Obstacle Crossing Characteristics in the Healthy Young Female and Elderly Female Subjects

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ABSTRACT

Objective: To investigate obstacle crossing characteristics in the young and the elderly subjects.
Methods: Twenty young and 20 elderly subjects were investigated for their obstacle crossing characteristics by using a 3D motion analysis system. Markers were placed on the bony prominences of the feet and obstacles. Obstacle crossing characteristics were determined with the obstacle crossing time, the vertical distance between toe and obstacle, and the maximum vertical toe clearance. The main effects and interaction effect of age (young and elderly) and limb [leading limb (LL) and trailing limb (TL)] were examined by two way analysis of variance. The obstacle crossing characteristics were also compared in each condition by using Independent sample *t*-test and Paired *t*-test.
Results: There were main effects of the age and the limb on the obstacle crossing time. No interaction effect of the age and limb was found in any variables. In each condition of age and limb, there was a significant difference ($p<0.05$) in the obstacle crossing time between the limbs in both the young and the elderly. Furthermore, the vertical distance between toe and obstacle between the LL and TL was found to be significantly different ($p<0.05$) in the young, but not in the elderly ($p>0.05$).
Conclusion: Age and limb were found to be the factors which related to the obstacle crossing time characteristic. The present findings suggested that the TL's clearance is critical and should pay more consideration for the elderly.

Keywords: Obstacle crossing, leading limb, trailing limb, crossing time, toe clearance

Siriraj Med J 2012;64:52-56
E-journal: http://www.sirirajmedj.com

INTRODUCTION

Falling is one of the violent problems for elderly people and considered as a major public health concern which has provided motivation for research into factors-related to alterations in gait and other tasks.[1-4] Slipping and tripping are the leading causes of fall accidents which can happen in any person, especially in the elderly who are over the age of 65 years.[5] Falling can cause serious injuries such as back injury, paralysis, fracture, head injury, and lead to disability or death.[6]

It is feasible that some parts of the foot contact with an obstacle on the ground during walking which can result in trip-related falls.[7] Age-related changes in the elderly and gait characteristic alterations cause adjustment to their walking pattern to avoid contact with an obstacle when walking on the ground.

To achieve the obstacle crossing task, people usually estimate the obstacle characteristics by using visual, vestibular, and other sensory receptors to adjust their gait characteristics.[8-10] Obstacle crossing during walking is essentially a multi-joint movement, requiring precise swing foot control and a high level of inter-joint coordination of the stance and swinging limbs. Body stability and motion sequences are the factors necessary for coordination which are important for the obstacle crossing achievement.[11]

During performance of this motion, the total body center of mass has to be balanced on only one foot and the contra-lateral foot has to swing to clear the toe over an obstacle concurrently. Chou et al in 2003[2] investigated postural balance in the elderly while performing the obstacle crossing task, and they found that the elderly increased their total body center of mass motion in the medio-lateral direction. This indicated a compensatory adjustment in the swinging limb for counter balance disturbance in the frontal plane.

Some clinical researches, reported that the elderly had more frequent contact the obstacle than the young especially in the time-constrained condition.[12,13] It has been suggested to be the variable linked to tripping mechanism because reduced toe clearance for a given step during walking

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Received 18 August 2011
Revised 26 September 2011
Accepted 29 September 2011

increases the susceptibility to tripping on an obstacle or due to undetected changes in surface height.[14]

In gait, an increase in the variability of toe clearance was observed in the elderly compared to the young[1] and increase in asymmetry of the left and right feet clearance in the elderly when performing the dual task together.[15] However, for the obstacle crossing task, it is not clear about the characteristic of the leading and trailing limbs in the elderly compared to the young. Thus, the purpose of this study was to investigate the kinematics of obstacle crossing during walking in the elderly compared to the young subjects.

MATERIALS AND METHODS

Subjects

Twenty healthy young female and 20 elderly female subjects were assessed for their obstacle crossing characteristics. The age of the young and the elderly were 20.90 ± 0.91 years and 67.89 ± 6.60 years respectively. All subjects were right leg dominant. Characteristics of the young and the elderly groups are presented in Table 1.

