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# Sex and Age Differences of Relationships among Stepping Parameters for Evaluating Dynamic Balance in the Elderly

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**Abstract** This study aimed to examine the relationships among various stepping parameters, sex, and age in the elderly. Healthy elderly Japanese individuals 60–85 years old (50 males and 61 females) performed 4 types of stepping motions for 20 s. Stepping motions included bilateral stepping (back/forth and right/left) and unilateral stepping (back/forth and right/left). The number of steps, the average connecting time of a foot during one step, and the average time of both feet touching the floor at the same time (bilateral connecting time) were measured with a foot switch sheet. The trial-to-trial reliability was very high (above 0.86) except for the bilateral connecting time in the bilateral stepping back/forth test for 70–85 year olds (males: 0.67, females: 0.68). With age, the number of steps was significantly smaller, and the average connecting time and the bilateral connecting time were shorter in all stepping tests. There were significant sex differences in bilateral connecting time for bilateral stepping right and left and the number of steps for the bilateral stepping back and forth and the unilateral stepping right and left tests. The number of steps and average connecting time showed high correlations between bilateral stepping right/left and back/forth ($r=0.71$–$0.94$) and between unilateral stepping back/forth and right/left ($r=0.87$–$0.99$). There were significant correlations of the average connecting time between bilateral and unilateral stepping motions ($r=0.51$–$0.83$), but both stepping motions are considered to have different motion properties from the viewpoint of center of gravity sway. The correlations between the bilateral connecting time and the number of steps in bilateral stepping were relatively low (males: $|r|<0.70$, females: $|r|<0.57$). The bilateral connecting time was near 0 s in many males; thus, it may depend greatly on individual or sex differences in stepping strategy. These results suggest that the stepping motions used in this study can evaluate dynamic balance ability, and that the unilateral test may be useful for the elderly who cannot walk independently with ease. *J Physiol Anthropol 27(4): 207–215, 2008* http://www.jstage.jst.go.jp/browse/jpa2

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**Keywords:** foot connecting time, foot sheet, trial-to-trial reliability

## Introduction

The ability to independently carry out the activities of daily life is dependent on walking. Quality of life scales (Tazaki and Nakane, 1997; Tazaki et al., 1998) by the World Health Organization or Sort form-36 (Ware and Sherbourne, 1992) measure mobility (physical functioning) in their subscales. Aging decreases strength and balance, thus influencing walking ability and resulting in decreased physical activity (Commissaris et al., 2002; Rogers et al., 2003). Decreased strength and balance also increases the risk of a fall and fractures (Gauchard et al., 2001; Rogers et al., 2001a), leading to walking anxiety and decreased mobility (Commissaris et al., 2002; Steffen et al., 2002). Use of the lower limbs and balance are associated with increased mobility and safe and rapid control of the body's center of gravity during movements. Hence, a rational test of these abilities is critical.

Dynamic balance has previously been assessed by the following performance tests: posture stability time on an unstable platform (Commissaris et al., 2002), Bass dynamic balance (Douglas and Alan, 1998), functional reach (Duncan et al., 1990; Rogers et al., 2001b), star-excursion balance (Kinzey and Armstrong, 1998), and Timed Up and Go (Morris et al., 2001). The balance mobility assessment (Tinetti, 1986) and the Berg balance scale (Berg et al., 1992) evaluate dynamic balance with questionnaires that assess the ability to perform daily activities that require moving the body's center of gravity.

Elderly with poor balance ability cannot even perform the Functional reach and Timed Up and Go tests, and in such cases, only the above questionnaires can be used. However, the questionnaires cannot evaluate properly individual differences

**Table 1** Characteristics of subjects

| | Males | | | | Females | | | |
|---|---|---|---|---|---|---|---|---|
| Age group (years) | 60–69 | | 70–85 | | 60–69 | | 70–85 | |
| Number of subjects | 26 | | 24 | | 26 | | 35 | |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Age (years) | 65.0 | 3.0 | 74.9 | 3.5 | 64.9 | 2.7 | 74.5 | 3.7 |
| Height (cm) | 163.9 | 5.2 | 161.8 | 6.3 | 152.0 | 4.8 | 147.3 | 5.7 |
| Body mass (kg) | 65.8 | 8.8 | 58.1 | 7.8 | 55.8 | 7.8 | 51.3 | 7.1 |

in healthy elderly people. In addition, neither of these tests can examine the step strategy in detail while walking. Hence, it is necessary to develop dynamic balance tests. Although a stepping motion is very easy for young adults, elderly with inferior balance ability and leg strength experience difficulty because supporting the body on only one leg is unstable and the body's center of gravity sways when changing steps (Morris et al., 2001). This observation was supported by a study by Sato et al. (1999) that investigated achievement rates of movements in 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 %. The same is true of existing tests such as the Timed Up and Go test, the eight figure test, and obstacle walking. In short, it is difficult for the elderly to step smoothly, and dynamic balance ability in the elderly can be evaluated from the number of steps taken during a fixed time (Guskiewicz and Perrin, 1996). In addition, their stepping strategy can be estimated from the analysis of unilateral support and bilateral support phases (Allum and Carpenter, 2005). Furthermore, stepping tests for the elderly are advantageous because they are safe and do not require expensive tools or large space.

