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Age and sex differences in various stepping movements of the elderly

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Aim: This study aimed to examine sex and age differences of various stepping movements in the elderly and to clarify useful stepping movements for evaluation of their dynamic balance.

Methods: Two hundred and eighty-six healthy elderly subjects who could walk independently (male mean age = 71.2 ± 7.1 years; female mean age = 71.5 ± 6.0) performed the following stepping tests: back and forth; up and down with a 5 cm tall step; and in-place stepping matching three tempos (44, 66 and 132 b.p.m.). Step number, single and double support times in the former two stepping tests, and time difference between metronome sound and grounding time in the latter tempo stepping tests were selected as evaluation parameters.

Results: An insignificant sex difference was found in all parameters. Hence, the data of men and women was pooled to examine age differences. Significant age differences were found in the step number and double support time of back and forth and up and down stepping tests and in the time difference of three tempo stepping tests. The step number in younger age groups and the support times in older age groups tended to be larger.

Conclusion: No sex difference was found in evaluation parameters of all stepping tests, and all parameters tended to be superior in the younger elderly. The elderly experienced more difficulty matching slow tempos than fast tempos in the in-place stepping test. The back and forth, up and down and in-place matching tempo stepping tests may be useful for evaluating dynamic balance ability of the elderly.

Keywords: age-related changes, dynamic balance, stepping movement.

Introduction

Until now, many fall predictive tests using daily living activities have been developed and relationships between the tests and balance ability or gait have been examined. Unipedal stance,[1] tandem stance[2] and functional reach[3] are representative tests that evaluate the ability to maintain an upright posture while correcting postural information obtained from the upper limbs, trunk and lower limbs. Meanwhile, the timed up and go test[4] and Berg balance test[5] evaluate subject's activity, balance ability, gait disorders and fall risk. One of the main causes of falls in the elderly is loss of balance induced by false steps and downfall during walking.[6] Their falls are largely related to a decrease in their ability to support body gravity with one leg. Therefore, although exercise tasks that involve transferring body gravity and maintaining balance with one leg are useful to evaluate elderly subjects' dynamic balance

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ability, these previous tests do not consider the above in detail.

The stepping test does not require a large space and can be conducted simply without risk of falls even in the elderly.[7–9] Nakada *et al.*[7,8] and Demura *et al.*[9] have attempted to evaluate elderly subjects' dynamic balance using stepping movements that involve transferring body gravity or matching tempos. Based on the examination of reliability, safety and practicality of the tests, stepping movements with back and forth transfer of body gravity or with slower or faster cycles are useful for the evaluation of dynamic balance.

Meanwhile, previous stepping tests for the elderly were developed mainly for detecting unilateral peripheral or central vestibular disorders.[10–11] In short, they were not developed for predicting falls or evaluating dynamic balance of the elderly. Their falls may result in the subjects being bedridden and dependent on nursing care, severely constrain independent life and markedly decrease quality of life. To prevent falls in the elderly, it will be necessary to devise a rational test and take measures to maintain and enhance their dynamic balance ability. Visual, leg muscle and peripheral or central nerve functions are intricately related to falls. Because these functions decrease with age and show sex differences, dynamic balance ability is assumed to show similar characteristics.

This study aimed to examine sex and age level differences of various stepping movements in the elderly and to clarify useful stepping movements and parameters for evaluating dynamic balance.

