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Differences in gait pattern between the elderly and the young during level walking under low illumination

JIN-SEUNG CHOI, DONG-WON KANG, YOON-HO SHIN, GYE-RAE TACK*

Department of Biomedical Engineering, Research Institute of Biomedical Engineering,
College of Biomedical & Health Science, Konkuk University, Chungju, South Korea

The purpose of this study was to compare changes in the gait pattern between the elderly and young during level (i.e., even surface) walking under low illumination. Vision during walking plays a role in avoiding obstacles and uneven surfaces, as well as an important role in the proactive control of dynamic stability and route planning for level walking. Fourteen elderly and fourteen young male subjects walked on a 7 m walkway with two illumination conditions using self-selected walking speed: walking with normal (>300 lux) and low illumination (<10 lux). Walking speed, stance phase ratio, toe clearance on swing phase, and range of motion at the center of mass were used to compare the differences in gait pattern between two illumination conditions and ages. During walking with low illumination, walking speed and stance phase ratio of the young decreased, and toe clearance of the young increased. However, there was no difference in these variables due to low illumination in the elderly subjects. Despite level walking conditions, there were some differences in gait pattern between the young and the elderly due to illumination conditions. This implies that the young showed a more positive change of gait pattern, due to low illumination, than that of the elderly. In this respect, further study is necessary to identify differences between the young and the elderly, when they walk on an uneven or obstacle walkway with low illumination.

Key words: *gait, illumination, elderly, stance ratio, toe clearance, safety margin*

1. Introduction

Falls cause direct physical injuries as well as have bad influences especially on the elderly psychologically; thus falls are directly and indirectly related to deteriorated mobility [1]. Due to the increased number of elderly people, fall incidents are consistently increasing. Falls are primarily due to both a decline in physical ability by aging and to environmental causes. The physical balance control system consists of the central nervous system for nervous command and delivery; the musculoskeletal system for body maintenance and its movement; and the sensory system for repeatedly performing feedback of movement [1]. Vision, from which external information for physical balance control is acquired, plays an important role in physical balance and movement, and it was reported that insufficient vision information could increase the risk of falls [2]–[4].

Low illumination in daily life, i.e., insufficient visual information, can increase the risk of falls by hindering discrimination of obstacles or by decreasing the stability of body control, especially for the elderly [5]. There have been several previous studies in this field. Brooke-Wavell et al. [5] compared the effects of vision, via eye-opened and eye-closed conditions, on the degree of body sway of elderly subjects during static standing, and reported that the eye-closed condition increased the body sway. Hamel, Okita, Higginson, and Canvanagh et al. [6] compared the differences in toe clearance (TC) due to age and illumination while descending stairs, and they reported that low illumination increased toe clearance of the young adults and

* Corresponding author: Gye-Rae Tack, Department of Biomedical Engineering, College of Biomedical & Health Science, Konkuk University, Chungju, South Korea, 322 Danwall-dong, Chungju, Chungbuk, 380-701, South Korea. Tel: 82-43-840-3762, fax: 82-43-851-0620, e-mail: grtack@kku.ac.kr
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that there was no change in TC of the elderly. Moe-Nilssen et al. [2] reported that low illumination decreased walking speed and reduced medio-lateral body stability while performing illumination adaptation experiment by the time during uneven surface condition.

Overall, these studies focused upon static standing or uneven surfaces and stair walking with low illumination simultaneously while the effects of low illumination were not considered alone [2], [5], [6]. Vision during walking plays a role in avoiding obstacles and uneven surfaces, as well as an important role in the proactive control of dynamic stability and route planning for even surface walking [4].

It was reported that during even surface walking there were differences in kinetic and kinematic gait patterns between the young and the elderly [7]–[9], and these differences could be reflective of a compensation or variation due to the aging of the neuro-musculoskeletal system in elderly subjects. Actually, since the frequency of fall incidents among the elderly is almost identical in even surface walking (24%) and uneven surface walking (24%) [10], it is necessary to consider the risk of fall incidents and gait adaptation during even surface walking for the elderly [11]. Therefore, to study the changes in level (i.e., even surface) walking between the elderly and the young groups under low illumination, the self-selected walking speed, stance and swing phase ratio, and minimum toe clearance, body stability using a medio-lateral range of motion at the center of mass (COM) were selected for comparison between two groups during level walking under low illumination.