Maki et al. (2000) suggested that rapid step training contributes largely to the maintenance of balance in the elderly. Hence, we considered that a rapid and repeated stepping test can evaluate dynamic balance ability. However, the role of age-related changes and the reliability of stepping parameters remain unclear. Moreover, the relationship between the number of steps and the length of unilateral or bilateral leg support phases has not been examined. In addition, sex differences in the above properties and dynamic balance were evaluated with these stepping tests.

This study aims to examine the relationships among various stepping parameters and sex differences according to age in the elderly.

## Methods

*Subjects*

Independent community-dwelling Japanese elderly aged 60–85 years were screened for participation in this study, resulting in the recruitment of 111 subjects. Informed consent was obtained from each subject after a full explanation of the experiment and procedure. They had no evidence or known

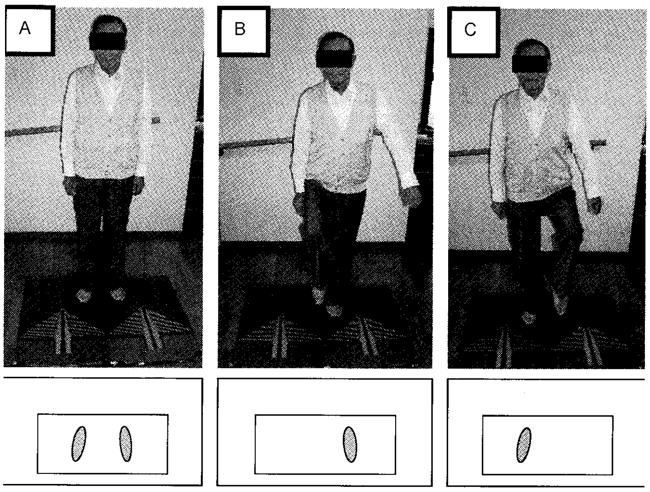


**Fig. 1** Bilateral stepping right and left. The subjects stood on the foot switch (A), and stepped continuously and alternately right and left (B, C).

history of mobility problems secondary to gait, posture, or skeletal disorders and could walk independently. Moreover, from the results of a preliminary test performed in 5 males and 5 females, the selected stepping tests were judged to be safe. To examine age differences, subjects were divided into two groups (60–69 and 70–85 yr) (see Table 1). There were no significant sex differences between the age groups.

*Stepping motion*

Stepping motions for 20 s were performed in 4 conditions: bilateral right and left alternate stepping (bilateral stepping right and left), bilateral back and forth alternate stepping (bilateral stepping back and forth), right and left repeated stepping using the dominant leg (unilateral stepping right and left), and back and forth repeated stepping using the dominant leg (unilateral stepping back and forth).

For bilateral stepping right and left (Fig. 1), the subjects stood on the foot switch sheet (see Materials) and stepped continuously and alternatively right and left. For bilateral stepping back and forth (Fig. 2), the subjects stood at the outside back edge of the foot switch sheet and continuously stepped on and off the foot switch sheet, that is to say, placing the right foot on the foot switch sheet and then the left foot, and returning the right and left feet to the original spot.

For unilateral stepping back and forth (Fig. 3), the subjects

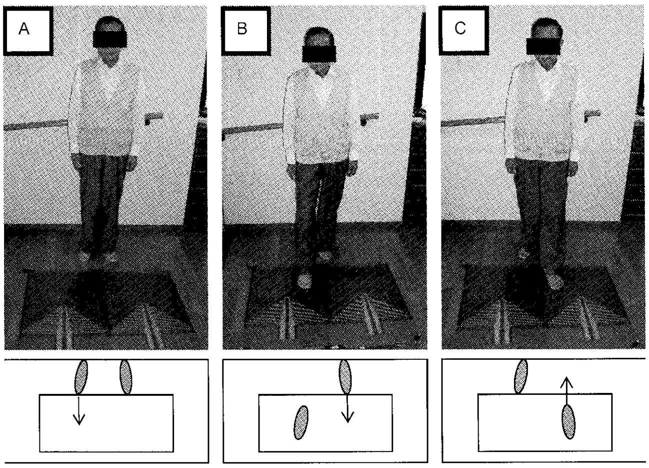


**Fig. 2** Bilateral stepping back and forth. The subjects stood at the outside back edge of the foot switch sheet (A), and continuously stepped on and off the foot switch sheet (B, C).

