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THE MOBILITY PERFORMANCE OF THE ELDERLY BEFORE, DURING AND AFTER CROSSING OVER AN OBSTACLE

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ABSTRACT

Purpose. Tripping over objects is a major cause of fall-related injuries. The elderly feature decreased locomotor velocity with aging and delays in locomotion when encountering obstacles. Numerous studies have analyzed how the mobility performance of the elderly is affected when crossing over an obstacle. However, how is mobility performance affected when performing sequences of various locomotor movements (gait, changing direction, standing up and sitting down) that make up activities of daily living? To answer this question, this study investigated the changes in locomotor velocity when encountering an obstacle during various locomotor movements in both older adults and young adults by using the TUG, a representative mobility test. **Methods.** Thirty older adults who were judged to be able to walk independently by the Berg Balance Scale (BSS) (age: 70.0 ± 6.94 yrs; BBS: 54.7 ± 1.78 pts) and seventeen male young adults (age: 21.7 ± 2.37 yrs) participated in the "Timed Up & Go" (TUG) test with and without an obstacle. Using the TUG score (the total time required to complete the test), a rate of the total times (with an obstacle/without an obstacle) was calculated to create an index of the decline in mobility performance by the obstacle. **Results.** The decline in the mobility performance of the elderly was significantly larger than the young adults for the following measurements: in the single stance phases just before and after an obstacle, the time needed to change direction 180 degrees, and for level walking after crossing over an obstacle. **Conclusions.** The elderly require a longer period of time for stepping over obstacles. Gait and the ability to change direction after encountering an obstacle was found to be slower when compared to the younger male population.

Key words: age difference, obstacle, fall, TUG

Introduction

Fall accidents in the elderly can easily develop into secondary disabilities, including the possibility of becoming bedridden due to a fall-related fracture, disuse syndrome, etc. Consequently, such accidents can be particularly devastating for the elderly. Additionally, even one fall experience can result in a significant restriction in activities of daily living due to fear of falling again, thereby further facilitating a decline in leg muscle function and even creating a greater fall risk. Accordingly, falls experienced by the elderly can markedly impair their quality of life [1–3]. Thus, it is important to examine the factors that characterize falls in the elderly.

The main causes leading up to a fall may be broadly divided into internal and external factors. The former includes a decline in physical functioning due to aging and a lack of physical activity, complications of physical and physiological disorders, medication, etc. The latter, i.e., environmental factors, can consist of dwelling design, the nature of a walkway, the type of footwear used, etc. [4]. In particular, tripping over an obstacle is one of the main risks in the group of external factors. Pavol et al. [5] reported that 53% of fall accidents in the elderly are caused by tripping. Falls from tripping often result in serious injury [5–8] and are compounded by the marked fragility of the body, the functional decline in muscle strength and various sensory organs and general cognitive decline. Hence, although crossing a small obstacle is a very easy task for the young, the elderly may find it much more difficult.

There have been many studies that analyze the elderly's ability to cross an obstacle. These previous studies were summarized in Galna et al.'s [9] literature review, in which 16 articles were perused from an initial compilation of 727 articles. According to Galna et al., young and older adults infrequently come into contact with an obstacle, such as stumbling into or tripping over it, if adequate time is available to adapt foot placement in relation to the obstacle. In such unconstrained conditions, participants are able to recognize the obstacle well in advance and, thus, have enough time to adjust their movements for crossing over it. In contrast, in time-constrained conditions, i.e., when an obstacle suddenly appears, older adults had a higher frequency of coming into contact with obstacles than younger people [9]. The elderly are forced to adopt a more conservative gait strategy with shorter step lengths and slower velocity [10] due to various declines in physical functions (vision, proprioception, visual-spatial cognition and attention) [11]. Another study has also confirmed these results by documenting that the elderly, featuring slower reaction times, are more likely to trip over on obstacles when compared to young adults, especially in time-constrained conditions [12].

