk while fixing their gaze on dangers and visibly recognize the dangers and compared the characteristics of indoor falls and stumbling and recognition of dangers of obstacles in the elderly with those in young and middle-aged individuals. The results of this study may contribute to fall and long-term care prevention in the elderly, improvement of the living environment from the perspective of managing the risk of falls and stumbling and further discussion on the development of a safe and secure community.

Subjects and Methods

Subjects

The subjects consisted of 55 people, including 30 elderly (aged 70-75 years), 14 middle-aged (40-45), and 11 young individuals (18-23) without wearing glasses.

The subjects were provided with information about the study objective, method, and problems involving the study, etc., and informed consent was obtained; all of subjects signed a consent form. From the perspective of personal information protection, all data were analyzed after anonymization, and data were managed by being stored in a depository that was locked in order to maintain confidentiality.

Methods

1) Experimental place and period

Experiments were conducted at the laboratory on the 4th floor of National Institute of Technology and Evaluation (NITE), and all experiments were carried out from May to October.

2) Experimental apparatus

We prepared a digital video disc (DVD) for experiments by the following method, and asked Vogts Art (Kobe, Japan) to shoot and edit videos and prepare the DVD.

Using video camera, We shot videos of premises and interior of a detached house from a 1.55-m height (approximate height for an adult) while walking at a speed normal for adults (approximately 1.4 m/sec, but this sloweded to the average ascending or descending speed when going up and down stairs). Regarding the walking path, we ascended steps from a local street, passed through the premises in front of the entrance, went indoors through the entrance, walked around rooms on the first floor, ascended the stairs to the second floor, went around rooms on that floor, descended the stairs again, went outside through the entrance, descended the steps and returned to the local street (Figure 1).

We edited the videos and prepared a DVD for experimental use. The DVD for experimental use was played back with a DVD player (Sony DVP-F35P) and projected onto a screen with a projector (Sony VPL-ES2). The videos used at this time were shot in a detached, two-story house considered typical housing within Kobe City.

Figure 1 shows points regarding the risk of falling and ones considered to be obstacles when walking within the premises and interior of a detached house. The walking paths shot in the videos and used in the experiment were divided into five path as shown in Table 1. The first path included ascending the steps from the local street, passing through the premises in front of the entrance and going into the entrance. The second path included going indoors through the entrance, walking around rooms on the first floor and then walking to a place just short of the stairs to the second floor near the bathroom. The third path included ascending the stairs to the second floor, walking around rooms on that floor and descending the stairs from the second floor to a place short of the first floor. The fourth path included descending the stairs to the entrance, and the fifth path included going outside through the entrance, descending the steps and returning to the local street.

3) Experimental method

When subjects entered the laboratory (about 20 m^2), they were asked to sit on a chair set 2.5 m away from a wall used as a screen. After adjusting the chair, we put an Eye Mark Recorder (EMR-8B, NAC Image Technology) on the subjects, adjusted it and prepared for measurement. Illuminance in the laboratory was set so that the subjects could easily see the videos on the screen. The laboratory had no soundproofing equipment; thus, we shut the doors and limited through-passage so that outdoor sounds could not be heard.

Before initiating the experiment, we first said “A video will be shown on the screen now. Please tell us if you feel that it is difficult to see,” and then verified that the subjects could see the video and that the screening environment was

