(ISSN: 0973-7049(P))

The Bioscan
AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES

21(2): S.I (2), 22227-22240, 2026

www.thebioscan.com

PLANTAR PRESSURE DISTRIBUTION AS A BIOMECHANICAL MARKER OF BALANCE IMPAIRMENT IN NEUROLOGICAL DISORDERS: A SENSOR PLATE–BASED OBSERVATIONAL STUDY

Akash Parasher[1], Dr. Shubham Menaria[2], dr. Kapil Aggarwal[3], Dr. Deepak Lohar[4], Dr. Jafar Khan[5], Dr. Dipika Balala[6], Dr. Farukh Mohammad Pinjara[7], Dr. Kapil Vyas[8], Dr. Nilesh Patira[9], Charu Kotai[10]

[*1]M.P.Th. scholar, Pacific college of Physiotherapy, Pacific medical university, Udaipur, Rajasthan
[2]Assistant Professor, Pacific college of Physiotherapy, Pacific medical university, Udaipur, Rajasthan
[3]*Associate Professor, Department of Radiodiagnosis, Pacific Medical College & Hospital,* Pacific Medical University, Udaipur, Rajasthan, India
[4]Professor, Pacific college of Physiotherapy, Pacific medical university, Udaipur, Rajasthan
[5]Dean & HOD, Pacific college of Physiotherapy, Pacific medical university, Udaipur, Rajasthan
[6]Associate Professor, Pacific college of Physiotherapy, Pacific medical university, Udaipur, Rajasthan
[7]Professor, Pacific college of Physiotherapy, Pacific medical university, Udaipur, Rajasthan
[8]*Professor, Department of Radiodiagnosis, Pacific Medical College & Hospital,* Pacific Medical University, Udaipur, Rajasthan, India
[9]*Professor, Department of General Medicine, Pacific Medical College & Hospital,* Pacific Medical University, Udaipur, Rajasthan, India
[10]M.P.Th. scholar, Pacific college of Physiotherapy, Pacific medical university, Udaipur, Rajasthan

Corresponding author: Akash Parasher, parasharakash999@gmail.com

DOI:https://doi.org/10.63001/tbs.2026.v21.i02.S.I(2).pp22227-22240

KEYWORDS

Plantar pressure, foot biomechanics, center of pressure, sensor plate, neurological disorders, balance.

Article Info
Received: 17.05.2026

Accepted: 07.06.2026

Published: 14.06.2026

Abstract

Background: The foot is the primary interface between the body and the ground, and excessive loading of the foot is a frequent occurrence in neurological gait and balance disorders. The sensor plate technology provides objective and quantitative measurements of the plantar pressure distribution, providing data on the biomechanical mechanisms of plantar instability that is not available through observational assessment.
Objective: To evaluate plantar pressure distribution using sensor plate technology in patients with neurological disorders related to gait and balance impairment and to investigate the relationship of plantar pressure distribution with center of pressure (COP) and the combined effect of plantar pressure distribution and age on postural instability.
Methods: Fifty patients (20–70 years) with gait and balance impairment due to a neurological condition were assessed using a sensor plate for plantar pressure. The correlation and regression analyses were used to investigate the relationship between the plantar pressure, COP and age.
Results: Mean pre-evaluation plantar pressure was 348 ± 18 kPa, reducing to 298 ± 15 kPa post-evaluation ($t = 8.90$, $p < 0.001$). Plantar pressure correlated strongly and positively with COP ($r = 0.81$, $p < 0.001$). The regression analysis revealed that age and plantar pressure accounted for 68% of the variance in COP ($R^2 = 0.68$). The overall improvement of the balance related parameters was approximately 24%.
Conclusion: Elevated plantar pressure is strongly related to postural instability in neurological patients, and together with age, explains a significant amount of the variation in center of pressure, suggesting that plantar pressure may be a clinically relevant, modifiable target for balance focused rehabilitation.

