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Original Article

A study on balance assessment according to the levels of difficulty in postural control

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Abstract. [Purpose] This study aimed to determine appropriate measures for assessing balance ability according to difficulty level during standing tasks. [Subjects and Methods] The subjects were 56 old (>65 years) and 30 young (20–30 years) adults. By using the Berg balance scale, the subjects were divided into three groups: 29 healthy older (Berg score≥52), 27 impaired older (Berg score≥40), and 30 healthy young (Berg score≥55). One inertial measurement unit sensor was attached at the waist, and the subjects performed standing tasks (1 min/task) with six difficulty levels: eyes open and eyes closed on firm ground, one foam, and two foams. Thirty-nine (24 time-domain, 15 frequency-domain) measures were calculated by using acceleration data. The slope of each derived measure was calculated through the least-squares method. [Results] Five (95% ellipse sway area, root mean squares [anterior-posterior and resultant directions], and mean distance [anterior-posterior and resultant directions] in time domain) of the 39 measures showed significant differences among the groups under specific standing conditions. The slopes of derived measures showed significant differences among the groups and significant correlations with the Berg scores. [Conclusion] The slope according to the difficulty level can be used to assess and discriminate standing balance ability.
Key words: Balance ability, Levels of difficulty, Least-squares method

INTRODUCTION

With aging, the balance ability usually decreases and the risk of falls increases. To assess balance ability, various standing tasks such as reducing the base of support, diminishing visual feedback or proprioceptive feedback, and performing secondary cognitive tasks have been used in previous studies[1, 2]. Postural sway by using various tasks has been applied to the study of falls and several neurodegenerative diseases, e.g., Parkinson's disease and dementia. The clinical utility of postural sway as an objective and quantitative measure of balance and postural instability has been discussed[3]. Especially, various time- and frequency-domain measures are used to determine the characteristics of decreased balance ability through the comparison of healthy young and elderly or faller and non-faller individuals[4–6]. However, some studies that investigated these parameters have shown difficulties in discriminating patients with Parkinson's disease and those with concussion, among individuals with poor postural balance control[7, 8]. Those parameters yield inconsistent results even for the same standing tasks and similar subject groups[9, 10]. Therefore, judging individual balance ability or discriminating impaired balance by using only specific standing tasks is problematic. In contrast, it has been reported that the differences in measured variables were more distinct during standing tasks that required greater balance ability (i.e., tandem stance, standing on a foam surface with eyes open or closed) than simple standing tasks (i.e., standing on a firm surface with eyes open or closed)[11–13]. Therefore, a difference in balance ability may be detected by increasing the difficulty level in standing tasks. Thus, results during standing task with various difficulty levels should be monitored, rather than specific standing tasks, to analyze the appropriate measures

for discriminating and reflecting individual balance ability.

Thus, this study aimed to determine appropriate measures for assessing balance ability according to standing tasks with various levels of difficulty. For this purpose, three groups of adults (healthy young, healthy older, and impaired balance older) with different levels of balance ability participated in this study, and each subject performed standing tasks with various levels of difficulty. Various measures (time- and frequency-domain measures) for the analysis of the measured postural sway during the tasks were used to identify measures for discriminating the balance ability of each group.

SUBJECTS AND METHODS

To investigate the discriminative ability of various measures, three groups were used. The subjects were 56 old (>65 years) and 30 young (20–30 years) adults. By using the Berg balance scale (BBS)[14], the elderly were divided into two groups: 29 healthy older (HO, BBS≥52, with normal balance ability and living independently) and 27 impaired older (IO, BBS≥40, with impaired balance ability and living independently)[11]. Healthy young (HY) adults were those with a BBS score of ≥55. The BBS, which has a maximum score of 56, consists of 14 tasks. A higher value indicates a higher balance ability. The subjects could walk>10 m without gait assistance; scored>24 points on the Mini-Mental State Examination, Korean version; did not have diabetes; and were not taking any medication that affects balance ability. Table 1 shows the characteristics of the subjects. The protocol of this study was approved by the ethics committee of the university. Before the experiment, the experimental procedures were explained to all subjects, and written informed consent was received.

