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Proper Assessment of the Falling Risk in the Elderly by a Physical Mobility Test with an Obstacle

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Demura, S. and Uchiyama, M. *Proper Assessment of the Falling Risk in the Elderly by a Physical Mobility Test with an Obstacle*. Tohoku J. Exp. Med., 2007, **212** (1), 13-20 ── The Timed "Up & Go" (TUG) is a representative mobility test for assessing the falling risk of the elderly. Although several tests have been developed, including the TUG, these do not include a "tripping" element, and tripping is a major cause of falling. This study examined the influence of various obstacle heights on test performance in the TUG test and test-retest reliability. Twenty-two healthy elderly women participated in the TUG test and in the TUG test with an obstacle (TUGO). The obstacle is a box (width 120 cm and depth 20 cm), the height of which varies (0, 5 and 17 cm). In the 0-cm height condition, a thin sheet was laid down instead of the box. In the TUGO, subjects stood up from an armchair, walked 5 m, stepped over the box, turned, stepped over the box again, walked back to the chair and sat down. The reliability of the time required for the motion around the obstacle was high and the total time in the TUGO test increased (intra-class correlation coefficient = 0.74-0.99). These parameters were significantly larger for the height order 17, 5, and 0 cm and exhibited significant correlations with time required for the TUG (r = 0.61 - 0.92) and the height of subjects. An obstacle with 5 cm height prolonged the time during standing on one leg just before the obstacle and the time during turning motion after stepping over it. By adding the obstacle to the TUG, the physical mobility of the elderly is assessed more properly. ──── Timed "Up & Go" test; obstacle; tripping; risk of falling; elderly

Among basic movements in daily life, movements shifting the center of gravity or requiring the use of the lower limbs, such as walking, standing up, sitting down and turning over the body position, are very frequently used. Functional physical mobility and balance ability relate closely to the achievement of the above movements. In particular, walking is achieved by repeating advanced dynamic balance control as follows: shifting the center of gravity out of the support base, collapsing dynamic equilibrium, and recovering equilibrium again (Yang et al. 1990). Physical mobility declines with impairments of the vestibular or visual organs (Badke et al. 2004), but it decreases with age even in healthy elderly individuals (Mary and Tinetti 1986). It is thus necessary to objectively assess the functional mobility of the elderly, because a decline in mobility can largely restrict the activities of daily life and the quality of life (Takahashi et al. 2004).

A decrease in functional mobility is also one of the major factors in increasing fall incidences

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(Whitney et al. 1998). Moreover, the limitation or cessation of physical activities due to the fear of falling or due to a decline in mobility can accelerate the deterioration in lower limb muscle function, further enhancing fall risk and markedly decreasing the quality of life (Cumming et al. 2000; Legters 2002; Boulgarides et al. 2003). Properly assessing functional mobility is, therefore, important also for preventing fall accidents. Tripping is a major factor in fall accidents of the elderly. Pavol et al. (2001) reported that 53% of fall accidents are due to tripping. Furthermore, falls from tripping often result in serious injury (Pavol et al. 1999, 2001; Schillings et al. 2005; Troy and Grabiner 2005).

Podsiadlo and Richardson (1991) developed the Timed "Up & Go" (TUG) test to evaluate functional mobility by using the basic mobility skills of daily life. This test measures the time taken by an individual to stand up from an armchair, walk a distance of 3 m, turn, walk back to the chair, and sit down again. They reported that this test, which requires only simple tools and is able to be completed within about 30 sec, has high intra- and inter-tester reliability and is very useful for screening of the elderly who are apt to fall. Shumway-Cook et al. (2000) utilized the TUG test for community-dwelling older adults and found that there was a significant difference in the total time required between groups with or without a history of a fall in the past 6 months. However, the TUG test includes only the basic mobility tasks of daily life, such as standing up, walking, turning, and sitting down, but not stepping over an obstacle which may be a cause of tripping. The functional mobility required to evade an obstacle in daily life may be measured by incorporating this criterion into the TUG test. Although there are tests assessing postural stability during gait tasks that involve ambulating over and around obstacles, such as the Dynamic Gait Index and the Functional Gait Assessment, both tests were developed only for patients with neurological diseases (Wrisley et al. 2004; Marchetti and Whitney 2006).