INTRODUCTION

The human foot is the only mechanical interface between the body and the supporting surface during standing and walking and it is the sole point at which the entire body weight must be dynamically balanced and redistributed with each step.

Although the foot's surface area is relatively small compared to the body's weight, it must continuously adjust the location, magnitude and timing of load transmission in order to maintain the body's center of mass within the continually changing base of support. Because of this the biomechanics of plantar loading - the distribution of pressures during the static standing position and walking under dynamic loading - has significant and direct implications for whole-body postural control. Alterations in foot kinematics such as abnormal pronation or supination, asymmetrical weight bearing across the planter surface, and delayed or incomplete loading response are known factors that can contribute to gait instability [1] and are often significantly greater in neurological populations, where impaired neuromuscular control and sensory dysfunction add to the biomechanical disturbance[2].

The measurement of plantar pressure using sensor plate technology can provide information that is traditionally been inferred only indirectly derived from clinical observation of gait, in a reproducible and objective manner. The clinician who observes the patient walking can observe that the gait is asymmetrical or there is a tendency to load one limb more cautiously than the other, but this is a qualitative observation and may not be easy to quantify, track over time, or compare to a normative reference. Peak pressure and its distribution pattern are indicative of the ability of the individual to distribute the load progressively across the foot in the stance phase of gait from initial heel contact through midstance to toe-off [1]. Whittle's introductory framework for gait analysis places this loading sequence in the context of the overall loading sequence throughout the stance phase that clinicians use to interpret plantar-pressure traces [10]. This information can now be continuously and reproducibly captured during repeated clinical visits via modern sensor-plate based or wearable in-shoe systems: In-shoe systems with wearable sensors have been proven to improve gait symmetry and balance control in neurological patient population [15]; wearable sensor based training programs balance and functional performance more broadly [16]; and specific reviews of wearable fall-risk technologies have confirmed that they are sensitive to subtle changes in loading and sway which would otherwise go unnoticed by observation [17]. In stroke hemiparetic weakness is commonly associated with an asymmetrical weight – bearing with excessive loading the unaffected side disproportionately with weight transfer that is avoided on the weaker side. In Parkinson's, bradykinesia and reduced power on ankle push-off is a characteristic that causes a modified, foreshortened weight transfer during late stance. The basic dysfunction in ataxia is not weakness of the muscles, but rather the poor timing and modulation of the adjustments in posture, resulting in abnormal, poorly modulated pressure patterns, which signify cerebellar dysfunction, not weakness [8]. The three distinct loading signatures, asymmetrical in stroke, foreshortened in Parkinson's disease and irregular in ataxia, highlight the fact that this single overall measure of plantar pressure is the end-result of significantly different impairments.

This close mechanical connection between plantar loading and whole body balance is not merely descriptive and is directly related to falls risk. Elevated and asymmetrically distributed planter pressure has been associated with reduced dynamic stability, since even loading narrows the effective margins within which the body’s centre of mass can be corrected before a fall becomes unavoidable[11]. This risk is compounded by the fact that overall gait speed is already slower in individuals than the age-expected reference range [26] and is part of a spectrum of modifiable and non-modifiable fall-risk factors that have been well described in the falls prevention literature [12]. Falling events in neurological populations are at a significantly higher risk of injury and a cascade of secondary complication, such as fracture, prolonged immobility, and a subsequent cascade of dehydration, deconditioning and fear of falling; understanding the biomechanical factors of abnormal loading is not an academic exercise. It has direct implications for clinicians triage of fall risk and for targeting rehab because a patient identified as having markly elevated asymmetrical plantar pressure may be a good candidate for closer follow-up, modifiable environment, or gait-aid prescription prior to overt gait deviations identified clinically on visual assessment.

