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GENDER AND AGE-RELATED DIFFERENCES OF DYNAMIC BALANCING ABILITY BASED ON VARIOUS STEPPING MOTIONS IN THE HEALTHY ELDERLY

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This study was aimed at examining the gender and age-related differences of dynamic balance based on four stepping tests for the elderly. One hundred and eleven healthy subjects aged 60-85 were classified into four age groups (60-64, 65-69, 70-74, and 75-85) to examine age-related differences. They conducted stepping motions lasting 20-sec, including both-leg stepping right/left, both-leg stepping back/forth, one-leg stepping back/forth and one-leg stepping right/left. There were significant differences by age in all stepping parameters, with the decreasing number of steps and the increasing average ground connecting time during stepping with age. In males of age 60-69 and all females, the individual differences in the number of steps and the average connecting time during both-leg stepping (back/forth and right/left) were larger than those during one-leg stepping. Both-leg stepping was, therefore, considered to be a useful test to evaluate the individual differences of dynamic balance in the elderly. Individual differences in the number of steps by both-leg stepping tended to decrease with age. In males aged 70 or more, the individual differences in the number of steps and the average connecting time in both-leg stepping were smaller than those in one-leg stepping. The relationships between the results by both-leg stepping and those by one-leg stepping were poor. This may be because of the difference in body-posture stability during stepping motions. One-leg stepping is a useful test for the elderly who have difficulty with both-leg stepping because of its small center of gravity sway. The relationships between back/forth steps and right/left steps in both-leg or one-leg stepping were notable. Either of the stepping motions, therefore, can be selected to evaluate dynamic balance ability. There may be gender differences in the strategy to keep a stable body posture during both-leg stepping.
Key words: stepping test, stable body posture, center of gravity

INTRODUCTION

In Japan, people aged 65 or over at present exceed 10 percent of the total population, and a super-aging society will appear with 25% or more of the population aged 65 or more by 2025. The elderly are increasingly expected to keep healthy and physical fitness to maintain quality of life (QOL) and so as to reduce medical expenses. The decline with age of activities using the lower limbs such as walking, standing up and keeping a standing posture, is the most marked in the activities of daily living (ADL) (Sato et al., 1999). In addition, it has been reported that daily activities of the elderly relate closely to their physical fitness level and ability to maintain of ADL (Sato et al., 1999). The decline of lower-limb muscle strength and ability to maintain a standing posture is the most com-

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mon risk factor for falling, fall-related injuries, and muscle disuse atrophy caused by physical inertia based on fear of falling (Sinaki and Lynn, 2002). Physical activity is given as one of the factors in increasing the elderly's QOL (Gauchard et al., 2001).

It is, therefore, important for the elderly to increase the ability for physical activities using the lower limbs and keep the ability for a standing posture. There is an urgent need for a rational test to evaluate these abilities. The ability to keep a stable body posture during physical activities is defined as dynamic balance (Commissaris et al., 2002). It can be judged as excellent, during voluntary movement with center of gravity sway, if the movement can be kept stable without losing body balance.

Dynamic or static balance has been assessed by the stability of a body posture on an unstable platform (path length of the center of gravity sway (Commissaris et al., 2002)) or the posture maintenance time, functional reach (Rogers et al., 2001), or one-leg standing with the eyes closed (Gauchard et al., 2001). The use of a physical fitness test for the elderly is desirable in selecting daily life activities and giving feedback to them, but the appropriate tests may be lacking for assessing dynamic balance.

Aoyagi et al. (1980) proposed the stepping stone test to evaluate dynamic balance. This test measured the distance moved from the start point after stepping at a standstill with the eyes closed. Although this test was primarily used as a screening test for disequilibrium patients in clinical settings, it is assumed that the distance moved reflects the control of the postural stability during stepping at a standstill even for a healthy person because it indicates individual differences. However, it can be very difficult for the elderly to keep a stable standing posture during stepping, because the stepping motion has an unstable phase in one-leg support in addition to an accompanying center of gravity sway when changing steps.

The authors, therefore, created a stepping test to evaluate dynamic balance by means of stepping motions on the spot. Generally, a stepping test for young people is used as a test of agility rather than balance because it measures the number of steps during a short period (Chapman et al., 1987). Individual differences in the number of steps may reflect speed or quickness (agility) because stepping on the spot without losing balance is a very easy task for young people. However, it is inferred that stepping tests for the elderly relate to balance rather than agility because quick step movement is difficult for them and they must step carefully to keep from falling (Rogers et al., 2001). Maki et al. (2000) suggest that quick step training plays an important role in keeping ability to balance.