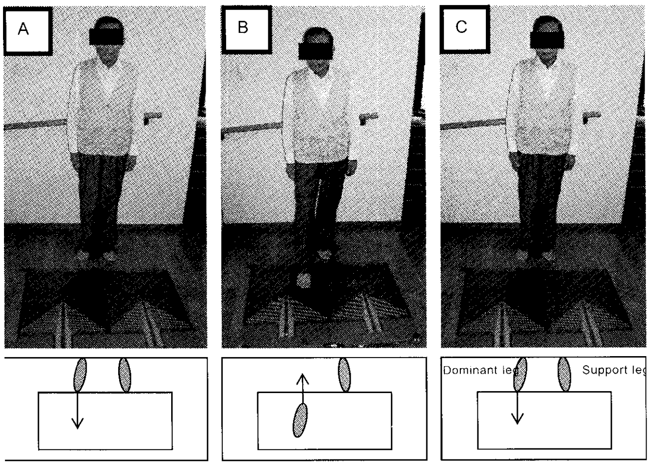


**Fig. 3** Unilateral stepping back and forth. The subjects stood at the outside back edge of the foot switch sheet (A), and continuously placed the dominant foot on the foot switch sheet to support the nondominant leg (B) and returned the dominant leg to the original spot (C).

stood at the outside back edge of the foot switch sheet and continuously placed the dominant foot on the foot switch sheet to support the nondominant leg and returned the dominant leg to the original spot. For unilateral stepping right and left (Fig. 4), the subjects stood at the outside side edge of the foot switch sheet, and continuously placed the dominant foot on the foot switch sheet supporting the nondominant leg and returning the dominant foot to the original spot.

The tests were performed after warm-up trials. Each stepping test was carried out twice on the same day with a 10-min interval between trials. Four tests were performed in random order. Before the unilateral stepping test, the dominant leg was determined using the dominant leg questionnaire established by Demura et al. (2001) based on the questionnaires of Chapman et al. (1987) and Fumoto (1989).

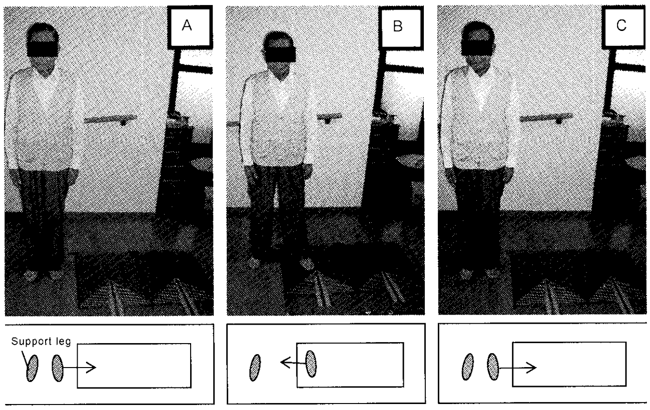


**Fig. 4** Unilateral stepping right and left. The subjects stood at the outside side edge of the foot switch sheet (A), and continuously placed the dominant foot on the foot switch sheet supporting the nondominant leg (B) and returned the dominant foot to the original spot (C).

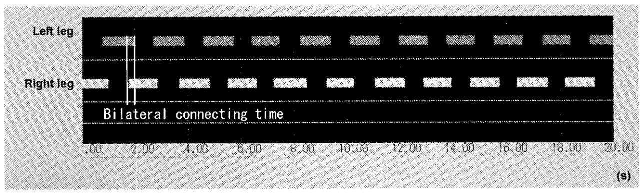


**Fig. 5** Typical measurements by the foot switch sheet.

Subjects performed two trials of each stepping motion according to the verbal instruction, "repeat the motion in the same place as quickly as possible to maintain balance and prevent falls during the test." A running step was defined as the lack of a double leg stance phase.

### *Materials and Stepping parameters*

The stepping test was performed using a foot switch sheet (480 (L)×560 (W) mm, Anima Ltd., Japan). The subject's feet were located on the foot switch sheet, and they stepped in place (Figs. 1–4). The pressure sensor of this device detected footsteps and the foot used for the step. The device measured the connecting time of each foot to the sheet. Figure 5 shows a typical example of the connecting time in each foot. Two bars in Fig. 5 indicate the connecting time of each foot as a measurement time on the abscissa axis. The total number of bars indicates the number of steps, and the length of each bar indicates the connecting time of a foot in one step. The average value (sum of connecting time/number of steps) defined the average connecting time.

In addition, the length of time when both feet were on the floor at the same time during the bilateral stepping test was defined as the bilateral connecting time. This device evaluated the rhythm (stability) of stepping by the connecting time of each foot in addition to the number of steps. Stepping data was relayed as signal data with a sampling frequency of 20 Hz to a personal computer.

