



Original Article

Foot pressure analysis of gait pattern in older Japanese females requiring different personal care support levels

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Abstract. [Purpose] This study evaluated gait parameters and foot pressure in two regions of the feet among older females with different personal care support needs to analyze factors that contribute to higher support requirements. [Subjects and Methods] Thirty-two older females were divided into support-need and care-need level groups. Gait parameters (speed, cadence, step length, step width, gait angle, toe angle, double support phase, swing phase, and stance phase) and foot pressure during a 5-m walk were measured and analyzed in the two groups. [Results] The percentage of the double support phase on both feet and the right stance phase were significantly higher in the care-need level group, while that of the right swing phase was significantly lower than that of the support-need level group. Additionally, the phase showing peak pressure on the left rear foot was significantly delayed and the left forefoot pressure in the terminal stance was significantly lower in the care-need level group than in the support-need level group. [Conclusion] These findings show that the temporal duration parameters and foot pressure on a particular side were significantly different between the two groups and suggest that these differences were associated with a higher care level.

Key words: Double support phase, Personal care need, Foot pressure analysis

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INTRODUCTION

The low birth rate and rapid population aging in Japan have resulted in increased national expenditures for healthcare or daily life assistance and has become a serious social issue¹⁾. To resolve this problem, it is essential to predict the decline in physical function and prevent functional disability at an earlier age in older adults.

In recent years, gait ability has been considered a useful parameter for predicting the decline in one's ability to perform activities of daily living (ADL). Previous studies reported that gait speed is a good predictor of the onset of physical dependence in older Japanese adults²⁻⁴⁾. Furthermore, recent advances in gait measurement techniques have enabled more detailed gait parameter assessments. Kim et al. reported that gait speed and other gait parameters (cadence, step length, step width, gait angle, toe angle, double support phase, swing phase, stance phase, laterality) are useful for the assessment of aging-associated risks⁵⁾. These parameters are also considered excellent indicators of gait function when measured using a sheet-type pressure sensor⁶⁾.

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Several studies have reported an association between gait parameters and ADL or aging-associated risks²⁻⁶) but focused on community-dwelling healthy older adults. Only a few studies have focused on individuals requiring assistance to perform ADL. The public long-term care insurance system in Japan defines two assistance levels: Support Levels 1–2 (requiring ADL support) and Care Levels 1–5 (requiring long-term care in daily life) depending on the degree of impairment performing ADL^{7,8}). Preventing progression in personal care level, particularly from the support-need level to the care-need level, is vital for decreasing national expenditures for daily care assistance.

This study aimed to evaluate gait parameters and foot pressure using a sheet-type pressure sensor in older females with different personal care need levels. We also aimed to analyze factors that changed as care levels increased.

SUBJECTS AND METHODS

This study enrolled 32 older females who visited the outpatient rehabilitation facility in Nara City and were assigned to the support-need level group, comprising those who could walk with assistance or support (Support Levels 1–2; n=19); or the care-need level group, comprising those who required a higher level of personal care (Care Levels 1–2; n=13). Exclusion criteria included severe cognitive deficit (e.g., dementia), rapidly progressive disease, and terminal stage disease, including severe hemiplegia. This study was approved by the Nara Women's University Ethics Committee (approval number: 12-04). Signed informed consent was obtained from each subject (and their family members, as applicable) after detailed information about the study was provided (objectives, methods, voluntary participation, and personal data utilization methods).

Gait parameters and foot pressure patterns were measured using a sheet-type pressure sensor (60 cm wide, 240 cm long; Walk Way, Anima Corp., Tokyo, Japan) placed in the middle of a 5-m walkway^{5,6,9}). The participants were instructed to walk barefoot along the walkway at a comfortable pace. They practiced the 5-m walk four times (two round trips).

The measured gait parameters included: (1) general parameters: speed (cm/s) and cadence (step/min); (2) spatial parameters: step length (%), step width (%), gait angle (degree), and toe angle (degree); and (3) temporal duration parameters: double support phase (%), swing phase (%), and stance phase (%^{6,10}). Step length and width were normalized by height. The double support, swing, and stance phases were expressed as relative values that were divided by gait cycle. The gait parameters of the left and right feet were recorded bilaterally (from the heel strike of one foot to that of the opposite foot; e.g., right step length [%] was defined as the distance normalized by height from the heel strike of the right to that of the left foot). An average parameter of four trials was obtained for each participant.

