Effects of Illumination on Toe Clearance and Gait Parameters of Older Adults when Stepping over an Obstacle: a Pilot Study

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Abstract. [Purpose] The purpose of this study was to investigate how older adults adjust gait patterns when stepping over a ground-based obstacle under two different lighting conditions. [Subjects] A total of 10 community-dwelling healthy older adults (mean age, 67.9 ± 2.12 years; age range, 65–72 years) were enrolled in this study. [Methods] All participants stood quietly in a self-selected foot position on the floor. Each participant was then instructed to step over a 10 cm high wooden obstacle under two illumination conditions (1 and 200 lx) at a self-selected pace with the right leg in response to the verbal cue “GO”, and continued walking with the left leg on a 5 m pathway. Toe clearances and step parameters were measured using an eight-camera motion analysis system. [Results] Under the low lighting condition, toe clearance of the trailing leg was significantly lower than under the normal lighting condition. However, no significant differences were observed in toe clearance of the lead leg, step velocity, stride length, step length, cadence, or swing/stance duration between the normal and low lighting conditions. [Conclusion] Older adults reduce toe clearance of the trailing leg under low lighting conditions while stepping over an obstacle, which places them at greater risk of falling.

Key words: Ageing, Illumination, Obstacle crossing (This article was submitted Aug. 1, 2012, and was accepted Aug. 30, 2012)

INTRODUCTION

Although the causes of falls by the elderly are many and heterogeneous, tripping over an obstacle is one of the most commonly reported causes of a fall1, 2. Age-related differences of negotiating obstacles have been reported. Older adults use a more conservative strategy to negotiate obstacles than young adults. They have a somewhat slower approach to an obstacle, a significantly slower obstacle crossing speed, and shorter step length before crossing an obstacle3. Older adults also appear to position both the leading and trailing feet farther from the obstacle edge when negotiating obstacles compared to young adults4. This risk-related foot placement strategy used by older adults results in less lead-foot clearance, little correction time in the event of foot contact with an obstacle, and requires a longer warning time for avoiding contact with an obstacle3.

Vision is important sensory information for crossing obstacles as it facilitates advanced planning and execution of appropriate adjustments during locomotion to avoid obstacles5. The risk of tripping during locomotion increases in conditions of poor lighting or poor contrast between the obstacle and walking surface6. Age-related changes occur in vision, which may affect the safety of crossing obstacles. The ability of the pupil to dilate is greatly attenuated with advancing age under low to moderate illumination5. This results in decreased retinal illumination in the elderly7. In addition, age-related changes in contrast sensitivity may reduce the ability to detect an obstacle edge, a phenomenon which is pronounced at low levels of lighting8. Older adults rely heavily on visual information for maintenance of postural stability and control due to age-related changes in the vestibular and somatosensory systems9–12. Low vision is correlated with poor performance in crossing obstacles13. Even small reductions in visibility affect the balance of the elderly14. Older adults with disordered gait show more variable and less steady gait while walking under dim lighting conditions15. Lighting affects elderly individuals’ ability to acquire visual information while moving in the environment. Age-related changes in vision may result in severely impaired balance control, leading to an increased risk of trip-related falls which more commonly occur among older adults14.

Older adults perform many daily activities of living...
(ADL) under reduced ambient lighting conditions, such as in a darkened cinema, or going to the bathroom at night when only a nightlight is used on the travel path. At present, there is a lack of research involving the analysis of kinematic data of older adults when they are avoiding obstacles under different illumination conditions. Therefore, the purpose of the current study was to investigate how older adults adjust gait patterns when stepping over a ground-based obstacle under two different types of lighting.

SUBJECTS AND METHODS

A total of 10 community-dwelling healthy older adults (mean age, 67.9±2.12 years; age range, 65–72 years) volunteered to participate in this study. Inclusion criteria for the older adults was a Berg Functional Balance Scale\(^{16,17}\) score > 50. All participants scored a minimum of 25 on the Mini Mental Status Examination (MMSE)\(^{18}\). This test was shown to be reliable and valid by a previous study\(^ {19}\). Subjects who had visual acuity worse than 20/40 when wearing their own corrective eyeglasses, if needed, were excluded. Those who had vestibular disorders were also excluded as were those taking medications that may have affected balance or vision. The elderly participants had no history of neurological, orthopedic or cardiac problems that prevented their participation. No elderly participant reported falls in the previous 12 months. All participants provided their written informed consent, and this study was approved by the University Institutional Review Board. Table 1 summarizes the subjects’ characteristics.