The most common outcome measure used to quantify postural sway is center of pressure (COP), which is mechanically downstream of plantar loading: the path of COP at any moment is determined by the instantaneous distribution of pressure under the feet at that moment. Based upon this, it should be expected that plantar pressure and COP should be strongly related variables, and that much of the variability of COP based measures of balance should be accounted for by the underlying distribution of plantar loading. Previous feature-selection analysis with stabilometric parameters yielded evidence that a relatively small number of force-platform derived parameters can explain a significant portion of the variance in overall postural sway [19] and direct comparison of postural steadiness in younger and older adults confirmed that this relationship is further modulated by age [18]. This is a mechanistically intuitive relationship, but intuitive plausibility is not same as empirical confirmation, and it is important to establish directly, within the single cohort, how strong this relationship is empirically confirmed and how much can be explained by including age as a factor in the relationship taken into consideration. Despite this close mechanical relationship, relatively few clinical studies have directly quantified the strength of the plantar pressure–COP relationship within a single neurological population, while even fewer have tried to model the statistical variance of postural sway that can be jointly attributed to plantar pressure and other patient-related factors such as age whose anthropometric sensitivity is well documented [7].

Age itself is well established as an independent factor associated with gait and balance impairment [4], through include that reduced muscle strength and diminished proprioceptive input [5], as well as slowed neuromuscular response time, as well as generally elevated fall risk [3]. This age-related decline is further complicated, in many patients, by a fear of falling that may develop after a single instability event and that independently restrict activity and further causes deconditioning, which can be hard to separate from the direct physiologic effects of aging alone [27]. When a neurological disorder is superimposed on this age related physiological decline, the biomechanical picture obtained will of course be multifactorial and distinguishing the relative contribution of age versus disease specific pathology to the overall instability in a patient will be difficult to do with observations alone, especially since balance and gait issues are already known to be common in older individuals without any other neurological pathology [28]. One practical approach to quantifying these relative contributions is through regression-based statistical modeling of objectively measured sensor plate variables, which can also help identify which variables are the most promising targets for intervention. A regression model that explains a substantial share the variance in COP with only age and plantar pressure as predictors would indicate that these variables, for their simplicity, accounted for a large proportion of what influences postural instability in this population — a result that is relevant to the assessment and treatment priorities in clinical practice.

From a rehabilitation perspective, planter pressure is, in principle, a modifiable target. Unlike age, which cannot be altered or the underlying neurological pathology, which may be only partially remediable, the compensatory loading strategies that result in abnormal plantar pressure patterns – widened base of support, shortened step length, and the loading of the limbs asymmetrically – are at least partially modifiable with targeted physiotherapy intervention [13]. Such wearable, sensor-assisted balance and gait rehabilitation programs have been shown to be effective in measurable improvements in these parameters [14], and biofeedback based methods, specifically, have been shown to improve gait symmetry and functional mobility in neurological populations [15]. The core and trunk strengthening exercises which support much of this compensatory control have also been shown to have a direct effect on postural stability [22], and structured postural stability and muscle strengthening programs generally are known to be an integral part of fall prevention practice [23]. Plantar pressure is a variable which is especially clinically relevant to characterize objectively: understanding its distribution can not only help quantify the severity of a patient's impairment, but also a potential target of a mechanical, modifiable abnormality to direct rehabilitation. Therefore, plantar pressure has a unique and clinically useful position among all the balance-related outcome measures because it is close to the underlying biomechanics and can therefore be directly influenced by the application of physiotherapy technique, while it is at the same time objective and quantifiable and can be measured reliably throughout the treatment process.

Despite clinically relevant, literature investigating plantar pressure specially as distinct from more general gait parameters in a diagnostically mixed neurological cohort is still limited, and there are few studies investigating plantar pressure in conjunction with a statistical model that also accounts for age as a covariate. The present study was therefore designed to quantify, using sensor plate technology, the plantar pressure distribution in patients with gait and balance impairment due to Parkinson's disease, stroke, multiple sclerosis, or ataxia and examine the relationship between plantar pressure and center of pressure, and model, by regression analysis, the combined role of plantar pressure and age in overall postural instability.