2. Materials and methods

2.1. Subjects

Fourteen community-dwelling elderly (age 72.92 ± 5.78 years; height 162.09 ± 5.30 cm; weight 63.16 ± 7.22 kg) and fourteen young (22.1 ± 2.21 years, 174 ± 3.74 cm, 68.86 ± 10.81 kg) male subjects without a medical history of problems in the lower extremities participated in this study. All subjects had normal vision, no difficulty in performing daily activities, and no color-blindness or color-weakness. The elderly scored 5 of 5 full points on the Function Ambulatory Category (FAC), which is a gait ability level test, and could walk more than 10 m consistently [12]. Their cognitive state was normal, scoring more than 24 points on the Mini-Mental State Exam (MMSE) test. Before the experiment, experimental procedures were explained to all subjects, and written consents were received.

2.2. Apparatuses

A three-dimensional motion capturing system (Motion Analysis Corps., USA) with six infrared cameras was used for acquisition and analysis of motion data with a sampling frequency of 120 Hz. Illumination was measured in the middle of the walkway using a digital illuminometer (LX801, NICETY, China) with 1 lux resolution and a 0 ~ 50000 lux measuring range.

2.3. Procedure

All experiments were performed on a 7 m × 3 m level (even surface) walkway in the gait lab. All subjects walked the walkway five times at a self-selected walking speed under normal walking conditions (>300 lux) and under low illumination conditions (<10 lux, only with infrared light of motion capturing camera). For low illumination conditions, the intensity of illumination was reduced after the start of walking. The total of 5 reflective markers were attached at the lumbar spine of the body (between fourth and fifth lumbar spine), heels (posterior calcaneus), and toes (centered between the second and third metatarsals).

2.4. Analysis

For analysis, a walking phase was defined as the period from one right heel strike to the next right heel strike. All subjects performed five walking experiments under both normal illumination conditions (Normal walking) and low illumination conditions (Low illumination walking). The young subjects reduced walking speed under low illumination conditions; thus, to isolate the effect of low illumination, an experiment was conducted with low speed walking (Slow walking), which was conducted at a walking speed similar to that used under low illumination and was performed an additional five times under normal illumination conditions. Selected parameters for gait comparison due to illumination were walking speed, stance ratio, toe clearance (TC), and range of motion at the center of mass (ROM at COM). To compare foot support time as a walking speed, stance ratio was defined as the time ratio of stance phase to stride. TC was defined as the vertical height of the toe marker during swing phase [13], and the magnitude of minimal TC was calculated as shown in Fig. 1. The medio-lateral directional ROM at COM, which represents the stability of the body by the maximum value of the sway of COM, was calculated. The coordinates of the lumbar spine marker were used as that of the COM [14]. All calculations of these parameters were conducted using MATLAB v7.0 (MathWorks Inc., USA).

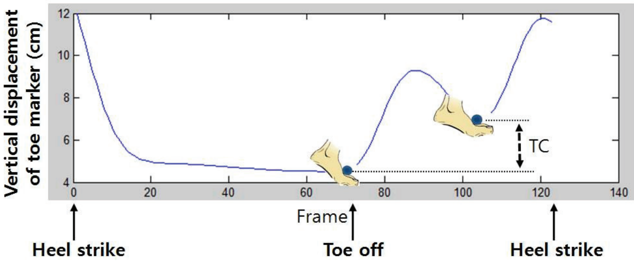

Fig. 1. The definition of Toe clearance (TC) using vertical displacement of toe marker

2.5. Statistics

SPSS v17.0k (PASW, SPSS Inc., USA) was used for statistical analysis. A two-way repeated ANOVA was used to evaluate effects of independent variables (illumination condition and age). When an interactive effect among variables was observed, a simple main effect analysis was performed as follows; paired *t*-test was performed among parameters for within-group comparisons due to illumination, and the standard *t*-test was used for between-group comparisons due to illumination. In the cases of young subjects, additionally, repeated ANOVA was performed for comparison among Normal, Low illumination and Slow walking. The significance level was set to $\alpha = .05$.

3. Results

In the case of walking speed and TC, there was interaction between illumination and age (p = .000 and p = .009, respectively). To analyze this interactive effect, a simple main effect analysis was additionally performed.

