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Original Article

Fall- and BBS-related differences in muscle strength and postural balance of the elderly

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Abstract. [Purpose] The purpose of this study was to compare the differences in muscle strength and postural balance between fallers and non-fallers. We also compared the difference between normal and impaired balance groups using the same subjects and the same variables. [Subjects and Methods] Seventy-one healthy elderly females (age: 75.1 ± 75 years; weight: 57.3 ± 57 kg; height: 150.1 ± 15 cm) who had high levels of physical activity participated [25 fallers (FG) vs. 46 non-fallers (NG); and 52 healthy balance group (HBG) and 19 impaired balance group (IBG) subjects]. To compare the groups, the muscle strengths of 9 muscle groups, and 20 variables of the instrumented standing balance assessment (2 area variables, 9 time-domain variables, and 9 frequency-domain variables) were assessed. [Results] The FG and NG could only be categorized based on the frequency-domain variables of the instrumented standing balance assessment. On the other hand, there were significant differences between HBG and IBG in height, 6 muscle strength, and 2 time-domain variables of the instrumented standing balance assessment. [Conclusion] These results suggest that muscle strength and standing balance are reflected in physical balance ability (i.e., BBS); however they are in sufficient for determining the actual occurrence of falls.
Key words: Fall assessment, Muscle strength, Physical balance

INTRODUCTION

In the elderly population, falls are the main reason for declining activity levels and death. Although various approaches to prevent falls have been considered, the reality is that the detection and prevention of falls remains inadequate. Generally, falls are thought to be closely related to age-related declines in muscle strength and physical balance[1, 2].

The Berg balance scale (BBS) is one of many methods used for assessing physical balance. It has the advantages of yielding highly reproducible results and being relatively simple[3]. Previous research has suggested that the BBS can be useful for detecting falls. However, the method has limitations because it yields a subjective value that is provided by an evaluator, and especially in relation to fall detection, its relevance has only been reported for the elderly with deteriorated physical abilities, such as multiple fallers and stroke survivors[4–6].

Recently, various sensors have been used to assess postural balance and falls[7–9]. The advantages of this approach are that it allows quantification of the existing subjective and fragmentary assessment methods such as measurements of performance time, and it enables the extraction of various factors and the application of novel nonlinear analyses. When conducting clinical tests of sensory interaction in balance (CTSIB), used in the standing balance assessment, an inertial sensor is attached to the subject's body in an attempt to analyze the subject's movement trajectory, and time-domain and frequency-domain variables can be calculated from the recorded data[8, 10].

Therefore, by comparing the physical characteristics, muscle strength, and postural balance of the elderly who demon-

Table 1. Physical characteristics and MMSE-K of the faller (FG) and non-faller (NG) groups, and of the healthy balance (HBG) and impaired balance (IBG) groups

	Fallers (n=25)	Non-fallers (n=46)	HBG (n=52)	IBG (n=19)
Age (years)	75.8 (5.8)	74.6 (5.4)	74.6 (5.8)	76.3 (4.8)
Height (cm)	149.5 (5.3)	150.5 (4.8)	151.5 (4.7)*	147.8 (5.0)*
Weight (kg)	55.6 (7.8)	58.3 (8.7)	57.1 (8.0)	57.9 (9.7)
MMSE-K	25.8 (1.3)	25.5 (2.2)	25.7 (2.2)	25.5 (1.4)
BBS	51.3 (2.6)	51.8 (2.8)	52.9 (1.4)*	48.2 (2.6)*

HBG: healthy balance group (BBS>50), IBG: impaired balance group (BBS≤50) Mean (SD); *Significant difference between groups (p<0.05)

strate high activity levels in their daily life, it should be possible to determine the variables that affect the occurrence of falls and the level of physical balance ability. This study took an important step toward this goal by attempting to categorize elderly subjects into faller and non-faller groups based on their physical characteristics, muscle strengths, and instrumented standing balance assessments. The differences between normal and impaired balance groups using the same subjects and the same variables were also compared.

SUBJECTS AND METHODS

Seventy-one elderly females with high activity levels in their daily life, who were recruited from a local senior citizens' center in Chungju city, South Korea, were the subjects of the present study (Table 1). The subjects were selected after considering their medical history (e.g. cardiovascular problems, neurological disorders of the vestibular or cerebellar systems and history of lower-limb or spinal surgery in the previous 12 months) and health conditions (e.g. no problems with communication and regular cognition, a mini-mental state examination-Korean version (MMSE-K) score >24, and no use of an assistive walking device such as cane, crutch or walker). According to a report by the World Health Organization (WHO), "Falls are commonly defined as inadvertently coming to rest on the ground, floor or other lower level, excluding intentional change in position to rest in furniture, wall or other objects"[11]. This definition was used in the present research.

