J. Phys. Ther. Sci. 30: 1086–1091, 2018

The Journal of Physical Therapy Science

Original Article

Dynamic balance assessment using an unstable board in community-dwelling elderly people

Kazunori Akizuki, RPT, PhD[1)*], Yuki Echizenya, RPT, MS[2)], Tatsuya Kaneno, OTR, MS[3)], Jun Yabuki, RPT, MS[4)], Yukari Ohashi, RPT, PhD[5)]

[1)] *Department of Physical Therapy, Faculty of Rehabilitation, Kobe International University: 9-1-6 Koyouchou, Higashinada-ku, Kobe-shi, Hyogo 658-0032, Japan*
[2)] *Saitama Rehabilitation Center, Japan*
[3)] *Department of Occupational Therapy, Faculty of Health Sciences, Mejiro University, Japan*
[4)] *Ibaraki Prefectural University of Health Sciences Hospital, Japan*
[5)] *Department of Physical Therapy, Ibaraki Prefectural University of Health Sciences, Japan*

Abstract. [Purpose] A new method for measuring dynamic balance was developed. The aim of this study was to describe the use of a novel "unstable board" to evaluate the balance ability of community-dwelling elderly individuals. [Participants and Methods] The following balance outcomes were evaluated in 59 community-dwelling elderly people: anteroposterior and mediolateral stability indexes on the unstable board, Mini-Balance Evaluation Systems Test score, the Functional Reach Test score, Timed Up-and-Go time, and the Figure-8 Walk Test time. [Results] With respect to the relationship between the stability indexes and functional balance scales, the anteroposterior stability index significantly correlated with the anticipatory postural adjustment component ($r=-0.422$), stability in the gait component ($r=-0.274$), and total score of the Mini-Balance Evaluation Systems Test ($r=-0.316$); timed up-and-go time ($r=0.320$); and figure-8 walk test time ($r=0.340$). No correlation was found between the mediolateral stability index and the functional balance scale scores. [Conclusion] The anteroposterior stability index correlated with the declines in postural adjustments and performance in the dynamic balance assessments. Therefore, the anteroposterior stability index, evaluated on an unstable board, could provide an efficient tool for predicting changes in dynamic balance capacity, which could not be identified using the most commonly used balance assessment tools.

Key words: Dynamic balance, Unstable board, High-functioning elderly

(This article was submitted Apr. 10, 2018, and was accepted May 15, 2018)

INTRODUCTION

Approximately one-third of community-dwelling adults over the age of 65 years fall at least once a year[1, 2]. Moreover, increasing age is correlated with an increase in the number and severity of falls[3], with almost 50% of falls among community-dwelling older adults leading to fall-induced injuries[4]. Age-related balance deficits are a major risk factor for falls[5, 6]. Clinically, the Berg Balance Scale (BBS), the Functional Reach Test (FRT) and the Timed Up-and-Go test (TUG) have been widely used to evaluate patients with balance deficits[7–9]. These tests are commonly used as screening tools for early identification of individuals with decreases in balance capacity, allowing interventions to be implemented in an effort to lower the likelihood of a fall[10, 11]. However, Brauer et al. found that BBS scores were close to the upper limit of the scale for individuals with and without a history of falling, indicating that the BBS may not be appropriate to predict falls for community-dwelling older adults[12]. Similarly, among a cohort of community-dwelling, high-functioning, elderly individuals, current clinical tests of balance were not sufficiently responsive at the upper end of their scale to differentiate individuals

*Corresponding author. Kazunori Akizuki (E-mail: akizuki@kobe-kiu.ac.jp)

at a higher risk of falling[13].