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

| Motion | Stepping parameters | | Males 60–69 years (n=26) ICC | 95% CI Lower | 95% CI Upper | Males 70–85 years (n=24) ICC | 95% CI Lower | 95% CI Upper | Females 60–69 years (n=26) ICC | 95% CI Lower | 95% CI Upper | Females 70–85 years (n=35) ICC | 95% CI Lower | 95% CI Upper |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bilateral right/left | Number of steps | (times) | .98 | .95 ~ | .99 | .97 | .93 ~ | .99 | .96 | .91 ~ | .98 | .98 | .96 ~ | .99 |
| | Average connecting time | (sec) | .97 | .94 ~ | .99 | .96 | .92 ~ | .98 | .98 | .95 ~ | .99 | .96 | .92 ~ | .98 |
| | Bilateral connecting time | (sec) | .95 | .90 ~ | .98 | .93 | .86 ~ | .97 | .93 | .85 ~ | .97 | .86 | .74 ~ | .93 |
| Bilateral back/forth | Number of steps | (times) | .94 | .88 ~ | .97 | .94 | .85 ~ | .97 | .98 | .95 ~ | .99 | .94 | .88 ~ | .97 |
| | Average connecting time | (sec) | .97 | .93 ~ | .99 | .94 | .86 ~ | .97 | .96 | .91 ~ | .98 | .96 | .92 ~ | .98 |
| | Bilateral connecting time | (sec) | .93 | .84 ~ | .96 | .67 | .38 ~ | .84 | .88 | .76 ~ | .92 | .68 | .45 ~ | .82 |
| Unilateral back/forth | Number of steps | (times) | .98 | .96 ~ | .99 | .94 | .86 ~ | .97 | .95 | .89 ~ | .98 | .95 | .91 ~ | .98 |
| | Average connecting time | (sec) | .96 | .94 ~ | .98 | .97 | .93 ~ | .99 | .91 | .81 ~ | .96 | .94 | .95 ~ | .99 |
| Unilateral right/left | Number of steps | (times) | .99 | .97 ~ | .99 | .98 | .96 ~ | .99 | .95 | .89 ~ | .98 | .97 | .94 ~ | .98 |
| | Average connecting time | (sec) | .96 | .91 ~ | .98 | .97 | .94 ~ | .99 | .91 | .81 ~ | .96 | .98 | .95 ~ | .99 |

ICC: Intra-class correlation coefficient, CI: Confidence interval

The following evaluation parameters were selected: number of steps, the average connecting time for all tests, and the bilateral connecting time for the bilateral test.

*Data analysis*

All parameters were examined to fit with the normal distribution by a Kolmogorov–Smirnov test. To examine the trial-to-trial reliability of each stepping parameter, the single measure intra-class correlation coefficient (ICC) by a one-way ANOVA model was calculated for sex and age groups. Repeated two-way ANOVA was used to reveal the sex- and age-related differences. Moreover, to compare the individual differences among stepping parameters, the coefficient of variation (CV) was calculated. To examine relationships among various stepping parameters, Pearson's correlation coefficient was calculated according to sex and age group. A probability level of 0.05 was indicative of statistical significance.

## Results

In the present results, a running step occurred in 7 males and one female in the right and left steps and two males and one female for the back and forth steps.

All parameters were confirmed to have a normal distribution by the Kolmogorov–Smirnov test ($p$=0.124 to 0.313).

Table 2 shows the ICC of each stepping parameter by sex and age level. The ICCs were very high (above 0.86) except for the bilateral connecting time in the bilateral stepping back and forth test for 70–85-year-olds (males: 0.67, females: 0.68).

Table 3 shows the results of repeated two-way ANOVA (sex and age group). All parameters showed an insignificant interaction effect and significant age differences. The number of steps was significantly larger, and the average connecting time and bilateral connecting time were shorter in the 60–69-year-old group than the 70–85-year-old group in all stepping tests. There were significant sex differences in bilateral connecting time for bilateral stepping right and left and the number of steps for the bilateral stepping back and forth and the unilateral stepping right and left. The former was longer in females.

All parameters except for average connecting times of unilateral stepping (back/forth and right/left) significantly correlated with age but were moderate or lower (males: $|r|$=0.35–0.43, females: $|r|$=0.31–0.51).

Tables 4–1~4–4 show the correlations among stepping parameters in each step motion according to sex and age. Figure 6 shows the scatter plots according to sex and age groups. The correlations between the number of steps and average connecting time were moderate or high in both sexes and age levels for all stepping motions (males: 60–69 yr); $|r|$=0.77–0.87, 70–85 yr); $|r|$=0.76–0.94, females: 60–69 yr); $|r|$=0.64–0.91, 70–85 yr ; $|r|$=0.76–0.95). The scatter plots tended to be similar in both sexes (Fig. 6A, B). The correlations between the number of steps and bilateral connecting time in the bilateral step motion were lower (males: $|r|<0.70$, females: $|r|<0.57$), and the bilateral connecting time was near 0 s in many males (Fig. 6C, D). Individual differences of bilateral connecting time (CV=44.9–61.9) in 70–85-year-old males tended to be larger than those of the number of steps (CV=26.6–43.9). In addition, the correlations among parameters in bilateral back/forth stepping were higher at 70–85 yr than at 60–69 yr in both sexes. The correlations of the average connecting time between bilateral and unilateral stepping motions were higher at 70–85 yr than at 60–69 yr. The individual differences of the average connecting time tended to

