J. Phys. Ther. Sci.
25: 901–903, 2013

Effect of Aging on Seated Stepping Variability

Shinya Ogaya[1,2)*], Yumi Higuchi[1)], Masao Tanaka[2)], Satoshi Fuchioka[1)]

[1)] *Division of Physical Therapy, Department of Comprehensive Rehabilitation, Osaka Prefecture University: 3-7-30 Habikino, Habikino-shi, Osaka 583-8555, Japan. TEL: +81 72-9502111, FAX: +81 72-9502130*

[2)] *Division of Bioengineering, Department of Mechanical Science and Bioengineering, Graduate School of Engineering Science, Osaka University*

Abstract. [Purpose] Accuracy in coordinating limb movements decreases with aging. The effect of aging on the variability of cyclic movements is not well known. The aim of this study was to examine the effect of aging on seated stepping variability. [Subjects and Methods] Twenty-six healthy young adults and 15 healthy elderly adults were instructed to walk at their preferred speed. Foot contact was monitored using reflective markers. Seated stepping was performed on force plates. The participants synchronized their stepping with 6 different metronome beats: 90–140 beats per minute (bpm). The time-series coefficient of variation (CV) was calculated. [Results] The cadence of young adults was 121 steps/min and that of the elderly adults was 125 steps/min in the elderly adults. The seated stepping CV decreased gradually from 90 to 120 bpm, but sharply increased at 130 and 140 bpm. Compared to young adults, the elderly adults had significantly higher CVs of seated stepping; however, the intergroup difference in the CV of seated stepping at 120 bpm was negligible. [Conclusions] Our results suggest that the stepping accuracy of the elderly is decreased; however, the rhythmic seated stepping accuracy does not decrease at the same rate as gait.

Key words: Aging, Stepping, Variability

(This article was submitted Feb. 20, 2013, and was accepted Mar. 20, 2013)

INTRODUCTION

Repetitive movements have a fluctuating motor output rhythm. A number of studies have examined gait variability with repetitive cyclical movements[1–6)]. Studies examining the effect of aging on gait variability show that the stride time variability of gait increases with age[1, 7)]. This variability may reflect neural motor control, but the mechanism underlying the increase in the variability of cyclical movements is currently not well known.

Previous studies have revealed that gait variability is minimal at a self-selected speed and increases at speeds that are faster or slower than the selected speed[8)]. Danion examined the variability of reciprocal aiming movements of the center of pressure during standing, and showed that minimal variability of the center of pressure excursion occurred at 0.6 Hz[9)]. These results imply that the variability of human cyclic movements decreases at a certain rate. Cyclic movements at a faster or slower rhythm would require more frequent adjustments of limb movement with consequent increases in movement variability. On the basis of this concept, elderly people with decreased limb coordination may show increased variability of cyclic movement at rhythms faster or slower than their preferred rhythm.

Cyclical movements (i.e., stepping or gait) have a common preferred rhythm for repetitive limb movements[9–11)]. This may be automatically controlled by the central pattern generator (CPG)[12, 13)]. Nonpreferred rhythms require cognitive commands to adjust the movement speed. The aim of this study was to investigate the effects of aging on seated stepping variability.

SUBJECTS AND METHODS

Twenty-six young adults (9 males and 17 females, age 20.2 ± 2.1 years, height 1.63 ± 0.08 m, weight 55.9 ± 8.2 kg) and 15 elderly adults (2 males and 13 females, age 74.4 ± 6.8 years, height 1.63 ± 0.08 m, weight 55.9 ± 8.2 kg) participated in this study. All the study participants were healthy and had no major neurological or musculoskeletal medical conditions. Table 1 shows the study participants' anthropometric data. This study was approved by the local ethics committee. All participants signed an informed consent form before participating in the study.

Gait parameters were recorded using VICON three-dimensional motion analysis system (Oxford metrics, UK). Six infrared cameras were used to track reflective markers that were attached to the participants' bodies. The timing of foot-to-floor contact in seated stepping was recorded using two synchronized force plates (AMTI Inc, USA) at sampling frequency of 100 Hz.

The experiment consisted of 2 parts: gait measurement by the motion analysis system and measurement of seated stepping by force plates. For gait measurement, 2 reflective markers were attached to the participants' left and

*To whom correspondence should be addressed.
E-mail: ogaya@rehab.osakafu-u.ac.jp

Table 1. Gait parameters

	Young adults	Elderly
Velocity (m/min)	76.4 ± 7.8	79.1 ± 10.2
Stride length (m)	0.63 ± 0.06	0.63 ± 0.05
Cadence (steps/min)	120.7 ± 6.9	125.0 ± 8.2
Gait CV (%)	4.6 ± 1.6	5.8 ± 1.4*

Values are mean ± SD
*Significant difference, $p<0.05$

right heels. They were instructed to walk at a comfortable speed around a 30-m rectangular path that included an 11-m straight walkway. Five sequential foot contacts in the middle of the straight section of the walkway were recorded during each circuit. The first circuit was regarded as a practice walk, and data were collected during the second to fourth circuits.

