Visual guidance of walking: effects of illumination level and edge emphasis

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N. Itoh. Visual guidance of walking: effects of illumination level and edge emphasis. Gerontechnology 2006; 5(4):246-252. This study concerns the visual guidance of walking. Viewing directions and step rate of young and old participants were assessed, focusing on the global effect of illumination level and the local effect of edge emphasis of walkways. Experiments were performed on a straight walkway (normal) and on a short cornered walkway without sufficient visual information (restricted). Restricted conditions included a completely white versus an edged-emphasized walkway, and low mesopic versus high photopic lighting level. In normal condition, both older and younger adults directed their line of sight to the upper level of the walking direction. In restricted conditions for older adults, there was no change in the photopic condition while in the mesopic condition older adults looked longer to the floor and edges and walked slower. Edge emphasis helped to keep their line of sight in the upper walking direction. Young adults looked consistently in the direction of walking in all conditions, although the restricted condition affected their step rate. If lighting level is insufficient, edge emphasis helps older people to maintain a stable walking pace.

Keywords: elderly, eye movements, walking, illumination level, edge emphasis

The ability to assess spatial information is essential for walking. Walking requires information on both static and dynamic conditions of the walking space. We set out to understand what types of visual cue are being used by walkers and how this information affects their walking.

Earlier studies have examined the coordination of gaze behavior and walking, in relation to viewing direction when walking[1-3], and the influence of age[4,5]. These studies investigated how visual information was used for obstacle avoidance or for stepping on certain markings. Another study investigated viewing directions of young and older adults while walking in natural conditions. The elderly appeared to rely on their central vision more than the young[6], indicating that age-related differences exist in the way visual information is used to control walking. Also it was observed that older adults looked longer at the edges of walkways (borderline of flat walkway and slope, edge between wall and floor)[7].

Age differences in vision may increase under challenging viewing conditions, such as low contrast and low luminance[8]. Therefore, global effects of the visual environment, such as illumination level, might affect daily activities of older adults since this group needs more light to have the same visual acuity as younger adults. However, a study on the effects of lighting on young and older women's gait parameters when walking on irregular surfaces reported no significant effects on both groups[9]. So the way they acquire global visual information from the environment during walking remains unclear.

In order to understand the appropriate visual walking environment for older adults, it is important to learn both about their walking behavior, as well as how they get information from the environment. Therefore, this study focuses on the age dependence of the perception of visual information of walkways, in particular global information supplied by the illumination level and local information on edges between wall and floor. Dependent parameters are viewing direction and step rate. From the results we try to derive design rules for easy and safe walkways for older adults.

Methods

Participants

A total of 24 older and 13 younger adults participated. To avoid effects of visual acuity, only participants with visual acuity >0.6 in photopic conditions were selected for analysis. Contact lenses or glasses could not be used in the eye movements analysis system. This left 10 older adults (69.2 ± 6.6 yrs; 60 to 82 yrs) and 7 younger adults (22.6 ± 2.5 yrs; 19 to 26 yrs) to be included in the final analysis.

Procedure

All experiments were conducted in the laboratory within the institute. Data for viewing direction and step rate were analyzed in two experiments. In Experiment 1, participants walked on a straight 38 m long and 2 m wide walkway for four times. This walkway was commonly used as to enter actual rooms, and all subjects had used it before. During the experiment, no outsiders were allowed to use it. First, participants were asked to walk twice as usual: free walking. Next, participants were asked to walk twice straight in the center of the walkway: controlled walking. There was no direct visual information to suggest where the center of the walkway was, and no indication of what represented a straight line. In both cases, the second trials were adopted as the data to be analyzed.

In Experiment 2, participants were asked to walk as usual on a walkway consisting of three straight lines and two corners. This walkway was 10 m in length and 1.8 m wide, had a white surface, and visual information was restricted. The sides were 3.0, 4.5, and 2.5 m. There were two conditions: a completely white (no edge) walkway and an edged (edge emphasis) walkway. Mean lighting levels were set to 1000 lx (photopic) and 10 lx (mesopic) (*Figure 1*); however, there was also a small amount of daylight from the window, which did not exceed 10 lx. First, all subjects walked this walkway prior to the experiment without wearing an eye movements' analysis system. Next, with the eye movement system attached, they were asked to walk each walkway twice as usual (free walking) and twice in the centre of the walkway (controlled walking). Again, only the second trials were adopted for data analysis.