**Table 3** Results of two-way ANOVA (gender×age-level).

| Step | Stepping parameters (unit) | Age | Males Mean | Males SD | CV | Females Mean | Females SD | CV | Two-way ANOVA | F | p | partial $\eta^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bilateral right/left | Number of steps (times) | 60–69 yr | 70.06 | 26.82 | 38.3 | 78.87 | 28.95 | 36.7 | Sex | 2.00 | .16 | .02 |
| | | 75–85 yr | 56.77 | 13.87 | 24.4 | 62.46 | 31.08 | 49.8 | Age | 8.41 | .00* | .07 |
| | | | | | | | | | Interaction | .09 | .76 | .00 |
| | Average connecting time (sec) | 60–69 yr | .41 | .16 | 39.1 | .38 | .16 | 40.5 | Sex | .40 | .53 | .00 |
| | | 75–85 yr | .49 | .13 | 26.1 | .56 | .24 | 42.3 | Age | 14.16 | .00* | .12 |
| | | | | | | | | | IInteraction | 1.62 | .21 | .01 |
| | Bilateral connecting time (sec) | 60–69 yr | 2.18 | 1.88 | 86.6 | 2.70 | 1.85 | 68.5 | Sex | 5.40 | .02* | .05 |
| | | 75–85 yr | 3.74 | 1.99 | 53.3 | 4.97 | 2.11 | 42.5 | Age | 25.55 | .00* | .19 |
| | | | | | | | | | IInteraction | .86 | .36 | .01 |
| Bilateral back/forth | Number of steps (times) | 60–69 yr | 29.10 | 10.92 | 37.5 | 34.37 | 12.13 | 35.3 | Sex | 4.91 | .03* | .04 |
| | | 75–85 yr | 22.58 | 6.83 | 30.3 | 27.19 | 14.04 | 51.6 | Age | 9.44 | .00* | .08 |
| | | | | | | | | | IInteraction | .02 | .88 | .00 |
| | Average connecting time (sec) | 60–69 yr | .51 | .19 | 37.2 | .44 | .16 | 36.9 | Sex | .78 | .38 | .01 |
| | | 75–85 yr | .64 | .18 | 28.5 | .64 | .26 | 40.3 | Age | 17.27 | .00* | .14 |
| | | | | | | | | | IInteraction | .71 | .40 | .01 |
| | Bilateral connecting time (sec) | 60–69 yr | .84 | .61 | 73.2 | .80 | .56 | 69.5 | Sex | .19 | .66 | .00 |
| | | 75–85 yr | 1.21 | .48 | 39.9 | 1.34 | .56 | 41.4 | Age | 18.38 | .00* | .15 |
| | | | | | | | | | IInteraction | .64 | .43 | .01 |
| Uniralteral back/forth | Number of steps (times) | 60–69 yr | 26.67 | 7.90 | 29.6 | 32.08 | 8.74 | 27.2 | Sex | 3.62 | .06 | .03 |
| | | 75–85 yr | 23.33 | 6.29 | 27.0 | 24.14 | 9.95 | 41.2 | Age | 11.93 | .00* | .10 |
| | | | | | | | | | Interaction | 1.98 | .16 | .02 |
| | Average connecting time (sec) | 60–69 yr | .20 | .12 | 59.7 | .14 | .05 | 35.2 | Sex | .49 | .49 | .00 |
| | | 75–85 yr | .24 | .12 | 52.6 | .26 | .15 | 55.9 | Age | 13.28 | .00* | .11 |
| | | | | | | | | | IInteraction | 3.39 | .07 | .03 |
| Unilateral right/left | Number of teps (times) | 60–69 yr | 28.00 | 8.12 | 29.0 | 33.67 | 8.20 | 24.4 | Sex | 4.83 | .03* | .04 |
| | | 75–85 yr | 24.08 | 6.64 | 27.6 | 25.56 | 9.91 | 38.8 | Age | 13.70 | .00* | .11 |
| | | | | | | | | | Interaction | 1.67 | .20 | .02 |
| | Average connecting time (sec) | 60–69 yr | .21 | .14 | 65.6 | .15 | .06 | 39.8 | Sex | .62 | .43 | .01 |
| | | 75–85 yr | .26 | .14 | 55.8 | .28 | .17 | 60.1 | Age | 11.45 | .00* | .10 |
| | | | | | | | | | IInteraction | 2.59 | .11 | .02 |

CV: coefficient of variation, * : $p<.05$.