Force platforms have been effectively used among elderly individuals to detect early signs of deteriorating balance abilities that are not distinguished by functional balance tests[14–16]. Prospective studies have reported that an increase in the displacement of the center of pressure (COP) during quiet standing was predictive of the risk of falling[17–19]. In particular, it has been reported that measurements incorporating dynamic elements, such as perturbation and leaning movements, provide greater responsiveness to identify declines in dynamic balance with aging than static balance activities[20]. Similarly, another study reported that measurements of balance control obtained under challenging conditions, such as incorporating more dynamic elements, was more effective than measures of static sway to detect early declines in balance capacity[21]. Rather than measuring the COP displacement, Biodex (Shirley, NY, USA) has developed a system that measures an individual's ability to control the position of his or her COP on an unstable surface that can tilt up to 20° in multiple directions[22, 23].

However, both force platforms and the Biodex balance system are expensive and will only be affordable in select facilities. In addition, these tools are impractical, if not impossible, to use in the community, which limits assessment of balance capacity to hospitals, universities, and research laboratories, rather than in local environments, which would be preferable. To address this specific issue, we developed a new method to measure dynamic balance, which mimics the Biodex balance system but uses relatively inexpensive equipment that is highly portable. Our aim in this study was to investigate the relationship between dynamic balance capacity measurements obtained with our novel "unstable board" and existing dynamic balance indices currently in broad use in physical therapy.

PARTICIPANTS AND METHODS

Sixty-four participants were recruited from areas around Mejiro University using the following inclusion criteria: age ≥65 years; independent walking without the need of any supporting equipment; and able to come to the study venue independently. Prospective participants were screened on the basis of the following exclusion criteria: history of serious orthopedic, cardiovascular, or neurological diseases or impairment; pain that might affect their capacity to perform test items; and a Mini-Mental State Examination (MMSE) score <24. All participants provided written informed consent. The study was approved by the institutional review board at Mejiro University (approval number: 17-004).

A quantitative measure of participants' capacity to maintain stability in a standing position was obtained using the unstable board (DYJOC BOARD, SAKAI Medical Co., Ltd.) fitted with a small 3-axes accelerometer and a 3-axes gyro sensor (multi sensor θ, SAKAI Medical Co., Ltd.). The board has a dimension of 300 × 500 × 30 mm, with 2 semicircular bosses (φ 160 × 60 mm) attached to the rear of the platform. For this study, we attached the 2 bosses to restrict the tilt movement to a single direction for testing, either in an anteroposterior (AP) direction or a mediolateral (ML) direction (Fig. 1). In addition, the maximum tilt angle of the unstable board was fixed at 12° for both the AP and ML directions by inserting boards under the left and right or front and back sides of the unstable board, respectively, when measuring the anteroposterior stability index (APSI) and mediolateral stability index (MLSI) (Fig. 2). The inclination of the unstable board, measured by the combined accelerometer and gyro sensor, was transmitted to a personal computer via a dedicated data logger (Data Logger, SAKAI Medical Co., Ltd.). The APSI and MLSI were calculated using analysis software (MS DYJOC, SAKAI Medical Co., Ltd.) and the following formulae:

$$APSI = \sqrt{\frac{\Sigma(0-y)^2}{n}}$$

$$MLSI = \sqrt{\frac{\Sigma(0-x)^2}{n}}$$

In the above formulae, y represents the degree of tilt in the AP plane and x represents that in the ML plane, with n being the number of samples (sampling frequency, 100 Hz). Because the given stability index reflects the change in the inclination of the unstable board per unit time, the larger the value, the greater the degree of fluctuation.

Participants were instructed to stand on the board with their feet placed shoulder width apart, with their arms along the side of the body, and to maintain the position of the unstable board as parallel to the floor as possible. Participants were asked to fix their gaze on a focal point placed 1 m in front of them and adjusted to eye level for each participant. All measurements were obtained with shoes removed. Participants completed three 20-s trials in both the AP and ML directions. The order of measurement was counterbalanced between participants, eliminating any learning effects.