MATERIAL AND METHOD

Research Design: Observational study

Study Setting: Pacific Medical College and Hospital, Bedla, Udaipur, Rajasthan.

Study Population: Male and female patients, aged 20-70 years,with gait and balance impairment secondary to a neurological disorder.

Sample Design: Purposive sampling

Sample Size: 50 participants

Study Duration: One year

Inclusion Criteria

- Gait and balance disorders caused by any neurological problem.
- Willingness to provide informed consent
- Age 20–70 years

Exclusion Criteria

- Cancer
- Spinal trauma or amputation.
- Systemic inflammatory disorders
- Pregnancy or open wound
- Use of NSAIDs, anticoagulants, or steroid medication
- High-degree burns

Outcome Measures

Plantar Pressure Distribution: Pre- and post-evaluation recorded with a foot sensor plate in Kilopascals (kPa), which represents the magnitude and distribution of loading on the plantar surface of the foot.

The Center of Pressure (secondary/relational variable): The COP values were recorded simultaneously in the same cohort and were analyzed statistically for the relationship between the plantar loading and postural sway and included as dependent variables in regression analysis alongside a age and planter pressure as predictors.

Procedure

All participants were screened for inclusion and exclusion criteria described above. Eligible participants were informed about the study protocol and provided written informed consent. . All participants were then examined in a standardized manner with a foot sensor plate while COP values and planter pressure were recorded. Testing was performed in a controlled environment with standardized foot positioning, to minimize the variability of the measurement due to factors other than the participant's underlying condition. Observations were noted down for every participant and compared to demographic and diagnostic variables.

Statistical Analysis: Descriptive data (mean ± SD) were calculated for planter pressure pre and post evaluations. Within-subject change was analysed using a paired t-test. Pearson correlation was used to analyse the correlation between plantar pressure and COP. Multiple regression analyses were used to investigate the combined effect of age and plantar pressures on variance in COP. The statistical significance was set at $p<0.05$.

DATA ANALYSIS AND RESULTS

All fifty participants completed sensor plate assessment without adverse event. The demographic and diagnostic characteristics of this cohort were detailed in the accompanying Center of Pressure Outcomes Analysis of this dataset; in summary, the participants were mostly between the ages of 51 and 60, equally distributed between sexes, and most commonly had Parkinson's disease or stroke, followed multiple sclerosis and ataxia.

Table 1: Pre- and Post-Evaluation Plantar Pressure Distribution (N=50)

Parameter	Pre-Evaluation	Post-Evaluation	t-value	p-value
Plantar Pressure (kPa)	348 ± 18	298 ± 15	t = 8.90	p < 0.001

Table 2: Correlation Analysis — Plantar Pressure and Center of Pressure

Variables	r (Pearson)	Interpretation	p-value

Plantar Pressure vs COP	r = 0.81	Strong positive correlation	p < 0.001

Table 3: Regression Analysis — Predictors of Center of Pressure Variance

Predictor Variables	R^2	Interpretation	Significance
Age + Plantar Pressure → COP	0.68	68% of variance in COP explained jointly by age and plantar pressure	Significant model fit

Table 4: Overall Improvement Summary

Parameter	Pre-Evaluation	Post-Evaluation	Approximate % Improvement
Center of Pressure (mm)	21.2	16.1	~24%
Plantar Pressure (kPa)	348	298	~14%
Combined balance-parameter improvement	—	—	**~24%**

Diagnosis-wise comparison showed that the patients with multiple sclerosis demonstrated the highest plantar pressure value followed by stroke and Parkinson's disease, whereas ataxia patients had lower pressure values comparatively, which was similar to the diagnosis-wise ranking as observed for COP. All diagnostic groups showed improvement in plantar pressure following evaluation. Plantar pressure was strongly correlated with COP (r=0.81, p<0.001) and regression analysis showed that plantar pressure and age together explained a significant proportion (68%), of the variance in COP suggesting that these two variables are important co-predictors of postural instability in this cohort.The overall reduction in balance-related parameters during the entire evaluation period was approximately 24% change which is considered clinically significant in neurological rehabilitation. however, the remaining 32% of variance in COP that is not accounted for by age and plantar pressure together may also be attributable to other, unmeasured factors that may add explanatory value to a two-predictor model, including diagnosis-specific coordination deficits, medication timing relative to testing, or individual variation in compensatory strategy.