Foot pressure patterns were measured simultaneously using the sheet-type pressure sensor. As with the gait parameters, foot pressure on the left and right feet were recorded bilaterally. The sampling frequency of foot pressure data was 100 Hz. Foot pressure data were time-normalized by the stance time and divided into 101 time points at each step; initial contact was defined as 0%, while toe off was defined as 100%¹¹). In addition, foot pressure data at each time point (i.e., 101 time points) was value-normalized by the maximum pressure detected at each step (i.e., maximum foot pressure at each step was defined as 100%). The average pressure was calculated at each time point.

An analysis of the detailed foot pressure was performed by separately analyzing total foot pressure into two regions, namely, the rear foot (50% of the foot length on the heel side) and the forefoot (50% of the foot length on the toe side)¹²). Each foot pressure value (rear foot or forefoot region) was the total sum of the foot pressure in each region. As with the total foot pressure, the foot pressure data were time-normalized by the stance time and divided into 101 time points at each step. Additionally, the data were value-normalized by total maximum pressure in both regions at each time point. The mean pressures for the right and left feet in the two regions were also calculated for the 0–20%, 21–50%, 51–90%, and 91–100% phases, called the loading response, mid-stance, terminal stance, and pre-swing phases, respectively¹¹).

Unpaired t-tests were conducted to analyze physical characteristics, gait speed, and cadence. To analyze the other gait parameters (step length, step width, gait angle, toe angle, percentage of double support phase, percentage of swing phase, and percentage of stance phase), the phase showing peak pressure, and the foot pressure for each phase (loading response, mid-stance, terminal stance, and pre-swing phases) in the two foot regions, two-way repeated measures analysis of variance was used to assess the main effects of and interaction between group (support-need level group, care-need level group) and foot (left, right). When interaction effects were detected, separate analysis of variance and post hoc comparisons were performed to assess group and foot differences. SPSS ver. 23 was used to perform the statistical analyses; values of $p < 0.05$ were considered statistically significant. Further, Cohen's d and partial η^2 values were calculated as measures of effect size^{13,14}).

RESULTS

The mean (\pm SD) age of the support-need level group was 79.6 ± 8.2 years; mean height was 149.5 ± 6.0 cm; mean body weight was 50.1 ± 9.4 kg; and mean body mass index (BMI) was 22.3 ± 3.6 kg/m². The mean age of the care-need level group was 82.5 ± 8.4 years; mean height was 151.3 ± 5.7 cm; mean body weight was 52.0 ± 11.7 kg; and mean BMI was 22.6 ± 3.8 kg/m². No significant intergroup differences were observed in age, height, body weight, or BMI.

The mean gait speeds of the support-need and care-need level groups were 66.5 ± 17.5 cm/s and 55.9 ± 29.7 cm/s, respectively, while the mean cadences were 101.5 ± 14.3 step/min and 98.4 ± 19.1 step/min, respectively. No significant intergroup differences were observed in gait speed or cadence. Table 1 compares the other gait parameters between the two groups. No

Table 1 . Gait parameters in the support-need and care-need level groups

	Support-need level group (n=19)		Care-need level group (n=13)		Main effect		Interaction effect
	Left	Right	Left	Right	Group	Foot	Group × Foot
Step length (%)	26.2 ± 5.8	25.7 ± 5.0	21.6 ± 8.1	21.2 ± 8.0			
Step width (%)	6.6 ± 2.1	6.1 ± 2.7	7.8 ± 2.5	7.7 ± 2.7			
Gait angle (°)	15.6 ± 8.4	14.5 ± 7.5	23.3 ± 13.3	23.5 ± 14.3	*		
Toe angle (°)	2.1 ± 7.9	5.4 ± 9.0	5.3 ± 6.5	9.3 ± 7.0		**	
Double support phase (%)	15.6 ± 2.7 [‡]	16.2 ± 2.4 ^{‡*}	18.0 ± 4.0 ^{††}	21.4 ± 6.8	**	**	*
Swing phase (%)	34.0 ± 3.1	34.0 ± 2.6	30.7 ± 5.9	29.2 ± 6.1	**		
Stance phase (%)	66.0 ± 3.1	66.0 ± 2.5	69.3 ± 5.9	70.9 ± 5.5	**		

Data are shown as mean ± SD. Two-way repeated-measures analysis of variance was performed.