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Although these age-related declines in locomotor velocity and the characteristics that define locomotor movement have already been demonstrated in previous studies, such as in Galna et al. [9] and Chen et al. [10], these studies (e.g., Chen et al. [10], [12]) analyzed the elderly's performance only when crossing over an obstacle on an even and level walkaway, which is a condition that is not entirely natural in daily life. A test that better determines daily locomotor activities, such as walking a few feet, changing direction, and standing up from a chair and sitting down again, was found in the "Timed Up & Go" test (TUG) [13]. Therefore, it seems appropriate to analyze how the mobility performance of the elderly is affected by an obstacle when performing sequences of various locomotor movements (gait, changing direction, standing up and sitting down) that make up activities of daily living.

As previously mentioned, numerous studies that investigated crossing over obstacle did not test this situation under conditions that included locomotor activities used in activities of daily life. It is possible that the elderly's pathognomonic feature of locomotor motion can be found in the phases before and after the obstacle crossing, as well as in the task of simply crossing over an obstacle. Therefore, the purpose of this study was to test 1) whether older adults slow down more than younger adults when an obstacle is introduced in the TUG test and 2) whether older adults slow down more during the approach and crossing over an obstacle, and in the turning and return phases during the TUG test when compared to a younger population.

Material and methods

The subjects in this study included 30 healthy elderly males and females (age: 70.0 ± 6.94 yrs; height: 153.0 ± 8.37 cm; weight: 56.9 ± 9.28 kg; BBS: 54.6 ± 1.78 pts) who were judged to be able to walk independently by the Berg Balance Scale [14], and 17 young males (age: 21.0 ± 2.4 yrs; height: 173.5 ± 5.2 cm; weight: 70.7 ± 13.4 kg). This study was approved by the institute's human research ethics committee and all subjects provided their informed consent.

Subjects completed the TUG test under the control and experimental conditions. A test track with a distance of 5 m was selected, as it was determined that such a length would allow the observers to adequately monitor the subjects' gait before and after crossing an obstacle. Under the control conditions, subjects performed the TUG without any modifications, i.e., no obstacles were placed on the pathway. In order to compare these results with the modified TUG test (where objects were placed on the pathway), colored tape was placed on the floor 5 m from the starting line for the control condition. The tape was 5 cm wide and 120 cm long (almost 0 cm in thickness). The subjects were instructed to perform the TUG test without stepping on the above-stated tape. The color of the tape and the obstacle was highly contrasted (off-white) from the floor (dark brown) to ensure visibility. For the modified TUG test, an obstacle was placed on the pathway. In this experimental condition, the obstacle was also set 5 m from the starting line and was 10 cm wide, 120 cm long and 5 cm tall [8]. Similarly, the subjects had to complete the TUG test without touching the obstacle.

The TUG test required the subjects to sit and then stand up from a standard 46 cm high chair. They then had to walk 5 m at a normal pace, step over the tape (control condition) or the obstacle (obstructed condition), make a 180 degree turn, step over the tape or obstacle again, walk back to the chair and sit down (Fig. 1). The elderly subjects were reminded to perform every movement at a safe and comfortable speed and to keep their personal safety in mind. Using a stopwatch, the tester recorded the total time elapsed from the moment the subject stood up from the chair to when they returned to the final sitting position.

In order to evaluate the subjects' performance in each movement phase for the control and experimental conditions, a gait analysis apparatus (WalkWay MG-1000, Anima, Japan) was used. This apparatus digitally records the time and spatial information of gait each time the subject's foot comes in contact with the pressure mat that covered the test track. The sampling frequency was set to 100 Hz. The WalkWay MG-1000 device recorded the time each subject took to complete each movement phase (i.e., the time it took to walk 5 m, the time spent in the single leg stance phase just before crossing over the obstacle, the time needed to turn 180 degrees, time spent again in the single leg stance phase just after

