J. Phys. Ther. Sci. 37: 134–140, 2025

The Journal of Physical Therapy Science

Original Article

Foot sole two-point discrimination is not associated with dynamic standing balance in healthy adults

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Abstract. [Purpose] To evaluate the association between foot sole two-point discrimination and dynamic standing balance. [Participants and Methods] This cross-sectional, observational study included 50 healthy adults. Participants were made to stand on a firm or foam surface with eyes open or closed, and the center of pressure length was measured for static standing balance and limits of stability for dynamic standing balance. Two-point discrimination and muscle strength were assessed using the two-point discrimination test and toe grip strength, respectively. We then analyzed the association with sensory-motor assessment and standing balance. [Results] Significant differences were observed for almost all factors between static and dynamic standing balance. Two-point discrimination was associated with static standing balance, and muscle strength was associated with dynamic standing balance on a firm floor. There was no significant association between two-point discrimination and dynamic standing balance. [Conclusion] These results indicate that foot sole two-point discrimination is not directly associated with dynamic standing balance in healthy adults. Therefore, postural stability must be evaluated considering the specific floor surfaces and sensory conditions in clinical situations, and assessment of dynamic standing balance based only on two-point discrimination should be avoided.

Key words: Standing balance, Two-point discrimination, Muscle strength

(This article was submitted Oct. 15, 2024, and was accepted Dec. 26, 2024)

INTRODUCTION

Standing balance is important for activities of daily living such as walking and reaching. Although many different theories have been suggested, standing balance is generally classified into static and dynamic standing balance[1)].

Static standing balance represents the ability to stand unsupported controlling the center of mass without voluntary weight shift when the base of support (BOS) does not change by keeping both feet on the floor[2)]. With static standing balance, the center of pressure (COP) must be kept in a comfortable position within the BOS during quiet standing. COP length represents the trajectory of COP displacement as recorded on a force platform, and is commonly used for balance quantification[3)]. In healthy adults, the smaller the COP length, the more stable the static standing balance.

Dynamic standing balance involves a voluntary COP shift. Dynamic standing balance represents the ability to weight shift, controlling the center of mass within the BOS[2)]. In dynamic standing balance, the limits of stability (LOS) test measures

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volitional control of the center of gravity[4]. LOS tests have been applied in clinical studies with Parkinson's disease patients, young children, and the elderly[5–7]. The larger the LOS, the more stable the dynamic standing balance.

Regarding the association between static and dynamic balance, Hrysomallis et al. reported that performance in the static balance test was not reflective of performance in the dynamic balance test[8]. Karimi and Solomonidis[9] and Sell[10] likewise found no correlations between static and dynamic postural measures. Few reports have considered associations between static and dynamic standing balance.

Various factors are associated with standing balance, including cognitive, sensory, motor, and environmental factors. Lord et al. reported that quadriceps strength, touch, and vibration senses were predictors for static standing balance[11]. Muscle strength and sensory functions have thus been considered important indicators for static standing balance.

Regarding muscle strength, a systematic review and meta-analysis by Muehlbauer et al. revealed weak correlations between measures of balance and muscle strength of the lower extremity in children, adolescents, and young, middle-aged, and old adults[12].

For sensory functions, an upright bipedal stance is described as depending on sensory information from the visual, somatosensory, and vestibular systems[13]. The clinical test of sensory integration and balance (CTSIB) was developed by Shumway–Cook and Horak to evaluate sensory contributions to balance[14]. The CTSIB evaluates static postural stability under six distinct standing conditions: with eyes open, with eyes closed, and with the use of a dome to alter visual inputs on both firm and foam surfaces[15]. The modified CTSIB (mCTSIB) was created because visual inputs from the dome were considered no different from the eyes-closed condition[16] The mCTSIB includes only four sway measures expressed with eyes open and eyes closed on firm and foam surfaces. The mCTSIB is the most popular method to explore the relative contributions of the somatosensory, visual, and vestibular systems to balance[17]. Lord et al. reported correlations between sensory assessments and static standing balance using the mCTSIB, and most sensorimotor system measures were significantly associated with all sway measures[11]. In addition, estimates of the relative contributions of the visual, somatosensory, and vestibular systems to postural stability were calculated using sway measures[11]. Di Berardino et al. also reported on sensory ratios based on the mCTSIB[18]. Lord et al. reported the somatosensory system as the most important system in the maintenance of static postural stability[19].