Based the above idea, after several preliminary tests, the authors designed more suitable stepping tests to evaluate dynamic balance. However, it will be necessary to clarify the degree of difficulty of each stepping motion according to gender and age differences with a view to establishing useful and safe tests for the elderly who vary widely in their physical fitness. It is very important to examine the validity of the stepping tests, that is, whether or not they exactly evaluate balance. It is difficult to say that the tests evaluate only balance for the elderly, since the results also relate to lower-limb muscle strength and ability. It may be a problem for the authors to define the related stepping test as a dynamic balance test while it may reflect more than balance. However, as stated above, moving the center of gravity is a very important activity in daily living for the elderly. The authors, therefore, propose a test using stepping on the spot, which is often carried out in daily living, as a convenient dynamic balance test.

In developing new physical fitness tests for the elderly, it is important that they can perform them safely, and that the results reflect their individual differences. We showed note that the difficulty level of a stepping motion with the moving center of gravity depends on the scale of the movement. If the difficulty level is too high, there is no safety secured. In contrast, if it is too low, there may be no individual differences reflected. It is thus necessary to examine various stepping motions with different difficulty levels.

The purposes of this study were to examine the gender and age-related differences of dynamic balance ability between four stepping tests for the elderly and to clarify their degree of difficulty.

METHODS

Subjects: One hundred and eleven healthy subjects aged 60-85 participated in this study. The authors obtained informed consent from each subject after a full explanation of the experimental project and its procedures. The subjects had no evidence or known history regarding gait and postural or skeletal disorders. Moreover, in a preliminary test, five elderly males and five elderly females carried out the stepping motions used in the four stepping tests of the study to confirm safety. The tests were judged to be safe for the stepping motions selected. To examine age-related differences, the subjects were divided into four different age groups (age 60-64, 65-69, 70-74 and 75-85) (see Table 1). Height and weight significantly decreased with age in both genders, and their values in each age-level were greater for males than females (Table 1). There was no significant gender difference in the mean age in each age group.

Table 1. Characteristics of the subjects

	Age	60-64		65-69		70-74		75-80		Two-way ANOVA			
Number of males/females		(10 / 11)		(16 / 15)		(14 / 18)		(10 / 17)		F- value			post-hoc
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Gender	Age	Interaction	(HSD)
Age (yr)	Males	61.6	1.2	67.1	1.6	72.3	1.2	78.5	2.5	2.28	407.24 *	1.56	60-<65-<70-<75-
	Females	62.1	1.2	66.9	1.5	71.6	1.2	77.0	2.3				
Height (cm)	Males	164.8	3.4	163.4	6.3	164.1	4.7	158.6	7.6	148.88 *	7.82 *	0.47	M>F
	Females	153.9	5.3	150.7	4.4	149.6	3.5	145.3	6.9				60->75-
Body mass (kg)	Males	65.9	6.0	65.7	10.7	60.5	8.7	54.7	5.5	26.22 *	6.34 *	1.13	M>F
	Females	58.0	8.8	54.3	7.2	51.6	6.0	51.0	8.7				60->70-, 75-; 65->75-

Note: *: P < 0.05, 60- indicates the 60-64 years old group, M: males, F: females

Dynamic balance: Balance ability is defined as the ability to keep a stable body posture with a stimulation disturbance (Commissaris et al., 2002), and classified roughly into static or dynamic balance. The former relates to keeping a still posture, such as upright standing and sitting positions, and the latter relates to keeping a stable posture during activities or when moving the center of gravity voluntarily. A stepping test for the young has, generally, been used to evaluate agility. However, for the elderly with a marked decrease of lower-limb muscle strength and balance, it is not easy to keep a stable body posture during a stepping motion similar to a walking motion because of the phase of supporting the body with one leg. Therefore, a test was developed to evaluate dynamic balance ability from the number of steps during a fixed time. It is assumed that a person who can step stably over a period has superior balance ability.