The participants underwent the Mini-Balance Evaluation Systems test (Mini-BESTest)[24], FRT[25], TUG[26], and Figure 8 Walk Test (F8W)[27] as functional balance tests. The Mini-BESTest consists of 14 items designed to assess dynamic balance in 4 categories: anticipatory postural adjustments (APA), reactive postural responses (PR), sensory orientation (SO), and stability in gait (SG)[24]. Each item is scored on a scale from 0 to 2, with a maximum score of 6 for anticipatory postural adjustments, reactive postural responses, and sensory orientation, and a maximum score of 10 for gait stability, with a total

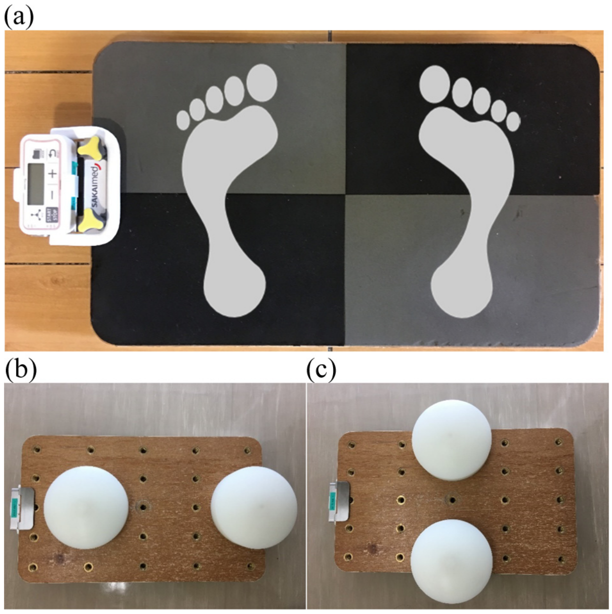

Fig. 1. An unstable board.
(a) A small 3-axes accelerometer and a 3-axes gyro sensor used during this study. The small measuring device was attached to the left side of the unstable board. (b) Positioning of the bosses during APSI measurement. (c) Positioning of the bosses during MLSI measurement.
APSI: anterior-posterior stability index; MLSI: medial-lateral stability index.

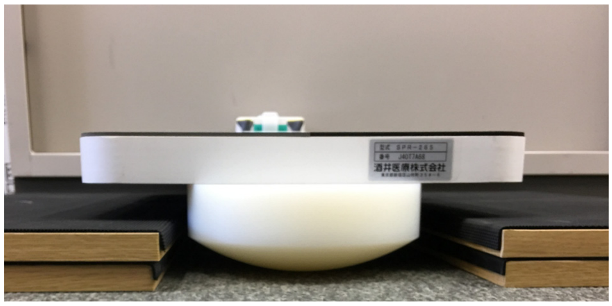

Fig. 2. Adjustment of the maximum angle of inclination.
The maximum angle of inclination was modified because the different lengths of the long and short sides of the unstable board were both restricted to 12° by inserting plates with different heights under the long and short sides. In the figure, 2 boards (3.5 cm) were inserted under the long edges of the unstable board to restrict its inclination angle.

possible score of 28, with higher scores indicative of better balance. The tests were performed in a random order.

For the purpose of this study, a "fall" was defined as "an unexpected event in which the participants come to rest on the ground, floor, or lower level"[28]. Participants were asked to report the number of falls they had experienced over the previous year. We excluded falls resulting from extraordinary environmental factors.

Descriptive statistics (mean, standard deviation [SD], 95% confidential interval [CI]) were calculated for all variables measured. To clarify the relationship between dynamic balance capacity measurements obtained with our novel "unstable board" and existing dynamic balance indices, we calculated Pearson's correlation coefficients between the stability indices for each direction of incline and the outcome of functional balance tests. The Mini-BESTest results used during these calculations included not only participants' total scores, but also their scores for each subsection. Statistical analyses were performed using SPSS (Version 24; IBM Corp., Armonk, NY, USA). The level of statistical significance was set at 5%.