While previous studies have revealed associations between sensory systems and static standing balance, associations between sensory systems and dynamic standing balance have not been elucidated. We rely on our sensory systems in daily life not only during static situations, but also in dynamic situations. For example, we perform voluntary COP movements during stepping and reaching in daily activities, relying on sensory inputs from the visual, somatosensory, and vestibular systems. In the present study, we assumed that for the sensory system, especially the somatosensory system, it would be desirable to conduct a two-point discrimination test (TPD) so that the participant can delicately self-recognize the range of COP movement. We hypothesized that TPD would be associated with dynamic standing balance not only during static standing balance. The aim of this study was to evaluate associations between TPD and dynamic standing balance. Clarification of such associations would allow the optimization of exercises for improving dynamic standing balance during daily life.

PARTICIPANTS AND METHODS

This investigation was a cross-sectional observational study. Participants stood on a force plate under four conditions following the mCTSIB[15]. We then measured COP length and LOS. In addition, participants performed the TPD and measurement of toe grip strength (TGS) in the sitting position to assess discrimination ability at the plantar level and muscle strength to control plantar pressure. Each participant performed all measurements in a single day. Inclusion criteria were healthy adult males and females in their 20s to 30s who were able to hold a quiet standing posture with eyes closed and feet together on a foam rubber surface for 60 seconds. Exclusion criteria included psychiatric disorders, diabetes, orthopedic or peripheral nerve disease of the lower extremities, cranial nerve disease, history of otorhinolaryngological consultation for vertigo-related symptoms, and medications that affect cognitive function (e.g., sleeping pills, antidepressants, central nervous system depressants). This study was conducted with the approval of the ethics committee of the Geriatrics Research Institute (Gunma, Japan, approval no. 98). Participants were informed of the study in writing and orally, and written consent was obtained. Fifty participants were included in this study. The variables used in this study were basic background information (age, sex, height, and weight), TPD and TGS for sensorimotor assessments, COP length for static standing balance, and LOS for dynamic standing balance. TPD was measured based on previous studies[20, 21]. TPD (ball of the big toe, ball of the little toe, heel) of both feet was measured using a discriminator (NC12776; North Coast Inc., Morgan Hill, CA, USA). The discriminator was applied in the direction of the long axis of the corresponding site. The tip of the discriminator was inspected at 1-mm intervals while making two points of contact, and two correct answers of three tests was considered a correct response. To increase the accuracy of the inspection, contact was sometimes made at one point instead of two points. Measurements were calculated by averaging the values of three sites: ball of the big toe, ball of the little toe, and heel. The average of both feet was then calculated. TGS was also measured based on previous studies[22], using a toe muscle strength analyzer (Toe Strength Meter II; Takei Scientific Instruments, Niigata, Japan). TGS was measured in the sitting position with both feet. The position of the feet was adjusted to a position that was easy to grip with the toes. Each foot was measured three times, and the maximum value of the three times was averaged for the left and right feet as the index.