DISCUSSION

The present study investigated plantar pressure distribution objectively using the sensor plate in 50 patients with neurological gait and balance abnormality and modeled the relationship between the plantar pressure distribution and the center of pressure and age. The principal findings showed: a statistically significant reduction in plantar pressure across the evaluation periods (348kPa to 298kPa, $p<0.001$); a strong positive correlation between plantar pressure and COP ($r=0.81$); and a regression model that explained 68% of the variance in COP when age and plantar pressure were combined.

The findings are consistent with the established biomechanical knowledge that the foot is the primary load-bearing interface controlling postural control. Since COP trajectory was mechanically downstream of the instantaneous pattern of plantar loading, so the strong correlation observed here ($r=0.81$) is generally in line with the first biomechanical principles [6], and consistent with previous stabilometric feature analysis studies that highlighted the close linkage between foot-level loading and whole-body sway [19]. The diagnosis-wise pattern Multiple sclerosis patients having the highest plantar pressure values followed by stroke and Parkinson's disease, and comparatively lower values for ataxia patients is likely related to differing underlying mechanisms of gait dysfunction among the various types of diagnoses as described below: stroke-related hemiparetic asymmetry tends to produces loading values that are concentrated in identifiable but diagnosis-specific patterns[8], whereas cerebellar coordination deficit of ataxia yields irregular loading values compared to other diagnoses, and composite balance measures are not always sensitive enough to capture the pattern of ataxia[21]. As in the companion analysis of COP, this lower absolute planter pressure value in the ataxia group caution should be used in interpreting this finding as being indicative of a more severe or more mild underlying plantar-pressure-related impairment, respectively; future analyses using other pressure-distribution parameters, such as pressure-distribution variability, rather than the mean peak pressure alone, would likely characterize the ataxia group more accurately

The regression findings – that age and planter pressure jointly explain 68% of the variance in COP – carries a meaningful clinical implication. It suggest that postural instability in this neurological group not a direct result of the diagnosis, it also suggests that the postural instability in this group is due to a large extent to two factors that, in various ways, are actionable: firstly, the age itself is not an modified factor; secondly, the compensatory loading strategies that produce abnormal plantar pressure are actionable, at least in principle, a legitimate target for physiotherapy intervention[13]. Wearable , technology-assisted gait and balance training have shown measurable benefits in just these compensatory patterns [14]and biofeedback-based rehabilitation has shown to improve gait symmetry and balance control in neurological populations [15]. The redefinition of plantar pressure as a passive indicator of impairment to a potential 'modifiable mechanical lever' through which postural stability might be improved. This is consistent with the increasing literature examining technology-assisted rehabilitation, in which virtual-reality-based (VR) balance training has shown to be effective for the improvement of postural control in older adults and people with neurological disorders [24], and video-game-based interventions for postural control in multiple sclerosis [25], which provides indirect evidence for the feasibility of technology-based, plantar-pressure-driven retraining methods like those proposed here. In practice, this means that biofeedback-guided weight-shifting exercises designed to normalise abnormally high or low pressures under each foot are not only used as a secondary treatment strategy for standard balance training, but used as a major treatment strategy, especially when the sensor plate analysis indicates that patients' excessive or asymmetrical loading pressures under their feet is a major source of the overall instability compared to their age-predicted baseline.

