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Effective Tempo of the Step Test for Dynamic Balance Ability in the Elderly

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Abstract This study aimed to examine the reliability and sex- and age-related differences of step tests with stipulated tempos as well as to clarify useful test parameters and tempos. One hundred forty elderly people and fifty young adults conducted tapping and stepping tests, matching the tempo provided by a metronome. Both tests involve movements where the subject touches a sheet with both the right and left hands or right and left legs at a designated spot. Evaluation parameters were the time difference between the beep sound and the time at which the sheet was touched in both tests as well as two-leg support and one-leg support times in the step test. The trial-to-trial reliability of the parameters in both tests was high. The time differences of both 40 bpm tests in the elderly were larger in males than in females. In the step test, the time difference and two-leg support times of the elderly were larger, in the order of 40, 60, and 120 bpm, and the one-leg support time was less in 40 bpm than 60 bpm or 120 bpm. The one-leg support time of the young subjects was larger, in the order of 40, 60, and 120 bpm. A significant age-related difference was found in the 40 bpm and 60 bpm test, and the time difference and two-leg support time were larger in the elderly while the one-leg support time was larger in the young subjects. The time difference at 40 bpm in the elderly was larger in the step test than in the tap test. There was no significant difference between both tests in the young subjects. In conclusion, the step test with the slow tempo, because it requires a long one-leg support phase, is effective for evaluating dynamic balance in the elderly. The time difference and two-leg and one-leg support times are effective evaluation parameters of the step test. *J Physiol Anthropol 26(6): 563–567, 2007* http://www.jstage.jst.go.jp/browse/jpa2
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Keywords: dynamic balance, the elderly, step test, tap test

Introduction

Dynamic balance is the ability to maintain stability of posture during movement, and is decreased by hypofunction of the skeletal muscle and sensory organ systems with age. Dynamic balance is very important in achieving the basic movements of daily life, and its decrease is largely related to falling in the elderly (Isles et al., 2004). Instability of posture in the standing position and during basic movements not only increases the falling risk of the elderly but also largely influences their quality of life by restricting their activities in daily life (Legter, 2002; Cumming et al., 2000). Until now, to predict falling, dynamic balance ability has been measured using various methods in the laboratory and in clinical settings (Patla et al., 1997). 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 life of the elderly in a nursing home setting. Hence, they are not effective for estimating the falling risk of the healthy elderly (O'Brien et al., 1998; Boulgarides LK et al., 2003). In addition, because any test consists of plural movements, ample space and sufficient measuring time are necessary. Hill et al. (1986) and Nakada et al. (2002) proposed a dynamic balance ability test with high simplicity and safety, using a stepping movement on a spot. Although steps in the above test do not use forward movement, this movement is necessary to shift the body's center of gravity to the left or right leg alternately, similarly to walking. In short, the ability to support the body weight by one leg is required. In addition, although the step test conducted with a usual walking tempo is relatively easy, due to the semi-automatic motion produced by the central pattern generator, the step test with a very slow or quick tempo is very difficult even for the healthy elderly.

In this study, to examine the effectiveness of the step test to evaluate dynamic balance ability, the following hypotheses were set.

1. When tapping using arms or stepping using legs with the same tempo, the elderly have more difficulty matching the tempo in the stepping portion, shifting their center of gravity, than in the tapping portion.
2. The step test with a slower tempo than the usual walking tempo requires a longer one-leg support time. Hence, the elderly have difficulty matching the tempos and need longer two-leg support times.

Methods

Subjects

One hundred forty healthy elderly people (65 males: age 71.8±5.3 yr, height 165.6±7.3 cm and weight 63.5±9.0 kg; 75 females: age 71.1±5.8 yr, height 149.9±5.4 cm and weight 53.9±7.2 kg) without disorders of the arms or legs and who were able to walk independently participated in the experiment. As a control group, fifty healthy young adults (25 males: age 21.0±1.8 yr, height 172.3±3.6 cm and weight 65.6±5.5 kg; 25 females: age 20.2±0.9 yr, height 161.3±5.5 cm and weight 54.8±6.4 kg) were selected. Prior to testing, the purpose and procedure of this study were explained to them in detail, and informed consent was obtained from all subjects.