Seated stepping measurements were obtained with the study participants seated in a chair with 2 force plates under their feet. The participants were instructed to synchronize the stepping of both feet to the beat of an electronic metronome (TM-40; Korg Inc., Japan) for 20 s. Six metronome rates were used: 90, 100, 110, 120, 130, and 140 beats per minute (bpm). The order of the metronome rates was randomized in the test.

The gait parameters that were analyzed were velocity, stride length, cadence, and coefficient of variation (CV) of gait stride (i.e., gait CV). Foot contact time was determined using the peak vertical acceleration, which was calculated from the position data of the reflective markers. After smoothing with a 50-ms sliding time window, the time to reach peak acceleration was determined from the foot contact. The stride duration between two consecutive foot contacts was measured, then the gait CV was calculated. The stride length and cadence were also calculated from the position data of the reflective markers.

Seated stepping parameters that were calculated from the force plate data were the CV. The foot contact time was defined as the time that the measured force was greater than 10 N. Stepping data were recorded from the initiation of stepping. To examine the stable phase, the initial 6 contacts were discarded, and the following 11 sequential steps were analyzed. The interval between 2 consecutive foot contacts was measured and established as the stepping duration. The 10 stepping durations between the 11 consecutive foot contacts were measured. The stepping CV was then calculated.

The gait parameters in the 2 groups were compared using t test. Two-way analysis of variance (ANOVA) was used to determine the effect of the metronome rate and the effect of the age of the participants in the two groups on their stepping interval variability. For all analyses, a value of $p<0.05$ was considered statistically significant.

RESULTS

Gait parameters are shown in Table 1. The gait CV was significantly greater in the elderly group, but there was no significant intergroup difference in cadence, stride length, or velocity.

Table 2. The seated stepping coefficient of variation (CV) at each metronome rate

	Metronome rate	Young adults	Elderly
CV (%)	90 bpm	5.01 ± 2.39	6.18 ± 2.50
	100 bpm	4.98 ± 1.96	5.83 ± 2.64
	110 bpm	4.69 ± 2.08	5.51 ± 1.49
	120 bpm	5.02 ± 1.76	5.28 ± 1.74
	130 bpm	5.02 ± 2.32	7.77 ± 3.27
	140 bpm	5.36 ± 2.76	7.23 ± 2.88

Values are mean ± SD
There were significant differences between the groups ($p<0.05$), between the metronome rates ($p<0.01$), and in their interaction effect ($p<0.01$).

Table 2 shows the seated stepping CV. Two-way ANOVA showed a significant difference between the 2 groups, between the metronome rates, and in their interaction effects. For the elderly, the CV decreased gradually from 90 bpm to 120 bpm, but then showed a sharp increase at 130 and at 140 bpm. In the young adults, the CV showed relatively little change among the metronome rates. All CV rates were higher for the elderly than the young adults. The difference was particularly significant at 130 bpm and 140 bpm.

DISCUSSION

The stepping CVs changed significantly between the 2 groups and between the metronome rates. The increase in the stepping CVs of seated stepping of the elderly group showed that the elderly had greater fluctuations in rhythm than the young group. The CVs were also correlated with the metronome rate. Minimal variability was recorded at 120 bpm, but variability increased at rates that were either slower or faster than 120 bpm. A significant interaction between the effects of aging and rates was observed; however, at 120 bpm, the seated stepping CV of the elderly did not increase. These results show that the ability to coordinate limb movements with a stipulated rhythm decreases with age, but the ability to coordinate limb movement with gait rhythm does not decrease.

Stepping CVs were typically correlated with the metronome rate and had minimal variability at 120 bpm, but showed increased variability at rates that were slower or faster than 120 bpm. Previous studies that investigated gait variability found a U-shaped correlation between cadence and variability, and reported that the minimum variability occurred close to the preferred gait rate[3, 14]. Our results imply that changes of the time variability in seated stepping and gait are similar. In addition to the similarity in the curve pattern, the minimum seated stepping CV at 120 bpm was close to that of the gait cadence.

The gait CV was increased significantly of the elderly adults, but there were no significant differences in cadence, stride length, or velocity between two groups. Grabiner examined the gait parameters of healthy elderly individuals who were approximately 75 years old and found that the subjects' stride time variability increased significantly, but their velocity remained unchanged[2]. It is likely that the increase in gait CV with aging is not accompanied by a change in gait velocity.