**Table 4-1** The correlation coefficients among stepping parameters in males aged 60–69

| No. | Motion | Stxepping parameters | unit | Bilateral right/left 1 | 2 | 3 | Bilateral back/forth 4 | 5 | 6 | Unilateral back/forth 7 | 8 | Unilateral right/left 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Bilateral right/left | Number of steps | (times) | | | | | | | | | | |
| 2 | | Average connecting time | (sec) | −.84 | | | | | | | | | |
| 3 | | Bilateral connecting time | (sec) | | .65 | | | | | | | | |
| 4 | Bilateral back/forth | Number of steps | (times) | .89 | −.73 | −.40 | | | | | | | |
| 5 | | Average connecting time | (sec) | −.77 | .83 | .54 | −.87 | | | | | | |
| 6 | | Bilateral connecting time | (sec) | −.46 | .65 | .62 | −.48 | .77 | | | | | |
| 7 | Unilateral back/forth | Number of steps | (times) | .77 | −.68 | | .91 | −.89 | −.51 | | | | |
| 8 | | Average connecting time | (sec) | −.53 | .56 | | −.65 | .83 | .59 | −.80 | | | |
| 9 | Unilateral right/left | Number of steps | (times) | .75 | −.67 | | .88 | −.88 | −.53 | .99 | −.81 | | |
| 10 | | Average connecting time | (sec) | −.49 | .62 | | −.57 | .78 | .53 | −.73 | .91 | −.77 | |

Note: Only significant correlations are described in the Table ($p<.05$).

**Table 4-2** The correlation coefficients among stepping parameters in females aged 60–69

| No. | Motion | Stxepping parameters | unit | Bilateral right/left | | | Bilateral back/forth | | | Unilateral back/forth | | Unilateral right/left | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | Bilateral | Number of steps | (times) | | | | | | | | | | |
| 2 | right/left | Average connecting time | (sec) | −.90 | | | | | | | | | |
| 3 | | Bilateral connecting time | (sec) | −.66 | .81 | | | | | | | | |
| 4 | Bilateral | Number of steps | (times) | .92 | −.84 | −.61 | | | | | | | |
| 5 | back/forth | Average connecting time | (sec) | −.88 | .91 | .70 | −.91 | | | | | | |
| 6 | | Bilateral connecting time | (sec) | −.51 | .47 | .56 | | .52 | | | | | |
| 7 | Unilateral | Number of steps | (times) | .86 | −.85 | −.68 | .89 | −.89 | −.46 | | | | |
| 8 | back/forth | Average connecting time | (sec) | −.45 | .63 | .45 | −.50 | .62 | | −.64 | | | |
| 9 | Unilateral | Number of steps | (times) | .84 | −.81 | −.66 | .83 | −.85 | −.49 | .95 | −.60 | | |
| 10 | right/left | Average connecting time | (sec) | −.52 | .70 | .63 | −.56 | .73 | | −.70 | .87 | −.66 | |

Note: Only significant correlations are described in the Table ($p<.05$).

**Table 4-3** The correlation coefficients among stepping parameters in males aged 70–85

| No. | Motion | Stxepping parameters | unit | Bilateral right/left | | | Bilateral back/forth | | | Unilateral back/forth | | Unilateral right/left | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | Bilateral | Number of steps | (times) | | | | | | | | | | |
| 2 | right/left | Average connecting time | (sec) | −.94 | | | | | | | | | |
| 3 | | Bilateral connecting time | (sec) | | .57 | | | | | | | | |
| 4 | Bilateral | Number of steps | (times) | .72 | −.69 | | | | | | | | |
| 5 | back/forth | Average connecting time | (sec) | −.70 | .71 | | −.91 | | | | | | |
| 6 | | Bilateral connecting time | (sec) | | .43 | .44 | −.70 | .72 | | | | | |
| 7 | Unilateral | Number of steps | (times) | .66 | −.58 | | .78 | −.72 | | | | | |
| 8 | back/forth | Average connecting time | (sec) | −.55 | .51 | | −.52 | .57 | | −.76 | | | |
| 9 | Unilateral | Number of steps | (times) | .80 | −.74 | | .85 | −.77 | −.42 | .92 | −.78 | | |
| 10 | right/left | Average connecting time | (sec) | −.57 | .54 | | −.51 | .53 | | −.65 | .92 | −.78 | |

Note: Only significant correlations are described in the Table ($p<.05$).

**Table 4-4** The correlation coefficients among stepping parameters in females aged 70–85

| No. | Motion | Stxepping parameters | unit | Bilateral right/left | | | Bilateral back/forth | | | Unilateral back/forth | | Unilateral right/left | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | Bilateral | Number of steps | (times) | | | | | | | | | | |
| 2 | right/left | Average connecting time | (sec) | −.95 | | | | | | | | | |
| 3 | | Bilateral connecting time | (sec) | −.57 | .64 | | | | | | | | |
| 4 | Bilateral | Number of steps | (times) | .94 | −.86 | −.57 | | | | | | | |
| 5 | back/forth | Average connecting time | (sec) | −.89 | .87 | .59 | −.91 | | | | | | |
| 6 | | Bilateral connecting time | (sec) | −.56 | .55 | .69 | −.55 | .62 | | | | | |
| 7 | Unilateral | Number of steps | (times) | .89 | −.83 | −.56 | .93 | −.87 | −.58 | | | | |
| 8 | back/forth | Average connecting time | (sec) | −.70 | .68 | .32 | −.70 | .81 | .42 | −.76 | | | |
| 9 | Unilateral | Number of steps | (times) | .91 | −.88 | .56 | −.89 | −.92 | .59 | −.94 | −.84 | | |
| 10 | right/left | Average connecting time | (sec) | −.71 | .69 | .32 | −.69 | .80 | .42 | −.76 | .98 | −.85 | |

Note: Only significant correlations are described in the Table ($p<.05$).