Stepping motions: In order to evaluate dynamic balance using stepping motions, it is important to select a target stepping motion. The difficulty level of stepping motions is in proportion to the scale of the center of gravity movement. A high difficulty test will reflect individual differences in the motions, but a test for the elderly should prioritize safety. The authors selected four 20-sec stepping motions with different difficulties. The stepping motions for both legs were back/forth and right/left motions, and those for one-leg were back/forth and right/left motions in the ascending order to the larger center of gravity movement. For both-leg stepping right and left (Figure1-1), the subject stood on the foot switch sheet (FSS, described in detail later) and stamped continuously, and alternatively on the right and left. For both-leg stepping (Figure 1-2), the subject stood at the outside back edge of the FSS and continuously stamped on and off the FSS, that is, stamping the right foot on the FSS and then the left foot, and returned the right and left feet to the original spot. For one-leg stepping back and forth (Figure 1-3), the subject stood at the outside back edge of the FSS and continuously stamped the dominant foot on the FSS and returned it to the original spot. For one-leg stepping right and left (Figure 1-4), the subject stood at the outside side edge of the FSS, and continuously stamped the dominant foot on the FSS and returned it to the original spot. The subjects were instructed to stamp as quickly as possible at the same place, and to keep the body balanced to prevent falls during the test. Each stepping test was carried out twice on the same day. Before the one-leg stepping test, a dominant leg was determined using a dominant leg questionnaire by Demura et al. (2001) based on a facilities questionnaire produced by Fumoto (1989) and Chapman et al. (1987).

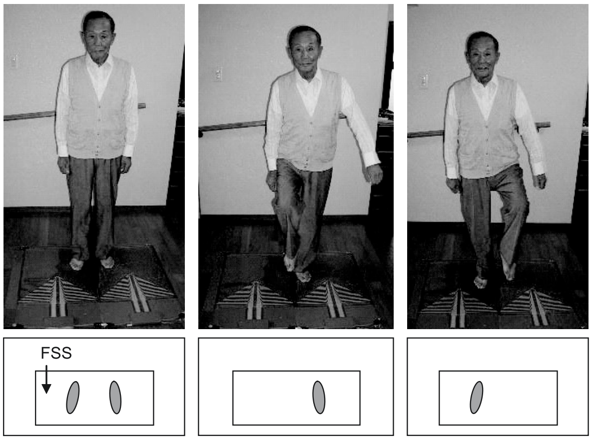


Fig. 1-1. Both-leg stepping right and left

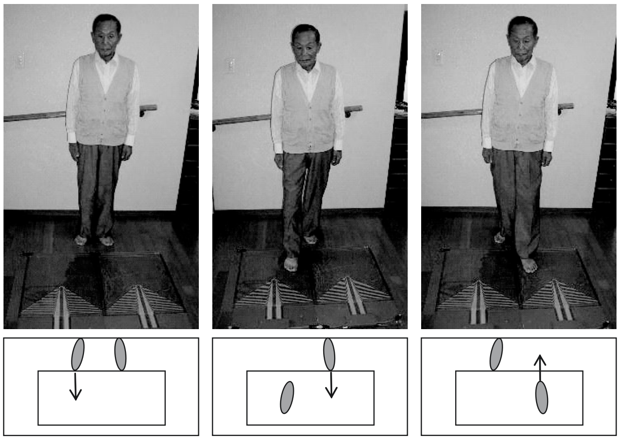


Fig. 1-2. Both-leg stepping back and forth

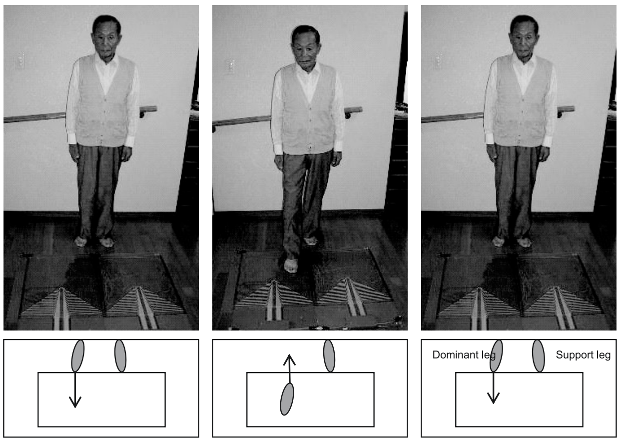
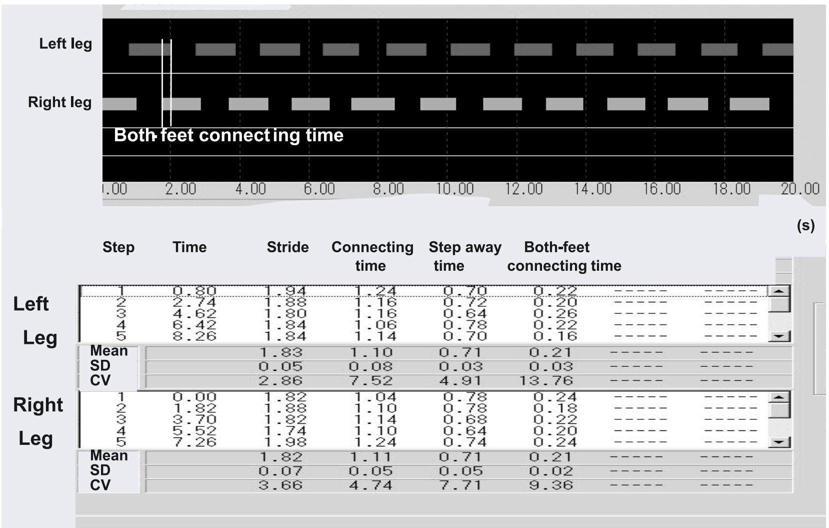