All subjects voluntarily participated in the study. The young were students from Mahidol University and the elderly came from the elderly assembly of Salaya area. They were explained the objectives, materials and methods, and details of the research project. The inclusion criteria were able to communicate and follow the data collecting process, able to perform daily activity and walk without using assistants or any orthotic devices, and no cognitive problem screened by Thai Mental State Examination (TMSE).[16] If subjects had any history of musculoskeletal surgery in the lower limb, neurological problems, blind or other vision problems which cannot be corrected by lens, and pain at any area which influenced their postural balance and gait, they were excluded from the study.

Procedures

The present study was performed in the Human Motion Laboratory, Faculty of Physical Therapy, Mahidol University, Thailand; and was approved by the Mahidol University Institutional Review Board (MU-IRB 2009/337.1712), Thailand. Researcher recorded demographic data and assessed their cognitive status, active range of motion, proprioceptive and exteroceptive sensations, and lower extremity muscles strength. After that, anthropometric data which included the height, weight, joint widths, and leg lengths were measured for each participant. Spherical markers were attached on both feet of the subjects at the second metatarsal, lateral malleolous, calcaneous, and on the obstacle. Prior to gait data collection, subjects practiced a 10-meter walk at their comfortable gait speed. The subjects were asked to walk through the pathway and cross the obstacle which was placed on the middle part of the walkway. Gait data were captured using 6 video cameras of the Vicon 612 (Oxford Metrics Ltd., Oxford, UK) at 100 Hz for kinematics and filtered by the Butterworth filtering technique at 5 Hz. The obstacle's height was adjusted to be approximately one third of the shank segment for each participant. The dominant side of the legs was assessed by letting the subjects use their foot and leg to perform tasks which included kicking a ball, draw a figure of eight on floor, and point the foot. All subjects in the present study were right leg dominant. Therefore, the dominant right leg was assigned to be a leading limb (LL) and the left leg then became the trailing limb (TL) when they performed obstacle crossing. Thus, the task was divided into the motions of the LL and TL. A representative picture of the motion in the laboratory has been illustrated in Fig 1.

TABLE 1. Subject characteristics (n=20 per group).

Variables	Young		Elderly	
	Mean	SD	Mean	SD
Age (yr)	20.90	0.91	67.89	6.60
Weight (kg)	50.50	6.25	59.00	10.53
Height (cm)	159.65	5.11	152.80	5.76
Gait speed [no obstacle] (m/s)	1.32	0.13	1.05	0.19
Gait speed [obstacle] (m/s)	1.12	0.17	0.83	0.14

Obstacle crossing variables

In the present study, we assessed the obstacle crossing characteristics which consisted of the obstacle crossing time, vertical distance between the toe and obstacle, and the maximum vertical toe clearance. For the obstacle crossing time, it is the time spent by each limb when crossing the obstacle starting from toe off to heel strike. The vertical distance between toe and obstacle was the distance between the toe and the obstacle markers and was obtained when the toe marker position was vertically furthest from the

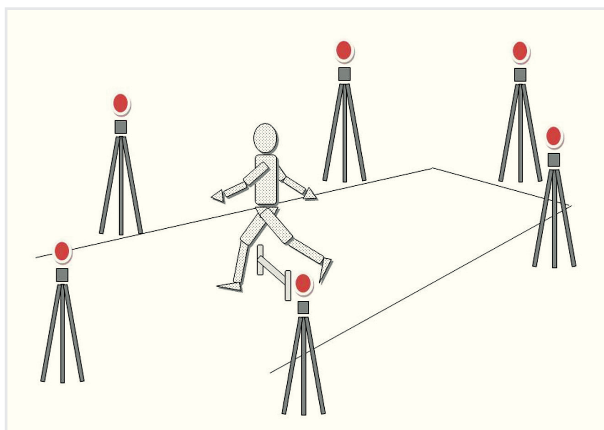

Fig 1. Representation of the obstacle crossing in the laboratory.