RESULTS

Of the 64 participants who satisfied our inclusion criteria, 3 were excluded because of a subsequent diagnosis of knee osteoarthritis, and 2 others were excluded because of acute onset back pain. All measurements were obtained for the remaining 59 participants. The average age of our study participants was 70.5 years (SD; 3.5 years), with an average height of 161.4 cm (SD; 8.7 cm), body weight of 60.7 kg (SD; 11.9 kg), BMI of 23.2 kg/m^2 (SD; 3.5 kg/m^2), and MMSE score of 28.6 (SD; 1.8). The study group included 21 females (35.6%), and 9 participants (15.3%) had experienced a fall during the previous year. However, no participant had experienced multiple falls.

Measured outcomes for the APSI, MLSI, and clinical balance tests are reported in Table 1. The APSI and MLSI had comparable values (6.82 and 6.54, respectively). With regard to the Mini-BESTest, some of the scores approached the maximum value for each subscale and for the total score. To evaluate the prevalence of a ceiling effect, the proportion of participants who attained the maximum score on each subscale and on the total score was calculated: APA, 41/59 participants (69.5%); PR, 16/59 participants (27.1%); SO, 55/59 participants (93.2%); SG, 7/59 participants (11.9%); total score, 1/59 participants (1.7%).

Table 2 summarizes the relationship between the APSI/MLSI and the functional balance index. A significant correlation was observed between the APSI and the APA component of the Mini-BESTest, SG component of the Mini-BESTest, total Mini-BESTest score, Timed Up-and-Go, and the Figure 8 Walk Test time. The MLSI did not correlate with any measure of functional balance.

Table 1. Results of functional balance tests (n=59)

	Mean (SD)	95% CI
APSI	6.82 (1.30)	6.48–7.15
MLSI	6.54 (1.00)	6.27–6.80
Mini-BESTest APA (0–6)	5.61 (0.67)	5.44–5.78
Mini-BESTest PR (0–6)	4.44 (1.29)	4.10–4.78
Mini-BESTest SO (0–6)	5.92 (0.34)	5.82–6.00
Mini-BESTest SG (0–10)	8.53 (1.07)	8.25–8.80
Mini-BESTest Total (0–28)	24.49 (2.20)	23.92–25.06
FRT (cm)	30.20 (4.10)	29.14–31.27
TUG (sec)	8.38 (0.96)	8.13–8.63
F8W time (sec)	7.59 (1.00)	7.33–7.86
F8W steps (n)	13.64 (1.46)	13.26–14.02

APSI: anterior-posterior stability index; MLSI: medial-lateral stability index; Mini-BESTest: Mini Balance Evaluation Systems Test; APA: anticipatory postural adjustments; PR: postural responses; SO: sensory orientation; SG: stability in gait; FRT: Functional Reach Test; F8W: Figure 8 Walking Test; TUG: Timed Up-and-Go.

Table 2. Correlation between APSI/MLSI and balance indices (n=59)

	APSI	MLSI
	r	r
Mini-BESTest APA	−0.422**	−0.220
Mini-BESTest PR	−0.047	0.114
Mini-BESTest SO	−0.173	−0.071
Mini-BESTest SG	−0.274*	−0.214
Mini-BESTest Total	−0.316*	−0.115
FRT (cm)	0.083	0.067
TUG (sec)	0.320*	0.054
F8W time (sec)	0.340**	0.054
F8W steps (n)	−0.030	−0.212

APSI: anterior-posterior stability index; MLSI: medial-lateral stability index; Mini-BESTest: Mini Balance Evaluation Systems Test; APA: anticipatory postural adjustments; PR: postural responses; SO: sensory orientation; SG: stability in gait; FRT: Functional Reach Test; F8W: Figure 8 Walking Test; TUG: Timed Up-and-Go.
*p<0.05, **p<0.01.