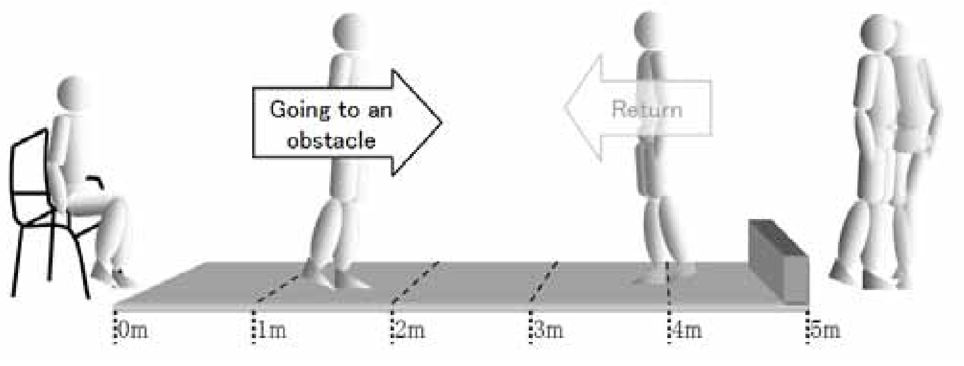

Figure 1. Schematic diagram of the modified TUG test. The analyzed movement sequence was as follows:
1) stand up from the chair,
2) walk and step over the obstacle,
3) turn 180 degrees,
4) return to the chair and sit down again

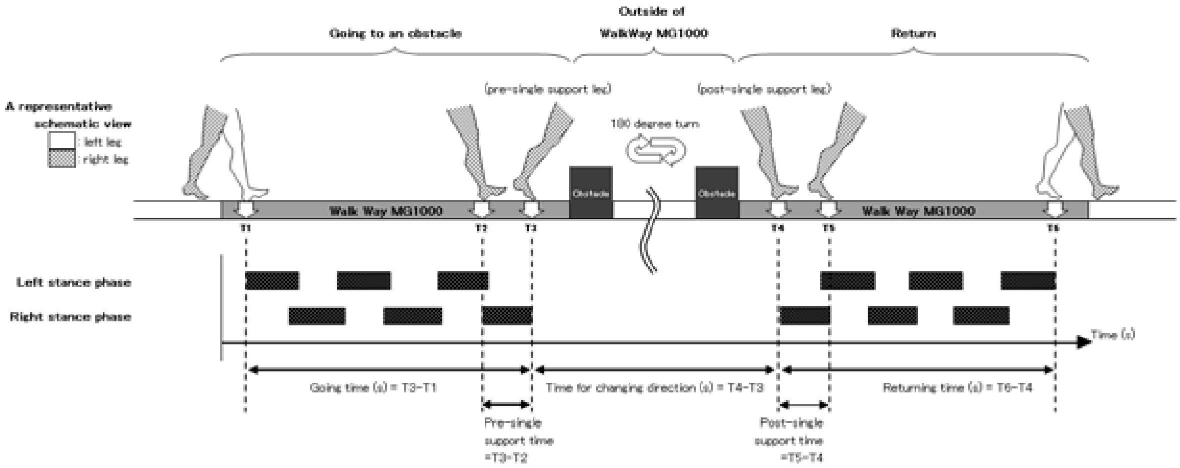

Figure 2. Explanation of analyzed gait parameter phases during the modified TUG test

crossing the obstacle and the time it took to walk 5 m back to the starting point). After one practice run, the subjects performed three trials of each TUG test with a 1 min rest between each trial. A mean value of the last two trials of each test was used for further statistical analysis.

To evaluate gait properties based on the measurements recorded by the WalkWay MG-1000, we defined the support leg just before stepping over the obstacle as the pre-single support leg and the support leg just after stepping over as the post-single support leg (see Fig. 2). The TUG test score, i.e., the total required time in seconds required to complete the TUG test, was divided into: Going Time (time required to go from T1 to T2 as in Fig. 2), Return Time (from T5 to T6), Time Required to Change Direction (from T3 to T4), Pre-single Support Time (from T2 to T3), and Post-single Support Time (from T4 to T5). As the total time required to complete the test included non-movement phases such as standing up from and sitting down on the chair, it was consequently larger than the sum of the times for each movement phase.