Fig. 1-3. One-leg stepping back and forth

Fig. 1-4. One-leg stepping right and left

Materials: The stepping test was measured using an FSS (480 (L) × 560 (W) mm, Anima Ltd., Japan). The FSS could measure the ground connecting time of the right or left foot and both feet in addition to the number of steps of the right or left foot during the test. Also, the FSS could evaluate the stepping period of connecting to and departing from the ground. Stepping data was relayed as signal data with a sampling frequency of 20 Hz to a personal computer. Figure 2 shows the FSS and the sample results of measurements.



	Step	Time	Stride	Connecting time	Step away time	Both-feet connecting time		
Left Leg	1	0.80	1.94	1.24	0.70	0.22	-----	-----
	2	2.74	1.88	1.16	0.72	0.20	-----	-----
	3	4.62	1.80	1.16	0.64	0.26	-----	-----
	4	6.42	1.84	1.06	0.78	0.22	-----	-----
	5	8.26	1.84	1.14	0.70	0.16	-----	-----
	Mean		1.83	1.10	0.71	0.21	-----	-----
	SD		0.05	0.08	0.03	0.03	-----	-----
	CV		2.86	7.52	4.91	13.76	-----	-----
Right Leg	1	0.00	1.82	1.04	0.78	0.24	-----	-----
	2	1.82	1.88	1.10	0.78	0.18	-----	-----
	3	3.70	1.82	1.14	0.68	0.22	-----	-----
	4	5.52	1.74	1.10	0.64	0.20	-----	-----
	5	7.26	1.98	1.24	0.74	0.24	-----	-----
	Mean		1.82	1.11	0.71	0.21	-----	-----
	SD		0.07	0.05	0.05	0.02	-----	-----
	CV		3.66	4.74	7.71	9.36	-----	-----

Fig. 2. FSS and the sample results of measurements
Note: The upper panel shows the connecting phase of the left and right legs. The lower panel shows the quantity data in every step of the right and left legs.

Stepping parameters: As evaluation parameters for the stepping test, the number of steps and the average of the ground connecting time during stepping (average connecting time) were used. The number of steps was counted by the times that the foot touched the FSS during the stepping test. Both-leg stepping tests counted the number of both the right and left foot stepping motions. In addition, both-leg tests used the total time when both feet contacted the ground at the same time (total connecting time).

Data analysis: This study examined trial-to-trial reliability of each stepping parameter using the intra-class correlation coefficient (ICC). Data analysis used the greater number of steps of two measurements. To examine the relationship between stepping parameters and age, a scatter plot of the average connecting time for each stepping motion was produced to calculate Pearson's correlation coefficient and use repeated two-way ANOVA for examining the gender and age-related differences in dynamic balance. Multiple comparisons used Tukey's HSD method. The probability level of 0.05 was indicative of statistical significance.

RESULTS

Table 2 shows the trial-to-trial reliability of each stepping parameter. The ICCs were very high for both genders (above 0.887).

Figures 3-1, 3-2, and 3-3 show the scatter plots between age and number of steps, the average connecting time and the total connecting time (see Method) in each stepping motion by gender. With age, the number of steps in each kind of stepping motions decreased and their individual differences tended to be small. On the other hand, there was a trend for the average connecting time to become longer with age in all stepping motions and the individual differences to become larger (Figures 3-1, 3-2, and Table 2). However, the average connecting time in one-leg stepping (right/left, back/forth) was very short in males aged below 65 and females aged below 70, and the individual differences were very small (Figure 3-2). The total connecting time for both-leg stepping tended to be longer with age, especially in both-leg back/forth stepping (Figure 3-3). Further, this parameter was nearly 0 s in many males. Although all stepping parameters except the average connecting time in one-leg stepping correlated significantly with age, their values were below 0.51 (males: $|r| = 0.25\text{-}0.43$, females: $|r| = 0.21\text{-}0.51$).