Methods

Subjects

One hundred and seven male elderly (aged 71.2 ± 7.1; range, 60–90 years) and 164 female elderly (age 71.5 ± 6.0; range, 60–88 years) subjects participated in this study. Subjects agreed to participate in this study after thorough explanation of the purpose of this study and the risk of experimentation. Subjects were required to have a certain level of physical fitness because various stepping tests were conducted. Hence, we asked the subjects to come to the experimental facility on foot to confirm that they had the physical function to live independently. In addition, before stepping tests, we confirmed the ability to take the step tests based on disease and dysfunction records and the activities of daily living (ADL) Questionnaire of the Physical Education Bureau of Ministry of Education, Culture, Sports, Science and Technology. From the above, it was judged that the subjects in this study were able to live independently and were healthy elderly individuals without disorders or disabilities. Subjects were divided into five different age groups: G1, 60–64 years; G2, 65–69 years; G3, 70–74 years; G4, 75–79 years; and G5, 80 years and older). Moreover, the experimental protocol was approved by the inquiry committee of study intended for humans of Kanazawa University Health and Sports Science Ethics Committee.

Stepping movements

Back and forth stepping, up and down stepping with a 5 cm tall step and in-place stepping matching three tempos (44, 66 and 132 b.p.m.) tests were selected in reference to previous studies (Fig. 1).[9] The back and forth stepping test involved the subject standing on a flat floor and stepping with their right or left leg alternately while moving forward or backward with each step. The up and down stepping test involved the same movement as back and forth stepping, but required the subjects to step back and forth onto a 5 cm step. Subjects were instructed to step as fast as possible during both stepping tests. The in-place stepping matching tempo test involved the subjects standing on a flat floor and stepping with their left or right foot alternately while matching three different tempos (44, 66 and 132 b.p.m.). All stepping tests were performed for 20 s with 1 min rest.

Parameters

Step number within regulation time and single and double support times were selected as evaluation parameters of the back and forth and up and down stepping tests in reference to previous studies.[9] Step number indicated back and forth or up and down step number within 20 s. Single and double support times indicated duration of either leg or both legs contacting the ground during each stepping movement, respectively. Both parameters were calculated by dividing the total time (20 s) by total step number. The time difference between the metronome sound and grounding time was measured in tempo stepping tests. The mean time difference was calculated by dividing the total time difference by the total step number.

Materials

The Walk-Way system (MG-1000, Anima, Tokyo, Japan) was used to measure the parameters stated above. This MG-1000 with plate sensors can determine times, dimensions and distances of the foot or feet when touching the sheet surface with grounding or non-grounding on the bearing surface as an on or off signal. Data obtained from this system were recorded at a sampling frequency of 100 Hz into a computer.

Procedure

Subjects received sufficient explanation of each stepping test before measurement, and performed each test twice after practice. Trial order of stepping tests was set