DISCUSSION

In this study we identified a significant correlation between the APSI and functional balance indices. Interestingly, while Maki et al. reported that ML movement of the COP had a greater predictive value to differentiate individuals at risk of falling than the AP COP movement[15)], we did not identify a correlation between the MLSI and indices of functional balance. Similarly, Melzer and Kaplanski reported that older adults, who used a narrow base stance, exhibited significantly greater ML sway than older adults with no history of falling[29)]. The higher association of ML than AP sway with the incidence of falling has been reported by various other researchers[15–18, 30)]. It is important to note that other researchers have used the velocity of displacement of the COP in the AP direction to predict the risk of falling. Pajala et al. conducted balance testing, using a force platform, with 434 female participants who were 63 to 76 years old (69.2 ± 3.6 years) and prospectively evaluated the incidence of falls over the subsequent 12 months[31)]. They reported that the velocity of AP displacement COP was significantly different between participants that went on to experience a fall and those who did not. Of note, participants in Pajala et al.'s study self-selected the distance between their feet, rather than having it imposed as in other studies. In their study, Pajala et al. also included the ability to walk 2 km without assistance as an inclusion criterion and, therefore, their study targeted relatively high-functioning elderly individuals, as in our study. Moreover, the age of the participants in our study group was similar to that in Pajala et al.'s study, and the distance between the participants' feet was also approximately shoulder-width, as in our study. As participants' physical characteristics and task requirements were comparable between our study and that of Pajala et al.'s, this may explain our mutual finding of the predictive value of the AP control of the COP in predicting the risk of falling.

Difference in postural control strategies employed by the participants, depending on the direction of motion, must also be considered. Previous studies have reported that AP control of the COM is largely determined by motions of the body around the axis of rotation of the ankle and hip joints, while the ML control of the COM is controlled primarily by the hip joints and trunk in the ML direction[32, 33)]. Moreover, for control of the COM in the AP direction, the hip strategy is predominantly used, with the ankle strategy being further recruited as necessary, with the relative contributions of the hip and ankle strategies varying between participants[34)]. In contrast, the COM in the ML direction is primarily controlled by the abductor and adductor muscles[35)]. Within the context of our task on the unstable board, participants with sufficient balance control were likely able to control AP fluctuations in the position of the unstable board via an ankle strategy. If the ankle strategy was insufficient, the hip would be recruited. As the hip joint strategy causes larger reaction movements in the position of the COM than the ankle strategy[36)], the resulting fluctuations in the position of the COM would increase, creating a condition of instability to be controlled in addition to the unstable board. This likely explains our findings of a significant correlation between the APSI and functional balance indices. In contrast, for postural control tasks in the MP direction, the effect of the control strategy employed by the participant was believed to be more difficult to detect because larger hip and trunk movements are exhibited from the start to compensate for the movements of the unstable board. As a result, it appeared that there was no significant correlation between the MPSI and the dynamic balance indices.

Because this study only included participants who were capable of attending the assessment sessions at the university on their own, we deem our study sample to be high functioning, with only 9 of the 59 participants having experienced a fall in the previous year. Therefore, we were unable to conduct a retrospective assessment to differentiate individuals with and without a history of previous falls. However, the purpose of our study was to characterize the dynamic balance capacity of the elderly using a newly-developed method, and as a result, we did find that participants' dynamic balance capacity in the AP direction correlated with other balance-related indices. In the future, it will be necessary to examine the extent to which dynamic balance estimated using this method can predict falls. Moreover, this study did not examine biomechanical aspects, via electromyography or 3-dimensional motion analysis, to assess participants' ability to maintain their posture on the unstable board. Therefore, we were not able to verify our hypothesis of a force control strategy. In the future, verification of the hypotheses established through our study, using biomechanical analyses of relevant muscles and joint motion, will be needed to fully characterize the balance strategies used to control the position of the COP on the unstable board.