Static and dynamic standing balance were each measured with the force plate (Gravicorder GW-10; ANIMA, Tokyo, Japan). A total of four conditions were set: open and closed eye conditions for the visual system, and with and without foam rubber (Balance-pad Elite; SAKAImed, Tokyo, Japan) for the somatosensory system. These four conditions were performed in order of increasing difficulty: open eyes and no foam rubber (firm floor × eyes open); closed eyes and no foam rubber (firm floor × eyes closed); open eyes with foam rubber (foam floor × eyes open); and closed eyes with foam rubber (foam floor × eyes closed). The foam rubber was placed on the center of the force plate and did not touch the ground. For static standing balance, the task with open eyes was performed while the participant gazed at a mark 2 m away at eye level to minimize the effect of disturbance from the external environment. The total trajectory of COP in quiet standing barefoot on the force plate was taken as COP length, reflecting body sway in detail. We collected the path length of COP displacement in the mediolateral and anteroposterior axes. To evaluate static stability in standing balance, participants stood with feet together for 30 seconds in each condition. The sensory contribution was calculated using the inter-condition ratio of each COP length. Sensory ratios were calculated using the following formulas[18].

Sensory ratio:

Visual (Vis): (firm floor × eyes open) / (foam floor × eyes open),

Somatosensory (Som): (firm floor × eyes open) / (firm floor × eyes closed),

Vestibular (Vest): (firm floor × eyes open) / (foam floor × eyes closed),

The values obtained were converted into percentages (sensory contribution rate):

%Visual (%Vis): 100 × Vis/(Vis + Som + Vest),

%Somatosensory (%Som): 100 × Som/(Vis + Som + Vest),

%Vestibular (%Vest): 100 × Vest/(Vis + Som + Vest)

The method of measuring dynamic standing stability was based on the method of Maktof et al.[23]. To assess dynamic stability in standing balance, participants performed maximum voluntary body leaning tasks in both anteroposterior and mediolateral directions with a 10-cm width stance. The choice of which task to perform first (anteroposterior or mediolateral) was randomized. For the anteroposterior directional task, maximum voluntary body leaning to the heel for 4 seconds, maximum voluntary body leaning to the midpoint for 4 seconds, maximum body leaning to the ball of the big toe side for 4 seconds, and maximum voluntary body leaning to the midpoint for 4 seconds were performed. For the mediolateral task, the same tasks as above were performed toward the medial and lateral ball of the little toe. During voluntary body leaning, participants were conscious of the corresponding area of the foot. The midpoint was determined as the participant's subjective fixed position during static standing while monitoring the COP trajectory. These tasks were repeated three times in 60 seconds. A timekeeper counted the seconds and the participant performed the tasks accordingly.

In the voluntary body leaning task, participants were required to keep the body rigid and to rotate around the ankle joints and the foot in contact with floor. Specifically, hip flexion, upper extremity abduction, and trunk lateral flexion were limited. LOS was taken as the voluntary body leaning distance in the anteroposterior and mediolateral lengths. Mediolateral length was measured between the fifth metatarsal heads of the right and left feet, and anteroposterior length was measured between the top of the longest toe and the heel. LOS was calculated as the percentage of COP length compared to foot length.

In statistical analyses, two-way analysis of variance was performed using COP length and LOS indices for two eye conditions (open and closed eyes) × two surface conditions (with and without foam rubber). Pearson's correlation analysis was performed between sensory assessments and standing balance index. Multiple regression analysis was performed between sensorimotor assessments and standing balance. All statistical analyses were performed using SPSS version 25.0 (IBM Corp., Armonk, NY, USA), with values of $p<0.05$ considered significant.

RESULTS

Basic information, TPD, and TGS are presented in Table 1. Mean (± standard deviation) participant characteristics were: age, 28.0 ± 4.7 years; height, 167.4 ± 8.7 cm; and weight, 61.2 ± 10.4 kg. The results of standing balance and sensory

Table 1. Participant characteristics and measurement results in this study (N=50)

Variable	Mean ± standard deviation
Age (years)	28.0 ± 4.7
Sex (M/F)	29/21
Height (cm)	167.4 ± 8.7
Body weight (kg)	61.2 ± 10.4
Dominant foot (right/left)	48/2
TPD (mm)	13.9 ± 2.8
TGS (kg)	16.3 ± 6.3