Experimental procedure

A 120 bpm tempo (40 times/20 s) is reported to be the most efficient interval (0.5 s) during walking (Toyama and Fujiwara, 1990). 60 bpm and 40 bpm tempos, which correspond to 1/2 and 1/3 intervals of 120 bpm, were selected as slower tempos. To eliminate an order effect, both tests were randomly allotted to each subject. After one practice run, they performed each test for 20 s twice with a 1 min rest.

1. Step test (Fig. 1-1)

The subjects stood on the step-sheet and stepped with their left or right foot alternately while matching the above-stated tempos.

2. Tap test (Fig. 1-2)

The subjects stood before the step-sheet laid on the table and tapped their left or right hand to the step-sheet alternately while matching the above-stated tempos.

Experimental instrument

A gait analysis meter (Walkway MG-1000, Anima and Japan) was used to evaluate the tapping and stepping abilities. When the subject's palm or foot touches the seat, analysis information can be recorded to a personal computer as a digital signal. The frequency of sampling was 100 Hz.

Evaluation parameters

Referring to previous studies (Nakada et al., 2002), the time difference in the step and tap tests with a stipulated tempo was selected as an evaluation parameter. In addition, one- and two-leg support times were selected in the step test as evaluation parameters. The time difference was defined as the difference between the metronome sound of each tempo and each subject's tap/step. The mean time difference was calculated by dividing the total time difference for 20 sec by the total tap/step number. One- and two-leg support times are the duration of either leg or both legs touching the ground during the step. Both parameters were calculated by dividing the total time for 20 sec by the total step number. One-leg support time is the time when the subject stands with one leg during stepping for 20 s. 40 bpm of a 1.5 s tempo is, in general, longer than 120 bpm of a 0.5 s tempo by a factor of about 3 (Fig. 2). Hence, in statistical analysis, the one-leg support time in 40 bpm and 120

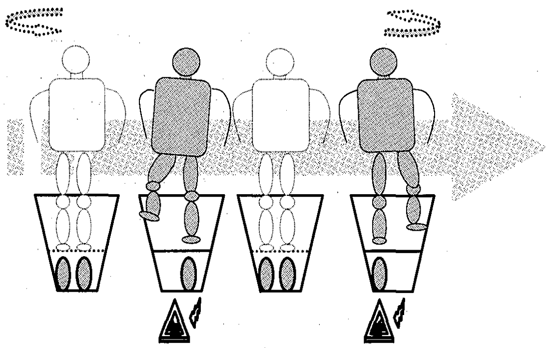

Fig. 1-1 Step test.

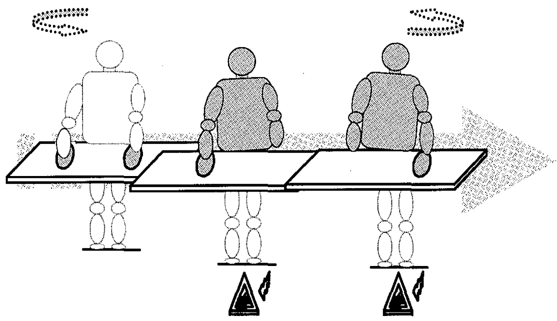

Fig. 1-2 Tap test.

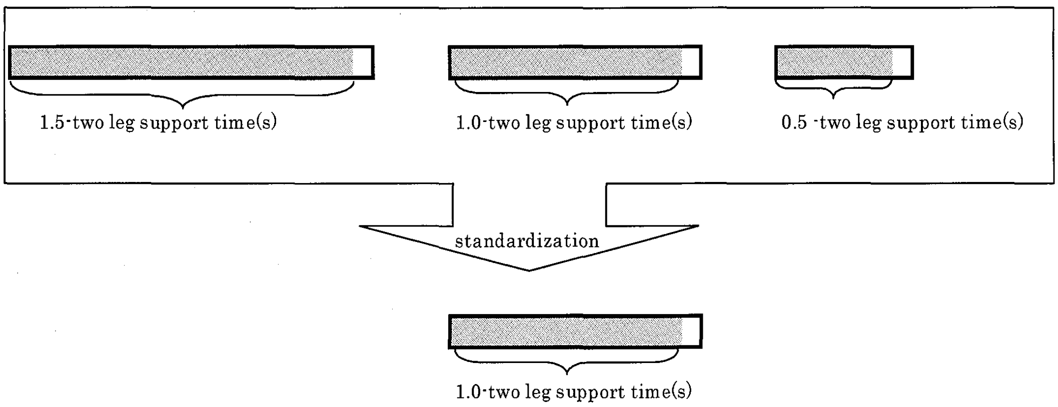

Fig. 2 Standardization in one-leg support times.

bpm was standardized by the time (1.0 second) of 60 bpm.