This study found that the unstable board was effective in measuring dynamic balance among healthy, independent, community-dwelling elderly adults. We identified a clear correlation between the APSI and indices of functional balance. We postulate that the APSI captures subtle declines in dynamic balance capacity that might affect the performance of activities of daily mobility. As such, there is a possibility that this method could provide a useful screening tool for the early identification of individuals with declining balance activities, providing the opportunity to implement interventions to limit further decline and prevent future falls.

Conflict of interest

None.

REFERENCES

1) Stevens JA: Falls among older adults—risk factors and prevention strategies. J Safety Res, 2005, 36: 409–411. [Medline] [CrossRef]
2) Lusardi MM, Fritz S, Middleton A, et al.: Determining risk of falls in community dwelling older adults: a systematic review and meta-analysis using posttest probability. J Geriatr Phys Ther, 2017, 40: 1–36. [Medline] [CrossRef]
3) Gale CR, Cooper C, Aihie Sayer A: Prevalence and risk factors for falls in older men and women: the English longitudinal study of ageing. Age Ageing, 2016, 45: 789–794. [Medline] [CrossRef]
4) Bergland A, Wyller TB: Risk factors for serious fall related injury in elderly women living at home. Inj Prev, 2004, 10: 308–313. [Medline] [CrossRef]
5) Tuunainen E, Rasku J, Jäntti P, et al.: Risk factors of falls in community dwelling active elderly. Auris Nasus Larynx, 2014, 41: 10–16. [Medline] [CrossRef]
6) Rubenstein LZ: Falls in older people: epidemiology, risk factors and strategies for prevention. Age Ageing, 2006, 35: ii37–ii41. [Medline] [CrossRef]
7) Bohannon RW, Wolfson LI, White WB: Functional reach of older adults: normative reference values based on new and published data. Physiotherapy, 2017, 103: 387–391. [Medline] [CrossRef]
8) Saso A, Moe-Nilssen R, Gunnes M, et al.: Responsiveness of the Berg Balance Scale in patients early after stroke. Physiother Theory Pract, 2016, 32: 251–261. [Medline] [CrossRef]
9) Schoene D, Wu SM, Mikolaizak AS, et al.: Discriminative ability and predictive validity of the timed up and go test in identifying older people who fall: systematic review and meta-analysis. J Am Geriatr Soc, 2013, 61: 202–208. [Medline] [CrossRef]
10) Gillespie LD, Robertson MC, Gillespie WJ, et al.: Interventions for preventing falls in older people living in the community. Cochrane Database Syst Rev, 2012, (9): CD007146. [Medline]
11) 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]
12) Brauer SG, Burns YR, Galley P: A prospective study of laboratory and clinical measures of postural stability to predict community-dwelling fallers. J Gerontol A Biol Sci Med Sci, 2000, 55: M469–M476. [Medline] [CrossRef]
13) Newton RA: Balance screening of an inner city older adult population. Arch Phys Med Rehabil, 1997, 78: 587–591. [Medline] [CrossRef]
14) Topper AK, Maki BE, Holliday PJ: Are activity-based assessments of balance and gait in the elderly predictive of risk of falling and/or type of fall? J Am Geriatr Soc, 1993, 41: 479–487. [Medline] [CrossRef]
15) Maki BE, Holliday PJ, Topper AK: A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. J Gerontol, 1994, 49: M72–M84. [Medline] [CrossRef]
16) Piirtola M, Era P: Force platform measurements as predictors of falls among older people—a review. Gerontology, 2006, 52: 1–16. [Medline] [CrossRef]
17) Bergland A, Jarnlo GB, Laake K: Predictors of falls in the elderly by location. Aging Clin Exp Res, 2003, 15: 43–50. [Medline] [CrossRef]
18) Stel VS, Smit JH, Pluijm SM, et al.: Balance and mobility performance as treatable risk factors for recurrent falling in older persons. J Clin Epidemiol, 2003, 56: 659–668. [Medline] [CrossRef]
19) Johansson J, Nordström A, Gustafson Y, et al.: Increased postural sway during quiet stance as a risk factor for prospective falls in community-dwelling elderly individuals. Age Ageing, 2017, 46: 964–970. [Medline] [CrossRef]
20) Baloh RW, Fife TD, Zwerling L, et al.: Comparison of static and dynamic posturography in young and older normal people. J Am Geriatr Soc, 1994, 42: 405–412. [Medline] [CrossRef]
21) Hageman PA, Leibowitz JM, Blanke D: Age and gender effects on postural control measures. Arch Phys Med Rehabil, 1995, 76: 961–965. [Medline] [CrossRef]
22) Arnold BL, Schmitz RJ: Examination of balance measures produced by the biodex stability system. J Athl Train, 1998, 33: 323–327. [Medline]
23) Arifin N, Abu Osman NA, Wan Abas WA: Intrarater test-retest reliability of static and dynamic stability indexes measurement using the Biodex Stability System during unilateral stance. J Appl Biomech, 2014, 30: 300–304. [Medline] [CrossRef]