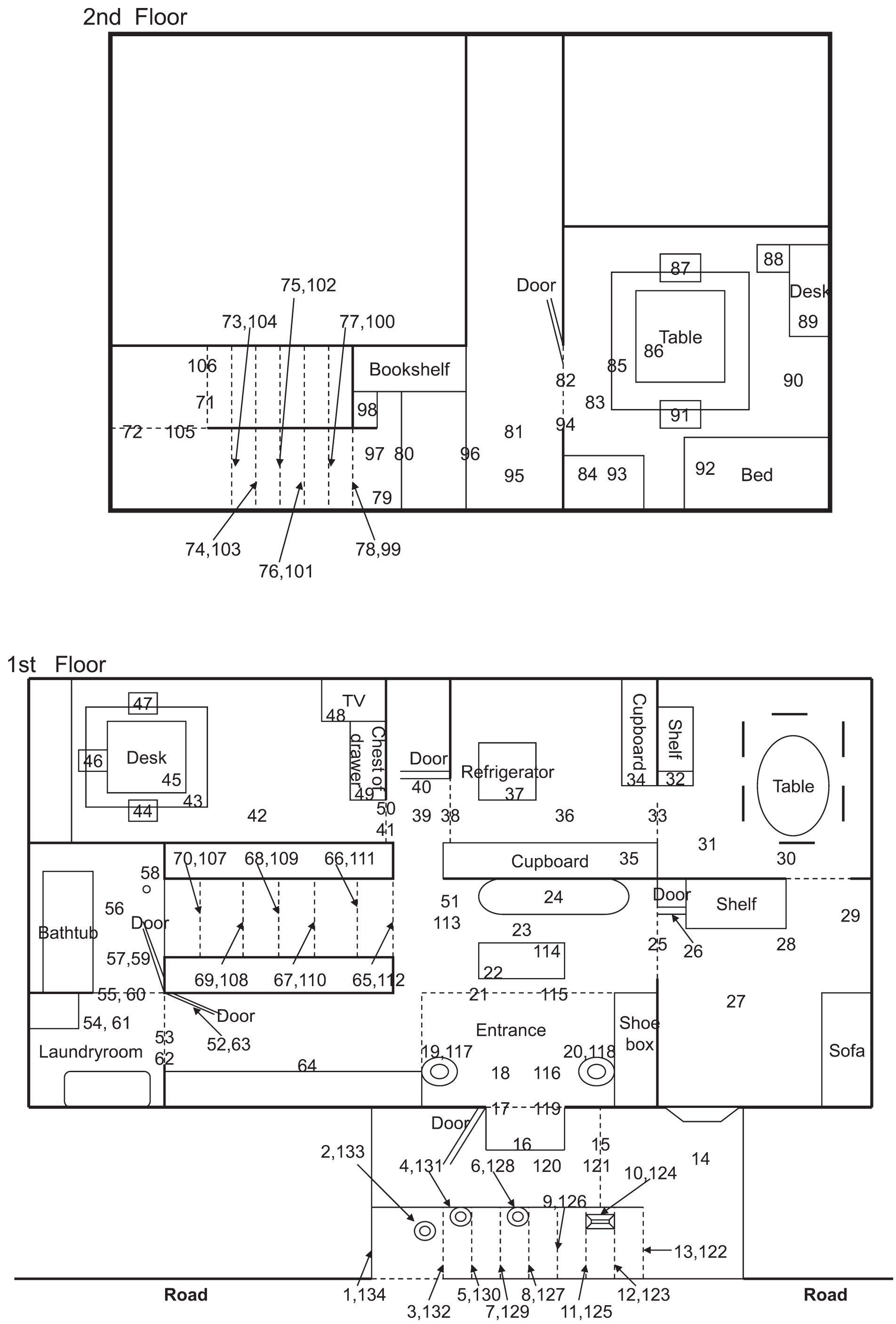

Figure 1 Walking path.

appropriate. We then said "A video will be shown on the screen now. Please watch the video while imagining that you are now actually walking there. The video will be shown for about 8 minutes. Please watch it closely until it finishes. We will tell you when the video is over." The naked vision of all subjects was 1.0 or higher. No subjects had impaired vision interfering with the experiment.

The subjects in the present study were shown a DVD containing video shot while walking in a home. Data such as the gaze points of the subjects were recorded onto video-