The analysis of variance examined the main effects of group (support-need level group, care-need level group) and foot (left, right) as well as the interaction between group and foot. * $p < 0.05$, ** $p < 0.01$.

^{††}Significant difference between the left and right feet in the individual groups (Bonferroni, $p < 0.01$).

[‡]Significant difference between individual feet in the support-need and care-need level groups (Bonferroni, $p < 0.05$).

^{‡*}Significant difference between individual feet in the support-need and care-need level groups (Bonferroni, $p < 0.01$).

significant main or interaction effects were found in terms of step length or width. In contrast, a significant main group effect on gait angle was found ($p = 0.033$, $\eta^2 = 0.14$), as was a main foot effect on toe angle ($p = 0.003$, $\eta^2 = 0.25$).

Among the temporal duration parameters, a significant main group effect ($p = 0.008$, $\eta^2 = 0.21$) and main foot effect ($p = 0.002$, $\eta^2 = 0.28$) were found on the percentage of double support phase. Furthermore, a significant interaction effect between group and foot was detected ($p = 0.028$, $\eta^2 = 0.15$). A post hoc comparison showed that the percentage of time the right foot spent in the double support phase was significantly higher than that of the left foot in the care-need level group only ($p = 0.001$, $d = 0.61$). Further, significant differences were noted between the support-need and care-need level group in the left and right feet, respectively ($p = 0.047$, $d = 0.73$; $p = 0.005$, $d = 1.1$). Significant main group effects were detected in the presence of the swing and stance phases, respectively ($p = 0.008$, $\eta^2 = 0.21$; $p = 0.005$, $\eta^2 = 0.23$). However, no significant interaction effect between group and foot was found.

The mean total foot pressure by group is shown in Figs. 1 A (left foot) and 1B (right foot). Total foot pressure was separately evaluated in two regions (rear foot and forefoot). The mean rear foot pressure is shown in Figs. 1C (left foot) and 1D (right foot), while the mean forefoot pressure is shown in Figs. 1E (left foot) and 1F (right foot).

Table 2 compares the phase showing peak pressure in the two regions. In the rear foot region, no interaction effects between group and foot were detected. The phase showing peak pressure was significantly delayed in the care-need level group compared to the support-need level group ($p = 0.022$, $\eta^2 = 0.16$). However, no significant main foot effect was found. In the forefoot region, an interaction effect between group and foot was detected ($p = 0.010$, $\eta^2 = 0.20$). Besides, no significant main group and foot effects were found. A post hoc comparison showed that the phase showing peak pressure on the left foot was significantly delayed compared to that on the right foot in only the care-need level group ($p = 0.006$, $d = 0.67$).

Table 3 compares the foot pressure of each phase (loading response, mid-stance, terminal stance, and pre-swing) in the two regions. In the rear foot region, an interaction effect between group and foot was detected in the terminal stance ($p = 0.018$, $\eta^2 = 0.17$). Besides, no significant main group or foot effects were found. A post hoc comparison showed that the foot pressure on the left foot of terminal stance was significantly higher than that on the right foot in only the care-need level group ($p = 0.016$, $d = 0.40$). In the forefoot region, a significant main group effect was found on terminal stance ($p = 0.049$, $\eta^2 = 0.12$). However, no significant main foot effect was found.

DISCUSSION

Here we evaluated gait parameters and foot pressure in two regions (rear foot and forefoot) of the feet of older Japanese females by personal care stage. The results showed that the temporal gait duration parameters (percentage of double support, swing, and stance phases) and foot pressure on a particular side differed significantly between the support-need and care-need level groups.