To examine the influence of an obstacle on various locomotor velocities in both age groups, two-way ANOVA for age groups and walkway conditions (control and experimental conditions) was performed. Tukey's Honestly Significant Difference (HSD) test was used as a multiple comparison test when two-way ANOVA showed a significant interaction effect between age and walkway conditions. The significance level was set at 0.05.

Results

Significant differences with respect to gender were found in the height and weight of the elderly, but not found in age, points assessed by the BBS and the total

Table 1. The difference of time required for each phase between age groups and between experimental conditions

			Control		Obstacle		Two-way ANOVA			Post-hoc, Tukey's HSD
	Unit		Mean	SD	Mean	SD	Factor	F-value	p-value	
Total required time	(s)	Young (n = 17)	9.11	1.18	9.19	1.22	Age	70.77	< .001 *	Elderly: Control < Obstacle
		Elderly (n = 30)	15.19	3.02	15.96	2.95	Obstacle	12.81	.001 *	Control, Obstacle: Young < Elderly
							Interaction	8.44	.001 *	
Going Time	(s)	Young (n = 17)	2.02	0.31	2.01	0.30	Age	119.35	< .001 *	Control, Obstacle: Young < Elderly
		Elderly (n = 30)	4.06	0.79	4.08	0.69	Obstacle	0.00	.99 n.s.	
							Interaction	0.32	.58 n.s.	
Pre-single support time	(s)	Young (n = 17)	0.50	0.09	0.53	0.08	Age	79.99	< .001 *	Elderly: Control < Obstacle
		Elderly (n = 30)	0.77	0.12	0.89	0.16	Obstacle	31.84	< .001 *	Control, Obstacle: Young < Elderly
							Interaction	10.35	.002 *	
Time for changing direction	(s)	Young (n = 17)	1.37	0.33	1.46	0.36	Age	11.90	.001 *	Elderly: Control < Obstacle
		Elderly (n = 30)	1.78	0.57	2.06	0.54	Obstacle	23.89	< .001 *	Control, Obstacle: Young < Elderly
							Interaction	5.89	.02 *	
Post-single support time	(s)	Young (n = 17)	0.53	0.06	0.53	0.07	Age	92.01	< .001 *	Elderly: Control < Obstacle
		Elderly (n = 30)	0.72	0.07	0.77	0.10	Obstacle	7.38	.01 *	Control, Obstacle: Young < Elderly
							Interaction	7.02	.01 *	
Returning Time	(s)	Young (n = 17)	2.08	0.27	2.07	0.29	Age	113.89	< .001 *	Elderly: Control < Obstacle
		Elderly (n = 30)	4.25	0.79	4.39	0.88	Obstacle	3.63	.06 n.s.	Control, Obstacle: Young < Elderly
							Interaction	4.20	.046 *	

*: p < .05; n.s.: not significant.