Table 1 Risky points regarding falling or stumbling inside at the house

The first path	Raod	
	Point1	Stairs (1st step)
	Point2	Flowerbed
	Point3	Stairs (2nd step)
	Point4	Flowerbed
	Point5	Stairs (3rd step)
	Point6	Flowerbed
	Point7	Stairs (4th step)
	Point8	Stairs (5th step)
	Point9	Stairs (6th step)
	Point10	Flowerbed
	Point11	Stairs (7th step)
	Point12	Stairs (8th step)
	Point13	Stairs (9th step)
	Point14	Floor
	Point15	Step
	Point16	Carpet
	Point17	Step
	Point18	Floor
	Point19	Tree
	Point20	Tree
	Point21	Step
The second path	Point22	Carpet
	Point23	Floor
	Point24	Obstacle
	Point25	Step
	Point26	Door
	Point27	Floor
	Point28	Shelf (Obstacle)
	Point29	Step
	Point30	Chair (Obstacle)
	Point31	Floor
	Point32	Shelf (Obstacle)
	Point33	Step
	Point34	Shelf (Obstacle)
The second path	Point35	Shelf
	Point36	Floor
	Point37	Refrigerator (Obstacle)
	Point38	Step
	Point39	Floor
	Point40	Door
	Point41	Step
	Point42	Floor
	Point43	Carpet
	Point44	Cushion
	Point45	Desk
	Point46	Cushion
	Point47	Cushion
	Point48	Television
	Point49	Chest of drawers
	Point50	Step
	Point51	Floor
	Point52	Door
	Point53	Step
	Point54	Floor
	Point55	Step
	Point56	Floor
	Point57	Door
	Point58	Obstacle
	Point59	Door
	Point60	Step
	Point61	Floor
	Point62	Step
	Point63	Door
	Point64	Floor
The third path	Point65	Stairs (1st step)
	Point66	Stairs (2nd step)
	Point67	Stairs (3rd step)
	Point68	Stairs (4th step)
The third path	Point69	Stairs (5th step)
	Point70	Stairs (6th step)
	Point71	Stairs (7th step)
	Point72	Stairs (8th step)
	Point73	Stairs (9th step)
	Point74	Stairs (10th step)
	Point75	Stairs (11th step)
	Point76	Stairs (12th step)
	Point77	Stairs (13th step)
	Point78	Stairs (14th step)
	Point79	Floor
	Point80	Carpet
	Point81	Floor
	Point82	Step
	Point83	Floor
	Point84	Obstacle
	Point85	Carpet
	Point86	Table
	Point87	Cushion
	Point88	Obstacle
	Point89	Desk
	Point90	Obstacle
	Point91	Cushion
	Point92	Bed
	Point93	Obstacle
	Point94	Step
	Point95	Floor
	Point96	Carpet
	Point97	Floor
	Point98	Obstacle
The forth path	Point99	Stairs (14th step)
	Point100	Stairs (13th step)
	Point101	Stairs (12th step)
	Point102	Stairs (11th step)
	Point103	Stairs (10th step)
The forth path	Point104	Stairs (9th step)
	Point105	Stairs (8th step)
	Point106	Stairs (7th step)
	Point107	Stairs (6th step)
	Point108	Stairs (5th step)
	Point109	Stairs (4th step)
	Point110	Stairs (3rd step)
	Point111	Stairs (2nd step)
	Point112	Stairs (1st step)
	Point113	Floor
	Point114	Carpet
	Point115	Step
The fifth path	Point116	Floor
	Point117	Tree
	Point118	Tree
	Point119	Step
	Point120	Floor
	Point121	Step
	Point122	Stairs (9th step)
	Point123	Stairs (8th step)
	Point124	Flowerbed
	Point125	Stairs (7th step)
	Point126	Stairs (6th step)
	Point127	Stairs (5th step)
	Point128	Flowerbed
	Point129	Stairs (4th step)
	Point130	Stairs (3rd step)
	Point131	Flowerbed
	Point132	Stairs (2nd step)
	Point133	Flowerbed
	Point134	Stairs (1st step)
	Road	

tapes (Sony DVM60) with an Eye Mark Recorder during the experiment.

Data analysis

Videotapes were played back with a video player (Sony GV-A700 NTSC). Gaze trajectories on walking within the detached house were displayed using the "fixation data gaze trajectory, which is comprised of gaze fixation data plotted and displayed on the coordinates of the visual field." In the present study, the analytical results of the fixation data gaze trajectory were used to analyze videos of gaze points and determine whether or not gaze points were fixed at points with a risk of falls and stumbling and obstacles within and around the house (Figure 1 and Table 1). Visual recognition of dangers was verified based on the analytical results regarding whether or not the gaze points were dangers and obstacles. The fixation data for the gaze trajectory of gaze points were analyzed using the EMR analysis system (NAC Image Technology). The rate of gaze points associated with a risk of falls and stumbling and obstacles (the rate of gaze point fixation) was calculated by age group (elderly, middle-aged and young individuals). The rate of recognizing dan-