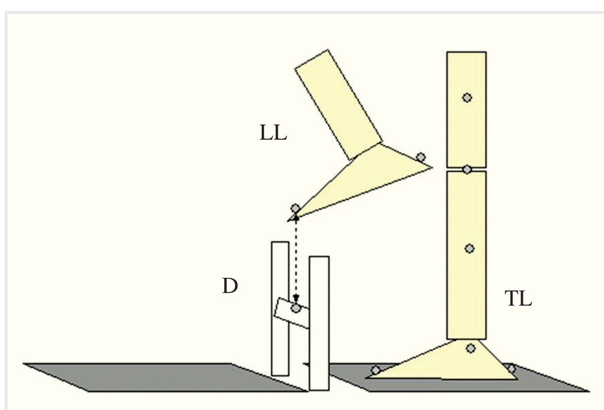

Fig 2. Representation of the obstacle crossing in the laboratory, D, Vertical distance between foot and obstacle, LL, Leading limb, and TL, Trailing limb.

TABLE 2. Comparisons of the variables between the LL and TL in the young (n=20) and the elderly (n=20) groups

Variables in the young	LL		TL		*p*-value
	Mean	**SD**	**Mean**	**SD**	
Obstacle crossing time (s)	0.52	0.07	0.50	0.05	0.023*
Vertical distance between toe and obstacle (cm)	16.42	6.24	12.66	6.67	0.001**
Maximum vertical toe clearance (cm)	29.68	6.58	30.13	7.19	0.475
Variables in the elderly	**LL**		**TL**		***p*-value**
	Mean	**SD**	**Mean**	**SD**	
Obstacle crossing time (s)	0.60	0.06	0.56	0.06	0.001**
Vertical distance between toe and obstacle (cm)	15.42	4.46	16.23	5.97	0.396
Maximum vertical toe clearance (cm)	29.56	4.43	31.12	5.61	0.054

Paired *t*-test
* Significant level at $p<0.05$
** Significant level at $p<0.01$
LL, leading limb; TL, trailing limb

obstacle position (Fig 2). The maximum vertical toe clearance was the highest vertical distance of the toe marker during crossing the obstacle which might have occurred prior to or after or above the obstacle position.

Statistical analysis

All data were analyzed by SPSS version 18.0. Demographic characteristics of the subjects were analyzed and presented by using descriptive statistics. Komogorov Smirnov Goodness of Fit test was used for determining the distribution of data and all data presented as normal distributions. The effects of age (young and elderly) and limb (LL and TL) and the interaction effect of age and limb on the obstacle crossing characteristics were analyzed by two way analysis of variance. Independent sample *t*-test and Paired *t*-test were used for assessing the differences between the young and the elderly in each limb and between LL and TL in each age group respectively.

RESULTS

Effect of age, limb, and interaction effects to obstacle crossing characteristics

An experiment was conducted to determine if the age and limb affect the obstacle crossing characteristics of the young and elderly. A two-way analysis of variance found a main effect of age on the crossing time, $F(1,76)=30.039$, $p<0.05$, indicating that the elderly spent more time to cross the obstacle than the young. There was also a main effect of the limb to the obstacle crossing time, $F(1,76)=5.690$, $p<0.05$, indicating that the LL spent more time to cross the obstacle than the TL. However, there was no interaction effect of the age and limb to the obstacle crossing time. In addition, there was no main effect and interaction effect of the age and the limb to the remaining variables; the vertical distance between toe and obstacle and the maximum vertical toe clearance.

Table 2 demonstrates comparisons of the obstacle crossing time, vertical distance between toe and obstacle, and maximum vertical toe clearance of the LL and the TL in the young and the elderly.

In the young group, the results demonstrated significant differences of obstacle crossing time ($p<0.05$) and vertical distance between toe and obstacle ($p<0.05$) between the LL and TL. For the obstacle crossing time, it was found that the LL spent more time than the TL. For the vertical distance between toe and obstacle, the LL swang over the obstacle higher than the TL. In addition, there was no significant difference of the maximum vertical toe clearance between LL and TL ($p>0.05$).

In the elderly group, there was only the obstacle crossing time ($p<0.05$) which was found to be significantly different between the LL and TL. Moreover, no significant differences of the vertical distance between toe and obstacle and the maximum vertical toe clearance were found between LL and TL ($p>0.05$).

Table 3 demonstrates comparisons of the obstacle crossing time, vertical distance between toe and obstacle, and maximum vertical toe clearance between the young and the elderly groups in the LL and TL.

Significant differences were found in the obstacle crossing time both in the LL ($p<0.05$) and the TL ($p<0.05$)

TABLE 3. Comparisons of the variables between the young (n=20) and the elderly (n=20) groups in the LL and TL.