Table 3 shows the results of two-way ANOVA (gender and age-level) and multiple comparisons. No parameter showed a significant interaction effect. There were significant gender differences in number of steps for one-leg right/left stepping and the total connecting time in both-leg right/left stepping. The former was larger in females than males, and the latter was longer in females. All parameters show a significant age-related difference. Although a significant age-related difference differed by each parameter, there was a trend for the number of steps to decrease and the ground connecting time to be longer with age (Table 3). Coefficients of variations (CV) of the number of steps and the average connecting time tended to be larger in males aged 60-69 and in females aged 70-74. In addition, CV of the total connecting time tended to be large for those aged.

The correlation coefficients of number of steps and the average connecting time in four stepping motions were very high between both-leg right/left stepping and back/forth stepping and between one-leg back/forth stepping and right/left stepping ($r = 0.88$, 0.84, and 0.93, 0.91 $P < 0.05$, respectively). In addition, the correlation coefficients of both-leg and one-leg stepping motions were relatively

Table 2. Trial-to-trial reliability of each stepping parameter

			Males					Females				
			Trial 1		Trial 2			Trial 1		Trial 2		
Motion	Stepping parameters	unit	Mean	SD	Mean	SD	ICC	Mean	SD	Mean	SD	ICC
Both legs right/left	Number of steps	(times)	62.2	21.6	65.1	22.9	0.992	69.0	31.9	69.9	30.0	0.986
	Average connecting time	(sec)	0.46	0.15	0.44	0.15	0.992	0.49	0.23	0.47	0.21	0.986
	Total connecting time	(sec)	3.01	2.12	2.85	2.04	0.976	4.06	2.34	3.95	2.30	0.953
Both legs back/forth	Number of steps	(times)	24.9	9.1	27.0	10.1	0.983	29.7	13.7	30.8	13.6	0.977
	Average connecting time	(sec)	0.59	0.19	0.55	0.20	0.989	0.56	0.24	0.54	0.24	0.982
	Total connecting time	(sec)	1.05	0.63	0.98	0.56	0.911	1.13	0.65	1.10	0.63	0.887
One leg back/forth	Number of steps	(times)	24.6	7.1	25.5	7.4	0.983	27.1	10.0	28.0	10.4	0.980
	Average connecting time	(sec)	0.23	0.12	0.21	0.12	0.982	0.22	0.13	0.21	0.13	0.989
One leg right/left	Number of steps	(times)	25.9	7.3	26.3	7.8	0.993	28.7	10.0	29.3	10.0	0.984
	Average connecting time	(sec)	0.23	0.13	0.23	0.15	0.982	0.23	0.15	0.22	0.14	0.988

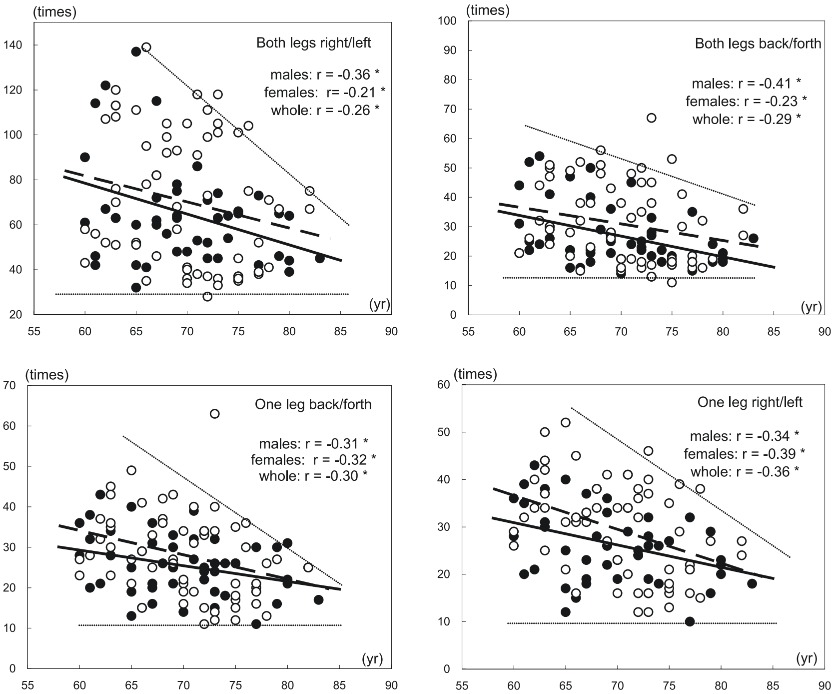


Fig. 3-1. Scatter diagram of age (X axis) and the number of steps (Y axis)
Note: Dotted lines show the rough tendency of scatter plots. Thick lines are regression lines for males. Broken lines are regression lines for females. ●: males, ○: females, *: $P < 0.05$