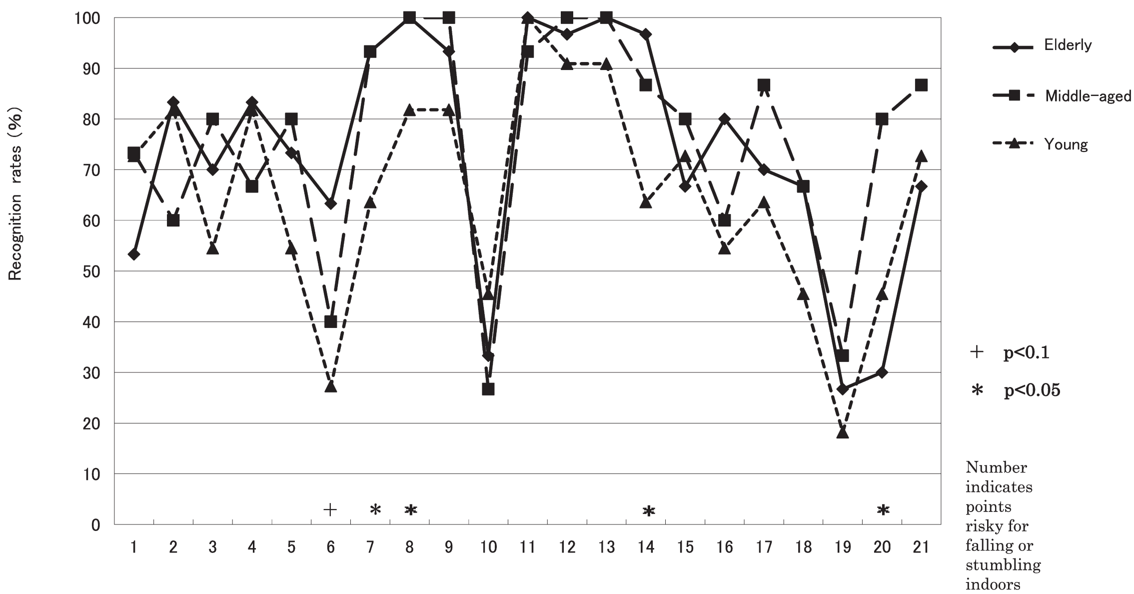

Figure 2 Visual recognition of points risky for falling or stumbling indoors at home.

gers and obstacles was calculated as: [(the number of subjects whose gaze was fixed on and recognized the danger/ the total number of subjects) × 100], and each danger point was compared.

For statistical analysis, we employed SPSS and the χ^2 test.

Results

We analyzed the fixation data for the gaze trajectory toward dangerous indoor steps of elderly, middle-aged and young individuals. Figures 2, 3, 4, 5 and 6 show the rates of recognizing points associated with a risk of falls and stumbling (the recognition rate) and the changes in this recognition rate.

Comparison of the danger recognition rate among elderly, middle-aged and young individuals

1) The first path (Figure 2)

Regarding the first path, all elderly, middle-aged, and young individuals showed a high recognition rate of or near 100% when ascending the steps (point 3-13). They showed a low rate of recognizing planters (point 6 and 10) and plants (point 19 and 20) placed on the steps, and young individuals showed a lower rate than the other age groups (point 6-8, 14 and 20).

2) The second path (Figure 3)

Regarding the second path, all elderly, middle-aged and young individuals showed a recognition rate of about 70-80%. High recognition rate points (point 23, 27, 31, 36, 39, 42 and 51) included obstacles such as floors, television and chests of drawers (point 28, 32 and 34). A low recognition rate and dangerous points included obstacles (point 58 and 59) in the bathroom (25%) and steps (point 60 and 62) on the path (50%). The recognition rates (point 26, 35, 53, 58 and 59) among age groups were significantly different for some dangers.

3) The third path (Figure 4)

Regarding the third path, all elderly, middle-aged and young individuals showed a high recognition rate of or near 100% when ascending the stairs (point 65-78) to the second floor. However, middle-aged and young individuals showed a low rate of recognizing doorsill steps (point 82 and 83) between a corridor and Japanese-style room (43% and 40%, respectively). They also showed a low rate of recognizing obstacles (point 80, 81, 85, 87, 91, 94, 96 and 98) in the Japanese-style room (nearly 35%).

4) The fourth path (Figure 5)

Regarding the fourth path, all elderly, middle-aged and young individuals showed a comparatively high recognition rate of 70%-90% when descending stairs (point 99-112) from the second to first floor. However, the recognition rate in the elderly was lower than that in young and middle-aged individuals, but was not significantly different.

5) The fifth path (Figure 6)

Regarding the fifth path, all elderly, middle-aged and young individuals showed a high recognition rate of approximately 60% when descending steps (point 122, 123