Variables in the LL	Young		Elderly		*p*-value
	Mean	**SD**	**Mean**	**SD**	
Obstacle crossing time (s)	0.52	0.07	0.60	0.06	<0.001**
Vertical distance between toe and obstacle (cm)	16.42	6.24	15.42	4.46	0.565
Maximum vertical toe clearance (cm)	29.68	6.58	29.56	4.43	0.944
Variables in the TL	**Young**		**Elderly**		***p*-value**
	Mean	**SD**	**Mean**	**SD**	
Obstacle crossing time (s)	0.50	0.05	0.56	0.06	0.002**
Vertical distance between toe and obstacle (cm)	12.66	6.67	16.23	5.97	0.083
Maximum vertical toe clearance (cm)	30.13	7.19	31.12	5.61	0.631

Independent sample *t*-test
** Significant level at $p<0.01$
LL, leading limb; TL, trailing limb

between the young and elderly groups. Whereas, the vertical distance between toe and obstacle and the maximum vertical toe clearance were not different between young and elderly groups either in the LL or TL (p>0.05).

DISCUSSION

Only effects of the age and the limb on obstacle crossing time were found in the present study. For the effect of age (young and elderly) on obstacle crossing time, the findings demonstrated that the elderly spent a longer time to cross obstacles than the young in both LL and TL. This is supported by previous studies[13,15] demonstrating the adverse effect of age on response time to cross an obstacle.

However, the vertical distance between toe and obstacle and the maximum vertical toe clearance were not different between the young and the elderly subjects. Slower obstacle crossing could also provide more time for adjusting the foot placement which related to the obstacle for reducing the risk of tripping in the elderly.

For the effect of limb (LL and TL) on obstacle crossing time, we found that the subjects spent longer time on the LL than the TL to cross an obstacle. In the aspect of the limb, it should be considered about the limb assignment and the limb position during crossing an obstacle. In the present study, we assigned the right dominant leg to be the LL and the left then be the TL. Unlike general movement, bipedal movement for the obstacle crossing requires the limb for moving and the contra-lateral limb for supporting concurrently and alternatively for progression. The task demonstrated the difficulty of the body to support and move the non-dominant limb over an obstacle. The subjects had to quickly swing the non-dominant TL over an obstacle to support the body stability in the next step.[2] For the limb position, the present study investigated the characteristics of obstacle crossing by letting the subjects walk through the obstacle which was placed at the middle path of the walkway. Prior to walking, the distance of the starting position was adjusted until the step length was near to the ordinary walking step of each individual. Thus, the position of the foot placement and the acceleration of walking can be cut off.

In the comparisons of the obstacle crossing variables in each group, both the young and the elderly spent more crossing time in the LL than the TL to cross an obstacle. Moreover, only the young showed higher vertical distance between toe and obstacle in the LL than the TL. In contrary, the elderly crossed the obstacle with similar distance of the toe and obstacle between LL and TL. The lower position of the TL during obstacle crossing in the young was not surprising because the TL was the non-dominant leg which may be harder for lifting over an obstacle than the dominant leg. Other possible causes may be explained by the unintentional trailing motion which could be considered as a normal pattern of healthy young adults. This finding supported the degree of attention demanded which found that the young were able to preserve their postural balance when performing a complex task.[17] In contrast, the elderly seemed to use more energy for toe clearance during crossing an obstacle. Previous research[18] suggested that the musculoskeletal system may have specific strategies to control the swinging foot with sufficient toe clearance. Previous research also reported that the elderly had more difficulty than did younger adults in employing the long-step crossing strategy.[13] Other possible reason for the difficulty of the TL to cross obstacles may result from the loss of visual cues. Thus, there was only the cutaneous and proprioceptive senses remaining which could be relied upon in this period.[19]

Adopting a conservative strategy with advancing age helps to clarify why the elderly have changed in their obstacle crossing characteristic. Furthermore, we should pay more consideration on the TL since it may be a factor for producing tripping in elderly when crossing an obstacle.

Limitation

The present study collected the obstacle crossing characteristic by standardizing the height of the obstacle in each individual to be approximately one third of the shank segment which was very low. For further study, the gait performance should be challenged by investigating the obstacle crossing characteristic when the height of obstacle is increased to simulate to the height of obstacle in the real situation. In addition, the present study did not control the speed of walking which may affect the results of the obstacle crossing pattern.