3.1. Walking speed and stance ratio

There was no significant difference in walking speed of the elderly subjects between the two illumination conditions (p = .617); however, there was a significant difference in that measured for the young

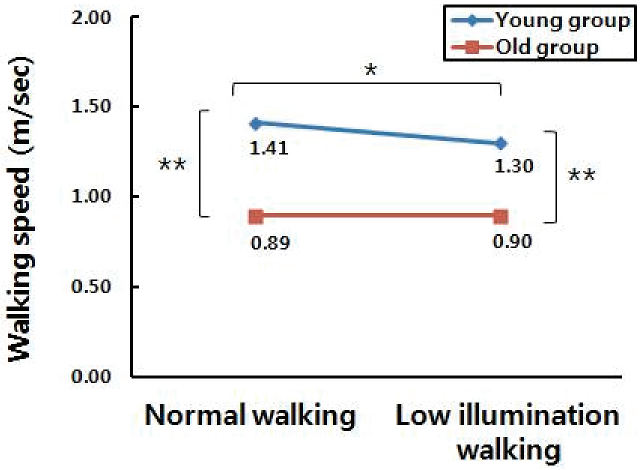

Fig. 2. Walking speed between groups and conditions
(* significant differences between walking conditions at $p < .05$;
** significant differences between groups at $p < .05$;
Normal walking: walking with normal illumination;
Low illumination walking: walking with low illumination;
Slow walking: Low speed walking with normal illumination)

Table 1. Results of variables in the elderly and young adults
(*,# : significant difference among walking conditions in each group at $p < .05$,
gray-scale: significant difference between older and young adult groups in each condition at $p < .05$)

Variables		Old group		Young group		
		Normal walking	Low illumination walking	Normal walking	Low illumination walking	Slow walking
Walking Speed	mean	0.89	0.90	**1.41***	**1.30***	–
(m/sec)	SD	0.13	0.14	0.20	0.18	–
Stance ratio	mean	58.82	59.45	**55.32***	**52.66 #**	**58.33*,#**
(%)	SD	1.77	3.62	5.43	5.58	4.26
Minimum toe clearance	mean	1.7	1.6	**2.3***	**2.9*,#**	2.4#
(cm)	SD	0.4	0.3	1.1	0.6	1.0
Medio-lateral	mean	3.7	3.8	3.5	4.1	4.1
range of motion at COM (cm)	SD	1.8	1.4	1.1	1.7	1.2

subjects (p < .001). There were statistical differences in Normal walking (p = .001) and Low illumination walking (p < .001) between the two groups (Fig. 2).

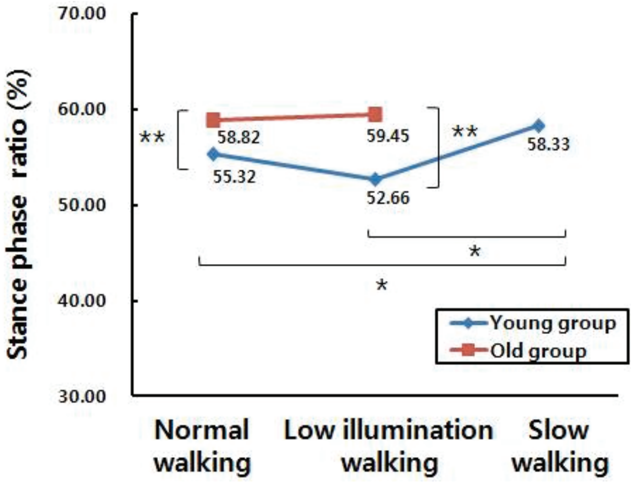

Fig. 3. Stance phase ratio between groups and conditions (* significant differences between walking conditions at p < .05; ** significant differences between groups at p < .05; Normal walking: walking with normal illumination; Low illumination walking: walking with low illumination; Slow walking: Low speed walking with normal illumination)

There was a significant difference both in stance ratio between the two groups (p < .001). There was no significant difference in stance ratio of the elderly and the young between walking under the two illumination conditions (p = .327). For the young subjects, there was a significant difference in stance ratio between Normal walking and Slow walking (p = .002) and a significant difference in stance ratio between Low illumination walking and Slow walking (p = .016). (Table 1, Fig. 3).