N: number of participants; M: male; F: female; TPD: two-point discrimination test; TGS: toe grip strength.

contributions are presented in Table 2. Significant interactions were seen between each condition, with a significant main effect except for eye effect in the anteroposterior direction of dynamic standing balance. Since significant interactions were identified, we analyzed each factor with paired t-tests. Significant differences were seen between almost all factors except between eyes opened and eyes closed on the foam surface. Sensory contributions were dominated by the somatosensory system. Correlations between COP length and LOS are shown in Table 3. No significant correlation was found between COP length and LOS. The results of multiple regression analysis with TPD and TGS as independent variables and standing balance as the dependent variable are shown in Table 4. TPD was associated with static standing balance on the firm floor, and TGS was associated with dynamic standing balance on the firm floor. No significant correlations were identified between

Table 2. Results of static and dynamic standing balance under each sensory condition

		Surface condition × Visual condition			
		Firm floor × Eyes open	Firm floor × Eyes closed	Foam floor × Eyes open	Foam floor × Eyes closed
COP length / Height (×100)		21.3 ± 4.3	32.0 ± 7.8†	44.8 ± 10.2‡	94.4 ± 25.6†‡
LOS	AP (%)	58.4 ± 6.7	53.4 ± 7.2†	45.6 ± 7.3‡	46.8 ± 7.8‡
	ML (%)	62.9 ± 9.3	56.0 ± 9.9†	51.9 ± 9.5‡	49.4 ± 9.5†‡
Floor×Eyes		COP length*		LOS(AP)*	LOS(ML)*
Floor effect		COP length*		LOS(AP)*	LOS(ML)*
Eyes effect		COP length*		LOS(AP)	LOS(ML)*
Sensory ratio (×100, Vis/Som/Vest)		48.7 ± 10.3 / 68.2 ± 12.3 / 23.7 ± 6.1			
Sensory contribution rate (%Vis/%Som/%Vest)		34.7 ± 5.1 / 48.6 ± 5.0 / 16.7 ± 2.8			

Values are the mean ± standard deviation.
*Two-way ANOVA, $p<0.05$.
floor × eyes, interaction; floor effect, main effect (floor); eyes effect, main effect (eyes).
†: t-test, $p<0.05$ eyes closed vs. eyes opened; ‡: t-test, $p<0.05$ foam floor vs. firm floor.
COP: center of pressure; LOS: limits of stability; AP: anteroposterior; ML: mediolateral; Vis: visual; Som: somatosensory; Vest: vestibular.

Table 3. Correlation coefficients between static and dynamic standing balance

	Surface condition × Visual condition							
	Firm floor × Eyes open		Firm floor × Eyes closed		Foam floor × Eyes open		Foam floor × Eyes closed	
	LOS							
	AP	ML	AP	ML	AP	ML	AP	ML
COP length / Height	0.10	0.07	0.02	0.02	−0.12	0.06	−0.03	0.05

Values are Pearson's correlation coefficient.
COP length: center of pressure length; LOS: limits of stability; AP: anteroposterior; ML: mediolateral.

Table 4. Results of multiple regression analysis between standing balance and sensory-motor measurement

		Surface condition × Visual condition							
		Firm floor × Eyes open		Firm floor × Eyes closed		Foam floor × Eyes open		Foam floor × Eyes closed	
		COP length / Height							
R^2		0.14*		0.20*		0.03		0.07	
β	TPD	0.38*		0.42*		0.18		0.26	
	TGS	−0.02		0.08		0.00		−0.01	
		LOS							
		AP	ML	AP	ML	AP	ML	AP	ML
R^2		0.11	0.13*	0.10	0.07	0.04	0.11	0.06	0.08
β	TPD	−0.08	0.18	−0.08	0.02	0.06	0.27	0.25	0.18
	TGS	0.35*	0.26	0.32*	0.26	0.16	0.12	−0.05	0.16

*$p<0.05$.
COP length: center of pressure length; LOS: limits of stability; AP: anteroposterior; ML: mediolateral; TPD: two-point discrimination test; TGS: toe grip strength.

somatosensory ratio or somatosensory contribution rate and TGS or TPD. Correlations between sensory ratio and LOS are shown in Table 5. No significant correlation was found between sensory ratios and LOS.