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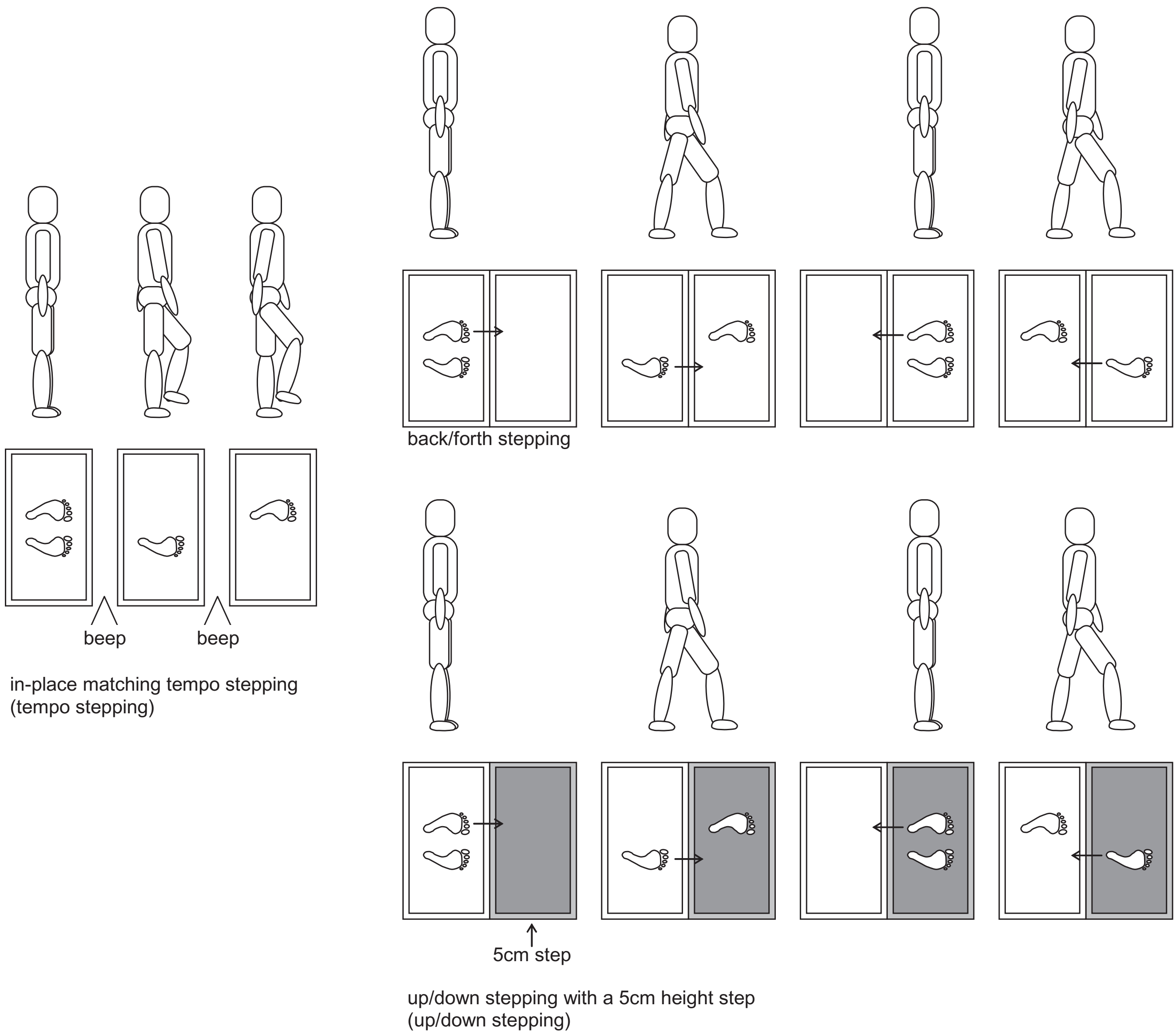

Figure 1 Stepping motion selected in this study. Beep, menotrome sound.

randomly. A helper stood next to each subject to ensure safety during the measurement.

Statistical analysis

Means and standard deviations of the subject's age, height and body mass were calculated. Two-way ANOVA was used to examine sex and age differences for age and each parameter. Partial correlations among each parameter and age was calculated considering the influence of height and body mass. ANCOVA using height and body mass as covariates was used to test age level differences for each parameter. Tukey's honest significant difference was used for the post-hoc test. A probability level of 0.05 was indicative of statistical significance.

Results

Table 1 shows means and standard deviations of age, height and body mass in each age group. Age significantly differed between men and women (degrees of freedom [d.f.] = 4, F = 907.2, $P = 0.000$), but a significant age difference was not found in all age groups (d.f. = 1, F = 0.1, $P = 0.824$). Table 2 shows the results of two-way (sex × age) ANOVA for single and double support times and step number of back and forth and up and down stepping tests and time differences of tempo stepping tests. Significant age level differences were found in the single and double support times and step number of the back and forth stepping test and the double support time and step number of the up and

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Table 1 Means and standard deviations of the subjects' age, height and body mass in each group

