

Relationship between the Step Test with Stipulated Tempos and Gait Ability in the Elderly

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Abstract This study aimed to examine the performance characteristics of a step test with stipulated tempos, used to evaluate the dynamic balance ability of the elderly, as well as the relationship between this step test and walking ability. Ninety-two healthy older women (age 70.9 ± 6.1 yr) who could walk independently, twice performed a 10 m walk at maximum speed and a step test for 20 sec with varying metronome tempos (40 bpm, 60 bpm, and 120 bpm). Subjects were divided into three groups (G1–G3) based on their 10 m gait time. Group 3 (G3), with the longest gait time, experienced the most falls.

One evaluation parameter was the total time difference between the metronome sound and the time when the subject's foot hit the ground. The gait time was significantly related to the time difference in the 40 bpm and 60 bpm tempos ($r=0.22-0.59$). In step tests with slower tempos (40 bpm and 60 bpm), group G3 had a significantly larger time difference than the other two groups. In conclusion, a step test with slow tempos has a close relationship with the walking ability of the elderly and may be useful in evaluating their dynamic balance ability related to locomotion. *J Physiol Anthropol* 28(2): 49–54, 2009 <http://www.jstage.jst.go.jp/browse/jpa2>
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Key words: dynamic balance, the elderly, step test, gait time

Introduction

Dynamic balance is the ability to maintain postural stability during physical movement, and it plays a very important role in the achievement of the basic movements of daily life (Huxham et al., 2001). However, dynamic balance ability decreases with the functional decline of the skeletal muscle and sensory organ systems that occurs with aging. The decline in dynamic balance ability largely influences the fall tendency in the elderly (Isles et al., 2004). Postural instability during a standing posture and basic locomotive movements not only increases the fall risk, but also greatly influences the decline in the quality of life (QOL) of the elderly (Legter, 2002;

Cumming et al., 2000). The proper evaluation of dynamic balance ability will be necessary for preventing falls in the elderly.

Until now, in order to predict the fall risk in the elderly, dynamic balance ability has been measured with various methods in the laboratory and in clinical settings. Typical tests include the Berg Balance Scale (BBS) (Berg et al., 1995), Tinetti Performance-Oriented Mobility Assessment (POMA) (Tinetti et al., 1986), and the Timed “Up & Go” Test (TUGT) (Podsiadlo and Richardson, 1991). However, these tests were developed mainly to evaluate the living ability of the elderly in the nursing home setting. Hence, they are not effective for estimating the fall risk of the healthy elderly (O'Brien et al., 1998; Boulgarides LK et al., 2003). In addition, because any test consists of plural movements, wide spaces and sufficient measuring time are necessary (Shin and Demura, 2007).

Hill et al. (1996) and Nakata (2002) have devised the spot step test, which more closely resembles natural gait, to evaluate the dynamic balance ability of the elderly. This test evaluates step number within a stipulated time and requires supporting the body on one leg (Hill et al., 1996; Nakada, 2002). The above spot step test can evaluate gait ability and gait strategy. However, because it requires quick stepping with maximal effort, it is difficult for the elderly with poor gait ability to perform, and it carries the risk of knee injury. In addition, the test is not representative of daily activity, which rarely requires stepping or walking with maximal effort. A test of submaximal effort may be more useful to evaluate the dynamic balance ability of the elderly. People with superior dynamic balance ability and leg strength can step at a slower than usual gait tempo. In contrast, people with inferior dynamic balance ability cannot maintain stable one-legged standing and thus experience difficulty stepping to match a slow tempo.

Gait speed has a high correlation with leg muscle strength and balance function (Schmid et al., 2007; van Iersel et al., 2007; Aoyagi and Katsuta, 1990; Laughton et al., 2003). In addition, an increase in the two-legged support time during walking is related to a decline of balance ability with aging (Yamamoto et al., 1995). A step movement to a stipulated

tempo was developed to evaluate the dynamic balance ability of the elderly. This test largely resembles gait movement, because it includes center of gravity changes and one-legged and two-legged supporting phases. Hence, it is assumed that the above step test has a high relationship to walking ability.

This study aimed to examine the performance characteristics of a step test to a stipulated tempo in order to evaluate the dynamic balance ability of the elderly as well as the relationship of this step test with walking ability.