This study aimed to examine the influence of various obstacle heights on performance in the TUG test and the test-retest reliability in a healthy elderly homogeneous group, considering their safety, as a fundamental study for the future proposal of a TUG test with an obstacle (TUGO test).

Materials and Methods

Subjects

Twenty-two healthy elderly women (age: mean = 68.7 yrs, s.d. = 6.19; height: mean = 149.8 cm, s.d. = 6.89; weight: mean = 54.07 kg, s.d. = 8.61) volunteered to participate in this study. All subjects were judged by the Berg Balance Scale (BBS) to have a low risk of falling in their daily life (Berg et al. 1992) (BBS score: mean = 54.57, s.d. = 1.78). Their physical characteristics were almost the same as the age-matched national standard value (Laboratory of Physical Education, Tokyo Metropolitan University 2000) (Table 1). Prior to the measurements, the purpose and procedures of this study were explained in detail to all subjects, and informed consent was obtained. This experimental protocol was approved by the ethics committee (Kanazawa University Health & Science Ethics committee).

Experimental conditions

The TUGO test, which was extended to 5 m, was conducted under three kinds of obstacle heights to exam-

Table 1. Subjects' characteristics (n = 22).

	Women		
	Mean	s.d.	Range
Age (y)	68.7	6.19	80.0 – 60.0
Height (cm)	149.8	6.89	162.0 – 130.0
Weight (kg)	54.1	8.61	67.0 – 35.0
Body mass index (weight [kg]/height [m]^2)	24.0	3.11	28.5 – 16.4
Berg Balance Scale (point)	54.9	1.31	56.0 – 52.0

ine the objective of this study. A 5 m walkway length was used to avoid any constraint on the gaits of the subjects, such as shortened strides. Obstacle heights were 0 cm (control condition), 5 cm (Troy and Grabiner 2005), and 17 cm (one-step height of stairs) and were positioned just before the turning-around point 5 m from a chair. Each subject's trial order for these 4 tests, including the original TUG test (with a 3 m walkway and without any obstacles), was randomly assigned using a table of random numbers.

Apparatuses and procedures

A gait analysis apparatus (WalkWay MG-1000, Anima, Tokyo) was used to observe the gait properties in each obstacle height condition. This apparatus can record time and spatial information as digital signals sent to a personal computer when the bottom of a subject's foot contacts the sensing sheet. The sampling frequency was set at 100 Hz.

The subjects were instructed to sit on a 46 cm high armchair, stand up from a 46 cm high armchair at the tester's start signal, walk 5 m on the sheet of the above-stated apparatus, step over the obstacle, turn the body 180 degrees, step over the obstacle again, walk back to the chair on the sheet, and sit down (Fig. 1). Each subject was instructed to perform the required motions at a comfortable and safe pace (Podsiadlo and Richardson 1991). Using a stopwatch, the tester recorded the total time elapsed from standing "Up" to when subjects sat down again. The size of the obstacle was 20 cm deep, 120 cm wide, and of 3 varying heights as indicated above (0, 5, and 17 cm). In the 0 cm height condition, a thin sheet with little thickness was laid instead of an obstacle. The color of the object was in high contrast (off-white) to the floor (dark brown) to ensure visibility. After subjects practiced once, they performed three trials with a 1min rest in between each trial.

Parameters

To evaluate gait properties during the stepping over an obstacle task, on the sensing sheet of the WalkWay MG-1000 we defined the support leg just before stepping over as the pre-single support leg and the support leg just after stepping over as the post-single support leg (Fig. 2). Going time (time required to go from T1 to T3 in Fig. 2), return time (from T4 to T6), and turn time (from T3 to T4) were calculated, in seconds, using data from the gait analysis system. Pre-single support time was determined from T2 to T3 and pre-single support distance was determined from tip of toe at T3 to the obstacle. Post-single support time was determined from T4 to T5 and post-single support distance was determined heel at T4 to the obstacle.