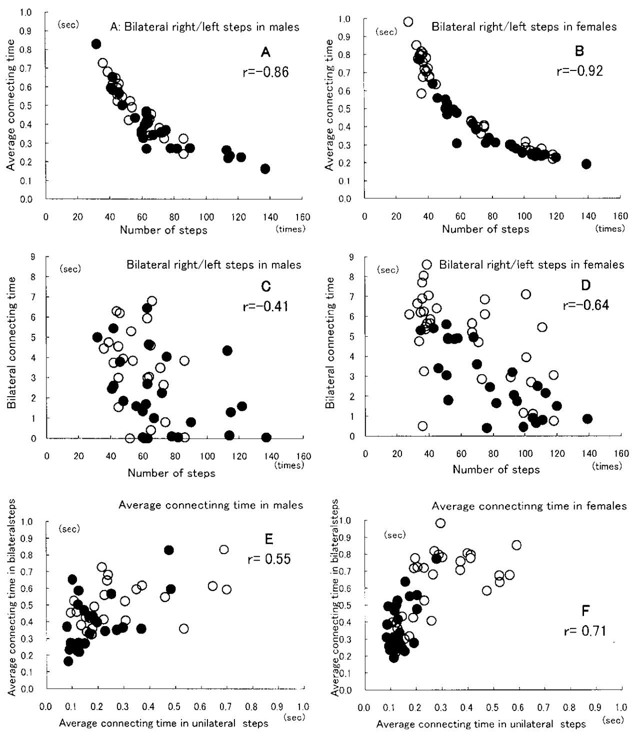


**Fig. 6** The scatter plots of stepping parameters between number of steps and average connecting time (A, B), between number of steps and bilateral connecting time (C, D), and between average connecting times in bilateral right/left and in unilateral back/forth (E, F). ○60–69 yr, ●70–85 yr.

be larger at 70–85 yr (males: 60–69 yr); 23.4, 70–85yr; 36.4, females: 60–69 yr; 21.3, 70–85yr; 32.4) (Fig. 6E, F).

## Discussion

The main findings in this study may be summarized below. With age, the number of steps tends to decrease, and the bilateral connecting time increases. Although the average connecting time may evaluate the same ability as the number of steps, it can also predict bilateral and unilateral leg support times during stepping by adding bilateral connecting time. That is, it is possible for both parameters to evaluate periodicity, right/left difference of stepping, and stepping strategy. Of four stepping motions selected in this study, bilateral stepping (right/left and back/forth) can select either stepping motion, and unilateral stepping may be applied according to the subject's physical fitness level.

The stepping tests proposed by this study required stepping as rapidly as possible in a definite period of time. 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%. Although the stepping tests have generally been used to evaluate the agility of young people, the elderly with markedly decreased lower strength and dynamic balance experience difficulty performing repeated rapid stepping while maintaining a stable standing posture.

The trial-to-trial reliability of all parameters in all stepping tests was good. The difficulty level of stepping motions may be nearly proportional to the size of the body's center of gravity movement (Commissaries et al., 2002). It is higher in a bilateral stepping motion with a long unilateral support phase than in a unilateral stepping motion. Although stepping difficulty may differ among stepping motions, parameters in any stepping test are considered to be highly reliable. Many researchers reported a decrease of balance ability and gait ability with age (Fujiwara et al., 2001; Hageman et al., 1995; Steffen et al., 2002). This study also confirmed significant differences among age groups in all parameters. Individual differences in the number of steps and the average connecting time in males tended to be the largest in bilateral stepping right/left at age 60–69 and in unilateral stepping at age 70 or more. In addition, those in females tended to be larger in bilateral stepping at both age levels. Both bilateral stepping motions were considered to be more reflective of individual differences of the elderly than unilateral stepping motions.

The number of steps was related to the average connecting time, but was poorly related to the bilateral connecting time. Maki (1997) reported that gait changes with decreased gait velocity, stride, cadence, and vertical changes in the body's center of gravity. In addition, it is altered by increased bilateral connecting time and decreased coordination of upper and lower limbs with age. All stepping parameters in this study showed similar aging changes to those in previous reports. However, bilateral connecting time had a poor relationship with the number of steps and showed a large individual difference. This parameter may evaluate a different factor than other stepping parameters. The bilateral connecting time was near 0 s in many males, and the aging change tended to be smaller in males than in females (Fig. 6C, D). Thus, it may largely depend on individual or sex differences.