	Men ($n = 107$)							Women ($n = 164$)						
	n	Age		Height		Body mass		*n*	Age		Height		Body mass	
		Mean	SD	Mean	SD	Mean	SD		Mean	SD	Mean	SD	Mean	SD
Total	107	72.1	7.1	160.7	6.7	61.3	9.4	164	71.5	6.0	148.6	5.2	52.0	7.4
G1	24	62.2	1.3	163.9	5.8	65.2	9.5	23	62.0	1.2	149.8	3.3	52.5	6.4
G2	24	67.2	1.4	163.0	4.7	63.1	9.8	37	67.5	1.3	150.5	4.9	54.8	7.1
G3	22	71.9	1.6	160.1	8.4	61.4	10.5	58	72.0	1.5	149.2	5.0	52.5	6.4
G4	22	76.8	2.5	156.9	6.7	58.3	5.9	30	76.9	1.6	146.3	5.1	48.9	7.6
G5	15	82.9	2.5	158.7	3.5	55.9	6.4	16	82.9	2.3	143.9	5.8	48.5	9.7

G1, 60–64 years old; G2, 65–69 years old; G3, 70–74 years old; G4, 75–79 years old; G5, ≥80 years old; SD, standard deviation.

down stepping test. No significant sex differences were found in any of the parameters. Hence, pooled data of men and women was used for further analysis. Table 3 shows partial correlations between age and stepping parameters after considering height and body mass, test results of ANCOVA using height and body mass as covariates, and multiple comparisons for stepping parameters. All parameters except for single support time significantly correlated with age ($r_{xy \cdot z} = -0.29$–0.38). Significant age level differences were found in the double support time and step number of back and forth and up and down stepping tests, and the step number in younger age groups and the other parameters in older age groups tended to be larger. Table 4 shows partial correlations, and test results of ANCOVA and multiple comparisons for stepping parameters. Significant age differences were found in the time difference of all tempo stepping tests, and they were greater in the older age groups. Moreover, significant differences were found among the tempo stepping tests and the difference was the greatest for the 44-b.p.m. tempo in all age groups. All parameters significantly correlated with age ($r_{xy \cdot z} = 0.18$–0.31). In addition, correlations between single and double support times in back and forth and up and down stepping tests were under 0.28 and correlations between the above two parameters and step number ranged –0.69 to –0.78 (Table 5). Namely, both support times tended to be shorter with increasing step number. Correlations among the three tempo stepping tests were under 0.39 (Table 5).

Discussion

One of the main causes of falls in the elderly is loss of balance caused by missteps and slips while walking.[6] A decrease in the ability to support the body with one leg or with elevation height of an idling leg during gait induced by a decrease of leg muscle function is considered to largely affect balance.[6] Hence, movement tasks that involve transferring body gravity and supporting the body with one leg are useful for evaluating elderly subjects' dynamic balance. This study examined sex and age level differences of parameters of backward and forward and upward and downward stepping tests and in-place matching tempo stepping tests. The elderly female has less leg muscle function than the elderly male[12] and this should be reflected in the dynamic balance ability and the stepping parameters. However, no sex differences were found. Women with inferior leg muscle function have less burden imposed on their legs because of decreased body mass. Hence, it was inferred that the sex difference of leg muscle function has little influence on leg burden, and no significant difference was found in any of the stepping parameters.

The double support time of back and forth and up and down stepping tests tended to be longer in older age groups. Takami and Fukui examined sex and age differences of gait using 128 young, middle-aged and elderly adults and reported that the percentage of double support time occupied in the gait cycle was 20% in young adults but 25–28% in the elderly.[13] Namely, elderly subjects with inferior dynamic balance ability may offset instability of body gravity by reducing single support time and enlarging double support time. Also in this study, the percentages of double support time increased with older age groups and ranged 27.6–39.4% in the back and forth stepping test and 23.4–41.8% in the up and down stepping test. These results were higher than those reported by Takami and Fukui.[13] From the above, it is inferred that stepping movements may be more useful for evaluating elderly subjects' dynamic balance than gait because they induce instability of body gravity more easily and do not require a wide space. Murray *et al.* examined characteristics of the gait cycle in elderly women and reported that, because elderly subjects' gait becomes instable due to a decrease of physical functions including leg muscle function, they experience more difficulty with transferring movements and psychological anxiety toward falls.[14] To solve the above problems, the elderly subjects try to increase body stability by enlarging their base of support (shortening step length and enlarging base width) and double