Statistical analysis

The test-retest reliabilities of the total time required and parameters of various gait properties in each obstacle height condition were examined using an intra-class correlation coefficient (ICC [1,1]). Relationships between these parameters and the total time required in the original TUG test, as well as physique data (age, height, weight and body mass index [BMI]), were examined by Pearson's correlation coefficient. One-way analysis of variance (ANOVA) for repeated measures was used to examine the mean differences between each obstacle height condition for the total times required and all gait parameters. Tukey's honestly significant difference (HSD) test was used for a multiple comparison test if

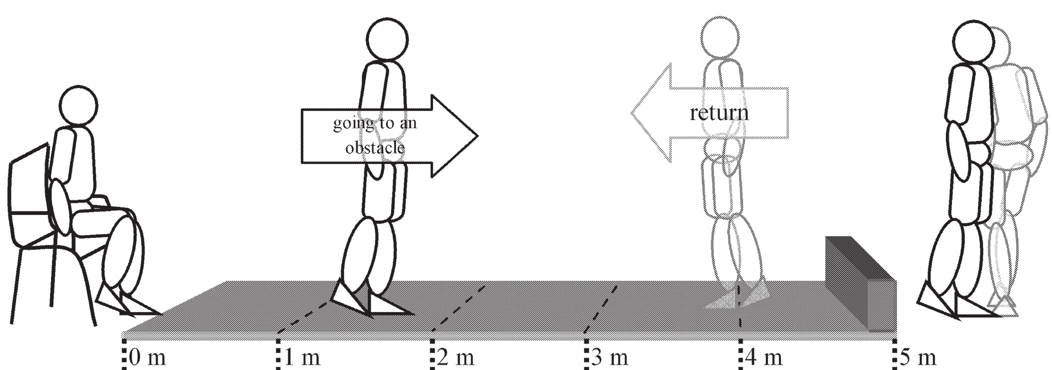

Fig. 1. Schematic diagram of the TUGO test.
Movement order is as follows: 1. Stand up from a chair, 2. Walk and step over an obstacle, 3. Turn 180 degrees in an arbitrary direction, 4. Return to the chair and sit down again.

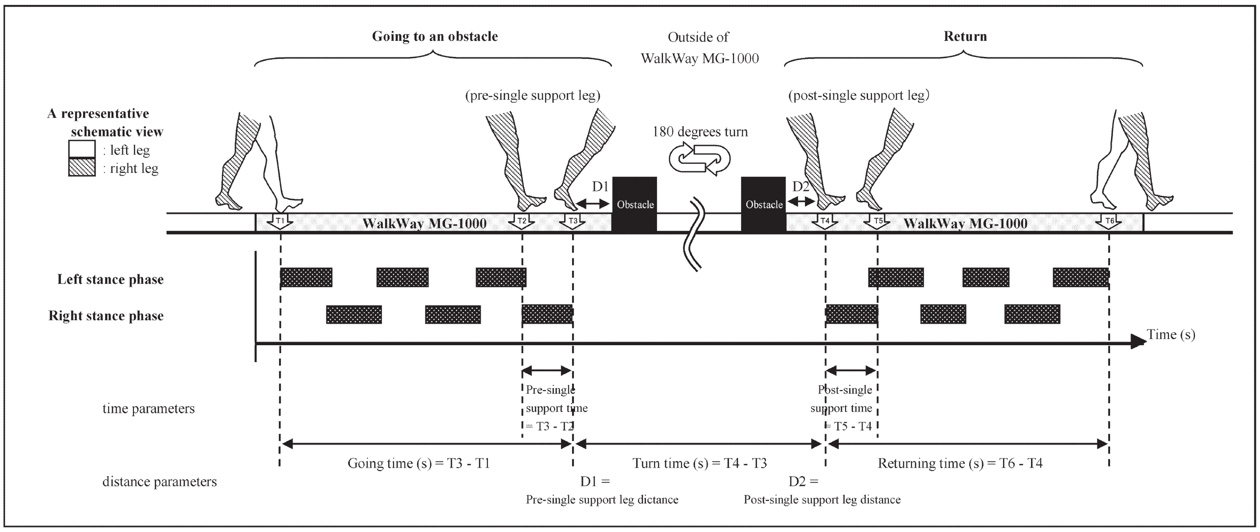

Fig. 2. Explanation of gait parameters of the TUGO test.
The gait properties, such as pre- and post-support times, and turn time differ in each subject.