Seated stepping CV would correlate with the gait CV if seated stepping and gait shared a common mechanism of motor output rhythm. In this study, the gait CV increased at 120 bpm but the seated stepping CV did not increase. This may be because gait CV of the elderly was not 120 steps/min but was relatively faster at 125 steps/min. An alternative explanation is that increased gait variability may be caused by demands of balance controlling the gait posture. The present study, which compared seated stepping and gait, did not find increased variability with aging.

This study did not address how the characteristics of the study participants vary in accordance with gender and race. This aspect requires further investigation in light of individual cadence parameters. A rate of 120 bpm reportedly corresponds to Japanese gait cadence[15]; however, cadence can be influenced by gender or race[15, 16]. In European studies, cadence was reported as 100–115 steps/min at subjects' preferred gait speed[17, 18]. Whether a preferred stepping rate coincides with gait cadence is worth investigating. This is the first report to measure seated stepping CV, but it is unclear how the results of the seated stepping method contribute to everyday functioning. Our results limited to documenting the functional importance.

The most consistent finding of this study was that the variability of the seated stepping time was influenced by the stepping rate. The stepping CV of the elderly study participants significantly increased, but the CV showed no increase at 120 bpm. This 120 bpm rhythm was at the same rhythm as that of their gait. Increased variability of seated stepping with aging was dependent on the movement rate.

REFERENCES

1) Callisaya ML, Blizzard L, Schmidt MD, et al.: Ageing and gait variability—a population-based study of older people. Age Ageing, 2010, 39: 191–197. [Medline] [CrossRef]
2) Grabiner PC, Biswas ST, Grabiner MD: Age-related changes in spatial and temporal gait variables. Arch Phys Med Rehabil, 2001, 82: 31–35. [Medline] [CrossRef]
3) Danion F, Varraine E, Bonnard M, et al.: Stride variability in human gait: the effect of stride frequency and stride length. Gait Posture, 2003, 18: 69–77. [Medline] [CrossRef]
4) Hartmann A, Murer K, de Bie RA, et al.: Reproducibility of spatio-temporal gait parameters under different conditions in older adults using a trunk tri-axial accelerometer system. Gait Posture, 2009, 30: 351–355. [Medline] [CrossRef]
5) Hollman JH, McDade EM, Petersen RC: Normative spatiotemporal gait parameters in older adults. Gait Posture, 2011, 34: 111–118. [Medline] [CrossRef]
6) Menz HB, Latt MD, Tiedemann A, et al.: Reliability of the GAITRite® walkway system for the quantification of temporo-spatial parameters of gait in young and older people. Gait Posture, 2004, 20: 20–25. [Medline] [CrossRef]
7) Plummer-D'Amato P, Altmann LJ, Reilly K: Dual-task effects of spontaneous speech and executive function on gait in aging: exaggerated effects in slow walkers. Gait Posture, 2011, 33: 233–237. [Medline] [CrossRef]
8) Holt KJ, Jeng SF, Rr RR, et al.: Energetic cost and stability during human walking at the preferred stride velocity. J Mot Behav, 1995, 27: 164–178. [Medline] [CrossRef]
9) Danion F, Duarte M, Grosjean M: Variability of reciprocal aiming movements during standing: the effect of amplitude and frequency. Gait Posture, 2006, 23: 173–179. [Medline] [CrossRef]
10) Sternad D, Dean WJ, Newell KM: Force and timing variability in rhythmic unimanual tapping. J Mot Behav, 2000, 32: 249–267. [Medline] [CrossRef]
11) Hausdorff JM: Gait variability: methods, modeling and meaning. J Neuroeng Rehabil, 2005, 2: 19. [Medline] [CrossRef]
12) Zehr EP: Neural control of rhythmic human movement: the common core hypothesis. Exerc Sport Sci Rev, 2005, 33: 54–60. [Medline]
13) Zehr EP, Balter JE, Ferris DP, et al.: Neural regulation of rhythmic arm and leg movement is conserved across human locomotor tasks. J Physiol, 2007, 582: 209–227. [Medline] [CrossRef]
14) Yamasaki M, Sasaki T, Torii M: Sex difference in the pattern of lower limb movement during treadmill walking. Eur J Appl Physiol Occup Physiol, 1991, 62: 99–103. [Medline] [CrossRef]
15) Sato H, Ishizu K: Gait patterns of Japanese pedestrians. J Hum Ergol (Tokyo), 1990, 19: 13–22. [Medline]
16) Finley FR, Cody KA: Locomotive characteristics of urban pedestrians. Arch Phys Med Rehabil, 1970, 51: 423–426. [Medline]
17) Garcia RK, Nelson AJ, Ling W, et al.: Comparing stepping-in-place and gait ability in adults with and without hemiplegia. Arch Phys Med Rehabil, 2001, 82: 36–42. [Medline] [CrossRef]
18) Auvinet B, Berrut G, Touzard C, et al.: Reference data for normal subjects obtained with an accelerometric device. Gait Posture, 2002, 16: 124–134. [Medline] [CrossRef]