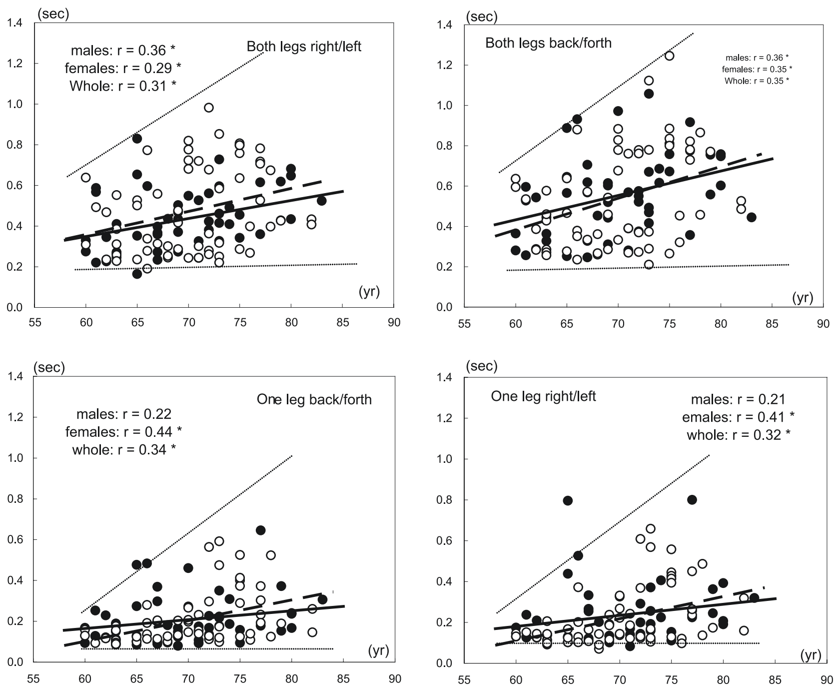


Fig. 3-2. Scatter diagram of age (X axis) and the average connecting time (Y axis)
Note: Dotted lines show the rough tendency of scatter plots. Thick lines are regression lines for males. Broken lines are regression lines for females. ●: males, ○: females, *: $P < 0.05$

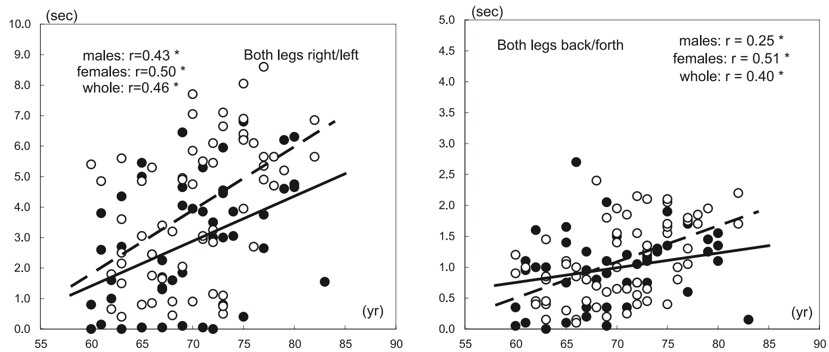


Fig. 3-3. Scatter diagram of age (X axis) and the total connecting time (Y axis)
Note: Thick lines show regression lines for males. Broken lines are regression lines for females.
●: males, ○: females, *: P < 0.05

Table 3. Results of two-way ANOVA (gender × age-level) and multiple comparisons.