The present results show that gait speed was not significantly different between the support-need and care-need level groups. This result supports previous research in older adults in the support-need and care-need level¹⁵). In contrast, the temporal duration parameters (percentage of double support, swing, and stance phases) were significantly different between the two groups. These results indicate that the duration of the support phase in one gait cycle was longer in the care-need level group than in the support-need level group. In healthy community-dwelling older adults, several studies have reported that gait speed is a good predictor of physical dependence onset²⁻⁴). In the present study, the gait speed in both groups (support-need and care-need level groups) was much slower than that reported in previous studies on healthy community-dwelling

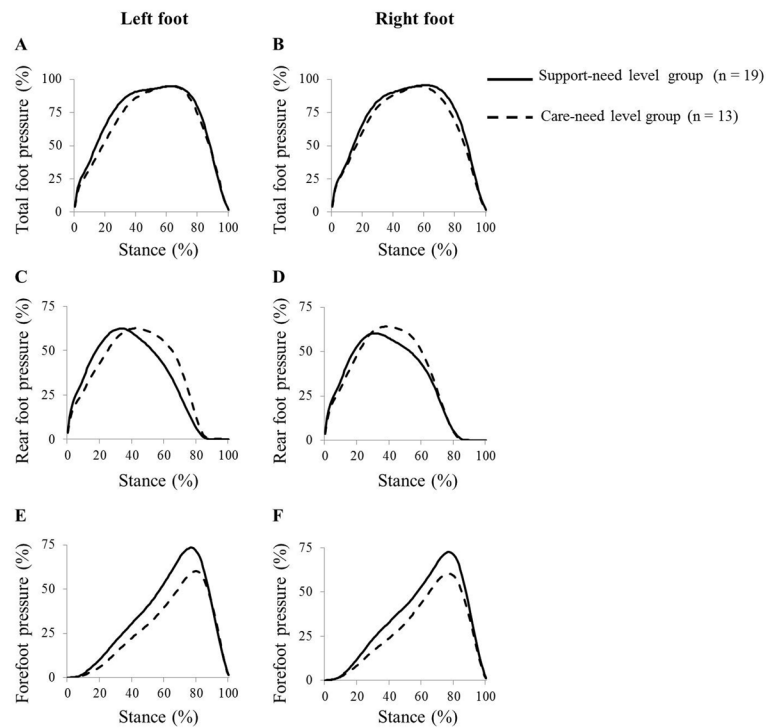


Fig. 1. Mean total foot pressure (A: left; B: right) and mean pressures of the rear foot (C: left; D: right) and forefoot (E: left; F: right) by stance phase in the support-need and care-need level groups with error bars removed for clarity. The rear foot region was defined as 50% of the foot length on the heel side, while the forefoot region was defined as 50% of the foot length on the toe side. Each foot pressure data set was time-normalized by the stance time and divided into 101 time points; initial contact was defined as 0%, while toe off was defined as 100%. In addition, each data set was value-normalized based on the maximum pressure detected at each step; maximum total foot pressure was defined as 100%. The average pressures for the right and left feet were calculated separately at each time point (i.e., for the 101 time points).

Table 2. Phase showing peak pressure in the support-need and care-need level groups

	Support-need level group (n=19)		Care-need level group (n=13)		Main effect		Interaction effect
	Left	Right	Left	Right	Group	Foot	Group × Foot
Rear foot (%)	31.5 ± 5.2	31.2 ± 6.9	39.6 ± 11.1	36.5 ± 10.9	*		
Forefoot (%)	76.1 ± 3.6	76.7 ± 2.7	78.4 ± 4.4 ^{††}	75.3 ± 4.8			*

Data are shown as mean ± SD. Two-way repeated-measures analysis of variance was performed.

The analysis of variance examined the main effects of group (support-need level group, care-need level group) and foot (left, right) as well as the interaction between group and foot. * $p < 0.05$.

^{††}Significant difference between the left and right feet in the individual groups (Bonferroni, $p < 0.01$).

older adults¹⁶). Therefore, these results suggest that temporal duration parameters, the percentage of support phase in one gait cycle in particular, were the important factors causing progression in care level compared to gait speed, particularly in older adults at a stage of personal care reflected by slow gait speed.