Kinematic data were acquired online at a sampling rate of 60 Hz utilizing an eight-camera motion analysis system (Motion Analysis Corporation, Santa Rosa, CA, USA). Nineteen reflective markers (20-mm spheres), modified from Kadaba et al.\(^ {20}\), were placed on the following anatomical landmarks: on the sacrum, and bilaterally on the anterior superior iliac spines, lateral femoral condyles, medial femoral condyles, mid-thighs, mid-shank, lateral malleoli, medial malleoli, heels, and metatarsal heads. Two reflective markers were placed on each end of the obstacle edge to define the position of the obstacle. OrthoTrack 4.0 software (Motion Analysis Cooperation, Santa Rosa, CA, USA) was used to calculate the kinematics of body motion using the 3D marker coordinates as input.

For each trial, the participants stood quietly in a self-selected foot position on the floor in a relaxed state. Each participant’s feet on the floor were traced and the tracings were used before starting a new trial of obstacle crossing to reposition the feet on the floor to increase the between-trial consistency. Each participant was then instructed to step over a 10 cm high wooden obstacle (length: 150 cm; width: 10 cm) under two illumination conditions (1 and 200 lx) at a self-selected pace with the right leg in response to the verbal cue “GO”, and continued walking with the left leg on a 5-m pathway of grey, industrial carpet. The order of the presentation of the lighting condition was randomized. All subjects were allowed to have adequate rest to adjust to the new visual environment. A physical therapist stood close by to ensure that older subjects did not fall if they should trip.

The 200 lx condition simulated office lighting while the 1 lx condition simulated cinema lighting levels (<1 lx). The ambient lighting of the obstacle was set to an average of 200 lx, and 1 lx was achieved by having the subject wear 1% luminance transmission goggles and placing two 12 V, 20 W lamps at the height of a typical wall outlet to illuminate the obstacle. For both conditions, each participant was instructed to complete two practice trials to familiarize themselves with the experiment, and performed approximately five successful experimental trials. All participants were required to wear flat-soled shoes normally used for everyday walking or sports activities.

The paired t-test was used to compare the differences between the two lighting conditions in spatiotemporal gait parameters and toe clearance. Null hypotheses of no difference were rejected if p values were less than 0.05, with Bonferroni correction to protect against Type I error from multiple comparisons. Parameters selected for analysis included spatiotemporal gait parameters and minimum toe clearance. For the minimum toe clearance, the distance between the reflective marker attached to the head of the fifth metatarsal of both legs and the one attached to the front edge of the obstacle was calculated, as the foot cleared the obstacle. The software package SPSS 14.0 KO (SPSS, Chicago, IL, USA) was used for statistical analyses.

RESULTS

All 10 subjects completed the obstacle crossing trials under the two illumination conditions. There were no adverse events reported during the study. Tables 2 and 3 present comparisons of gait parameters between the two lighting conditions while crossing the obstacle. There was a significant difference in toe clearance of the trailing leg between the low and normal light conditions. Under the low lighting condition, toe clearance of the trailing leg was significantly less than that under the normal lighting condition (6.81 cm ± 4.92 cm vs. 10.75 cm ± 5.82) (p<0.01). In contrast, no significant difference was found in toe clearance of the leading leg between the normal and low lighting conditions (11.39 cm ± 6.35 cm vs. 10.63 ± 6.35 cm). In addition, no significant differences were observed in step velocity, stride length, step length, cadence, or swing/stance duration between the results of the normal and low lighting conditions.
suggests that reduced visual input while walking is strongly reduced ambient lighting when stepping over an obstacle increased their minimum foot clearances. In their study, the elderly group showed lack of increased foot clearances over stairs, whereas the young subjects significantly increased their minimum foot clearances.