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Table 2 Results of two-way ANOVA (sex × age) for each parameter of in-place, back and forth and up and down stepping

		n	Men G1 24	Men G2 24	Men G3 22	Men G4 22	Men G5 15	Women G1 23	Women G2 37	Women G3 58	Women G4 30	Women G5 16	Two-way ANOVA (sex × age) Sex	*P*	Age	*P*	Int	*P*
In-place stepping	Single support time	Mean	0.51	0.47	0.53	0.48	0.48	0.47	0.44	0.46	0.45	0.48	6.50*	0.011	1.24	0.296	0.71	0.584
		SD	0.07	0.10	0.10	0.13	0.12	0.09	0.08	0.10	0.09	0.09						
	Double support time	Mean	0.14	0.17	0.17	0.17	0.21	0.15	0.14	0.18	0.22	0.21	1.21	0.273	11.25*	0.000	3.87*	0.005
		SD	0.03	0.05	0.05	0.06	0.08	0.03	0.04	0.06	0.06	0.06						
	Number of step	Mean	34.23	35.24	33.70	36.32	34.00	36.88	37.32	35.83	34.65	34.37	1.64	0.202	0.66	0.622	0.89	0.471
		SD	4.23	6.43	6.58	9.06	7.04	5.06	6.02	6.70	6.22	6.29						
Back and forth stepping	Single support time	Mean	0.46	0.43	0.49	0.46	0.45	0.45	0.43	0.45	0.44	0.49	0.56	0.454	2.89*	0.023	1.99	0.096
		SD	0.06	0.06	0.07	0.05	0.08	0.07	0.06	0.07	0.07	0.09						
	Double support time	Mean	0.22	0.24	0.22	0.25	0.29	0.17	0.19	0.22	0.24	0.31	2.58	0.110	7.74*	0.000	1.22	0.303
		SD	0.10	0.09	0.10	0.11	0.11	0.04	0.07	0.07	0.08	0.12						
	Number of step	Mean	33.85	35.35	32.96	34.51	32.22	37.06	36.58	34.15	33.48	30.64	0.77	0.381	4.67*	0.001	1.42	0.227
		SD	5.31	5.49	3.77	6.19	4.42	4.38	5.77	5.23	4.48	4.84						
Up and down stepping	Single support time	Mean	0.45	0.45	0.48	0.45	0.43	0.44	0.42	0.44	0.45	0.49	0.21	0.644	1.02	0.399	2.99*	0.020
		SD	0.05	0.07	0.07	0.06	0.08	0.08	0.07	0.07	0.06	0.07						
	Double support time	Mean	0.21	0.20	0.22	0.25	0.29	0.16	0.18	0.21	0.25	0.27	2.99	0.085	8.12*	0.000	0.66	0.623
		SD	0.12	0.06	0.09	0.11	0.12	0.04	0.06	0.07	0.09	0.08						
	Number of step	Mean	36.35	36.56	33.98	34.88	33.79	38.96	38.38	36.23	33.90	30.76	0.41	0.523	5.14*	0.001	1.54	0.192
		SD	6.50	6.37	5.53	6.01	4.15	6.18	6.13	5.59	4.47	4.88						
In-place matching tempo stepping	44 b.p.m.	Mean	0.09	0.10	0.14	0.15	0.14	0.10	0.09	0.11	0.13	0.14	2.82	0.094	4.54*	0.002	0.58	0.680
		SD	0.04	0.06	0.08	0.06	0.05	0.04	0.05	0.06	0.06	0.06						
	66 b.p.m.	Mean	0.05	0.05	0.06	0.06	0.07	0.05	0.05	0.06	0.07	0.07	1.07	0.302	4.36*	0.002	0.36	0.839
		SD	0.02	0.02	0.03	0.02	0.02	0.01	0.02	0.02	0.02	0.02						
	132 b.p.m.	Mean	0.03	0.02	0.02	0.03	0.03	0.02	0.02	0.03	0.03	0.03	0.04	0.836	2.75*	0.029	1.11	0.352
		SD	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.01						