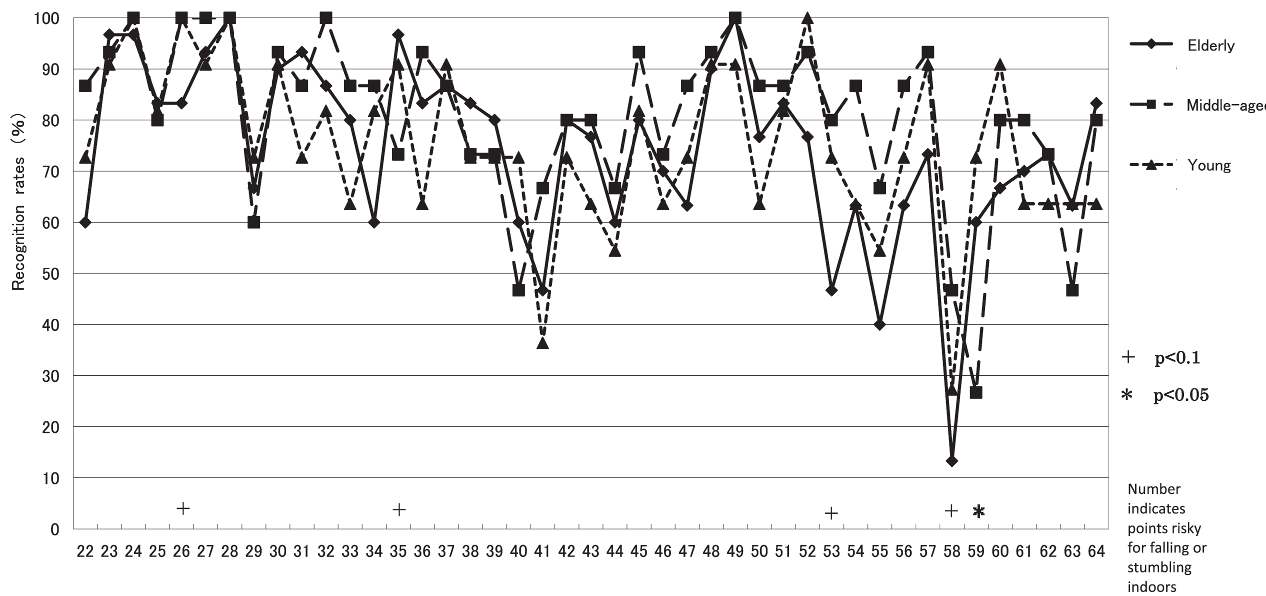

Figure 3 Visual recognition of points risky for falling or stumbling indoors at home.

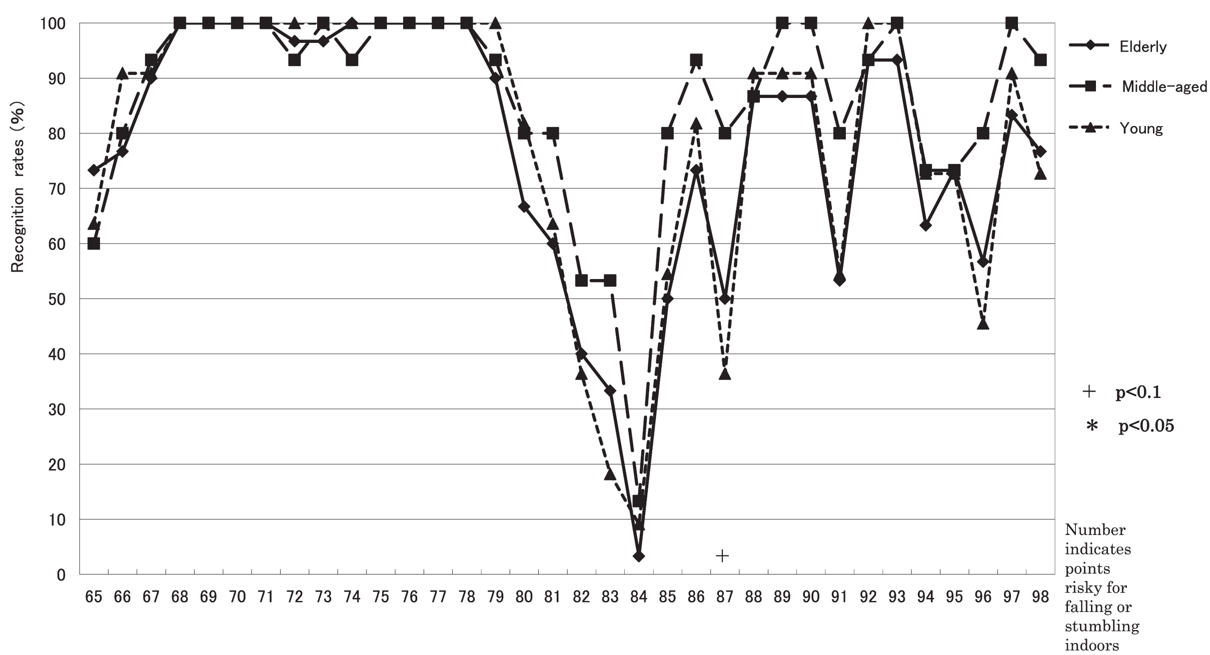

Figure 4 Visual recognition of points risky for falling or stumbling indoors at home.

and 134), from the premises to the local street. However, the rate of recognizing steps (point 125-127, 129, 130 and 132) in the middle of a staircase in the elderly was lower than that in the young and middle-aged individuals and significantly different in point 126 and 127.