All subjects completed the MMSE-K and the BBS tests. To compare the groups according to falls, and balance using a reference BBS score of 50 points, muscle strength and postural balance were measured. The protocol of this study was approved by the Ethics Committee of Konkuk University. Before the experiment, all experimental procedures were explained to all of the subjects and their written informed consent was received.

To measure the muscle strength, we used a hand-held dynamometer (Citec, CIT technics BV, Groningen, Netherlands) to measure the maximal voluntary isometric muscle strength of nine muscle groups (grip force, three-point grip, hip abductors, hip flexors, knee extensors, knee flexor, foot dorsiflexors, foot plantar flexors, hallux plantar flexors)[12]. The measured muscle strength was normalized using each subject's height and weight, as shown in the equation below[13]:

$$\text{Normalized muscle strength} = \frac{strength\,(kg)}{height\,(m) \times weight\,(kg)} \times 100$$

Standing balance was assessed with the eyes closed while standing on foam for 1 min, which is a part of the CTSIB, and the results were used to evaluate postural balance in this experiment. The foam (50 × 50 × 7.5 cm) was made of sponge. An APDM sensor module (APDM Inc., Portland, OR, USA) was attached to the subject's waist during the test. According to a previous study, this method is reliable for standing balance assessment, and can be used for clinical balance and mobility tests[14]. Twenty variables including two sway area measures [total sway area and 95% ellipse sway area in two-dimensional space (AP, ML)], nine time-domain measures [root mean square (RMS), mean velocity, and mean frequency in the anterioposterior (AP), medio-lateral (ML), and resultant (Res) directions] and nine frequency-domain measures (mean frequency, total power, and median frequency in the AP, ML, and Res directions) were calculated using the tri-axial acceleration data recorded at a sampling frequency of 128 Hz.

The independent t-test was used to compare variables between the faller group and non-faller group, and between the healthy balance group (HBG) and impaired balance group (IBG). The SPSS software ver. 23 (SPSS Inc., Chicago, IL, USA) was used and the level of significance was chosen as p=0.05.

RESULTS

Table 1 presents the subjects' physical characteristics, MMSE-K score, and BBS score, for the faller and non-faller groups. There were no significant differences between the faller and the non-faller groups, but the HBG and IBG groups showed a significant difference in height (p=0.014).

Table 2 presents the results of muscle strength measurements. There were no significant differences between the faller

Table 2. Normalized isometric muscle strengths of the faller (FG) and non-faller (NG) groups, and of the healthy balance (HBG) and impaired balance (IBG) groups

	Fallers (n=25)	Non-fallers (n=46)	HBG (n=52)	IBG (n=19)
Grip	65.9 (25.5)	58.3 (18.8)	64.6 (21.5)*	51.0 (18.7)*
Three point grip	59.2 (22.7)	57.8 (17.1)	62.3 (17.2)*	47.2 (20.2)*
Hip abductors	81.1 (36.6)	80.0 (29.8)	83.3 (32.4)	72.6 (30.6)
Hip flexor	65.7 (24.4)	58.9 (16.4)	64.3 (19.7)*	53.2 (17.8)*
Knee extensors	72.4 (34.1)	66.8 (18.1)	71.4 (25.4)	61.8 (61.8)
Knee flexor	35.4 (12.2)	35.0 (11.3)	36.1 (12.1)	32.5 (9.5)
Foot dorsiflexors	65.1 (16.7)	66.2 (13.3)	68.2 (13.7)*	59.2 (14.8)*
Foot plantar flexor	99.1 (28.7)	92.3 (17.8)	99.7 (21.7)*	81.2 (18.4)*
Hallux plantar flexors	82.6 (28.2)	78.1 (18.0)	84.1 (21.0)*	67.7 (20.8)*

HBG: healthy balance group (BBS>50), IBG: impaired balance group (BBS≤50)
Mean (SD); Unit: normalized score=[muscle strength(kg)/{height(m)×weight(kg)}]×100%
*Significant difference between groups ($p<0.05$)

Table 3. Results of instrumented standing balance assessments of the faller (FG) and non-faller (NG) groups, and of the healthy balance (HBG) and impaired balance (IBG) groups