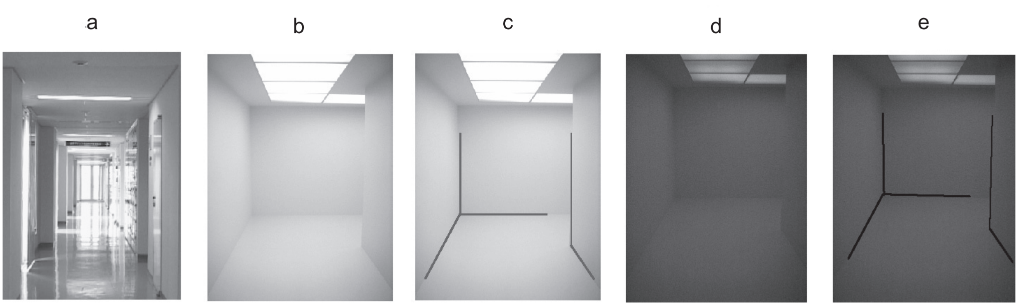

Figure 1: Experimental set up; a: Normal walkway; b: No-edge condition, photopic; c: Edge condition, photopic; d: No-edge condition, mesopic; e: Edge conditions, mesopic

During walking, eye movements were measured by a lightweight eye mark recorder with an infrared sensor measuring corneal reflection (EMR8; NAC Image Technology Inc., Japan). Sampling frequency was 30 Hz; precision within 0.1 degree in width. Eye movements were superimposed on a videotaped image of the scene through which the persons walked, which was recorded by a CCD camera attached under the cap between both eyes. Step rate was derived from video tape, which was recorded by a camera placed on the back of subjects during the first experiment, and 3 CCD cameras attached to the ceiling of the sides of the walkways, and one video camera at the starting point of the walkway in the second experiment.

Experimental protocols were approved by The National Institute of Advanced Industrial Science and Technology (AIST) Ethics Committee and all participants gave written informed consent prior to data collection.

Results

Free and controlled walking

Step rate and range of eye movement distribution were calculated as the product of the standard deviation of the range of horizontal direction (X) and vertical direction (Y) movements (*Table 1*). Two way ANOVA showed that there were significant effects of range of eye movements and step rate between free and controlled walking (range: n=1, F=18.114, p<.01, rate: n=1, F=9.746, p<.01). There were no significant effects of age, and no interactions were found.

Edge and illumination

Viewing directions

Videotaped analysis of viewing direction

Table 1. Subject characteristics, and area and range of the distribution of viewing direction and step rate in the free and controlled walking experiment; Range of viewing directions was calculated by the product of the standard deviation of horizontal (X) and vertical (Y) viewing directions; E = Older adults; Y = Younger adults; F = female; M = male; FW = Free-walking; CW = Controlled walking

Subject	Gender	Age	Visual acuity	Viewing Direction	Range (X*Y) FW	Range (X*Y) CW	Step rate (steps/min) FW	Step rate (steps/min) CW
E1	M	60	1.5	In heading direction	21.20	3.43	125.24	121.53
E2	M	78	1.0	In heading direction	9.28	1.68	90.83	89.50
E3	F	71	1.0	In heading direction	5.04	4.61	117.81	107.67
E4	M	64	1.0	In heading direction	18.53	1.63	123.74	127.32
E5	M	82	0.6	In heading direction	0.47	0.36	120.67	110.77
E6	M	68	1.2	Left wall	20.34	5.43	93.33	82.53
E7	M	70	1.0	Left wall	23.30	6.38	114.11	110.20
E8	F	66	1.0	Left wall	5.43	5.81	117.81	112.92
E9	F	65	0.9	Left and right wall	90.82	38.59	123.80	117.63
E10	M	68	0.9	Floor	33.63	31.23	121.19	123.04
E_{mean}		69±7	1.0±0.2		23±26	10±13	115±12	110±14
Y1	F	19	0.6	In heading direction	12.65	5.37	115.57	109.15
Y2	M	25	1.0	In heading direction	92.18	0.71	107.63	111.38
Y3	M	21	1.5	In heading direction	29.46	1.44	113.54	110.00
Y4	F	26	1.0	In heading direction	8.11	3.71	115.31	111.91
Y5	F	24	1.5	In heading direction	24.16	0.41	118.58	105.88
Y6	M	22	0.9	In heading direction	71.27	1.14	114.25	113.11
Y7	F	21	1.5	Ceiling	43.18	8.68	115.68	116.20
Y_{mean}		23±3	1.1±0.4		40±31	3±3	114±3	111±3

was conducted, and areas of eye marks were located and recorded frame by frame. Total walking time varied among participants, and the time ratio of the location of eye movements was calculated. Categorized locations included: heading direction (upper area of direction of walking), floor, edge, other (for instance, ceiling, side wall), and error (uncertain eye marks). Figure 2 shows the comparison of the time ratio of each area of distribution of viewing directions for every lighting condition. In the photopic condition, both older and younger adults looked predominantly in the heading direction. In the mesopic condition, older adults more often looked at the floor or the edge, especially without edge emphasis, while there was no significant change in the younger adults' gaze direction.