In the current study, the obstacle was distanced approximately 30 cm from the initial foot position. Thus, after crossing the obstacle, the subjects performed unobstructed walking on an approximately 4-m pathway (80% of total distance walked). Unobstructed walking may not have been perceived as a challenging environment by the older adults.

In contrast to the trailing leg, older adults maintained a similar toe clearance for the leading leg in both the normal and low lighting environments. This suggests that older adults may have adopted a tripping avoidance strategy for the leading leg, rather than stability-oriented safety strategy, in order to minimize and ensure safety when crossing an obstacle. However, in order to ensure the expected safety margin to avoid tripping in a low lighting environment, executing a larger toe clearance of the leading leg (10.62 cm ± 6.82 cm for the leading leg vs. 6.81 ± 4.92 cm for the trailing leg in the 1 lx condition) would have required greater time spent in single-leg support, which would ultimately increase the period of greatest risk of instability.

Under the low lighting condition, the older adults did not change their velocity, step/stride length, cadence, or swing/stance time. These results should be viewed with caution because we expected that the older adults would reduce their gait velocity and step length or cadence under the low lighting condition when negotiating the obstacle. Our findings are not consistent with the findings of a previous study in which older adults reduced step velocity and step length while maintaining a similar step width under a low lighting condition (<1 lx). A reduced step velocity may be necessary to adapt gait to an environment with reduced visual input in order to decrease the likelihood of obstacle contact. Reducing the step length when crossing an obstacle could result in stepping closer to the obstacle which may actually increase the likelihood of obstacle contact.

In the current study, the older adults were similarly impacted by two different visual inputs (1 lx vs. 200 lx), as measured by step velocity and length, stride length, cadence, and swing/stance time. The lack of significant differences between the two lighting conditions in these gait parameters could be due to the nature of the task in the current study. In the current study, the obstacle was distanced approximately 30 cm from the initial foot position. Thus, after crossing the obstacle, the subjects performed unobstructed walking on an approximately 4-m pathway (80% of total distance walked). Unobstructed walking may not have been perceived as a challenging environment by the older adults.

**Table 2.** Toe clearances presented as mean ± standard deviation

<table>
<thead>
<tr>
<th>Variable</th>
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<td>Leading leg</td>
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<td>Trailing leg*</td>
<td>6.81 ± 4.92</td>
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*significant difference between the lighting conditions (p<0.01)

**Table 3.** Step parameters presented as mean ± standard deviation

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<td>Velocity (cm/s)</td>
<td>87.2 ± 9.1</td>
<td>83.9 ± 11.6</td>
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<td>Stride length (cm)</td>
<td>117.5 ± 10.9</td>
<td>116.9 ± 5.9</td>
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<td>Step length (cm)</td>
<td>61 ± 8.9</td>
<td>58.9 ± 3.4</td>
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<td>Cadence (step/min)</td>
<td>89.2 ± 9.2</td>
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<td>Swing phase (%)</td>
<td>34.8 ± 1.9</td>
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In contrast to the trailing leg, older adults may have adopted a tripping avoidance strategy for the leading leg, rather than stability-oriented safety strategy, in order to minimize and ensure safety when crossing an obstacle. However, in order to ensure the expected safety margin to avoid tripping in a low lighting environment, executing a larger toe clearance of the leading leg (10.62 cm ± 6.82 cm for the leading leg vs. 6.81 ± 4.92 cm for the trailing leg in the 1 lx condition) would have required greater time spent in single-leg support, which would ultimately increase the period of greatest risk of instability.

In the current study, the older adults were similarly impacted by two different visual inputs (1 lx vs. 200 lx), as measured by step velocity and length, stride length, cadence, and swing/stance time. The lack of significant differences between the two lighting conditions in these gait parameters could be due to the nature of the task in the current study.

In the current study, the obstacle was distanced approximately 30 cm from the initial foot position. Thus, after crossing the obstacle, the subjects performed unobstructed walking on an approximately 4-m pathway (80% of total distance walked). Unobstructed walking may not have been perceived as a challenging environment by the older adults.