G1, 60–64 years old; G2, 65–69 years old; G3, 70–74 years old; G4, 75–79 years old; G5, ≥80 years old; *: $p < 0.05$, Int, Interaction; SD, standard deviation.

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Table 3 Partial correlations between age and stepping parameters after considering height and body-mass, and test results of analysis covariance using height and body-mass as covariates, and multiple comparison for stepping parameters

		$r_{xy \cdot z}$	p	G1 Mean	G1 SD	G2 Mean	G2 SD	G3 Mean	G3 SD	G4 Mean	G4 SD	G5 Mean	G5 SD	ANCOVA F-value	ANCOVA p	partial η^2	post-hoc (Tukey's HSD)
back/forth stepping	Single support time	0.07	*0.140*	0.45	0.06	0.43	0.06	0.47	0.14	0.44	0.06	0.45	0.10	1.76	*0.138*	0.03	
	Double support time	0.30	*0.000*	0.20	0.08	0.20	0.07	0.23	0.10	0.24	0.09	0.27	0.11	6.80	*0.000*	0.10	G5 > G4, G3, G2, G1, G4 > G1
	Number of step	−0.21	*0.001*	35.67	5.70	36.11	6.58	33.17	6.51	34.46	5.76	31.19	6.50	4.03	*0.004*	0.06	G2, G1, G4, G3 > G5, G2 > G3
up/down stepping	Single support time	0.07	*0.157*	0.44	0.07	0.44	0.08	0.47	0.14	0.45	0.06	0.45	0.11	0.74	*0.568*	0.02	
	Double support time	0.38	*0.000*	0.18	0.09	0.18	0.06	0.24	0.09	0.25	0.10	0.31	0.19	7.87	*0.000*	0.14	G5 > G3, G2, G1, G4 > G2, G1
	Number of step	−0.29	*0.000*	37.92	6.44	38.40	8.12	35.33	6.55	34.33	5.81	31.98	7.30	4.75	*0.001*	0.09	G2, G1, G3 > G5, G2, G1 > G4, G1 > G3

$r_{xy \cdot z}$: partial correlation with age, G1, 60–64 years old; G2, 65–69 years old; G3, 70–74 years old; G4, 75–79 years old; G5, ≥80 years old; SD, standard deviation.

Table 4 Partial correlations between age and stepping parameters after considering height and body-mass, and test results of analysis covariance using height and body-mass as covariates, and multiple comparisons for stepping parameters

		$r_{xy \cdot z}$	p	G1 Mean	G1 SD	G2 Mean	G2 SD	G3 Mean	G3 SD	G4 Mean	G4 SD	G5 Mean	G5 SD		MANCOVA F-value	MANCOVA p	partial η^2	post-hoc (Tukey's HSD)
in-place	44 bpm	0.31	*0.000*	0.10	0.05	0.10	0.07	0.10	0.06	0.14	0.08	0.14	0.07	age	6.89	*0.000*	0.13	G1, G2, G3, G4, G5: 44 bpm > 66 bpm, 132 bpm
matching tempo	66 bpm	0.29	*0.000*	0.06	0.03	0.05	0.02	0.06	0.02	0.07	0.02	0.07	0.05	bpm	322.33	*0.000*	1.14	44 bpm, 66 bpm, 132 bpm: G5, G4 > G2, G1
stepping	132 bpm	0.18	*0.004*	0.02	0.01	0.02	0.01	0.03	0.01	0.03	0.01	0.03	0.01	interaction	4.73	*0.001*	0.09	

$r_{xy \cdot z}$: partial correlation with age, G1, 60–64 years old; G2, 65–69 years old; G3, 70–74 years old; G4, 75–79 years old; G5, ≥80 years old; SD, standard deviation.