ANOVA indicated a significant difference. Level of significance was set at $p < 0.05$.

Results

Table 2 shows the comparative result between ICCs calculated from the second and third trials and ICCs calculated from all three trials of the original TUG and TUGO tests. ICCs of performances in the original TUG test (total time required), whether using data from the second and third trials or data from the first through third trials, were very high (0.97 and 0.98, respectively). In contrast, in the TUGO test ICCs were higher in the higher obstacle height conditions when using data from the second and third trials rather than when using data from the first through third trials. Mean values of the latter 2 trials were used for further statistical analysis.

Table 3 shows the results of ANOVA, multiple comparison tests of the total time required and each gait parameter in the TUGO test as well as correlations with the total time required in the original TUG test.

Time parameters had high reliability (ICC = 0.74-0.99) and showed significant relationships with the total time required in the original TUG test (r = 0.61-0.92). The time parameters were significantly higher for the height order 17 cm,

Table 3. Results of ANOVA and multiple comparison tests of each gait parameter in the TUGO

	0 cm height condition			5 cm height condition		
	Mean	s.d.	r	Mean	s.d.	r
Total time (s)	14.56	2.60	0.92*	15.10	2.25	0.85*
Going time (s)	4.71	0.77	0.79*	4.82	0.70	0.81*
Pre-single support time (s)	0.76	0.10	0.70*	0.85	0.11	0.71*
Turn time (s)	1.66	0.56	0.80*	1.90	0.46	0.61*
Post-single support time (s)	0.72	0.06	0.80*	0.75	0.07	0.63*
Returnning time (s)	4.85	0.71	0.82*	4.97	0.74	0.80*
Pre-single support leg distance (cm)	11.11	3.20	−0.35	12.91	5.17	−0.45*
Post-single support leg distance (cm)	12.95	4.32	0.10	13.48	3.45	−0.04

* $p < 0.05$; r, correlation coeficient between total time required in the TUG test and each gait parameters

TABLE 2. Comparative results of ICCs calculated from the second and third trials and ICCs calculated from the first through third trials (n = 22).

	The 2nd and 3rd trials				From the 1st to 3rd trials				Differences of ICCs			
	TUGO 0 cm	TUGO 5 cm	TUGO 17 cm	TUG	TUGO 0 cm	TUGO 5 cm	TUGO 17 cm	TUG	TUGO 0 cm	TUGO 5 cm	TUGO 17 cm	TUG
	ICC	ICC	ICC	ICC	ICC	ICC	ICC	ICC	ICC	ICC	ICC	ICC
Total time (s)	0.99	0.97	0.97	0.99	0.99	0.94	0.71	0.98	0.00	0.04	0.25	0.01
Going time (s)	0.98	0.98	0.97		0.98	0.86	0.75		0.00	0.11	0.22	
Pre-single support time (s)	0.78	0.89	0.91		0.77	0.49	0.76		0.00	0.40	0.15	
Turn time (s)	0.93	0.92	0.92		0.93	0.63	0.62		–0.01	0.28	0.30	
Post-single support time (s)	0.74	0.81	0.92		0.84	0.83	0.89		–0.10	–0.02	0.04	
Returnning time (s)	0.98	0.97	0.96		0.98	0.94	0.90		0.00	0.03	0.06	
Pre-single support leg distance (cm)	0.58	0.69	0.73		0.57	0.73	0.67		0.02	–0.04	0.06	
Post-single support leg distance (cm)	0.87	0.50	0.66		0.72	0.53	0.64		0.15	–0.04	0.02	

0 cm, 5 cm and 17 cm: obstacle height conditions; ICC, intra-class correlation coefficient; Differences of ICCs: values calculated by subtracting ICC (1st - 3rd trials) from ICC (2nd and 3rd trials).