CONCLUSION

The findings suggested that the temporal variable, the obstacle crossing time is sufficiently sensitive for detecting the difference between limbs and groups' effect. Therefore, the obstacle crossing time should be evaluated in clinical situations when clinicians aim to investigate the obstacle crossing characteristics and this variable is easy to collect and interpret. Results also demonstrated that the TL is significantly related to tripping which might occur especially in the elderly group who are presented with more challenge to cross an obstacle.

ACKNOWLEDGMENTS

This research project is supported by Mahidol University. We would like to thank all subjects who participated in the research.

REFERENCES

1. Mills PM, Barrett RS, Morrison S. Toe clearance variability during walking in young and elderly men. Gait Posture. 2008 Jul;28(1):101-07.
2. Chou LS, Kaufman KR, Hahn ME, Brey RH. Medio-lateral motion of the center of mass during obstacle crossing distinguishes elderly individuals with imbalance. Gait Posture. 2003 Dec;18(3):125-33.
3. Di Fabio RP, Kurszewski WM, Jorgenson EE, Kunz RC. Footlift asymmetry during obstacle avoidance in high-risk elderly. J Am Geriatr Soc. 2004 Dec;52(12):2088-93.
4. Brown LA, McKenzie NC, Doan JB. Age-dependent differences in the attentional demands of obstacle negotiation. J Gerontol A Biol Sci Med Sci. 2005 Jul;60(7):924-27.
5. Fuller GF. Falls in the elderly. Am Fam Physician. 2000 Apr;61:2159-68.
6. Aschkenasy MT, Rothenhaus TC. Trauma and falls in the elderly. Emerg Med Clin N Am. 2006 May;24(2):413-32.
7. Galna B, Peters A, Murphy AT, Morris ME. Obstacle crossing deficits in older adults: a systematic review. Gait Posture. 2009 Oct;30(3):270-75.
8. Deshpande N, Patla AE. Visual-vestibular interaction during goal directed locomotion: effects of aging and blurring vision. Exp Brain Res. 2007 Jul;176(1):43-53.
9. McFadyen BJ, Bouyer L, Bent LR, Inglis JT. Visual-vestibular influences on locomotor adjustments for stepping over an obstacle. Exp Brain Res. 2007 May;179(2):235-43.
10. Reynolds RF, Day BL. Visual guidance of the human foot during a step. J Physiol. 2005 Dec;569(Pt 2):677-84.
11. Yen HC, Chen HL, Liu MW, Liu HC, Lu TW. Age effects on the inter-joint coordination during obstacle-crossing. J Biomech. 2009 Nov;42(15): 2501-06.

12. Brown LA, Doan JB, McKenzie NC, Cooper SA. Anxiety-mediated gait adaptations reduce errors of obstacle negotiation among younger and older adults: implications for fall risk. Gait Posture. 2006 Dec;24(4):418-23.
13. Chen HC, Ashtonmiller JA, Alexander NB, Schultz AB. Age effects on strategies used to avoid obstacles. Gait Posture. 1994 Sep;2(3):139-46.
14. Barrett RS, Mills PM, Begg RK. A systematic review of the effect of ageing and falls history on minimum foot clearance characteristics during level walking. Gait Posture. 2010 Oct;32(4):429-35.
15. Sparrow WA, Begg RK, Parker S. Variability in the foot-ground clearance and step timing of young and older men during single-task and dual-task treadmill walking. Gait Posture. 2008 Nov;28(4):563-67.
16. Train The Brain Forum Committee. Thai Mental Status Exam (TMSE). Siriraj Hosp Gaz. 1993 June;45(6):359-74.
17. Harley C, Wilkie RM, Wann JP. Stepping over obstacles: attention demands and aging. Gait Posture. 2009 Apr;29(3):428-32.
18. Huang SC, Lu TW, Chen HL, Wang TM, Chou LS. Age and height effects on the center of mass and center of pressure inclination angles during obstacle-crossing. Med Eng Phys. 2008 Oct;30(8):968-75.
19. Lu TW, Chen HL, Chen SC. Comparisons of the lower limb kinematics between young and older adults when crossing obstacles of different heights. Gait Posture. 2006 Jun;23(4):471-79.