3.2. Toe clearance

There was no significant difference in TC of the elderly between the two illumination conditions (p = .461). For the young, there was a significant difference both in TC for walking under the two illumination conditions (p = .018) and in TC between Low illumination walking and Slow walking (p = .019) (Fig 4). There were significant differences in the TC of the two groups both during Normal walking (p = .031) and during Low illumination walking (p < .001) (Table 1, Fig. 4).

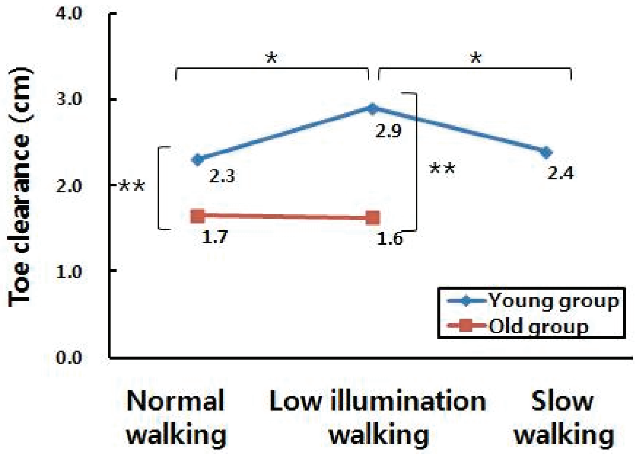

Fig. 4. Toe clearance between groups and conditions (* significant differences between walking conditions at p < .05; ** significant differences between groups at p < .05; Normal walking: walking with normal illumination; Low illumination walking: walking with low illumination; Slow walking: Low speed walking with normal illumination)

3.3. Range of motion at COM

There was no significant difference in medio-lateral ROM at COM between the elderly and the young (p = .150). For the elderly, there was no significant difference in medio-lateral ROM at COM between Normal walking and Low illumination walking (p = .195) (Table 1). For the young, there was also no significant difference in medio-lateral ROM at COM among Normal walking, Low illumination walking, and Slow walking (p = .116) (Table 1).

4. Discussion

This study compared changes in the gait pattern between the elderly and the young during level walking under low illumination. In general, walking speed of the elderly is slower than that of the young [7]–[9]. This is known to be a strategy that enhances physical stability of the elderly, who have deteriorated control in motor, sensory, and nervous systems [1]. The results of this study showed that, for the elderly, there was no significant difference in walking speed and stance ratio between normal walking and low illumination walking (Table 1, Figs. 2 and 3). Also, walking speed of the young under low illumination was slower than that under normal illumination, and the stance ratio during low illumination walking was reduced compared to that during slow walking, which was the same speed as the walking speed under low illumination, i.e., during Low illumination walking condition, the walking speed decreased, but the stance ratio did not show any difference from normal illumination walking. This suggests that the gait characteristic of decreased walking speed due to low illumination is different from that of increased stance ratio due to decreased walking speed during normal and slow walking. In particular, visual information can directly affect the determination of footfall position after the swing phase [15], [16], and the absence of visual information due to low illumination may cause a relatively longer swing ratio in order to increase the adaptation to obstacles and/or the determination of footfall position. Thus increased swing ratio can have a positive effect on body stability and fall prevention.

For all conditions, the TC of the young was larger than that of the elderly. In particular, the young subjects showed increased TC during low illumination walking, but there was no change in TC for the elderly. Mills et al. (2008) reported that there was a relationship between variability of TC and joint angle [16], i.e., it is believed that the difference between the range of motion of the joint of the elderly and that of the young may induce a fundamental difference in TC [7]–[9]. Graci et al. [17] reported that TC with blocked ambient vision increased compared to TC with ambient vision. It can be deduced that a result of present study, a decrease in TC due to low illumination, is similar to their result. Since TC generally represents the safety margin for a walking environment, it can be deduced that increased TC in the young subjects was due to an adaptation to walking with low illumination, and the young might show positive gait adaptations to low illumination conditions such as a decreased stance phase ratio (increased swing phase ratio).

Finally, even though TC and swing phase ratio increased, there was no significant difference in mediolateral ROM at COM (which is related to body stability) between the elderly and the young or between illumination conditions. This agreed with the result of Thies et al. [18] that there was no significant difference in the step width variability between the elderly and the young during level walking under low illumination since the step width variability is closely related to the body stability. From this study, it was verified that the safety margin of the young under a new challenge or walking environment was larger than that of the elderly.