5cm, and 0 cm. In contrast, the two distance parameters showed low to high ICCs (0.50-0.87) and insignificant differences between each obstacle height condition. The total time required in the original TUG test had significant and positive relationships with the time parameters in the TUGO test for all obstacle height conditions.

Table 4 shows the relationships between a subjects' physique and the parameters of the TUGO test in each obstacle height condition (n = 22). Significant and positive correlations were found between height and the total time in the original TUG and pre- and post-single support times in the TUGO test. A significant and negative correlation was found between age and the post-single support distance in the 0 cm obstacle height condition of the TUGO test.

test and their correlations with the total time required in the original TUG test (n = 22).

17 cm height condition			One-way ANOVA		Post-Hoc, HSD
Mean	S.D.	r	F	P	
15.84	2.78	0.86*	17.12	0.00*	0 cm < 5 cm < 17 cm
5.03	0.75	0.79*	14.63	0.00*	0 cm, 5 cm < 17 cm
0.93	0.16	0.73*	55.68	0.00*	0 cm < 5 cm < 17 cm
2.18	0.67	0.75*	27.68	0.00*	0 cm < 5 cm < 17 cm
0.85	0.11	0.66*	47.35	0.00*	0 cm, 5 cm < 17 cm
5.09	0.79	0.85*	8.14	0.00*	0 cm < 17 cm
11.89	3.71	–0.13	1.72	0.19	
13.02	2.93	0.10	0.27	0.77	

in the TUGO test.

Table 4. Relationships between subjects' physique and TUGO test parameters in each obstacle height condition (n = 22).

		Age	Height	Body mass	BMI
Total time (s)	TUG test	–0.10	0.43	0.25	0.02
	0 cm (TUGO)	–0.03	0.31	0.20	0.04
	5 cm (TUGO)	0.02	0.30	0.29	0.15
	17 cm (TUGO)	–0.13	0.29	0.26	0.12
Going time (s)	0 cm (TUGO)	0.02	0.17	0.09	–0.02
	5 cm (TUGO)	0.03	0.20	0.11	0.00
	17 cm (TUGO)	–0.13	0.17	–0.04	–0.17
Pre-single support time (s)	0 cm (TUGO)	–0.18	0.41	0.19	–0.04
	5 cm (TUGO)	–0.34	0.53	0.27	–0.01
	17 cm (TUGO)	–0.19	0.45	0.34	0.12
Turn time (s)	0 cm (TUGO)	0.01	0.31	0.30	0.17
	5 cm (TUGO)	–0.08	0.32	0.34	0.21
	17 cm (TUGO)	–0.16	0.28	0.30	0.19
Post-single support time (s)	0 cm (TUGO)	–0.21	0.59	0.23	–0.11
	5 cm (TUGO)	–0.37	0.55	0.35	0.08
	17 cm (TUGO)	–0.38	0.39	0.32	0.14
Returnning time (s)	0 cm (TUGO)	0.00	0.23	0.14	0.00
	5 cm (TUGO)	0.00	0.28	0.23	0.08
	17 cm (TUGO)	–0.05	0.22	0.18	0.07
Pre-single support leg distance (cm)	0 cm (TUGO)	0.04	–0.18	0.12	0.26
	5 cm (TUGO)	–0.07	–0.29	–0.14	0.01
	17 cm (TUGO)	0.23	0.01	0.35	0.42
Post-single support leg distance (cm)	0 cm (TUGO)	–0.50	0.37	0.20	0.03
	5 cm (TUGO)	–0.3	0.07	0.06	0.05
	17 cm (TUGO)	–0.10	0.32	0.13	–0.04

Shaded cell: $p < 0.05$. 0, 5 and 17 cm mean heights of the obstacle in TUGO test.