In short, it was divided by 1.5 s in 40 bpm, and by 0.5 s in 120 bpm.

Data Analysis

The trial-to-trial reliability of each parameter was examined using the intra-class correlation coefficient (ICC). Three-way analysis of variance (ANOVA) (sex, age-level and movement) for repeated measures was used to test the mean differences between both tests. Multiple comparison was examined by Tukey's HSD method. The probability level of 0.05 was indicative of statistical significance.

Results

Table 1 shows the ICC for each parameter. ICCs for the elderly (ICC=0.70–0.92) and the young (ICC=0.70–0.90) were relatively high. There were significant trial-to-trial differences in the time difference and one-leg support time for the step test in the elderly, but their effect size (ES) was very small (0.01–0.02). Hence, a mean value of 2 trials was judged to be valid as a representative value. Table 2 shows the test results for sex- and age-related differences of the time difference in the step and tap tests. In both tests there was no significant difference between tempos in the young, but the difference was significantly larger in the elderly in the order of 40, 60, and 120 bpm. Any tempo in both tests showed a significant difference in the elderly, but not in the young. In the

Table 1 ICC of parameters in the elderly and the young

The elderly (n: 140)		ICC	F-value	*p*-value	The young (n: 50)		ICC	F-value	*p*-value
Time difference	40 bpm	0.71	0.97	0.33	Time difference	40 bpm	0.72	1.22	0.28
(Tap)	60 bpm	0.71	0.52	0.47	(Tap)	60 bpm	0.75	0.08	0.78
	120 bpm	0.70	0.27	0.61		120 bpm	0.70	2.94	0.09
Time difference	40 bpm	0.73	11.22	0.00 *	Time difference	40 bpm	0.74	3.57	0.07
(Step)	60 bpm	0.71	2.47	0.12	(Step)	60 bpm	0.78	2.67	0.11
	120 bpm	0.80	3.45	0.07		120 bpm	0.90	0.81	0.37
Two-leg support	40 bpm	0.90	1.18	0.28	Two-leg support	40 bpm	0.73	2.46	0.12
time	60 bpm	0.92	0.59	0.45	time	60 bpm	0.88	0.04	0.85
	120 bpm	0.91	2.79	0.10		120 bpm	0.81	0.26	0.61
One-leg support	40 bpm	0.91	0.88	0.35	One-leg support	40 bpm	0.84	0.00	0.97
time	60 bpm	0.91	0.22	0.64	time	60 bpm	0.87	1.94	0.17
	120 bpm	0.82	9.64	0.02 *		120 bpm	0.85	0.01	0.91

Note 1: *: $p<0.05$ ICC: Intraclass correlation coefficient

Table 2 Results of three-way analysis in difference time (sex, age, and tempo)

movement	age	sex		40 bpm		60 bpm		120 bpm		3-way ANOVA		Post-hoc, HSD		
				Mean	SD	Mean	SD	Mean	SD	F-value				
Tap	The young	male	n=25	0.048	0.02	0.034	0.01	0.026	0.01	F1	67.93 *	tempo	(Y)ma, fe: n.s	(E)ma, fe: 40>60>120
		female	n=25	0.052	0.02	0.039	0.01	0.033	0.01	F2	2.38	sex	(Y)ma,fe: n.s	40, 60: (E)ma>fe
	The elderly	male	n=65	0.116	0.06	0.078	0.04	0.044	0.02	F3	72.66 *	age	40, 60: (E)ma>(Y)ma	40: (E)fe>(Y)fe
		female	n=75	0.088	0.04	0.057	0.02	0.041	0.02	F4	8.37 *			
										F5	17.02 *			
										F6	2.41	note	(E): The elderly	ma: male
										F7	1.51		(Y): The young	fe: female
Step	The young	male	n=25	0.052	0.02	0.036	0.01	0.019	0.01	F1	65.00 *	tempo	(Y)ma, fe: n.s	(E)ma, fe: 40>60>120
		female	n=25	0.056	0.02	0.041	0.02	0.022	0.01	F2	1.40	sex	(Y)ma, fe: n.s	40: (E)ma>fe
	The elderly	male	n=65	0.154	0.07	0.076	0.04	0.034	0.02	F3	120.85 *	age	40, 60: (E)ma	40: (E)fe>(Y)fe>(Y)ma
		female	n=75	0.127	0.08	0.061	0.02	0.032	0.02	F4	2.73			
										F5	35.10 *			
										F6	1.04	note	(E): The elderly	ma: male
										F7	0.92		(Y): The young	fe: female