Hallemans et al. [19] reported that normal subjects visually restricted with black glasses showed a similar gait pattern to that of blind subjects, which suggests that, for normal young subjects, only visual restriction can produce gait characteristics or strategy of the blind. For the normal young subjects when visual information was restricted, a proper change in gait pattern occurs to maintain the safety margin of the body to protect it from unstable external information. On the contrary, elderly subjects could not maintain this safety margin sufficiently, and it can be deduced that it is not possible for the elderly subjects to maintain body stability or to prevent fall incidents as successfully as young subjects do. It seems that changes in gait pattern of the young due to low illumination as shown in the present study may be related to insufficient visual information or visual restriction.

Discussions of the predictions of this study are summarized as follows. Changes in the gait patterns of the young might be due to the change in illumination. In the young, walking speed and TC while walking under low illumination differed from those while walking under normal illumination. However, these differences are different from the results for stance phase ratio and TC of slow walking conditions under the same speed as that for low illumination. In other words, it could be concluded that gait change due to low illumination induced changes in gait pattern, not only gait speed. Also, the elderly had no change in gait pattern due to illumination conditions; thus, this is a different result from that seen in the young, who showed a change in gait pattern due to illumination. It is known that, in general, to compensate for deterioration in motor, sensory, and nervous control, the range of motion of the joints of the elderly decreases and their walking speed slows [1]. In other words, elderly subjects demonstrate changes in gait safety strategy due to changes in the external environment. The most common gait strategy adaptation for the external environment is a slower gait speed, which increases physical stability by an increase in stance ratio [2]. It can be judged that the elderly, who are slow to react to a new environment, cannot achieve the necessary safety margin sufficiently [20].

Although there was a significant difference in gait adaptation between the elderly and the young due to low illumination, there was no difference in mediolateral ROM at COM, which represents body stability, between the two groups. This suggests that even though there was a difference in gait pattern (walking speed, stance phase ratio, and TC) between the two groups during walking under low illumination, the body stability of the two groups was maintained due to level walking without disturbance. This, however, implies that the change in gait pattern of the young during walking with low illumination was a positive change contrary to the elderly.

The results of the present study agreed with the previous study by Helbostad et al. [21] that vision manipulation with low illumination had an effect on footfall parameters. It also showed that low illumination alone, without uneven walkway and vision manipulation, had made some differences between level walking pattern of the young and that of the elderly in point of the safety margin. In other words, for the normal young subjects when visual information was restricted, a proper change in gait pattern occurs to maintain the safety margin of the body to protect it from unstable external information. On the contrary, elderly subjects could not maintain this safety margin sufficiently, and it can be deduced that it is not possible for the elderly subjects to maintain body stability or to prevent fall incidents as successfully as young subjects.

Present study focused on only level walking under low illumination. During walking vision has two roles to both plan (feed-forward control, i.e., planning) and guide foot placement (on-line control) [4], [15]. Based on current experimental design, several differences between level walking pattern of the young and that of the elderly due to low illumination were found. However, it is not enough to conclude the causes of these differences specifically according to aging and illumination. Therefore, further study is necessary to evaluate changes in gait pattern between two groups using various experimental designs, including gait adaptation strategy by gait condition, use of vision information as gait phase and accuracy of foot placement [15]. It is also necessary to work with more subjects, investigate additional external environments, assess various gait parameters such as variability of temporal and spatial variables, and evaluate gait pattern of fallers (older adults having fall experience), for whom their TC and COM sway are generally larger than in non-fallers [22], under low illumination.

5. Conclusion

This study compared changes in the gait pattern between young and elderly groups during level walking under low illumination, and it investigated gait adaptation patterns due to illumination by aging. Results showed that, under low illumination, the young showed changes in gait pattern (walking speed and stance phase ratio decreased, TC increased) but the elderly did not. Medio-lateral motion at COM was uniform between the young, who showed a change in gait pattern, and the elderly. Despite level walking conditions, there was a difference in gait pattern between the young and the elderly. This implies that, from a gait adaptation point of view, the young showed a positive gait strategic change due to low illumination, and it was verified that the adaptation strategy changed with age.

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