The Clinical Test of Sensory Interaction with Balance (CTSIB)[15] was used to assess standing posture. The original test included six conditions: (i) standing with eyes open on a firm surface (EO), (ii) standing with eyes closed on a firm surface (EC), (iii) standing with a visual conflict dome on a firm surface, (iv) standing with eyes open on a foam surface (EO-1foam), (v) standing with eyes closed on a foam surface (EC-1foam), and (vi) standing with a visual conflict dome on a foam surface. However, the CTSIB was modified because the conditions with the visual conflict dome (conditions iii and vi) yielded scores that did not differ significantly from those obtained under conditions without the dome[16]. The modified CTSIB (mCTSIB)[16] consists of four conditions: (i) EO, (ii) EC, (iii) EO-1foam, and (iv) EC-1foam, in which the foam (50 × 50 × 7.5 cm) was made of sponge. In this study, to assess balance ability with various levels of difficulty, two new tasks, standing with eyes open on two foams (EO-2foam) and eyes closed on two foams (EC-2foam), were added to the mCTSIB. The trials were randomized, and sufficient rest was provided to participants between trials for stabilization of the given posture. A wireless inertial measurement unit sensor module (APDM Inc., Portland, OR, USA) was attached on the posterior trunk at the L5 level, near the body center of mass. Acceleration signals of the sensor were collected with a 128-Hz sampling frequency, and filtered with a 3.5-Hz cutoff, zero-phase, low-pass Butterworth filter[12]. Data were collected during six tasks (1 min/task). A total of 39 measures consisting of 24 time-domain (jerk; mean distance; root mean square [RMS]; path length; range of acceleration; mean velocity and mean frequency in the anteroposterior [AP], medio-lateral [ML], and resultant [Res]) directions; total sway area; 95% circle sway area; and 95% ellipse sway area in two-dimensional space [AP, ML]) and 15 frequency-domain (total power; median frequency; 95% power frequency; centroidal frequency; and frequency dispersion in the AP, ML, and Res directions) measures[12] were calculated by using acceleration data in the AP, ML, and Res directions measured by using the sensor module.

One-way between-subjects analysis of variance was performed on the 39 measures from six standing tasks, and Scheffe's post hoc analysis ($p<0.05$) was used to identify measures with discriminative ability according to the level of difficulty (HY vs. HO, HY vs. IO, HO vs. IO). Pearson's correlation coefficient between each derived measure and BBS according to level of difficulty was calculated ($p<0.05$). The slope of each derived measure was calculated by using the least-squares method (LSM). The LSM facilitates estimation of the overall trend of data points, and the slope of the LSM was used to demonstrate the degree of changes between the levels of difficulty and individual balance ability. Thus, a difference in slope indicates a difference in balance ability. The slope was defined by using the alternate Romberg ratio (aRR) as the x-axis and each of the 39 measures as the y-axis. aRR is the modified Romberg ratio and calculated as follows:

$$\frac{\text{Eyes closed (EC) measure} - \text{eyes open (EO) measure}}{\text{EC measure} + \text{EO measure}} \times 100$$

aRR has the advantage of a greater consistency between consecutive tests than the traditional Romberg ratio[13]. In this

Table 1. Subjects' characteristics

	N	Age (years)	Weight (kg)	Height (cm)	BBS
Healthy young	30	22.7 ± 2.1	63.7 ± 13.5	170.5 ± 10.4	55.9 ± 0.3
Healthy older	29	76.6 ± 4.9	61.2 ± 10.2	157.1 ± 8.9	53.3 ± 1.1
Impaired older	27	76.2 ± 6.2	58.8 ± 9.3	153.5 ± 7.3	48.2 ± 3.2

Mean ± SD. BBS: Berg balance scale

study, aRR was calculated by changing the EC measure to the EO-1foam, EC-1foam, EO-2foam, and EC-2foam measures, respectively. The slope was used to identify significant differences among the groups and correlations with BBS. All statistical analyses were performed in SPSS v. 19 (SPSS Inc., Chicago, IL, USA), and computational analysis was performed by using MATLAB v. 7.7 (The MathWorks Inc., Natick, MA, USA).

RESULTS

Five (95% ellipse sway area, RMS [AP, Res], and mean distance [AP, Res] in time domain) of the 39 measures showed significant differences among the groups for the specific standing condition (Table 2). Moreover, there were significant differences among the groups and significant correlations with BBS for the EC-2foam condition. As a result, the standing task with a high level of difficulty showed discriminative ability between groups and was correlated with the BBS score ($r=-0.52$ to -0.47).

The slope of derived measures was also calculated by using the LSM (Table 3). The slope of all measures increased in the order HY, HO, and IO. The greater the increase in aRR, the greater the gaps among the groups. Thus, as the balance ability decreased, the absolute value of derived measures increased rapidly according to the level of difficulty. As shown in Table 3, the slopes of derived measures indicated significant differences among the groups and correlations with the BBS score, and there existed a more negative correlation with BBS ($r=-0.64$ to -0.57) than the correlation shown in Table 2 ($r=-0.52$ to -0.47).