Note: F1-age, F2-sex, F3-tempo, F4: interaction (age, sex): F5: interaction (age, tempo) F6: interaction (tempo, sex) F7: interaction (age, sex, tempo); *: $p<0.05$

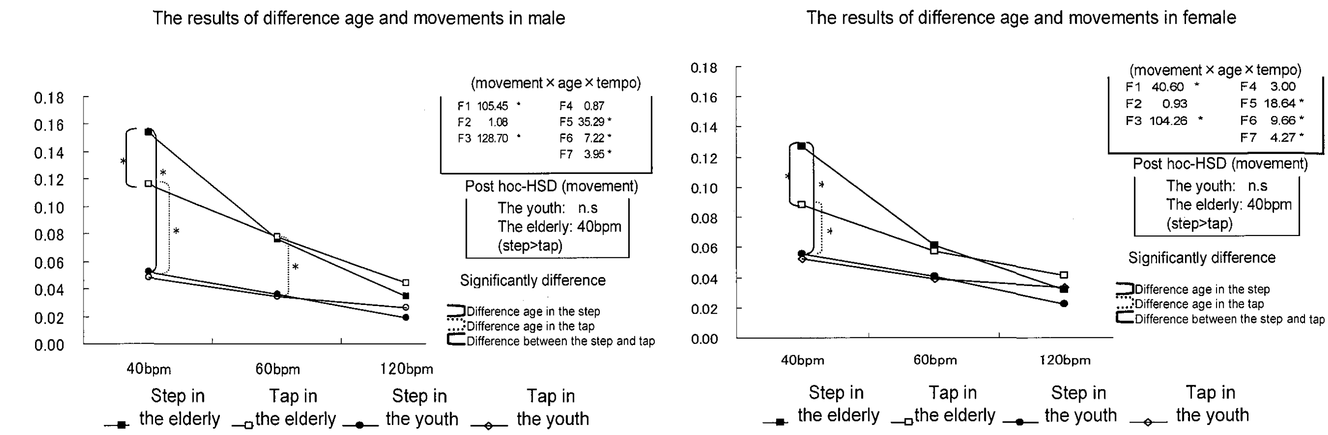

Fig. 3 Results of three-way analysis (sex, age and tempo) in both tests.

Table 3 Results of three-way analysis in two-leg and one-leg support times (sex, age, and tempo)

movement	age	sex		40 bpm Mean	40 bpm SD	60 bpm Mean	60 bpm SD	120 bpm Mean	120 bpm SD	3-way ANOVA F-value		Post-hoc, HSD		
Two-leg support	The young	male	n=25	0.212	0.07	0.188	0.05	0.141	0.03	F1	34.64 *	tempo	(Y)ma, fe: n.s	(E)ma, fe: 40>60>120
		female	n=25	0.200	0.05	0.175	0.04	0.140	0.02	F2	0.28	sex	(Y)ma, fe: n.s	(E)ma, fe: n.s
	The elderly	male	n=65	0.463	0.23	0.274	0.12	0.134	0.05	F3	102.71 *	age	40: (E)ma, fe<(Y)ma, fe	
		female	n=75	0.429	0.24	0.257	0.11	0.147	0.04	F4	0.01			
										F5	44.30 *			
										F6	0.70	note	(E): The elderly	ma: male
										F7	0.24		(Y): The young	fe: female
One-leg support	The young	male	n=25	0.872	0.05	0.811	0.05	0.722	0.06	F1	22.64 *	tempo	(Y)ma, fe: 40, 60>120	
		female	n=25	0.868	0.04	0.829	0.04	0.724	0.04	F2	0.24		(E)ma: 40<60, 120	(E)fe: 40<60
	The elderly	male	n=65	0.672	0.18	0.729	0.13	0.751	0.11	F3	12.66 *	sex	(Y)ma, fe: n.s	(E)ma, fe: n.s
		female	n=75	0.699	0.18	0.751	0.11	0.737	0.07	F4	0.05	age	40, 60: (E)ma, fe<(Y)ma, fe	
										F5	50.24 *			
										F6	0.82	note	(E): The elderly	ma: male
										F7	0.71		(Y): The young	fe: female