DISCUSSION

The most interesting result in this study was the absence of any association between TPD and dynamic standing balance. If associations existed between TPD and LOS, we would use sensory practices to prevent falls in clinical situations. However, we cannot recommend performing sensory practices simply to improve dynamic standing balance. Since LOS was associated with various functions, we must integrate the sensory and motor systems using the central nervous system[24]. To improve dynamic standing balance, motor-sensory skills may need to be learned using repeated activities in actual performance using the central nervous system.

Decreases in sensory information were accompanied by increases in COP length and decreases in LOS. This was attributed to the paucity of material to adequately control the COP. In other words, this was due to a lack of sensory information. The present systematic demonstration that LOS becomes smaller as sensory information decreases was a novel finding in this study. The somatosensory system showed a higher sensory ratio than the other sensory systems. Such dominance of the somatosensory system is consistent with findings from previous studies. Di Berardino et al. reported the somatosensory contribution rate as 44.9 ± 7.1% on a monolayer rubber foam pad[18]. The somatosensory contribution was 48.6 ± 4.9% in this study. These results underscore the importance of somatosensory perception in the standing position.

Multiple regression analysis indicated that TPD was related to static postural control ability on a firm surface. Lord et al. reported that the proprioceptive sensation is a predictor of sway on the floor[19]. However, LOS was less affected by the TPD in the present study, suggesting that LOS is less involved in the sensory aspect. We believe this is because LOS contains a complex sensory system that is constantly changing and difficult to quantify.

The results of the multiple regression analysis suggest that TGS is influential in dynamic standing postural control. Binda et al. reported that the ability to move the center of gravity correlated with lower limb muscle strength and fear of falling[25]. The present results support those of Binda et al.; namely, that expansion of LOS may require an increase in TGS. We must clarify the differences in the sensory and motor aspects of static and dynamic standing balance to develop suitable standing balance exercises.

The results of correlations between static or dynamic standing balance, sensory ratio, and sensorimotor assessment suggest that no relationship exists between these indices. Many previous studies have shown no significant relationship between static balance and dynamic balance. Sell[10] and Gonçalves et al.[26] reported no significant relationship between static and dynamic balance in healthy young participants. Rizzato reached the same conclusion for healthy older participants[27]. In addition, Hrysomallis reported no correlations between one-leg standing on a firm surface and stepping on a foam surface[8]. The present findings support those reports.

Somatosensory information is reportedly more important in older individuals and people with cataracts, and balance disorders[28]. We believe that it is necessary to conduct exercises that focus on somatosensory information, such as performing tandem stance and standing on one leg on foam rubber[29]. In addition to strengthening the muscles of the lower extremities to reduce the risk of falls and improve physical performance, we would like to see consideration given to exercises that focus on somatosensory perception for balance disorders.

The present results showed that sensory ratios were not associated with LOS. In other words, the results suggest that sensations in static and dynamic standing should be considered separately. We believe it is important to consider whether the function to be improved is static or dynamic when considering what measures to implement.