Methods

1) Subjects

Ninety-two healthy older women (age 70.9 ± 6.1 yr, height 150.2 ± 5.7 cm, weight 53.8 ± 6.7 kg) without leg disorders and who were able to walk independently participated in the present experiment. Kimura (2000) reported that the elderly with slow gait speeds experience many falls and that the elderly with many fall experiences also have inferior dynamic balance ability. Tainaka and Aoki (2007) examined the relationship between the presence or absence of fall experiences and gait time. They reported that the 10 m gait time in 40 people with fall experiences and 51 people without fall experiences was 8.34 sec and 7.14 sec, respectively. Similarly, Lee et al. (2007) reported that the 10 m gait time of 14 people with fall experiences and 23 people without fall experiences was 8.68 sec and 7.40 sec, respectively. Based on the gait times in these previous studies, the present subjects were classified into 3 groups: a fast walking group (G1: $7.22 \text{ sec} = (51 \times 7.14 + 23 \times 7.4) / 74$), a normal walking group (G2: $7.22 \text{--} 8.4 \text{ sec}$), and a slow walking group (G3: $8.4 \text{ sec} = (40 \times 8.34 + 14 \times 8.68) / 54$). In short, the elderly who take more than 8.40 sec and less than 7.22 sec to complete the 10 m gait test were judged to be slow and fast walkers, respectively. This study assumed that the elderly with longer gait times have more fall experiences and have inferior dynamic balance ability, while the elderly with shorter gait times and no fall experiences have superior dynamic balance ability. Prior to testing, the purpose and procedure of this study were explained in detail, and informed consent was obtained from all subjects. Approval for this study was obtained from the Kanazawa University Department of Education Ethical Review Board.

2) Apparatuses and methods

① The step test

A gait analysis meter (Walkway MG-1000, Anima and Japan) was used for the step test. This device can measure in real time when the subject's right or left foot touches the step sheet and takes off from a footprint based on foot pressure information. The sampling frequency was 100 Hz. The subjects stood on the step sheet and stepped to match the tempo of a metronome. A 120 bpm tempo was reported to be the most efficient interval during walking (Toyama and Fujiwara, 1990). Sixty bpm and 40 bpm tempos, which correspond to 1/2 and

1/3 intervals of 120 bpm, were selected as slower tempos (Shin and Demura, 2007).

② The 10 m gait test

The 10 m gait test was performed on flat ground along a 10 m line of 10 cm wide tape. Each subject was requested to walk as fast as possible on the 10 m line. A tester measured the time required for subjects to walk from the beginning to the end of a 10 m line with a stopwatch.

3) Procedure

The measurement order of the step test and gait test was chosen at random. After one practice, the step test was executed with the different tempos in the order of 40 bpm, 60 bpm, and 120 bpm. Each test was performed twice for 20 sec with a 1 min rest period in between. The gait test was also performed twice, and the shorter time was used as the representative value.

4) Evaluation parameter

The time difference between the metronome sound of each tempo and the plantar grounding time was selected as an evaluation parameter in the step test. It was judged that a person with a smaller time difference can better match the tempos and therefore has superior dynamic balance ability. A mean of the 2 trials was used as the representative value. If the total difference between the tempo sound and the grounded time of the stepping foot was small, we judged the dynamic



Fig. 1 Step test.



Fig. 2 10 m gait test.

Table 1 Results of mean differences of physique characteristics and gait times among three groups

		N	Mean	SD	Min	Max	F-value	Multiple comparison (Tukey's HSD)
10 m gait time (s)	G1	50	6.08	0.80	3.90	7.20	126.68*	G1<G2<G3
	G2	26	7.76	0.25	7.30	8.11		
	G3	16	10.22	1.69	8.40	13.80		
Age (yr)	G1	50	68.60	5.26	60.00	81.00	14.24*	G1<G2, G3
	G2	26	72.85	5.65	64.00	84.00		
	G3	16	76.40	5.04	70.00	86.00		
Height (cm)	G1	50	152.41	6.11	140.10	171.50	2.54	
	G2	26	151.00	6.30	141.00	165.50		
	G3	16	148.10	8.67	131.00	170.00		
Weight (kg)	G1	50	53.88	5.97	38.60	64.70	1.58	
	G2	26	56.70	6.99	41.00	70.40		
	G3	16	53.26	10.89	38.50	78.00		

* G1, G2 and G3 are three groups with different gait times. G1 and G3 were the fast and slow gait groups, respectively.