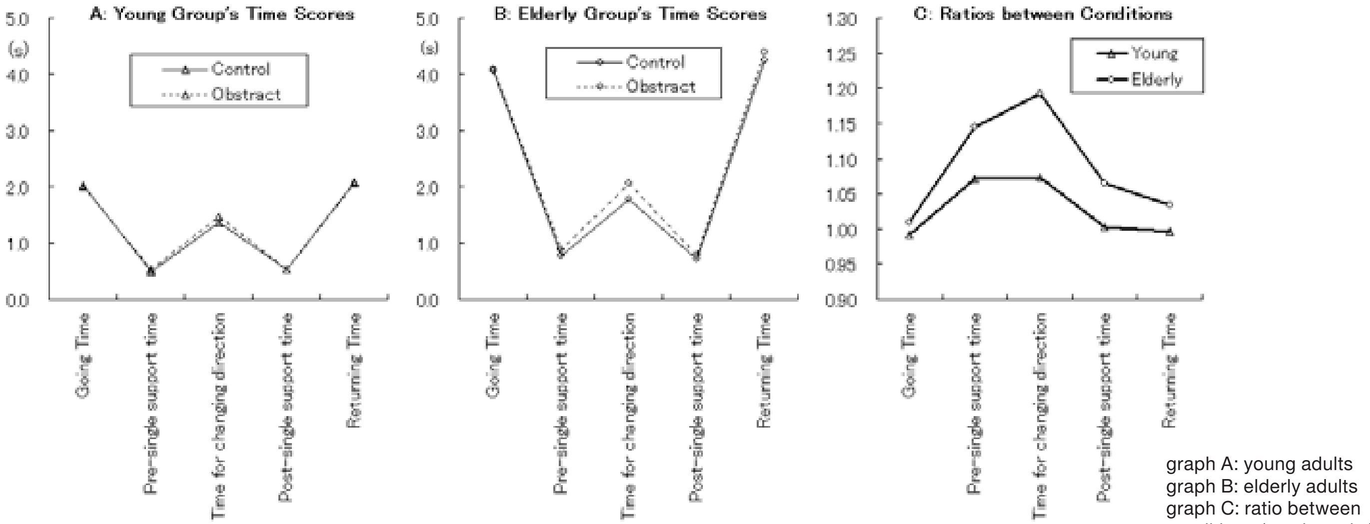

Figure 3. The time scores for each phase

time needed to complete the TUG test (*t*-value = 0.73, *p*-value = 0.471). Hence, data obtained from the male and female elderly were pooled for statistical analysis.

Table 1 shows the test results after two-way ANOVA was performed. Significant interaction effects were found in all of the parameters other than Going Time. The multiple comparisons test found that the elderly participants took significantly longer to perform the experimental (with an obstruction) than the control (no obstruction) test in all of the studied parameters except Going Time. For the group of young adults, the obstacle was found to have no influence on time. Regardless of the presence or absence of an obstacle, the elderly performed all phases significantly longer than the younger participants.

Figure 3 (graphs A and B) shows the raw time scores in each movement phase in the control condition (thin, solid line) and the obstructed condition (thin, dashed line) for both age groups. Graph C in Figure 3 shows the ratio of time scores (thick line) between both walkway conditions (obstructed and unobstructed) in each movement phase for each age group. For the movement phases other than Going Time, the elderly (graph B) tended to slow down more when compared to the young adults (graph A). The time ratios showing the delay caused by an obstacle (graph C), particularly during Pre-single Support Time and Time Required to Change Direction, tended to be greater for the elderly than for the young subjects.

Discussion

In this study, the characteristics describing locomotor performance before, during and after crossing over an obstacle were examined for two age groups: elderly individuals over 65 years in age able to walk independently and healthy young adults. Their locomotor performance during the TUG test were divided into five phases: when approaching the obstacle, the single leg stance phase just before crossing over the obstacle, when changing direction 180 degrees after crossing over the obstacle, the single leg stance phase just after crossing, and when returning to the chair. During most of these locomotor phases, the elderly showed marked discrepancies in performing the TUG with an obstacle compared to the young adults.

The data obtained in this study support previous findings. Thus, regardless of the presence or absence of an obstacle, the elderly require a longer amount of time to perform various locomotor movements than in the case of younger adults. Such a finding was predicted in advance due to conclusive proof that the elderly feature a decrease in gait velocity [15], changes in gait pattern [16] and deficits in various physical functions [11]. Although there are some differences in the experimental conditions that were used, Chen et al. [10] also examined obstacle crossing performance on a level walkway and reported that the crossing speed was slower for the elderly when compared to young adults.