DISCUSSION

In this study, a 1-min static standing task was carried out to assess balance ability with six levels of difficulty; that is, two additional levels of difficulty compared with the mCTSIB. By using the BBS, the subjects were divided into three groups (HY, HO, and IO). In the study by Martinez-Mendez et al.[17], the difference in postural sway between HY and HO was investigated. Postural sway was measured at the waist (L3 level) by using a tri-axial accelerometer under two standing conditions (eyes open and closed), and a total of 59 measures in the time and frequency domains were calculated by using acceleration data. Thirty subparameters detected differences according to age with eyes open, and 18 with eyes closed. In Liu et al.'s study[18], resultant acceleration was used to analyze differences among the HY, HO, and fall-prone old (faller) groups under three conditions: EO (standing with feet open as the subjects felt comfortable), EO with feet together, and EC (with feet open as the subjects felt comfortable). There were no significant differences in all variables among the groups. However, in Greene et al.'s study[19], a significant difference was found in acceleration and the RMS of acceleration under EO and EC between fallers and non-fallers. Owing to the difference in the subjects, the findings of this study cannot be directly compared with those of previous studies; however, several measures were found to have discriminative ability among the three groups

Table 2. Discriminative measures and correlation coefficients with BBS

	Measure (unit)	Axis	Correlation coefficient (r)					
			EO-firm	EC-firm	EO-1foam	EC-1foam	EO-2foam	EC-2foam
Time domain	95% Ellipse sway area (m^2/s^4)	2D	−0.51*	−0.45*	−0.48*	**−0.52***	−0.56*	**−0.48***
	RMS (m/s^2)	AP	−0.41*	−0.39*	−0.38*	−0.45*	−0.56*	**−0.49***
		Res	−0.45*	−0.42*	−0.42*	−0.48*	−0.59*	**−0.52***
	Mean distance (m/s^2)	AP	−0.40*	−0.39*	−0.37*	−0.44*	−0.53*	**−0.47***
		Res	−0.45*	−0.43*	−0.42*	−0.47*	−0.57*	**−0.51***

BBS: Berg balance scale; RMS: root mean square; 2D: two-dimensional space (AP, ML); AP: anteroposterior; ML: medio-lateral; Res: resultant. *Significant at the 0.05 level (two-tailed). Bold: significant difference among the groups.

Table 3. Slopes of derived measures and correlation coefficients with BBS

	Measure (unit)	Axis	The slope of LSM (mean ± SD)			Correlation coefficient (r)
			HY	HO	IO	
Time domain	95% Ellipse sway area (m^2/s^4)	2D	0.0016 ± 0.0003	0.0028 ± 0.0003	0.0045 ± 0.0003	−0.63*
	RMS (m/s^2)	AP	0.0017 ± 0.0001	0.0023 ± 0.0001	0.0029 ± 0.0001	−0.60*
		Res	0.0020 ± 0.0001	0.0026 ± 0.0001	0.0034 ± 0.0001	−0.64*
	Mean distance (m/s^2)	AP	0.0014 ± 0.0001	0.0018 ± 0.0001	0.0023 ± 0.0001	−0.57*
		Res	0.0017 ± 0.0001	0.0021 ± 0.0001	0.0028 ± 0.0001	−0.62*

BBS: Berg balance scale; LSM: least-squares method; 2D: two-dimensional space (AP, ML); AP: anteroposterior; ML: medio-lateral; Res: resultant. *Significant at the 0.05 level (two tailed)

according to age and impaired balance. In particular, five derived measures (95% ellipse sway area, RMS [AP, Res], and mean distance [AP, Res] in time domain) showed significant differences among the groups and significant correlations with the BBS score for the EC-2foam condition. The results of the time-domain measures showed that the derived measures were in the AP and Res directions, not the ML direction. Thus, AP sway exceeded ML sway during a comfortable stance, likely owing to stabilization of the ML sway by the hip-width stance[20]. The slopes of the derived measures from the LSM had a more negative correlation with the BBS scores ($r = -0.64$ to -0.57) than those reported previously ($r = -0.52$ to -0.47) according to the difficulty level, and increased in the order HY, HO, and IO. Thus, as the balance ability increased, the slope of the derived measures decreased according to the difficulty level. In Mancini et al.'s study[12], it was observed that while standing, there was a correlation between acceleration measures and clinical postural stability score, and between the center of pressure and sway area, RMS, and mean distance (0.68–0.74). The sway area, RMS, and mean distance derived in this study showed reliable (0.70–0.84) intraclass correlation values[12]. Thus, the slopes of five derived measures according to difficulty level can be used as a quantitative measure of balance ability, and for quantifying the effect of rehabilitation and treatment for loss of balance ability. However, the findings of this study are limited in terms of the causes of balance loss-related clinical problems other than balance ability. Further work should involve the analysis of subjects with various diseases and disabilities, and the application of diverse methods of analysis of changes in postural sway other than time- and frequency-domain measures.

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