Discussion

Falls in community-dwelling elderly occur most frequently in the living room followed by on stairs[2] and are likely to be caused by stumbling over small steps and behavior to avoid obstacles interfering with walking[5]. Stumbling

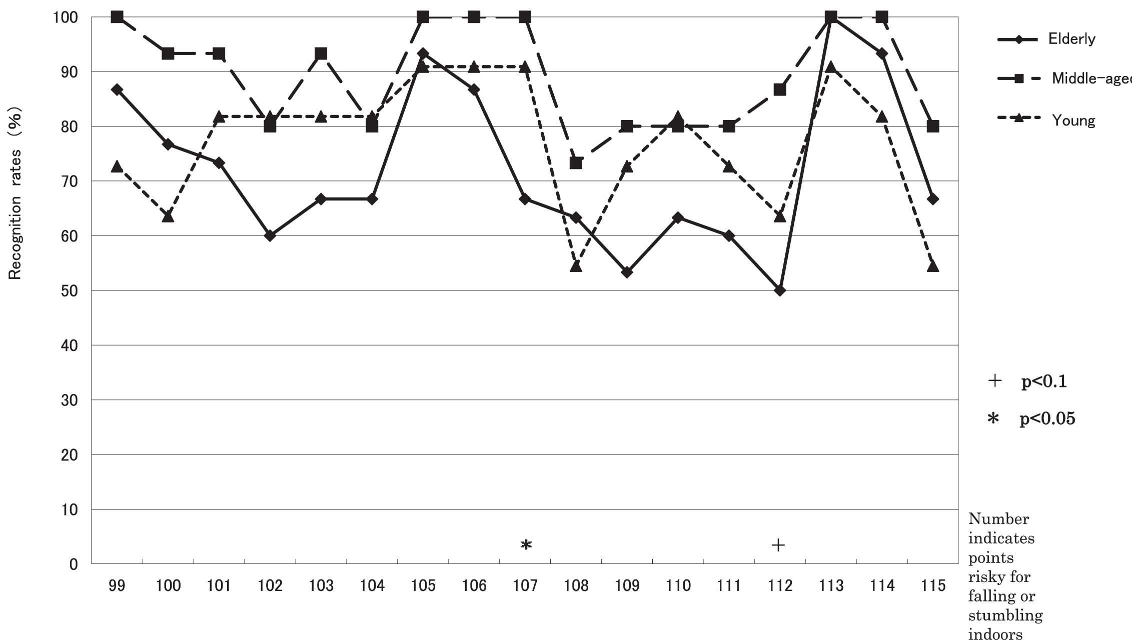

Figure 5 Visual recognition of points risky for falling or stumbling indoors at home.

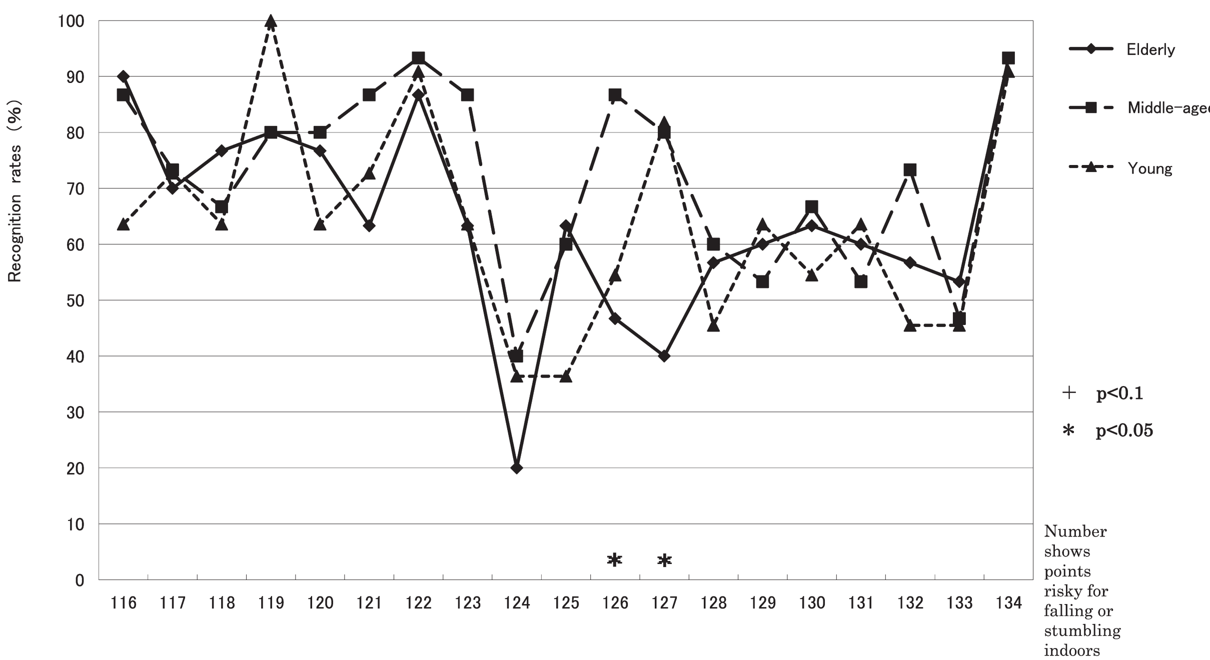

Figure 6 Visual recognition of points risky for falling or stumbling indoors at home.