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Table 5 Correlations among parameters

			A	B	C	D	E	F	G	H
Back and forth stepping	Single support time	A								
	Double support time	B	0.24*							
	Number of steps	C	−0.77*	−0.69*						
Up and down stepping	Single support time	D	0.69*	0.27*	−0.62*					
	Double support time	E	0.29*	0.86*	−0.67*	0.28*				
	Number of steps	F	−0.68*	−0.67*	0.86*	−0.78*	−0.69*			
In-place matching tempo stepping	44 b.p.m.	G	0.05	0.10	−0.07	0.02	0.09	−0.07		
	66 b.p.m.	H	−0.04	0.20*	−0.09	−0.12	0.16*	−0.01	0.39*	
	132 b.p.m.	I	0.07	0.38*	−0.27*	0.12	0.31*	−0.23*	0.09	0.29*

*: $p < 0.05$.

support time. Movement tasks in this study are similar to gait but differ by involving forward and backward movement of body gravity. Stepping in a backward direction differs greatly from that of forward movements and the former may produce, especially for elderly subjects, larger instability of movement and larger psychological anxiety than stepping in a forward direction because of the lack of visual information. Dynamic balance ability relates closely to vision, somatesthesia and the vestibular organ.[15] Therefore, because back and forth and up and down stepping movements selected in this study are involved in transfer of body gravity and limitation of visual information, they may be useful to evaluate elderly subjects' dynamic balance ability. In addition, it was confirmed that relationships between single and double support times of both stepping tests are low and the latter parameter better reflects age differences.

Meanwhile, parameters (time difference) selected in the in-place stepping matching tempo tests differed significantly among each age group at any tempo. According to Takami and Fukui, the 80-b.p.m. tempo best fits the gait cycle of healthy people.[13] The 44-b.p.m. tempo increases the time for supporting the body with one leg and the 132-b.p.m. faster tempo makes matching the tempo very difficult. Namely, both tempos, except for the 66-b.p.m. tempo, which is similar to the healthy gait cycle, easily induced instability of body gravity for the elderly subjects with inferior leg muscle and nerve functions. Hence, both tempos were considered useful for evaluating elderly subjects' dynamic balance ability. However, similar age differences in all tempos were confirmed as follows: subjects of 75 years or more were less able to complete the task than subjects of less than 70 years old. Moreover, relationships among the three tempo stepping tests were lower and the time difference was larger at a 44-b.p.m. tempo than the others in all age groups. Stepping with a fixed cycle may be difficult for the elderly at any tempo. However, slow tempos in particular may cause more difficulty because instability of body gravity increases and forces single support time to enlarge. From the above, stepping at a fixed cycle is also judged to be useful for evaluating elderly subjects' dynamic balance ability.

Relationships of all parameters except for single support time of the back and forth and up and down stepping test with age were not high but significant ($r = -0.29$–0.38). Callisaya *et al.* examined the relationship between gait characteristics (gait speed, cadence, step length and double support time) and age, and reported significant relationships between all parameters except for cadence and age after considering height and body mass.[16] Although characteristics of subjects and experimental condition differed from the present study, a significant relationship with age was found in the same parameter (double support time). Moreover,

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age-level differences were also found in these parameters. Hence, stepping tests selected in this study were judged to be useful and reflective of age-level differences.

In conclusion, no sex difference was found in any stepping test while age differences were found in the double support time of back and forth and up and down stepping tests and in the time difference of stepping tests with fixed tempo. Stepping at a fixed cycle is more difficult at the slower 44-b.p.m. tempo than at faster tempos. Back and forth and up and down stepping or in-place tempo stepping are useful as movements for dynamic balance tests in the elderly.

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