Certain limitations should temper the interpretation of these findings.The cross-sectional, observational study does not establish causality and effect, and the regression model was statistically significant, but had a relatively small sample size compared to the number of diagnostic subgroups represented, which limits the precision in making inferences specific to the diagnosis. This is particularly relevant when the established critiques suggest that simply using clinical balance assessment tools may not be sensitive enough to distinguish the specific biomechanical mechanism responsible for a specific balance deficit [21],a limitation the present planter pressure based approach is well positioned help to address . Also, plantar pressure was measured with COP simultaneously in the study and not the experimental modification of plantar pressure through targeted intervention which produces a corresponding causal change in COP – a question that would require an intervention rather than observational design to answer directly.The regression model was also limited to two predictors; a more comprehensive model with all diagnosis, disease duration, and medication status as additional variables as covariates would account for a larger proportion of the residual variance and would represent a valuable extension of the present analysis in a larger cohort.

CONCLUSION

In the present study, the plantar pressure distribution measured objectively with the sensor plate technology was compared in 50 patients with gait and balance impairment secondary to Parkinson's disease, stroke, multiple sclerosis or ataxia, and examined its the statistical relationships of the plantar pressure distribution with center of pressure and age. A significant reduction in plantar pressure was seen throughout the evaluation period and plantar pressure had a strong correlation with the center of pressure..

The regression analysis demonstrated that age and plantar pressure combined accounted for 68% of the variance in center of pressure, which suggests that these two are significant, measurable factors in postural instability in this population. The findings supports the concept that neurological disease-induced balance impairment is multifactorial, caused by the interaction of disease-specific biomechanical distruption and physiological changes associated with age, rather than from either factor in isolation.

Because planter pressure reflects, at least in part, to compensatory loading strategies, which are potentially modifiable via physiotherapy intervention, whereas age which cannot be modified and thus makes plantar pressure an important and potentially modifiable target for rehabilitation. Diagnosis wise pattern observed, with the highest plantar pressures for patients with multiple sclerosis and relatively lower plantar pressures for patients with ataxia, also indicate that sensor plate assessment could be useful in describing condition-specific loading profiles for individualized treatment planning, but this is a descriptive pattern only, due to the small number of subjects available.

Future research using an interventional design direct influence of plantar pressure on gait change via gait retraining or biofeedback with subsequent prospective measurement of the change in plantar pressure would enable determination of whether the strong association presented here is a truly causal pathway or one that is merely associative, and would further support the use of plantar pressure–focused rehabilitation in standard neurological physiotherapy practice.

REFERENCES

1. Perry J, Burnfield JM. Gait analysis: normal and pathological function. 2nd ed. Thorofare (NJ): Slack Inc; 2010.
2. Nordin M, Frankel VH. Basic biomechanics of the musculoskeletal system. 4th ed. Philadelphia: Lippincott Williams & Wilkins; 2012.
3. Cuevas-Trisan R. Balance problems and fall risks in the elderly. Clinics in Geriatric Medicine. 2019;35(2):173-83.
4. Osoba MY, Rao AK, Agrawal SK, Lalwani AK. Balance and gait in the elderly: a contemporary review. Laryngoscope Investigative Otolaryngology. 2019;4(1):143-53.
5. Song Q, Zhang X, Mao M, Sun W, Zhang C, Chen Y, et al. Relationship of proprioception, cutaneous sensitivity, and muscle strength with the balance control among older adults. Journal of Sport and Health Science. 2021;10(5):585-93.
6. Winter DA. Human balance and posture control during standing and walking. Gait & Posture. 1995;3(4):193-214.
7. Chiari L, Rocchi L, Cappello A. Stabilometric parameters are affected by anthropometry and foot placement. Clinical Biomechanics. 2002;17(9-10):666-77.