Furthermore, to analyze the difference in temporal duration parameters between the support-need and care-need level groups, we evaluated foot pressure patterns. In this study, only one peak of the total pressure was obtained from both feet in the support-need and care-need level groups (Figs. 1A and 1B). A previous study reported that two peaks caused by the weight acceptance phase (first force peak) and push-off phase (second force peak) were obtained in healthy community-dwelling older adults¹⁷. Foot pressure decreases due to dampening of the force loaded by the slight stance leg knee flexion when approaching mid-stance¹⁸. However, only one peak of the foot pressure pattern was observed in the present study. This result showed no load dampening in mid-stance, which indicates a difference in knee flexion mechanisms between healthy community-dwelling older females and older females requiring personal care assistance. This difference may be due to the

Table 3. Average foot pressure over each phase in the support-need and care-need level groups

		Support-need level group (n=19)		Care-need level group (n=13)		Main effect		Interaction effect
		Left	Right	Left	Right	Group	Foot	Group × Foot
Rear foot (%)	Loading response	35.8 ± 8.2	35.4 ± 7.1	29.8 ± 10.1	33.0 ± 10.8			
	Mid-stance	58.5 ± 9.2	57.8 ± 7.3	58.3 ± 10.9	60.7 ± 8.0			
	Terminal stance	20.9 ± 11.8	22.4 ± 9.6	30.6 ± 15.7 [†]	25.1 ± 11.3			*
	Pre-swing	0.001 ± 0.002	0.006 ± 0.024	0.105 ± 0.366	0.000 ± 0.000			
Forefoot (%)	Loading response	3.4 ± 3.0	3.9 ± 3.5	2.6 ± 3.2	3.3 ± 2.1			
	Mid-stance	26.9 ± 11.4	28.2 ± 9.5	20.4 ± 11.2	22.0 ± 8.4			
	Terminal stance	62.4 ± 12.6	60.9 ± 10.3	51.2 ± 16.5	53.4 ± 14.2	*		
	Pre-swing	16.0 ± 4.4	16.0 ± 3.9	16.8 ± 3.4	13.9 ± 2.9			

Data are shown as mean ± SD. Two-way repeated-measures analysis of variance was performed.

The analysis of variance examined the main effects of group (support-need level group, care-need level group) and foot (left, right) as well as the interaction between group and foot. * $p < 0.05$.

[†]Significant difference between the left and right feet in the individual groups (Bonferroni, $p < 0.05$).

muscle atrophy that occurs in the lower limb muscles in elderly individuals requiring a higher care level and is associated with independent daily living among Japanese older females requiring personal care assistance.

To compare the foot pressure of these phases (weight acceptance and push-off phases) in the support-need and care-need level groups, we separately evaluated total foot pressure in the rear foot (Figs. 1C, 1D) and forefoot (Figs. 1E, 1F). The present study showed that the peak of the rear foot pressure was delayed in the care-need level group compared to the support-need level group. Additionally, in the forefoot region, the phase showing peak pressure on the left foot was delayed compared to that on the right side in the care-need level group. Interestingly, this difference was observed only on the left side. Furthermore, in the care-need level group, the rear foot pressure of the terminal stance on the left foot was significantly higher than that on the right foot. The terminal stance is the phase when the body moves ahead of the limb and weight is transferred onto the forefoot¹⁹. These results indicate that participants requiring care (care-need level group) are unable to transfer their body weight from the rear foot to the forefoot, especially on the left foot. Regarding gait parameters, the percentage of time spent in the right swing phase was significantly lower and that in the right stance phase was significantly higher in the care-need level group than in the support-need level group, which may be attributed to the delay in the center of pressure from the rear foot to forefoot, particularly on the left side.

One lower limb is mainly responsible for supporting and transferring one's body weight, while the contralateral limb contributes to propelling the body during gait^{20–22}. In addition, several studies on bilateral task behavior reported that the left limb contributes to stabilization^{23, 24}. Therefore, the present results suggested that balance ability on the left side (considered to be the support leg), which has a role in stabilization, was particularly impaired in the care-need level group. This is supported by a previous study that reported that dynamic balance ability was associated with center of pressure displacement time²⁵. Moreover, previous studies reported that tibialis anterior muscle activity can influence the rear foot to forefoot motion during the stance phase²⁶, and this muscle showed markedly regressive changes after 60 years of age²⁷. Because the present participants required assistance in daily life, we could not evaluate their muscular strength. Therefore, future studies are needed to clarify the association between left foot peak pressure and tibialis anterior muscle activity in older females requiring personal care assistance.