As key limitations to this study, the sample size for analysis was small, and only healthy adults were included. The present study also only examined a portion of static and dynamic balances. For example, we did not examine cases in which the

Table 5. Association between sensory contribution and dynamic standing balance

				Vis	Som	Vest	%Vis	%Som	%Vest
LOS	Surface condition × Visual condition	Firm floor × Eyes open	AP	−0.07	0.19	0.17	−0.22	0.12	0.17
			ML	0.00	0.03	0.01	0.01	−0.02	0.02
		Firm floor × Eyes closed	AP	−0.12	0.22	0.07	−0.25	0.22	0.06
			ML	−0.14	0.13	−0.03	−0.18	0.20	−0.03
		Foam floor × Eyes open	AP	0.08	−0.04	0.15	0.05	−0.16	0.18
			ML	0.03	0.13	0.08	−0.08	0.06	0.04
		Foam floor × Eyes closed	AP	0.05	0.04	0.16	−0.02	−0.05	0.13
			ML	0.09	0.06	0.01	0.07	−0.05	−0.05

Values are Pearson's correlation coefficient.
LOS: limits of stability; AP: anteroposterior; ML: mediolateral; Vis: visual; Som: somatosensory; Vest: vestibular.

position or size of the BOS changed. In addition, we were unable to measure muscle activity in the trunk or proximal lower extremities, nor brain activity. Further, the present study classified balance by the presence or absence of spontaneity in the same BOS in the standing position with both feet on the floor, but other methods of classifying balance should be examined from various angles. Another limitation of this study is that we have not been able to examine touch and vibration senses other than two-point discrimination. In future studies, we must clarify the sensory side of dynamic standing balance in patients with sensory disorders and fall risks. Once the contributions of sensory systems to dynamic standing balance are better elucidated, we can consider programs to better prevent falls and enhance physical performance.

Funding and Conflict of interest

The authors have no funding or conflict of interest to disclose.