	Fallers (n=25)	Non-fallers (n=46)	HBG (n=52)	IBG (n=19)
Total sway area	0.012 (0.010)	0.011 (0.010)	0.010 (0.010)	0.017 (0.015)
95% ellipse area	0.127 (0.088)	0.110 (0.088)	0.102 (0.088)	0.154 (0.119)
RMS (AP)	0.140 (0.045)	0.121 (0.045)	0.121 (0.045)	0.146 (0.058)
RMS (Res)	0.148 (0.047)	0.131 (0.047)	0.129 (0.047)*	0.157 (0.060)*
RMS (ML)	0.048 (0.017)	0.046 (0.021)	0.044 (0.021)*	0.054 (0.021)*
Mean velocity (AP)	0.604 (0.0312)	0.479 (0.263)	0.504 (0.263)	0.574 (0.337)
Mean velocity (Res)	0.650 (0.307)	0.539 (0.539)	0.560 (0.266)	0.628 (0.336)
Mean velocity (ML)	0.170 (0.074)	0.174 (0.115)	0.174 (0.115)	0.169 (0.110)
Mean distance (AP)	0.110 (0.034)	0.095 (0.035)	0.096 (0.035)	0.113 (0.043)
Mean distance (Res)	0.123 (0.037)	0.108 (0.038)	0.108 (0.038)*	0.129 (0.046)*
Mean distance (ML)	0.037 (0.013)	0.035 (0.016)	0.034 (0.016)*	0.043 (0.017)*
Mean frequency (AP)	0.418 (0.121)	0.471 (0.142)	0.455 (0.142)	0.447 (0.159)
Mean frequency (Res)	0.433 (0.120)	0.481 (0.126)	0.466 (0.126)	0.459 (0.145)
Mean frequency (ML)	0.758 (0.186)	0.823 (0.258)	0.807 (0.258)	0.781 (0.275)
Total power (AP)	12.152 (8.304)	12.815 (13.843)	11.001 (13.843)	16.909 (18.186)
Total power (Res)	6.814 (4.505)	6.096 (6.347)	5.521 (6.347)	8.615 (8.775)
Total power (ML)	1.809 (1.491)	2.030 (2.133)	1.716 (2.133)	2.597 (2.238)
Median frequency (AP)	0.367 (0.074)	0.373 (0.082)	0.375 (0.082)	0.359 (0.074)
Median frequency (Res)	0.408 (0.408)*	0.467 (0.103)*	0.444 (0.103)	0.452 (0.096)
Median frequency (ML)	0.548 (0.278)	0.557 (0.259)	0.556 (0.259)	0.547 (0.296)

HBG: healthy balance group (BBS>50), IBG: impaired balance group (BBS≤50); Mean (SD);
Unit: Total sway area (m^2/s^5), 95% ellipse area (m^2/s^4), RMS (m/s^2), mean velocity (m/s),
mean distance (m), mean and median frequency (Hz), total power (m/s^2) $^2 \times Hz^{-1}$
*Significant difference between groups ($p<0.05$)

and non-faller groups, but there were statistically significant differences between the HBG and IBG groups in terms of their grip, three-point grip, hip flexor, foot dorsiflexors, foot plantar flexor, and hallux plantar flexor strengths: p=0.018, p=0.003, p=0.034, p=0.018, p=0.002, and p=0.005, respectively.

Table 3 presents the instrumented parameters of the standing balance assessment. A statistically significant difference (p=0.018) between the fallers and non-fallers was observed in the median frequency (Res). Between the HBG and IBG, there were significant differences in the RMS (Res), RMS (ML), Mean Dist. (Res), and Mean Dist. (ML): p=0.028, p=0.034, p=0.039, and p=0.029, respectively.

DISCUSSION

Research related to falls considers the deterioration of postural balance in the elderly as the main reason underlying falls, and focuses on this phenomenon for detecting falls. The BBS is widely used for assessing the physical balance of the elderly. Although the BBS uses the sum of evaluator's subjective scores, its accuracy and reproducibility in the assessment of balance has been reported[3]. Based on this, various attempts have been made to apply the BBS to fall detection, which is closely related to physical balance. However, when examining the existing methods of fall detection that utilize the BBS, the effectiveness of this approach has only been observed for categorizing the elderly with very low activity levels as fallers and non-fallers, such as those receiving stroke rehabilitation or multiple-times fallers[4, 5]. When applied to the active elderly, the BBS showed considerably less accuracy than is the case for the inactive elderly[15].