Moreover, the present study showed that forefoot pressure during the terminal stance was significantly lower in the care-need level group than it was in the support-need level group. Previous studies reported that forefoot pressure during the terminal stance was associated with push-off movement²⁸, and the plantar flexor muscle is a major contributor at this phase²⁹. Therefore, the present results imply that plantar flexor muscle strength may have differed between the support-need and care-need level groups. In this study, we could not evaluate the participants' muscular strength or equilibrium function (because the participants required assistance in daily life). Therefore, future studies are needed to investigate the association between these parameters and foot pressure.

The public long-term care insurance system in Japan defines two assistance level types: the support-need level (Support Levels 1–2: receiving support for ADL) and care-need level (Care Levels 1–5: requiring long-term care in daily life) depending on the degree of impairment performing ADL^{7, 8}. Here we showed that the temporal duration parameters (percentage of double support, swing, and stance phases) and foot pressure are significantly different between the two groups. In particular, foot pressures separately analyzed of the rear foot and forefoot revealed that gait pattern differed in specific stance phases (functional decline of the support leg) between the support-need and care-need level groups. These results suggest that these differences were closely related with balance ability during walking and with a higher care level and independent daily living among older females requiring personal care assistance. These findings may provide a good basis for a longitudinal study in the future to determine if changes in these gait parameters are actually predictive of an advancement in the required care level.

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Conflict of interest

None.