24) Franchignoni F, Horak F, Godi M, et al.: Using psychometric techniques to improve the Balance Evaluation Systems Test: the mini-BESTest. J Rehabil Med, 2010, 42: 323–331. [Medline] [CrossRef]
25) Duncan PW, Weiner DK, Chandler J, et al.: Functional reach: a new clinical measure of balance. J Gerontol, 1990, 45: M192–M197. [Medline] [CrossRef]
26) Podsiadlo D, Richardson S: The timed "Up & Go": a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc, 1991, 39: 142–148. [Medline] [CrossRef]
27) Hess RJ, Brach JS, Piva SR, et al.: Walking skill can be assessed in older adults: validity of the Figure-of-8 Walk Test. Phys Ther, 2010, 90: 89–99. [Medline] [CrossRef]
28) Lamb SE, Jørstad-Stein EC, Hauer K, et al. Prevention of Falls Network Europe and Outcomes Consensus Group: Development of a common outcome data set for fall injury prevention trials: the Prevention of Falls Network Europe consensus. J Am Geriatr Soc, 2005, 53: 1618–1622. [Medline] [CrossRef]
29) Melzer I, Benjuya N, Kaplanski J: Postural stability in the elderly: a comparison between fallers and non-fallers. Age Ageing, 2004, 33: 602–607. [Medline] [CrossRef]
30) Park JW, Jung M, Kweon M: The mediolateral CoP parameters can differentiate the fallers among the community-dwelling elderly population. J Phys Ther Sci, 2014, 26: 381–384. [Medline] [CrossRef]
31) Pajala S, Era P, Koskenvuo M, et al.: Force platform balance measures as predictors of indoor and outdoor falls in community-dwelling women aged 63–76 years. J Gerontol A Biol Sci Med Sci, 2008, 63: 171–178. [Medline] [CrossRef]
32) Day BL, Steiger MJ, Thompson PD, et al.: Effect of vision and stance width on human body motion when standing: implications for afferent control of lateral sway. J Physiol, 1993, 469: 479–499. [Medline] [CrossRef]
33) Samuel A, Solomon J, Mohan D: A critical review on the normal postural control. Physiother Occup Ther J, 2015, 8: 71–75. [CrossRef]
34) Runge CF, Shupert CL, Horak FB, et al.: Ankle and hip postural strategies defined by joint torques. Gait Posture, 1999, 10: 161–170. [Medline] [CrossRef]
35) Henry SM, Fung J, Horak FB: EMG responses to maintain stance during multidirectional surface translations. J Neurophysiol, 1998, 80: 1939–1950. [Medline] [CrossRef]
36) Winter DA: Human balance and posture control during standing and walking. Gait Posture, 1995, 3: 193–214. [CrossRef]