Minami et al. (1998) determined that the sustained time of unilateral standing with eyes closed is longer in males than females and inferred that the sex difference depends on differences in exercise experience in the past and present. In this study, males had a shorter phase of floor connecting time for both feet. Males may be accustomed to an insecure motion from more exercise experience in the past (Minami et al., 1998). The unilateral support phase in stepping motions is the most unstable phase during movement of the body's center of gravity. People with fall anxiety usually use a shorter unilateral support phase (Maki, 1997). This study suggests that this phase has a large individual difference even if the number of steps remains the same. The unilateral support phase can be evaluated from average connecting time and bilateral connecting time. These parameters may reveal previous fall experience, fall anxiety, and lower limb disease. The dynamic balance tests in previous studies (Duncan et al., 1990; Rogers et al., 2001b; Kinzey and Armstrong, 1998; Morris et al., 2001) used achivement degree or time of motion as well as the number of steps as evaluation parameters.

These parameters can be measured very simply. However, when designing a test to prevent falls in the elderly, bilateral connecting time and average connecting time which reflect individual differences of stepping strategies may be more useful parameters. A stepping motion is performed periodically and is divided into leg support and leg swing phases (Commissaris et al., 2002). The former further consists of unilateral and bilateral leg supporting phases. The average connecting time reflects the unilateral leg support phase and shows the time until the center of gravity shifts to the other leg. Therefore, because the number of steps generally increases if the average connecting time becomes shorter, both parameters evaluate the same ability. However, when evaluating gait ability with a stepping test, it is important to evaluate the smoothness of the gait as well as the number of steps. That is, the stability of gait cadence should be evaluated. The variations of average and bilateral connecting times in each step reflect this. In addition, these parameters can be used to analyze step strategy. The stepping motion may be used to stabilize posture. For example, some people maintain posture by prolonging the bilateral support phase while others shorten it or prolong the unilateral leg support phase. The stepping strategy may even change in the same person because the difficulty differs with the magnitude of the center of gravity movement. Hence, the average connecting time will be able to evaluate dynamic balance in more detail than the number of steps.

The number of steps in both sexes decreased with aging, but it tended to be larger in females than in males. The balance ability of the elderly as evaluated by the center of foot pressure during the upright posture with eyes either open or closed is better in females than males (Era et al., 1996, 1997). On the other hand, it was reported that functional reach proposed as a dynamic balance test for the elderly is superior in males (Duncan et al., 1990), however another study found no significant sex difference (Demura and Yamada, 2007). On the other hand, muscle strength and walking are lower than in males (Samson et al., 2001). Thus, the findings regarding sex differences of balance and gait ability in the elderly have not been consistent. The individual differences of physical fitness are very large, and age and sex may not always be important factors influencing physical fitness performance. Rather, performance may be influenced by other factors, such as the presence of a handicap, the degree of the handicap, or individual differences of lower-limb strength and walking ability (Grisso et al., 1991). It will be necessary to further examine the relationships between stepping parameters in this study and the above related factors and fall risk.

The number of steps and the average connecting time correlated highly between bilateral stepping right/left and back/forth (males: $r=0.71$–$0.89$, females: $r=0.87$–$0.94$), and between unilateral stepping back/forth and right/left (males: $r=0.91$–$0.99$, females: $r=0.87$–$0.98$). Thus, we can select either stepping motion (right/left or back/forth) to evaluate dynamic balance ability. There were significant correlations of the average connecting time between bilateral and unilateral stepping motions (males: $r=0.51$–$0.83$, females: $r=0.62$–$0.81$), but both stepping motions have different motion properties from the viewpoint of center of gravity sway. In Figs. 6E and F, individual differences of the average connecting time in unilateral stepping back/forth tended to be smaller at 60–69 yr than at 70–85 yr), while that in bilateral stepping back/forth was large in both age groups. This may be the result of a difference in the difficulty of unilateral and bilateral stepping motions from the viewpoint of center of gravity sway. In short, although unilateral stepping always fixes the support leg and sets the center of gravity around it, bilateral stepping moves it to the right or left leg. Hence, the method of maintaining a stable posture differs in both stepping motions. The above suggests that the difficulty of bilateral and unilateral stepping differs, and tests should be selected based on the elderly's physical fitness level. That is, for the elderly who cannot walk independently with ease, the unilateral test may be used with safety precautions.

In conclusion, all parameters in the stepping test have good trial-to-trial reliability. In all stepping tests, the number of steps tends to decrease, and the average connecting time and the bilateral connecting time become shorter with age. The number of steps relates fairly well to average connecting time but poorly to bilateral connecting time. The difference of the stepping strategy reflects differences in the bilateral connecting time and may differ by sex. The relationships of number of steps and the average connecting time between back/forth and right/left stepping are very good. Therefore, we can select either stepping motion (right/left or back/forth). There were significant correlations between average connecting times in bilateral and unilateral stepping motions. Either motion can be selected according to the subject's physical fitness level because both motions differ in difficulty.

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