occurs in places with small steps, such as doorsills and tatami mat borders[2, 5]. Dangers causing falls and stumbling in a living room include steps of a doorsill, tatami mat borders, carpets, rugs, and obstacles (children's toys, magazines, newspapers, etc.). Meanwhile, stairs, which differ from places where one is free to place their feet, are said to be an area where you regulate your physical exertion in more detail through your legs[5] and falls are likely to occur when descending stairs[1]. Therefore, reportedly, it is necessary for the elderly to recognize the danger by gazing at the steps under their feet and to move their gaze points to obstacles in their way, in order to walk safely without falling or stumbling[4, 6]. Thus, this study analyzed dangers causing falls and stumbling as well as gaze points within a house, which is a living space where the elderly most frequently fall, using the Eye Mark Recorder. We ascertained whether or not the gaze points of elderly were fixed on steps, stairs and obstacles that may be a risk for indoor falls and stumbling, and empirically verified whether or not they walk while visually recognizing these dangers. Few studies like this have been reported so far.

Comparison among young, middle-aged and elderly individuals concerning visually recognizing steps at the time of going up and down stairs

Regarding the rate of recognizing risks on going up and down stairs inside and outside the house, the subjects showed a high recognition rate when ascending stairs both indoors and outdoors, but, according to the age group, elderly and middle-aged individuals showed a high rate near 100%, while younger persons showed a comparatively low rate of 60 to 80%. Meanwhile, all age groups showed a lower recognition rate of about 60% when descending stairs compared to when ascending inside and outside the house. The recognition rate was high around the first stairs they started to descend and became lower as they descended more stairs. The elderly showed a lower rate of recognizing steps in the middle of a staircase when descending than young and middle-aged individuals, and the recognition rate decreased to 40% on some steps.

Going up and down stairs increases the risk of falls. Falling when descending stairs may cause fractures. However, this study revealed that the rate of recognizing steps was lower when descending than when ascending and that the recognition rate in the elderly was high when they started to descend, but it decreased in the middle of the staircase. This suggests that decreased visual recognition in the middle of a staircase may cause falls.

Reportedly, visual information-searching when descending stairs is different from that when ascending. When ascending stairs, the fall risk is limited, and you can safely walk unless you frequently gaze at your feet; therefore, gaze points move step-by-step to look at stairs at the level of your eyes rather than under your feet. Thus, forward vision becomes clear[6, 7]. Meanwhile, the fall risk increases when descending stairs, necessitating confirmation of the foot position by gazing at the next surface before descending; therefore, gaze points frequently move around the feet[4, 6]. The recognition rate was also high at the first stairs subjects started to descend. When you start to descend stairs, you clarify information concerning the underfoot environment and the environment adjacent to the body in combination with that of the neighboring environment, making stair descent smoother and faster[7]; therefore, it is suggested that, on descending stairs, subjects visually recognized the steps and adopted behaviors to avoid falls by gazing at the steps under their feet, particularly the first step.

In middle age or later, people recognize stairs as a dangerous place with a high risk of falling[2]; thus, they are strongly fearful of falls on stairs[10]. The results revealed that stairs are places where the elderly are at a risk of falling[1] and that elderly individuals clarify information concerning the underfoot environment and the environment adjacent to the body in combination with that of the neighboring environment, like younger[4, 6] and middle-aged individuals, gazing at the first step and moving their gaze points around the feet before descending stairs[4, 6]. This visual recognition may enable the elderly to descend stairs smoother and faster[6]. The risk of falling may increase on descending stairs[1]; therefore, people need to visually recognize the steps. However, the recognition rate in the elderly is high at the first stair they start to descend, but at later stairs, it is not always high. This study suggested that, as one of the reasons for falling, decreased visual recognition of steps in the middle of a staircase may increase the risk of falling.

We reported in earlier studies[11, 12] that the speed of gaze point movement is faster in the order of young individual, middle-aged individuals, elderly individuals who have not fallen and elderly individuals who have fallen. Regarding the trajectory of gaze points, the gaze point of young individuals moved through points associated with a risk of falling, revealing that they searched for dangers. The speed of gaze point movement was faster and the gaze range was broader in young individuals than that in middle-aged and elderly individuals, revealing that younger persons moved gaze points to any direction, in vertical, horizontal (width of walking place) and path-perspective directions, while confirming the underfoot environment and visually recognized the space including obstacles. These results, corresponding to the analytical results of the gaze-point trajectory evaluations involving students[6], may be characteristic of young individuals in relation to visually searching for environmental information.