Table 2 The fall experience in each group

Group	N	Experiencer		Non experiencer		Difference between groups	
		%		N	%	χ^2	Bonferroni
G1	45	90.0%		5	10.0%	10.76*	G1 ,G2<G3
G2	23	88.5%		3	11.5%		
G3	9	56.3%		7	43.8%		
Total	77	83.7%		15	16.3%		

* G1, G2 and G3 are the fast, normal and slow gait groups, respectively.

balance ability to be superior. The gait time was the 10 m gait time.

5) Data Analysis

Pearson's correlation was used to examine the relationships between stepping parameters and the 10 m gait time. To test the mean differences among tempos and among the 3 groups for each parameter, two-way ANCOVA (group [gait time] × tempo), using age as a covariance parameter, was employed. Multiple comparisons were evaluated using Tukey's HSD method. The probability level of 0.05 was indicative of statistical significance.

Results

Table 1 shows the results of mean differences of physique characteristics and gait times among the 3 groups (G1, G2 and G3). The gait time was significantly longer in the order of the G1, G2, and G3 groups, and the age was significantly lower in the G1 group than in the G2 and G3 groups. Insignificant group differences were found for height and weight.

Table 2 shows the number and percent (%) of fall experiences in the three groups. A significant group difference was found such that the number of falls in the G3 group was higher than that in the G1 or G2 groups.

Table 3 shows correlations and partial correlations between time differences and gait times. Correlations, except for at 120

Table 3 The correlations and partial correlations between time differences and gait times

	Age	40 bpm	60 bpm	120 bpm
Gait (correlations)	0.46	0.59	0.55	0.17
Gait (partial correlations)		0.55	0.52	0.22

$p < 0.05$: ■

bpm, were significant and moderate. Partial correlations, excluding the influence of age, were significant (0.22–0.59) in all tempos.

Table 4 shows the results of two-way ANCOVA (group × tempo) for the time difference. A significant interaction was found. A multiple comparison showed that the time difference is larger in the order of the tempos 40 bpm, 60 bpm, and 120 bpm. The time difference for the 40 bpm condition was smaller in the order of G1, G2, and G3 groups, and the time difference for G1 and G2 was smaller than G3 in the 60 bpm condition.

Table 5 shows the results of mean differences between the groups with and without fall experiences for the 10 m gait test and the step test. The group with fall experience was significantly inferior in both tests.

Table 4 Results of two-way ANCOVA (group×tempo) excluding the influence of age for the time difference

		40 bpm		60 bpm		120 bpm		2-way ANOVA		Post-hoc HSD			
		Mean	SD	Mean	SD	Mean	SD	F-value		tempo	group		
Time difference	G1	0.11	0.04	0.06	0.02	0.02	0.01	F1	14.9*	G1	40>60>120	40 bpm	G1<G2<G3
	G2	0.14	0.06	0.06	0.01	0.02	0.02	F2	197.1*	G2	40>60>120	60 bpm	G1, G2<G3
	G3	0.21	0.11	0.10	0.05	0.03	0.02	F3	9.4*	G3	40>60>120		

* G1, G2 and G3 are the fast, normal and slow gait groups, respectively.

Table 5 Results of mean differences between the groups with and without fall experience for the 10 m gait test and step test