Three way ANOVA revealed overall effects of age, edge emphasis, and illumination. The effects of age were significant when looking at areas, but not for illumination or edge emphasis. To figure out the effects of edge emphasis and illumination within each group of participants, two-way ANOVA was conducted on the ratio of distribution of viewing directions. When looking at each area, for instance, two-way ANOVA of younger adults revealed no significant effects on any of parameters on looking at the area, heading direction, floor, or edge. For older adults, two-way ANOVA on looking at heading direction and floor revealed no significant effects, but there was a significant effect of illumination level on looking at the edge ($n=1$, $F=5.682$, $p<.05$).

Step rate

In mesopic conditions, step rate of older subjects slowed down (*Figure 3*). Three way ANOVA revealed no overall ef-

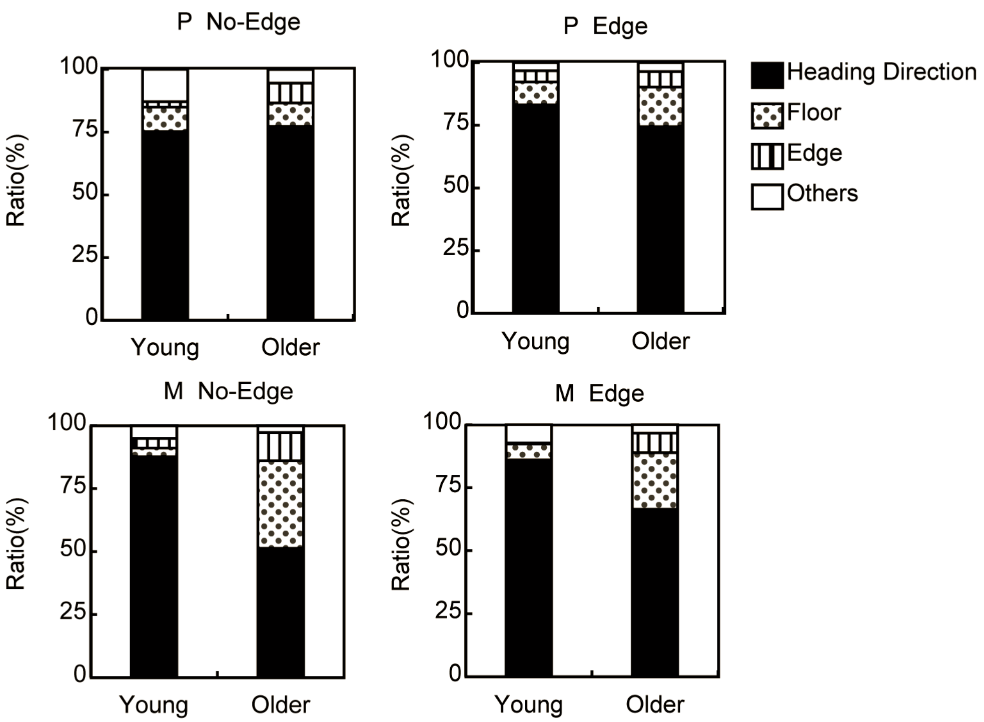

Figure 2: Average time ratio of viewing directions in controlled walking in the edge and illumination experiment; Heading direction = direction of walking towards the wall; Floor = floor and foot area; Edge = edge between floor and wall; P = photopic; M = mesopic

fects of age, edge emphasis, and illumination. Within each group of participants, two-way ANOVA of younger adults revealed that there was a significance difference due to the presence of the edge (n=1, $F=8.779$, $p<=.05$), and interaction between edge and illumination (n=1, $F=6.352$, $p<=.05$), while for the older adults there was only a significant difference on illumination level (n=1, $F=17.735$, $p<=.01$).