Step	Stepping parameters (unit)	Age	Males Mean	Males SD	Males CV	Females Mean	Females SD	Females CV	Two-way ANOVA Gender	Two-way ANOVA Age	Two-way ANOVA Interaction	Post-hoc Tukey's HSD
Both legs right/left	Number of steps	60-64 yr	78.1	29.4	37.6	77.6	28.8	37.1				
	(times)	65-69 yr	67.9	26.8	39.5	80.3	28.5	35.6	1.183	3.496 *	0.344	60-, 65- > 75-
		70-74 yr	60.0	15.2	25.4	69.1	35.6	51.5				
		75-80 yr	54.9	12.7	23.1	56.4	22.8	40.5				
	Average connecting time	60-64 yr	0.35	0.13	38.0	0.37	0.14	38.0				
	(sec)	65-69 yr	0.42	0.17	39.9	0.38	0.16	42.0	0.618	5.382 *	0.544	60-, 65- < 75-
		70-74 yr	0.46	0.13	27.5	0.52	0.26	50.8				
		75-80 yr	0.51	0.12	24.2	0.58	0.19	33.3				
	Total connecting time	60-64 yr	1.70	1.59	93.5	2.58	2.02	78.1				Males<Females
	(sec)	65-69 yr	2.40	2.10	87.4	2.70	1.69	62.5	5.834 *	10.715 *	0.571	60- < 70-, 75-
		70-74 yr	3.24	1.82	56.1	4.04	2.49	61.6				65-, 70- < 75-
		75-80 yr	4.16	2.11	50.5	5.83	1.41	24.1				
Both legs back/forth	Number of steps	60-64 yr	34.9	11.9	34.2	34.1	11.7	34.2				
	(times)	65-69 yr	27.5	10.5	38.2	36.5	13.0	35.6	3.320	4.780 *	0.823	60-, 65- > 75-
		70-74 yr	24.8	8.3	33.6	30.6	15.9	51.8				
		75-80 yr	21.4	5.7	26.8	24.0	11.0	46.0				
	Average connecting time	60-64 yr	0.40	0.12	30.4	0.43	0.14	33.2				
	(sec)	65-69 yr	0.54	0.20	37.2	0.42	0.18	42.1	0.219	7.369 *	0.887	60- < 70-, 75-
		70-74 yr	0.59	0.21	35.7	0.57	0.27	48.1				65- < 75-
		75-80 yr	0.66	0.17	25.6	0.70	0.25	35.2				
	Total connecting time	60-64 yr	0.69	0.54	77.6	0.73	0.40	54.2				
	(sec)	65-69 yr	0.96	0.73	75.8	0.79	0.64	80.4	0.455	6.845 *	0.931	60-, 65- < 75-
		70-74 yr	1.03	0.32	30.6	1.14	0.62	54.8				
		75-80 yr	1.24	0.52	41.9	1.56	0.49	31.6				
One leg back/forth	Number of steps	60-64 yr	30.8	7.3	23.6	32.6	7.4	22.6				
	(times)	65-69 yr	24.8	7.7	31.1	32.0	9.2	28.9	2.613	4.586 *	1.049	60- > 75-
		70-74 yr	24.5	6.9	28.0	27.3	13.2	48.5				
		75-80 yr	23.0	6.8	29.5	22.1	7.1	32.2				
	Average connecting time	60-64 yr	0.16	0.05	33.4	0.12	0.03	25.9				
	(sec)	65-69 yr	0.21	0.14	65.7	0.15	0.05	35.5	0.259	5.484 *	1.021	60- < 70-, 75-
		70-74 yr	0.21	0.10	48.5	0.24	0.15	64.0				65- < 75-
		75-80 yr	0.26	0.16	62.5	0.28	0.14	49.6				
One leg right/left	Number of steps	60-64 yr	32.1	7.6	23.6	35.7	7.8	21.8				Males<Females
	(times)	65-69 yr	25.6	8.4	32.7	33.1	9.0	27.2	4.595 *	6.898 *	0.836	60- > 70-, 75-
		70-74 yr	25.8	6.8	26.5	27.7	11.0	39.6				65- > 75-
		75-80 yr	22.4	6.7	29.7	23.5	8.0	34.1				
	Average connecting time	60-64 yr	0.16	0.04	25.4	0.13	0.03	23.5				
	(sec)	65-69 yr	0.25	0.19	75.7	0.15	0.08	48.9	0.597	5.035 *	1.277	60- < 75-
		70-74 yr	0.22	0.10	44.6	0.26	0.18	69.7				
		75-80 yr	0.30	0.20	65.5	0.30	0.15	50.0				

Note: *: P < 0.05, CV: coefficient of variation low (r = 0.71-0.75, $P < 0.05$).

DISCUSSION

The stepping tests proposed in this study have generally been used to evaluate agility for young people. However, the stepping motions have an unstable phase during one-leg support in addition to the accompanying center of gravity sway when changing steps (Aoyagi et al., 1980). For the elderly with a marked decrease of lower-limb muscle strength and equilibrium, it is therefore difficult to keep a stable standing posture. Sato et al. (1999) investigated achievement rates of movements for 448 healthy elderly Japanese, reporting that the rates for "walking with a hurried gait" were 63.7-84.3%, while those for "walking in a straight line" were 86.3-95.5 %. This may mean that it is not easy to walk fast even for the ambulatory elderly. The preliminary test suggested that the four stepping motions selected in this study were achievable for the elderly. Many researchers reported a decreasing ability to balance with age (Fujiwara et al., 2001; Hageman et al., 1995; Steffen et al., 2002).