From the perspective of visually searching for environmental information[13], it is speculated that the elderly cannot efficiently or rapidly acquire environmental information from a broad range compared with young individuals, and cannot search for and recognize fall-related dangers. Moreover, elderly individuals who have fallen slowly move gaze points, and the movement range is narrow[11]. Therefore they cannot efficiently search for environmental information. It is speculated that, as a result of overlooking steps owing to limited information on dangerous environments, falls and stumbling are likely to occur in fallen elderly. Their decreased ability to visually recognize environments may be involved in falls and stumbling.

Comparison of visual recognition indoors among young, middle-aged and elderly individuals

The danger-recognition rate was high when going up and down stairs inside and outside the house. However, within the house, there are no big steps except for stairs; thus, the recognition rate decreased to approximately 60-70%. A high recognition rate of nearly 80% is shown when walking in a place with few steps and there are obvious obstacles in the walking direction. Meanwhile, the rate of recognizing the doorsill forming the division between a Japanese-style room and corridor was low, 43%, and 40%. The rate of recognizing obstacles in the bathroom (25%) and steps on the path (50%) was low, but the rate of recognizing small steps except for the doorsill (e.g., steps of tatami mat borders and tiles) and comparatively big steps (e.g., upper frame and doorsill in the entrance) was higher than for the doorsill of the Japanese-style room. This low recognition rate is related to the fact that falls are caused by small steps such as doorsills[1], and suggested that the failure of the elderly to visually recognize small steps leads to a risk of falls and stumbling[14].

However, the recognition rate may differ even when both steps are similarly small; thus, there may be environmental conditions in which steps are likely to be overlooked. As one of the reasons why a doorsill is hard to visually recognize, the colors of the corridor and doorsill are relative. Discussing safety[13] from the perspective of the light environment, viewability consists of four conditions: brightness, size, contrast and time. In the present study, the doorsill between the corridor and Japanese-style room was hard to see, and so architectural improvement to prevent falls and stumbling, such as changing the color of dangerous points and method of lighting steps, may be effective.

Another noteworthy point is below. On the third pathway position 84 and position 93 are the same place. But the recognition rate of position 93 is higher than that of position 84. The reason for this difference is considered to be that position 84 is blind for a walker on walking clockwise[6].

In this study middle aged tend to have high recognition rates in comparison with other age groups. It is well known in elderly and middle-aged Japanese that falls is one of main causes of the bedridden and that Japanese cushion (position 87) is a risk of falling at home[1]. So middle-aged is considered to pay more attention to such a risk position indoor as Japanese cushion.

Limitations of this study

In the present study, videos shot while actually walking were employed unlike past studies in which videos created by computer graphics were employed[4]. Thus, subjects did not walk in the house themselves. The reasons for this included ethical considerations to avoid the risk of falling because the subjects included elderly individuals and the fact that the experimental methods were constrained because the measurement instrument was not mobile. Thus, this experiment was performed not in a real space, but in a virtual reality space. However, Fukuda *et al.* revealed, based on analytical results of gaze points, that subjects gaze in a virtual reality space as much as in a real space[8]; therefore, this may have had a limited influence on the results.

Although the results were obtained under the above-mentioned experimental conditions, visual recognition of dangers and obstacles within a house was different among ages. This difference may be associated with falls and stumbling in the elderly[11, 12]. The results may provide specific suggestions for maintaining living environments. We will accumulate empirical results concerning the reasons for falls in the elderly from detailed analysis of the recognition of risks of falls and stumbling through gazing and, from the perspective of risk management, put forward proposals to improve living environments.

Conclusion

This study verified the recognition of dangers and obstacles within a house in the elderly when walking based on analyses of gaze point fixation. The rate of recognizing indoor dangers was compared among elderly, middle-aged and young individuals using the Eye Mark Recorder, generating the following results:

1) All of the elderly, middle-aged and young individuals showed a high recognition rate of 100% or near 100% when ascending outdoor steps, but a low rate of recognizing obstacles placed on the steps. They showed a recognition rate of about 60% when descending steps from residential premises to the street. The rate of recognizing middle steps in the elderly was significantly lower than that in the young and middle-aged individuals. Regarding inside the house, all of the elderly, middle-aged and young individuals showed a high recognition rate of nearly 100% when ascending stairs. When descending stairs, they showed a recognition rate of 70-90%. However, although the recognition rate in the elderly was lower than in the young and middle-aged individuals, no significant difference was observed.

2) When moving indoors, all of the elderly, middle-aged and young individuals showed a recognition rate of 70%-80%. The recognition rate was high regarding obstacles

such as floors, televisions and chests of drawers but low for obstacles in the bathroom and steps on the path. The rate of recognizing steps of doorsills forming the division between a Japanese-style room and corridor as well as obstacles in the Japanese-style room was low, and the rate in the elderly was low, being 40% or less.

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