REFERENCES

1) Guillou E, Dupui P, Golomer E: Dynamic balance sensory motor control and symmetrical or asymmetrical equilibrium training. Clin Neurophysiol, 2007, 118: 317–324. [Medline] [CrossRef]
2) Sibley KM, Straus SE, Inness EL, et al.: Balance assessment practices and use of standardized balance measures among Ontario physical therapists. Phys Ther, 2011, 91: 1583–1591. [Medline] [CrossRef]
3) Pizzigalli L, Ahmaidi S, Rainoldi A: Effects of sedentary condition and longterm physical activity on postural balance and strength responses in elderly subjects. Sport Sci Health, 2014, 10: 135–141. [CrossRef]
4) Juras G, Słomka K, Fredyk A, et al.: Evaluation of the Limits of Stability (LOS) Balance Test. J Hum Kinet, 2008, 19: 39–52. [CrossRef]
5) Bekkers EM, Dockx K, Heremans E, et al.: The contribution of proprioceptive information to postural control in elderly and patients with Parkinson's disease with a history of falls. Front Hum Neurosci, 2014, 8: 939. [Medline] [CrossRef]
6) Blanchet M, Prince F, Messier J: Development of postural stability limits: anteroposterior and mediolateral postural adjustment mechanisms do not follow the same maturation process. Hum Mov Sci, 2019, 63: 164–171. [Medline] [CrossRef]
7) Vermette MJ, Prince F, Bherer L, et al.: Concentrating to avoid falling: interaction between peripheral sensory and central attentional demands during a postural stability limit task in sedentary seniors. Geroscience, 2024, 46: 1181–1200. [Medline] [CrossRef]
8) Hrysomallis C, McLaughlin P, Goodman C: Relationship between static and dynamic balance tests among elite Australian Footballers. J Sci Med Sport, 2006, 9: 288–291. [Medline] [CrossRef]
9) Karimi MT, Solomonidis S: The relationship between parameters of static and dynamic stability tests. J Res Med Sci, 2011, 16: 530–535. [Medline]
10) Sell TC: An examination, correlation, and comparison of static and dynamic measures of postural stability in healthy, physically active adults. Phys Ther Sport, 2012, 13: 80–86. [Medline] [CrossRef]
11) Lord SR, Ward JA, Ward JA: Age-associated differences in sensori-motor function and balance in community dwelling women. Age Ageing, 1994, 23: 452–460. [Medline] [CrossRef]
12) Muehlbauer T, Gollhofer A, Granacher U: Associations between measures of balance and lower-extremity muscle strength/power in healthy individuals across the lifespan: a systematic review and meta-analysis. Sports Med, 2015, 45: 1671–1692. [Medline] [CrossRef]
13) Ivanenko Y, Gurfinkel VS: Human postural control. Front Neurosci, 2018, 12: 171. [Medline] [CrossRef]
14) Shumway-Cook A, Horak FB: Assessing the influence of sensory interaction of balance. Suggestion from the field. Phys Ther, 1986, 66: 1548–1550. [Medline] [CrossRef]
15) Horn LB, Rice T, Stoskus JL, et al.: Measurement characteristics and clinical utility of the Clinical Test of Sensory Interaction on Balance (CTSIB) and modified CTSIB in individuals with vestibular dysfunction. Arch Phys Med Rehabil, 2015, 96: 1747–1748. [Medline] [CrossRef]
16) Cohen H, Blatchly CA, Gombash LL: A study of the clinical test of sensory interaction and balance. Phys Ther, 1993, 73: 346–351, discussion 351–354. [Medline] [CrossRef]
17) Goble DJ, Brown EC, Marks CR: Expanded normative data for the balance tracking system modified clinical test of sensory integration and balance protocol. Med Devices Sens, 2020. [CrossRef]
18) Di Berardino F, Filipponi E, Barozzi S, et al.: The use of rubber foam pads and "sensory ratios" to reduce variability in static posturography assessment. Gait Posture, 2009, 29: 158–160. [Medline] [CrossRef]
19) Lord SR, Clark RD, Webster IW: Postural stability and associated physiological factors in a population of aged persons. J Gerontol, 1991, 46: M69–M76. [Medline] [CrossRef]
20) Zimney K, Dendinger G, Engel M, et al.: Comparison of reliability and efficiency of two modified two-point discrimination tests and two-point estimation tactile acuity test. Physiother Theory Pract, 2022, 38: 235–244. [Medline] [CrossRef]
21) Zarkou A, Lee SC, Prosser LA, et al.: Foot and ankle somatosensory deficits affect balance and motor function in children with cerebral palsy. Front Hum Neurosci, 2020, 14: 45. [Medline] [CrossRef]
22) Ryu JW, Hwang IS, Jin S, et al.: Toe grip strength is associated with improving gait function in patients with subacute stroke. Brain Sci, 2024, 14: 215. [Medline] [CrossRef]
23) Maktouf W, Durand S, Boyas S, et al.: Combined effects of aging and obesity on postural control, muscle activity and maximal voluntary force of muscles mobilizing ankle joint. J Biomech, 2018, 79: 198–206. [Medline] [CrossRef]
24) Ting LH: Dimensional reduction in sensorimotor systems: a framework for understanding muscle coordination of posture. Prog Brain Res, 2007, 165: 299–321. [Medline] [CrossRef]
25) Binda SM, Culham EG, Brouwer B: Balance, muscle strength, and fear of falling in older adults. Exp Aging Res, 2003, 29: 205–219. [Medline] [CrossRef]

26) Gonçalves C, Bezerra P, Clemente FM, et al.: The relationship between static and dynamic balance in active young adults. Human Mov, 2022, 23: 65–75. [CrossRef]
27) Rizzato A, Paoli A, Andretta M, et al.: Are static and dynamic postural balance assessments two sides of the same coin? A cross-sectional study in the older adults. Front Physiol, 2021, 12: 681370. [Medline] [CrossRef]
28) Pasma JH, Engelhart D, Maier AB, et al.: Changes in sensory reweighting of proprioceptive information during standing balance with age and disease. J Neurophysiol, 2015, 114: 3220–3233. [Medline] [CrossRef]
29) Thompson LA, Savadkoohi M, de Paiva GV, et al.: Sensory integration training improves balance in older individuals. Annu Int Conf IEEE Eng Med Biol Soc, 2020, 2020: 3811–3814. [Medline]