This study also confirmed significant differences between age groups. Thus, dynamic balance ability may be evaluated by means of all the stepping motions selected. Individual differences in the number of steps and the average connecting time in males tended to be the largest at age 60-69 in both-leg stepping right/left and at age 70 or more in one-leg stepping. The both-leg stepping motions in males of age 60-69 and all females may be more appropriate for evaluating the individual differences in dynamic balance more than one-leg stepping motions. A one-leg stepping test has a small center of gravity sway and low difficulty. It is, therefore, considered that almost all elderly can achieve it easily and an individual difference did not occur.

In the elderly aged 60-70 and over, number of steps were larger in females than in males (Table 3). This suggests a gender difference in dynamic balance. The number of steps in both genders showed a decrease with age, but a gender difference in the both-leg motions with high difficulty tended to increase compared with one-leg motions. The average Japanese female life span is about 7 years longer than males (males 78.1 yr, females 84.9 yr) (Health, Labor and Welfare Ministry of Japan, 2002). Consequently, the influence of aging may affect the gender difference in physical fitness in the age period above 70. That is, in males aged 70 or more, the both-leg stepping motion was hard to achieve because of a decrease in balance ability. Individual differences in these parameters may become small. This may mean that the one-leg stepping test with a relatively low difficulty will reflect the individual differences in dynamic balance among males aged 70 or over better than other tests.

However, since the correlation between age and each parameter was not very high, aging may not always be a main factor in determining stepping motions or dynamic balance. Other factors such as the existence of a handicap, the degree of the handicap, lower-limb muscle strength, or walking ability may influence them. To establish a safe dynamic balance test with a stepping motion, an examination of the relationships between balance ability and other factors such as lower-limb muscle strength or impediments will be needed. If the correlation among four stepping motions for each parameter was high, the authors may select one of the from four motions as the test motion. The relationship of the number of steps and the average connecting time in four stepping motions was very good between both-leg stepping right/left and back/forth, and between one-leg stepping back/forth and right/left (r = 0.88, 0.84, and 0.93, 0.91 $P < 0.05$, respectively). Either stepping motion (right/left or back/forth) can be selected. In addition, the relationship between both-leg and one-leg stepping motions was only fair (r = 0.71-0.75, $P < 0.05$). Either stepping test (both-leg or one-leg) can be selected for evaluating dynamic balance ability.

From the viewpoint of the center of gravity sway, the difficulty between one-leg and both-leg stepping motions is different. This suggests that a useful test reflecting individual differences in dynamic balance ability differs at each age level. In one-leg stepping, the supporting leg is always fixed and the center of gravity is set around it, but both-leg stepping moves the center of gravity to the right or left leg. Accordingly, the way of keeping a stable body posture is considered to be different between the two kinds of stepping motions. Discordant stepping by the right and left legs may influence walking and body-posture control in daily living. The both-leg stepping test can be used to reveal a symptom of some kinds of lower-limb disorder or potential disease. It will therefore be useful when examining impediments or latent diseases of the legs.

Hageman et al. (1995) and Wolfson et al. (1994) reported that there is no gender difference in the elderly's balance ability. Fujiwara et al. (2001) also reported that there was no gender difference in the elderly's dynamic balance ability in horizontal oscillation. In this study, a gender difference was only noted in the total connecting time in both-leg stepping right and left and in the number of steps in one-leg right/left stepping. There was no gender difference in the number of steps and the average connecting time in stepping right and left. For that reason, a gender difference may exist in the strategy to keep a stable posture by making both feet connect on the sheet during the stepping motion. Accordingly, females may be more likely to ensure stability in the phase of ground connecting by both feet, whereas males may keep stability on the phase of raising the leg. Since males may become accustomed to insecure motions, such as one-leg standing, from exercise experience in the past, they may have a shorter phase of ground connecting by both feet in the strategy of stepping motions than females.

Subjects in this study were healthy and were living independently. They had no evidence of a gait and postural disorder. A person with a lower limb disorder may find it hard to perform this test. It is necessary to examine the applicability for such people, and to further clarify the relationship between dynamic balance and lower limb muscle strength or disorder.

In conclusion, there was a trend with age for the number of steps to decrease and the average connecting time to extend in any kind of stepping motions. The difference in difficulty based on the magnitude of the center of gravity sway during the stepping motion relates to an individual difference in the number of steps and average connecting time. In males of age 60-69 and all females, both-leg stepping will be useful for tests to evaluate individual differences in dynamic balance of the elderly. The one-leg stepping test is suitable for males of age 70 or over because the both-leg stepping test has high difficulty. It is suggested that a gender difference exists in the strategy of stepping motions to make the body posture stable in both-leg stepping. The relationships between back/forth and right/left for both-leg or one-leg stepping are good and either stepping motion can be selected for evaluating dynamic balance ability.

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