In this study, the same 71 subjects were divided into groups based on whether or not they had experienced falls (FG vs. NG) and also on their postural balance (HBG vs. IBG), and we compared the physical characteristics, muscle strength, and postural balance of the pairs of groups. The faller and non-faller groups could only be distinguished by a frequency-domain variable derived from the standing balance assessment; other variables displayed no significant differences between the groups. The BBS, which is often used as a tool for evaluating the general physical balance ability was especially unhelpful for separating the two groups (p=0.445). Thus, the active and healthy elderly could not be categorized as fallers and non-fallers by using the BBS score alone, a result that is consistent with the results of previous research[5, 15]. The comparison of the HBG and IBG groups, that were divided according to the BBS, confirmed differences between the groups in terms of subjects' height, 6 muscle strengths, and 2 time-domain variables of the standing balance assessment. These results suggest that while height, muscle strength, and time-domain variables of the standing balance assessment are reflected in the BBS, this method is not suitable for the actual detection of fallers.

From these results, it can be seen that by relying on fragmentary muscle strength measurements and BBS, the classification and prediction of falls, which are a complex interplay of neuro-musculo-skeletal and psychological factors, is not possible. The practical conclusion is that a variety of sensors should be employed simultaneously for the elucidation of time-domain and frequency-domain variables. This implies that further research is needed to develop methods and to identify variables (such as frequency-domain and nonlinear variables) that can provide information regarding the intrinsic characteristics of neuro-musculo-skeletal systems. In addition, the physical characteristics of individuals and specific fall scenarios should be categorized using these variables.

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REFERENCES

1) Cho SI, An DH: Effects of a fall prevention exercise program on muscle strength and balance of the old-old elderly. J Phys Ther Sci, 2014, 26: 1771–1774. [Medline] [CrossRef]

2) Rubenstein LZ: Falls in older people: epidemiology, risk factors and strategies for prevention. Age Ageing, 2006, 35: ii37–ii41. [Medline] [CrossRef]

3) Downs S, Marquez J, Chiarelli P: The Berg Balance Scale has high intra- and inter-rater reliability but absolute reliability varies across the scale: a systematic review. J Physiother, 2013, 59: 93–99. [Medline] [CrossRef]

4) Blum L, Korner-Bitensky N: Usefulness of the Berg Balance Scale in stroke rehabilitation: a systematic review. Phys Ther, 2008, 88: 559–566. [Medline] [CrossRef]

5) Muir SW, Berg K, Chesworth B, et al.: Use of the Berg Balance Scale for predicting multiple falls in community-dwelling elderly people: a prospective study. Phys Ther, 2008, 88: 449–459. [Medline] [CrossRef]

6) Neuls PD, Clark TL, Van Heuklon NC, et al.: Usefulness of the Berg Balance Scale to predict falls in the elderly. J Geriatr Phys Ther, 2011, 34: 3–10. [Medline]

7) Giné-Garriga M, Guerra M, Manini TM, et al.: Measuring balance, lower extremity strength and gait in the elderly: construct validation of an instrument. Arch Gerontol Geriatr, 2010, 51: 199–204. [Medline] [CrossRef]

8) Boulgarides LK, McGinty SM, Willett JA, et al.: Use of clinical and impairment-based tests to predict falls by community-dwelling older adults. Phys Ther, 2003, 83: 328–339. [Medline]

9) Hubble RP, Naughton GA, Silburn PA, et al.: Wearable sensor use for assessing standing balance and walking stability in people with Parkinson's disease: a systematic review. PLoS One, 2015, 10: e0123705. [Medline] [CrossRef]

10) Chaikeeree N, Saengsirisuwan V, Chinsongkram B, et al.: Interaction of age and foam types used in Clinical Test for Sensory Interaction and Balance (CTSIB). Gait Posture, 2015, 41: 313–315. [Medline] [CrossRef]

11) WHO: WHO global report on falls prevention in older age. Geneva: World Health Organization, 2007. http://www.who.int/ageing/publications/Falls_prevention7March.pdf.

12) Merlini L, Mazzone ES, Solari A, et al.: Reliability of hand-held dynamometry in spinal muscular atrophy. Muscle Nerve, 2002, 26: 64–70. [Medline] [Cross-

Ref]

13) Spink MJ, Fotoohabadi MR, Menz HB: Foot and ankle strength assessment using hand-held dynamometry: reliability and age-related differences. Gerontology, 2010, 56: 525–532. [Medline] [CrossRef]

14) Mancini M, Salarian A, Carlson-Kuhta P, et al.: ISway: a sensitive, valid and reliable measure of postural control. J Neuroeng Rehabil, 2012, 9: 59. [Medline] [CrossRef]

15) Santos GM, Souza AC, Virtuoso JF, et al.: Predictive values at risk of falling in physically active and no active elderly with Berg Balance Scale. Rev Bras Fisioter, 2011, 15: 95–101. [Medline] [CrossRef]