Discussion

Visual anchoring

In controlled walking in normal conditions, distribution areas of viewing directions of both younger and older adults were significantly smaller compared to free walking. One older subject did not consistently look in the direction of walking, but still the distribution area was smaller in controlled walking. Therefore, it appears common for both older and younger adults to keep looking at certain areas and not look around when controlling direction and position of walking. Similar behavior has been reported earlier: when stepping on a marked area or on stairs, older adults looked longer at certain points before the action[6,7]. Also, a stable fixation point adds to the stability of posture[10], and sports experts had the strategy to fixate the eye to get information from the peripheral visual field[11]. So it seems that the act of 'visual anchoring' (fixation) has two different functions. Early studies reported that participants use information from central vision[6,7], while later studies mentioned peripheral vision[10,11]. In the present study, most participants kept looking at the direction of walking (for instance, heading direction or wall) although no clear visual targets were present there. Therefore, the purpose of the stable viewing directions of this experiment was to get information from peripheral vision, and both age groups used this anchoring strategy.

Young adults looked in the direction of walking most of the time even in the restricted visual information condition and this did not change much with less light and without edge emphasis. But older adults looked more downward in restricted conditions and especially in the mesopic condition. In mesopic conditions that tendency was slightly reduced with edge emphasis. Consequently, older adults seem to use their central vision more in the mesopic-restricted condition. This is in accordance with the finding that older adults looked sooner to targets, and fixated the targets for longer, than younger adults[5].

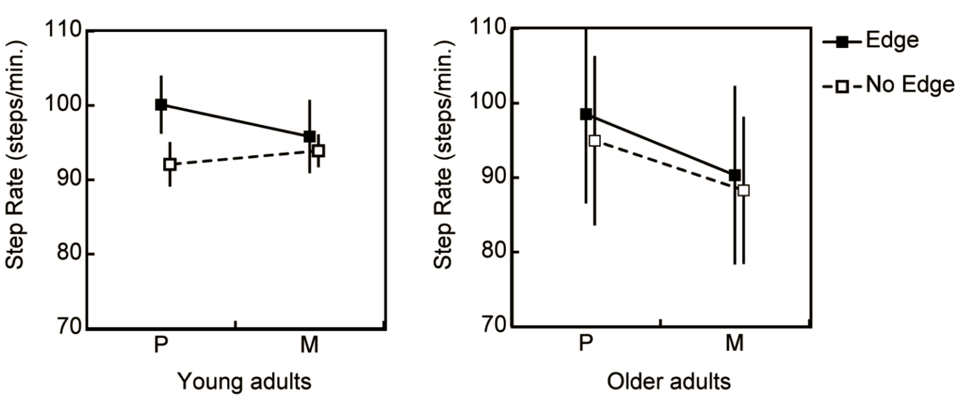

Figure 3: Average step rate in controlled walking for young and old adults in the edge and illumination experiment; P = photopic, M = mesopic

Lighting and edge

Step rate of older adults was illumination-dependent, without effects of edge emphasis. For young adults, walking was fastest in photopic-edge emphasis followed by mesopic-edge emphasis, mesopic-no edge, and photopic-no edge. The relatively good results for the mesopic conditions may be due to the dim extra light from the ceiling, which produced a heterogeneous brightness of the walls. As several young adults reported, the walkway was more easily visible in the mesopic condition than in the photopic condition. So this illumination artefact may have aided visual orientation. Probably, young adults changed their step rate according to the visibility of information from peripheral vision, which was enough for keeping this strategy at any lighting and edge conditions. However, for older adults, heterogeneous brightness of the walls in mesopic conditions was not sufficient for the visual control of walking.

In summary, the present results indicate that for older adults sufficient light is necessary in order to keep their view in the heading directions and for keeping a normal step rate. Only if the lighting is insufficient, local visual cues may help to keep looking at heading directions.

The next step

The present findings demonstrate an age-related usage of the visual field for controlling walking, in which good illumination is more effective for old adults than edge emphasis. Further investigations are needed to establish what lighting level is critical for the visual orientation of older adults. Such information is needed for the proper design of safe walking environments.

Conclusions

(i) For controlling direction and position while walking in normal walkways, both older and younger adults had the strategy to keep the eyes directed at a certain area.

(ii) With impoverished visual information, age effects were significant. Younger adults reduced step rate but kept their eyes to the direction of walking. Older adults also decreased step rate but looked more often at the floor and at the edges of the walkways.

(iii) The results supply basic data for the design of easily perceptible walking spaces for older adults. Both edge emphasis and sufficient illumination are basic ingredients, serving visual orientation for walking control.

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