	With fall experience		Without fall experience		1: The group difference in gait time (t-value) 2: The tempo and group difference in the step test (F-value)				
	Mean	SD	Mean	SD					
1: 10 m gait time	8.49	2.41	7.07	1.56	t-value		2.89*		With fall experience>Without fall experience
2: The step test									(Post hoc. Tukey's HSD)
40 bpm	0.18	0.12	0.13	0.06	F-value	Group	5.84*	Tempo	40<60<120 (Both groups)
60 bpm	0.08	0.04	0.07	0.03		Tempo	107.05*	Group	40 bpm
120 bpm	0.03	0.02	0.02	0.01		Interaction	3.05		(With fall experience>Without fall experience)

note: * $p<0.05$

Discussion

This study classified subjects into 3 groups (G1–G3) having different gait times, based on the reports of Lee et al. (2007) and Tainaka and Aoki (2007). G1 was the fast gait group, with a 10 m gait time of less than 7.22 sec, and G3 was the slow gait group, with a gait time of more than 8.40 sec. A significant difference was found in the mean gait times of the 3 groups (G1<G2<G3). Lee et al. and Tainaka et al. also reported that the elderly with a slow gait speed experienced more falls. Also in this study, it was confirmed that G3, the group with the longest gait time, had significantly more fall experiences than the other two groups. Because a difference in the fall experience rate was not found between G1 and G2, both of which have a shorter gait time than G3, it is considered that the elderly with a longer 10 m gait time (>8.40 sec) have a higher fall risk. From the present results, it is judged that the 10 m gait test is effective for making fall risk predictions for the elderly.

Toyama and Fujiwara (1990) reported that the 120 bpm tempo used in this study is the most stable tempo during gait. Shin and Demura (2007) reported that the elderly can easily perform the step test to the 120 bpm tempo, as can young adults. Also in the present results, the 120 bpm tempo showed insignificant differences among groups with different gait times, and the time difference among the three groups was minimal as compared with the other two tempo conditions. Hence, it is judged that all three groups with different gait times could step easily while matching any of the stipulated tempos. The 120 bpm tempo may not be effective, because even the elderly with inferior balance and gait ability can achieve it easily; thus, the 120 bpm tempo does not reflect individual differences.

On the other hand, the time difference showed a higher value

in the order of 40 bpm, 60 bpm, and 120 bpm in all groups. The 40 bpm and 60 bpm tempos doubled and tripled the unstable one-legged support time over the 120 bpm tempo. Hence, the step test with slower tempos may have made it more difficult for the elderly to move their center of gravity to the right and left in accordance with the tempo due to the longer one-legged standing phase.

Many researchers have examined the relationships between falls in the elderly and the speed and stability of gait (Tainaka and Aoki, 2007; Smeesters et al., 2001; Iersel et al., 2007; Prince et al., 1998). Choi and Shin (2005) reported that the elderly with fall experience are more unstable in their gait than those without fall experience. Lee et al. (2007) reported that a difference between fall experience and nonexperience groups was found in the 2.45 m round-trip walk, 10 m gait time, cadence, and one-leg standing time. It was clarified in this study that the elderly with fall experience had a longer gait time and performed inferiorly in the step test with the slowest tempo (40 bpm). Ikai et al. (2006) reported that factors such as age, muscular strength, joint range of motion, motion control, and proprioceptive sensation influence gait and that postural reflection and control (i.e., balance ability) are also closely involved in gait.

In this study, the gait time showed moderate correlation with the slow tempo step test. It is inferred that the instability of gait movement reflects the postural instability resulting from a longer one-legged support phase at the slower tempos. In addition, the time difference in the slower 40 bpm and 60 bpm conditions was larger in the longer gait time group (G3) than in the faster gait time groups. In short, it was confirmed that the G3 group is inferior in the step test when required to match slower tempos. Because the step movement performed on the spot is not accompanied with an extension of the hip joints, a

kick out by the toes, or a forward movement, it may be somewhat different from real gait. However, the spot step movement demonstrates alternating one-legged and two-legged support phases and resembles natural gait movement in that a prolongation of the two-legged support time is a feature of gait in the elderly.

Furthermore, because the step test using a slower tempo than the normal gait cycle produces a longer one-legged support phase, we can observe more unstable postures in this condition. Hence, this test may evaluate not only gait ability but also balance ability related to exchanging steps.

Conclusion

The slow gait group, who require more than 8.40 sec to complete a 10 m walk, has a high fall risk. The time differences of the step test with slower tempos (40 bpm and 60 bpm) has a relationship to gait time. Furthermore, the slow gait group (G3) has a larger time difference than the normal (G2) and fast (G1) gait groups. Hence, a step test with a slow tempo is effective for the evaluation of the balance and gait ability of the elderly.

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