Note: F1-age, F2-sex, F3-tempo, F4: interaction (age, sex): F5: interaction (age, tempo) F6: interaction (tempo, sex) F7: interaction (age, sex, tempo); *: $p<0.05$

tap test at 40 and 60 bpm and the step test at 40 bpm, males had larger values. In addition, both tests showed a significant age-related difference: 40 and 60 bpm in males and 40 bpm in females were larger in the elderly than in the young (Table 2). Figure 3 shows the test results of three-way ANOVA for the step test time difference. Differences between tap and step tests were significant at 40 bpm in the male and female elderly, with larger differences in the step than the tap test. However, significant differences were not found in the young. Table 3 shows the test results of three-way ANOVA for one- and two-leg support times. They showed a significant sex difference in the elderly and the young. Significant differences between tempos in two-leg support time were only seen in the elderly, being larger in the order of 40, 60, and 120 bpm in both sexes. The one-leg support time showed a significant difference between tempos (40, 60, and 120 bpm) in the elderly and the young. 40 and 60 bpm were larger than 120 bpm in the young males and females, 40 bpm was smaller than 60 and 120 bpm in the male elderly, and 40 bpm was smaller than 60 bpm in the female elderly. The one-leg and two-leg support times showed a significant age-related difference. The elderly had smaller values in the latter test at 40 bpm and in the former test at 40 and 60 bpm.

Discussion

The time difference showed significant sex differences at 40 and 60 bpm in the tap test and at 40 bpm in the step test. Nakada et al. (2002) performed the step test using elderly subjects over 70 years of age and reported that both males and females showed a decrease of achievement times with age. Furthermore, they reported a large sex difference in the one-leg support step (stepping back/forth or stepping right/left with one leg while the other leg supports the body) with high difficulty as compared with the two-leg step (stepping back/forth or right/left alternately by both legs). Also in this study, the female elderly were superior at 40 bpm or 60 bpm out of the three tempo conditions. Stepping with slower tempos requires a longer one-leg supporting time. The female elderly are, on average, 7 years older than the male elderly (Ministry of Health, Labour and Welfare, 2001). Hence, females may be superior in leg strength or balance ability to males in the oldest-old category. Dynamic balance ability is judged to be superior when the time difference and two-leg support time are less and the one-leg support time is larger in the present step test. The elderly were inferior at the slower tempo than at the 120 bpm usual walking tempo. Nakada et al. (2002) compared the two-leg support time of the step test between the elderly groups 75 years old and over 75 years old and reported that the latter group's value was significantly longer. Sugano et al. (2004) reported that due to decreasing leg strength and equilibrium with age, the two-leg support time becomes longer to keep postural stability during movement. The one-leg support time in this study was longer in the test with the slow tempo in the young but shorter in the elderly. Since, in spite of the slow tempo, the elderly one-leg support time did not increase, it can be concluded that they experienced difficulty keeping a stable posture with one leg, and the two-leg support time consequently became longer. The time difference between the step and tap tests was significant only at the 40 bpm tempo in the elderly. 120 bpm showed a significant time difference in neither the elderly nor the young. In short, the young did not show a significant difference between tap and step tests, and the elderly did not show a significant difference at the fast 120 bpm tempo similar to normal walking tempo. In daily life, the arms are mainly used to regulate various fine movements. In contrast, the legs are mainly used for walking, which requires a shifting of the center of gravity of the body to the left and right alternately. Therefore, for the elderly, stepping at 40 bpm, which requires a long one-leg supporting time, the time difference between stepping of the legs becomes longer than between tapping of the arms. Bernstein (1967) reported that the stepping motion resembles the walking motion and that adults can achieve both motions easily. Toyama and Fujiwara (1990) reported that the fastest tempo of 120 bpm selected in this study is close to walking tempo and provides high stability. The present results suggest that 120 bpm in the elderly, just as in the young, is the tempo needed to be able to achieve stepping stability. A significant difference was found between the tap and step tests at the slowest 40 bpm tempo. Hence, the elderly can easily achieve movements at the 40 bpm tempo using their arms but have greater difficulty performing movements using the legs only. From the present results, the hypotheses in this study have been supported.

In conclusion, an effective tempo for the step test to evaluate dynamic balance in the elderly is 40 bpm or 60 bpm, which are both slower than the usual walking tempo. In addition, the time difference and two- and one-leg support times are effective evaluation parameters of the step test.

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