Discussion

Injuries from fall accidents largely affect the quality of life of elderly individuals (Troy and Grabiner 2005). To decrease or ideally prevent fall accidents, it is important to properly evaluate functional mobility. Until now, many researchers have attempted to develop tests to evaluate physical mobility in the elderly (Whytney et al. 1998). The TUG test, which consists of the basic mobility skills of daily life developed by Mathias et al. (1986), is a representative one. Podsiadlo and Richardson (1991) improved the TUG test to increase the ease with which it can be carried out and the test-retest reliability. However, this test does not include a "tripping" element, which is a major cause of fall accidents in the elderly. This study examined the influence of obstacles with various heights positioned on the walkway of the TUG test on test performance (total time required and gait parameters) in healthy female elderly individuals.

The test-retest reliabilities of the TUGO with three kinds of obstacle height conditions were very high for the total time required (ICC [1, 1] = 0.97-0.99) and the time parameters (ICC [1, 1] = 0.74-0.98). Furthermore, many previous studies have examined the test-retest reliability of the total time required for the TUG test and have reported (ICCs [n = 10-30]) (ICC = 0.92-0.99) with the same values as those found in the present study (Podsiadlo and Richardson 1991; Hughes et al. 1998; Shumway-Cook et al. 2000).

The influence of obstacle height was seen only on the time parameters of gait but not on the two distance parameters of pre- and post-single support leg distance. Because the latter showed a higher standard deviation as compared to the former, the precise positions of the supporting legs just before and after stepping over an obstacle are somewhat uncertain. The total time required, as well as the gait parameters just before and after an obstacle, significantly increased even with an obstacle height as low as 5 cm as compared with no obstacle. These results suggest that even a small obstacle, such as a house door sill, can largely affect gait motion in the elderly.

Since the total time required for the original TUG test has significant correlation with the total time and time parameters of gait in the TUGO test, both tests are thought to assess almost the same physical mobility. However, the contribution may slightly decrease with an obstacle (0 cm condition: $R^2 = 0.85$; 5 cm condition: $R^2 = 0.72$; 17 cm condition: $R^2 = 0.74$). The TUGO test on a walkway may assess a different physical capacity, primarily that of safely evading an obstacle, than the original TUG test.

Relationships between various physical mobility tests have been examined in previous studies, and it was reported that significant and negative correlations were found between the TUG test and the BBS, gait velocity, and the Barthel Index (Podsiadlo and Richardson 1991; Whitney et al. 1998). The present study showed significant correlations between the characteristics of the subjects (such as height and age) and their performance in the TUGO test. A subject's physique affects their performance in tests that assess physical mobility and/or balance. Thus, for example, we utilized the maximum length of one step test, a parameter which is divided by a subject's height or leg length (Komatsu et al. 2000). Furthermore, a significant relationship has been reported between a subject's physique and their risk of falling (Sakagami and Sato 2005). The present results showed significant and moderate relationships between height and pre- and post-single support times and between age and post-single support distance. The elderly with a taller physique may take the longer single support phase just before and after stepping over an obstacle. A significant and negative correlation between age and post-single support leg distance was found only in the 0 cm obstacle height condition; this may result from the shortened stride length of the older subjects.

However, because the sample size in this study is not sufficiently large (n = 22), the above conclusion should not be overemphasized. In the future, this problem should be examined in detail with a larger sample size. All subjects in this study were judged able to walk independently and to have no risk of falling. Although it is easy to examine the influence of obstacle heights in the group with similar functional physical mobility, it is difficult to judge whether the present TUGO test has high validity or not to measure physical mobility. It may be necessary to perform a cross-validity test or to compare the TUG test performances of subjects with inferior physical mobility level, i.e., low BBS score group (the elderly who have had many fall accidents or individuals with equilibrium disorders).

Conclusion

The test-retest reliability of the TUGO test is very high. In the healthy elderly, an obstacle with a height as low as 5 cm prolongs the movement time during standing on one leg just before the obstacle and the time during turning motion after stepping over it. Thereafter, the total time required in the TUGO test significantly increases. By adding the obstacle to the TUG, the physical mobility of the elderly may be assessed more properly.

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