**DISCUSSION**

This pilot study determined how older adults adjust locomotor control strategies used during obstacle crossing under reduced ambient lighting condition. Subjects stepped over an obstacle under normal and reduced ambient lighting conditions. Generally, the older adults exhibited significant less mean toe clearance of the trailing leg under the dark condition than that of the normal lighting condition. This suggests that with reduced visual input the elderly placed themselves at greater risk of contact with the obstacle surface, by being closer to it. However, the adjustments made by the older adults to other gait parameters measured in the presence of the obstacle were not influenced by the lighting condition. Older adults were not affected by the low lighting condition (1 lx) as measured by toe clearance of the leading leg, velocity, stride/step length, cadence, or swing/stance time. This further suggests that although the low lighting environment may have posed a greater threat to stability, resulting from the increased likelihood of obstacle contact due to decreased visual input, the low illumination condition, older adults chose to maintain a gait pattern similar to that under the normal lighting condition.

Under the dark condition, toe clearance of the trailing leg was less than that of the normal lighting condition. It appears that the elderly did not increase their margin of safety in response to what should have been perceived as a threat to safety. This result is similar to the findings of Hamel et al., although their study was about foot clearance over stairs. In their study, the elderly group showed lack of increased foot clearance under a low illumination condition (3 lx) while negotiating stairs, whereas the young subjects significantly increased their minimum foot clearances.

This riskier toe clearance used by older adults under reduced ambient lighting when stepping over an obstacle suggests that reduced visual input while walking is strongly associated with an increased possibility of tripping. The lack of an increase in toe clearance under low lighting conditions (particularly when sensory information was reduced) may be linked to age-related limitation in frontal plane pelvic motion and in the interplay of lower extremity energy patterns within the sagittal plane. Alternatively, reduced toe clearance may also be related to the significant reduction in mediolateral (ML) center of mass (COM)-center of pressure (COP) separation determined for older adults, which results in reduction in sideways momentum of the body. Without adequate sideways momentum of the body more energy would have been required to lift the swing leg sufficiently to clear the obstacle edge, because elevation of the swing leg occurs with a sideways tilting motion of the body. Older adults appeared to adopt a stability-oriented strategy to minimize the risk of ML instability by reducing toe clearance of the trailing leg. Such a strategy would require less time spent in single-leg support, thereby decreasing the period of greatest risk of instability.

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In the current study, the obstacle was distanced approximately 30 cm from the initial foot position. Thus, after crossing the obstacle, the subjects performed unobstructed walking on an approximately 4-m pathway (80% of total distance walked). Unobstructed walking may not have been perceived as a challenging environment by the older adults.

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adults even in the reduced ambient lighting environment, as compared to crossing a 10-cm high obstacle. A previous study\textsuperscript{24} demonstrated that older adults showed decreased step velocity when crossing an obstacle, as compared to unobstructed walking. In addition, the imposition of a low lighting environment in the presence of an obstacle resulted in a significantly reduced step length in older adults\textsuperscript{25}.

Some limitations of this study must be acknowledged. This experiment lacked a control group and was also limited by a convenience sample. Because of these limitations, the results are only preliminary and the generalization of the present findings to subjects who have high-level gait disorders should only be done with caution. There was also a relatively small sample size. Thus, a larger sample size might have increased the statistical power of the study to detect subtle differences between the lighting conditions. Despite these limitations, the current study contributes valuable insight into how older adults adjust their gait parameters as they negotiate an obstacle in a reduced lighting environment. Further studies using a more complex multi-obstacle course under various illumination conditions will be needed to examine how older adults use vision to negotiate obstacles. The results could be further strengthened by adding more age groups to the study, both younger and older healthy adults.

In conclusion, the findings of this study provide preliminary data on how older adults modulate gait parameters when avoiding an obstacle under different lighting conditions. Older adults reduced toe clearance of the trailing leg in avoiding an obstacle under different lighting conditions. The lack of significant differences between the two lighting conditions in the other step parameters suggests that unobstructed walking in reduced ambient lighting environment does not challenge the limits of stability of an older adult.

REFERENCES