REFERENCES

- 1) Organization for Economic Co-operation and Development: OECD Health Statistics 2016. <http://www.oecd.org/els/health-systems/health-data.htm> (Accessed Nov. 10, 2017)
- 2) Shinkai S, Watanabe S, Kumagai S, et al.: Walking speed as a good predictor for the onset of functional dependence in a Japanese rural community population. *Age Ageing*, 2000, 29: 441–446. [[Medline](#)] [[CrossRef](#)]
- 3) Suzuki T, Yoshida H, Kim H, et al.: Walking speed as a good predictor for maintenance of I-ADL among the rural community elderly in Japan: a 5-year follow-up study from TMIG-LISA. *Geriatr Gerontol Int*, 2003, 3: S6–S14. [[CrossRef](#)]
- 4) Tainaka K, Takizawa T, Katamoto S, et al.: Six-year prospective study of physical fitness and incidence of disability among community-dwelling Japanese elderly women. *Geriatr Gerontol Int*, 2009, 9: 21–28. [[Medline](#)] [[CrossRef](#)]
- 5) Kim H, Suzuki T, Yoshida H, et al.: [Are gait parameters related to knee pain, urinary incontinence and a history of falls in community-dwelling elderly women?]. *Nippon Ronen Igakkai Zasshi*, 2013, 50: 528–535 (In Japanese). [[Medline](#)] [[CrossRef](#)]
- 6) Sudo M, Yamashiro Y, Ueno K, et al.: Estimation of age from the difference between left and right gait parameters measured by a walk analysis system with plate sensors. *Jpn J Physiol Anthropol*, 2013, 18: 125–132 (In Japanese).
- 7) Matsuda S, Yamamoto M: Long-term care insurance and integrated care for the aged in Japan. *Int J Integr Care*, 2001, 1: e28. [[Medline](#)] [[CrossRef](#)]
- 8) Shimada H, Suzuki T, Suzukawa M, et al.: Performance-based assessments and demand for personal care in older Japanese people: a cross-sectional study. *BMJ Open*, 2013, 3: e002424. [[Medline](#)] [[CrossRef](#)]
- 9) Furui Y, Kim H, Mitsuya Y, et al.: Changes in walking styles in the elderly after the presentation of walking patterns. *Adv Exerc Sports Physiol*, 2015, 21: 59–65.
- 10) Demur T, Demura S: Relationship among gait parameters while walking with varying loads. *J Physiol Anthropol*, 2010, 29: 29–34. [[Medline](#)] [[CrossRef](#)]
- 11) Tome J, Nawoczenski DA, Flemister A, et al.: Comparison of foot kinematics between subjects with posterior tibialis tendon dysfunction and healthy controls. *J Orthop Sports Phys Ther*, 2006, 36: 635–644. [[Medline](#)] [[CrossRef](#)]
- 12) Gravante G, Pomara F, Russo G, et al.: Plantar pressure distribution analysis in normal weight young women and men with normal and claw feet: a cross-sectional study. *Clin Anat*, 2005, 18: 245–250. [[Medline](#)] [[CrossRef](#)]
- 13) Cohen J: *Statistical power analysis for the behavioral sciences*, 2nd ed. New Jersey: Lawrence Erlbaum, 1988.
- 14) Uemura K, Yamada M, Nagai K, et al.: Fear of falling is associated with prolonged anticipatory postural adjustment during gait initiation under dual-task conditions in older adults. *Gait Posture*, 2012, 35: 282–286. [[Medline](#)] [[CrossRef](#)]
- 15) Hato S, Suzukawa M, Hayashi Y, et al.: Factors associated with the level of disability in elderly adults based on the Japanese long-term care insurance system. *Nippon Ronen Igakkai Zasshi*, 2014, 51: 69–73 (In Japanese). [[Medline](#)] [[CrossRef](#)]
- 16) Ishii S, Tanaka T, Akishita M, et al. Kashiwa study investigators: Metabolic syndrome, sarcopenia and role of sex and age: cross-sectional analysis of Kashiwa cohort study. *PLoS One*, 2014, 9: e112718. [[Medline](#)] [[CrossRef](#)]
- 17) Laroche DP, Cook SB, Mackala K: Strength asymmetry increases gait asymmetry and variability in older women. *Med Sci Sports Exerc*, 2012, 44: 2172–2181. [[Medline](#)] [[CrossRef](#)]
- 18) Fineberg DB, Asselin P, Harel NY, et al.: Vertical ground reaction force-based analysis of powered exoskeleton-assisted walking in persons with motor-complete paraplegia. *J Spinal Cord Med*, 2013, 36: 313–321. [[Medline](#)] [[CrossRef](#)]
- 19) Gotz-Neumann K: *Gehen verstehen Ganganalyse in der Physiotherapie*. Tokyo: Igaku Shoin, 2005.
- 20) Herzog W, Nigg BM, Read LJ, et al.: Asymmetries in ground reaction force patterns in normal human gait. *Med Sci Sports Exerc*, 1989, 21: 110–114. [[Medline](#)] [[CrossRef](#)]
- 21) Sadeghi H, Allard P, Duhaime M: Functional gait asymmetry in able-bodied subjects. *Hum Mov Sci*, 1997, 16: 243–258. [[CrossRef](#)]
- 22) Seeley MK, Umberger BR, Shapiro R: A test of the functional asymmetry hypothesis in walking. *Gait Posture*, 2008, 28: 24–28. [[Medline](#)] [[CrossRef](#)]
- 23) Sadeghi H, Allard P, Prince F, et al.: Symmetry and limb dominance in able-bodied gait: a review. *Gait Posture*, 2000, 12: 34–45. [[Medline](#)] [[CrossRef](#)]
- 24) Sadeghi H, Sadeghi S, Allard P, et al.: Lower limb muscle power relationships in bilateral able-bodied gait. *Am J Phys Med Rehabil*, 2001, 80: 821–830. [[Medline](#)] [[CrossRef](#)]
- 25) Park S, Ko YM, Park JW: The correlation between dynamic balance measures and stance sub-phase cop displacement time in older adults during obstacle crossing. *J Phys Ther Sci*, 2013, 25: 1193–1196. [[Medline](#)] [[CrossRef](#)]
- 26) Cornwall MW, McPoil TG: The influence of tibialis anterior muscle activity on rearfoot motion during walking. *Foot Ankle Int*, 1994, 15: 75–79. [[Medline](#)] [[CrossRef](#)]
- 27) Kimura T, Hamai T, Shiraishi Y: Age-related functional and morphological changes in the anterior tibial muscle of men: Muscular atrophy and decrease in the number of muscle fibers. *Anthropol Sci*, 2002, 110: 403–413. [[CrossRef](#)]
- 28) Barela AM, de Freitas PB, Celestino ML, et al.: Ground reaction forces during level ground walking with body weight unloading. *Braz J Phys Ther*, 2014, 18: 572–579. [[Medline](#)] [[CrossRef](#)]
- 29) Winter DA, Robertson DG: Joint torque and energy patterns in normal gait. *Biol Cybern*, 1978, 29: 137–142. [[Medline](#)] [[CrossRef](#)]