For all of the movement phases analyzed in this study, the locomotor performance of young adults was found not to be influenced by an obstacle (Tab. 1 and Fig. 3, graph A). Other studies found that young adults adjust their gait with a longer step length for stepping over obstacles [17] and use a more optimal foot placement strategy [18] under unconstrained conditions (in terms of time). This study confirmed that there is no significant decrease in the locomotor performance of young adults when encountering an obstacle, even when performing multi-locomotor tasks such as the one used in this study.

In contrast, although there were no elderly participants who made contact with the obstacle in this study, this group slowed down during all movement phases except in the phase when approaching the obstacle (Going Time). The drop in speed by elderly subjects was larger when compared to the young adults, particularly in the single leg stance phase during obstacle crossing and in the turning phase just after obstacle crossing (Fig. 3, graph C).

However, the results in the present study could not be compared or confirmed as no other study has yet examined the influence of obstacles on the sequence of various locomotor tasks both before and after crossing an obstacle. Nonetheless, some previous studies could provide further clarification on the matter. For example, Weerdesteyn et al. [19] reported that older adults showed larger foot-obstacle clearance than young adults, although their experiment was conducted under time-constrained conditions. In addition, it was also reported that older adults demonstrated greater hip flexion, hip adduction and ankle dorsiflexion than young adults during the stance phase for both lower limbs when crossing over an obstacle [9]. Therefore, it can be reasoned that the single leg stance phases just before and after crossing an obstacle were prolonged for the elderly subjects as they required more foot clearance and, therefore, their joint angle variation increased. In addition, changes in the movement kinematics of the elderly participants might have also influenced their turning motion.

The drop in speed observed in the elderly due to an obstacle could be also caused by a shortened step length. Patla [20] reported that the gait control patterns for negotiating an obstacle include adjusting step length, achieving appropriate foot clearance over an obstacle and changing direction or the amount of steps, and that adjustment of step length is the most frequently used strategy. According to Patla [21], humans adjust their step length five steps ahead before crossing an obstacle if recognized in advance, i.e., not in time-constrained conditions. Nakano and Ohashi [17] also reported that older adults adopted a shortened step length five steps ahead before crossing over an obstacle. Older adults were also found to use a shortened step length strategy more frequently than young adults [19]. However, the elderly's gait strategy of using a shortened step length for negotiating an obstacle could lead to an increased frequency of stepping on or coming into contact with the encountered obstacle especially if the obstacle was not recognized in advance, as there could be not enough time to appropriately modify step length. In situations where an increase in step length is required, humans need to increase their muscle activity up to ten times more than when shortening their step length [22]; such a strategy may pose major difficulties for the elderly due to overall decreased physical functioning.

In this study, the effect of an obstacle on locomotor performance appeared not only immediately before and after stepping over an obstacle, but also during the act of changing direction and returning to the start point. This suggests the possibility that the movement employed when stepping over a small object disturbs the smooth transition between subsequent movement tasks, which may result in a further decline in the performance of additional locomotor movements. In daily life, the elderly are required to perform several motor tasks in order to avoid and negotiate obstacles on the ground such as door thresholds, small objects on the floor, curbs, etc. Hence, based on the results found in the study, the elderly's ability to maintain an appropriate level of motor performance even after stepping over an obstacle may be somewhat more diminished than usual, which may increase the possibility of suffering from fall accidents and bone fractures.

It is very important to understand the locomotor characteristics of the elderly in order to reduce their risk of falling. Future studies may provide more fruitful dialogue on this subject by examining the correlation between fall risk and parameters other than the timed performance of locomotor activities, such as the foot clearance adopted when stepping over an obstacle.

Conclusions

Even for an elderly population that can walk independently, the movements phases executed when crossing over an obstacle and the subsequent locomotor movements sequences (changing direction or gait) were significantly prolonged when compared to the group of younger male adults. The elderly need to pay due attention not only when encountering an obstacle but also to subsequently performed movement phases in order to decrease the risk of falling.

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