8. Hausdorff JM. Gait dynamics in Parkinson's disease: common and distinct behavior among stride length, gait variability, and fractal-like scaling. Chaos. 2009;19(2):026113.
9. Maki BE. Gait changes in older adults: predictors of falls or indicators of fear. Journal of the American Geriatrics Society. 1997;45(3):313-20.
10. Whittle MW. Gait analysis: an introduction. 4th ed. Oxford: Butterworth-Heinemann; 2007.
11. Owings TM, Grabiner MD. Variability of step kinematics in young and older adults. Gait & Posture. 2004;20(1):26-9.
12. Lord SR, Sherrington C, Menz HB. Falls in older people: risk factors and strategies for prevention. 2nd ed. Cambridge: Cambridge University Press; 2007.
13. Woollacott MH, Tang PF. Balance control during walking in the older adult: research and its implications. Physical Therapy. 1997;77(6):646-60.
14. Horak F, King L, Mancini M. Role of body-worn movement monitor technology for balance and gait rehabilitation. Physical Therapy. 2015;95(3):461-70.
15. Bowman T, Gervasoni E, Arienti C, Lazzarini SG, Negrini S, Crea S, et al. Wearable devices for biofeedback rehabilitation: a systematic review and meta-analysis to design application rules and estimate the effectiveness on balance and gait outcomes in neurological diseases. Sensors. 2021;21(10):3444.
16. Gordt K, Gerhardy T, Najafi B, Schwenk M. Effects of wearable sensor-based balance and gait training on balance, gait, and functional performance in healthy and patient populations: a systematic review and meta-analysis of randomized controlled trials. Gerontology. 2018;64(1):74-89.
17. Chen M, Wang H, Yu L, Yeung EHK, Luo J, Tsui K-L, et al. A systematic review of wearable sensor-based technologies for fall risk assessment in older adults. Sensors. 2022;22(18):6752.
18. Prieto TE, Myklebust JB, Hoffmann RG, Lovett EG, Myklebust BM. Measures of postural steadiness: differences between healthy young and elderly adults. IEEE

Transactions on Biomedical Engineering. 1996;43(9):956-66.

19. Rocchi L, Chiari L, Cappello A. Feature selection of stabilometric parameters based on principal component analysis. Medical & Biological Engineering & Computing. 2004;42(1):71-9.
20. Nashner LM. Practical biomechanics and physiology of balance. In: Jacobson GP, Newman CW, Kartush JM, editors. Handbook of Balance Function Testing. St. Louis: Mosby; 1997. p. 261-79.
21. Mancini M, Horak FB. The relevance of clinical balance assessment tools to differentiate balance deficits. European Journal of Physical and Rehabilitation Medicine. 2010;46(2):239-48.
22. Oliva-Lozano JM, Muyor JM. Core muscle activity during physical fitness exercises: a systematic review. International Journal of Environmental Research and Public Health. 2020;17(12):4306.
23. Milton K, Varela AR, Strain T, Cavill N, Foster C, Mutrie N. A review of global surveillance on the muscle strengthening and balance elements of physical activity recommendations. Journal of Frailty, Sarcopenia and Falls. 2018;3(2):114-24.
24. Babadi SY, Daneshmandi H. Effects of virtual reality versus conventional balance training on balance of the elderly. Experimental Gerontology. 2021;153:111498.
25. Dalmazane M, Gallou-Guyot M, Compagnat M, Magy L, Montcuquet A, Billot M, et al. Effects on gait and balance of home-based active video game interventions in persons with multiple sclerosis: a systematic review. Multiple Sclerosis and Related Disorders. 2021;51:102928.
26. Bohannon RW. Comfortable and maximum walking speed of adults aged 20-79 years: reference values. Physiotherapy. 1997;83(7):364-6.
27. Merchant RA, Chen MZ, Wong BLL, Ng SE, Shirooka H, Lim JY, et al. Relationship between fear of falling, fear-related activity restriction, frailty, and sarcopenia. Journal of the American Geriatrics Society. 2020;68(11):2602-8.
28. Viswanathan A, Sudarsky L. Balance and gait problems in the elderly. Handbook of Clinical Neurology. 2012;103:623-34.