Original Article

doi: 10.16926/par.2025.13.08

Influence of leg dominance on the symmetry in body balance measurements

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Authors' Contribution: A – Study Design, B – Data Collection, C – Statistical Analysis, D – Manuscript Preparation, E – Funds Collection

Abstract: *Background:* This study aimed to assess the influence of leg dominance on the symmetry of body balance during one-leg standing tasks. *Methods:* Ninety-six healthy adults were enrolled in this study. Leg dominance was defined using Waterloo Footedness Questionnaire-Revised (WFQ-R) and body balance was measured in one-leg standing test on firm surface (eyes open and closed) and on the foam surface (eyes open). Symmetry Index (SI) of balance parameters was correlated with the results of WFQ-R. *Results:* The analysis showed that each participant had better test results for one leg compared to the other, and for most participants and test conditions, the more stable lower limb was the right one. No significant correlations were found between WFQ-R and SI. *Conclusions:* Leg dominance does not seem to affect the ability to maintain body balance on one leg standing on a stable or foam surface within the conditions tested in this study. Nevertheless, some asymmetry between right and left leg standing is visible in healthy adults.

Keywords: body balance; leg dominance; one-leg standing; symmetry index

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Recevied: 14.10.2024; Accepted: 16.12.2024; Published online: 8.01.2025

Citation: Hadamus A, Gulatowska M, Ferenc A, Shahnazaryan K, Brzuszkiewicz-Kuźmicka G, Błażkiewicz M. Influence of leg dominance on the symmetry in body balance measurements. Phys Act Rev 2025; 13(1): 88-96. doi: 10.16926/par.2025.13.08

INTRODUCTION

Postural stability is essential for maintaining functional efficiency, which is related to everyday activities and can be measured by f.e. a Barthel scale. It enables control of body position during stillness and movement by keeping the center of gravity within the base of support [1,2]. Maintaining balance requires detecting body movements, integrating sensory information, and generating motor responses. Sensory input from the visual, vestibular, and somatosensory systems provides essential information about the body's position and movement. The brain integrates this information and formulates the necessary motor responses through muscle activation, coordination, and reflexes to stabilise the body [3].

Postural stability changes throughout life, often deteriorating with age or during less comfortable positions that reduce the base of support [4]. Ageing and uncomfortable postures impact sensory, central nervous, and musculoskeletal systems, leading to delayed and less precise responses to correct imbalances [5]. Proper body balance enables smooth and efficient movement, reducing the energy expenditure required for daily activities, and sports performance and minimising fatigue risk [6,7].

Human movements and posture often exhibit lateral asymmetries [8], influenced by various factors, including the level of motor experience (e.g., high versus low) [9], the nature of movements (e.g., specialised versus non-specialized) [10], environmental context (e.g., easy versus difficult motor tasks) [11], individual intrinsic factors (e.g., proprioception, hemispheric laterality, motor output) [12], and limb dominance [13]. Leg dominance refers to the natural preference or greater proficiency in using one leg over the other for specific tasks or activities [14-17]. In this context, one leg is usually preferred for activities requiring strength and coordination, such as kicking a ball, the other leg often provides stability and balance, supporting the body's weight during various activities. Laterality is the broader concept encompassing the preference for one side of the body, which is a manifestation of the brain's lateralization, where each hemisphere specializes in controlling different functions and parts of the body [18-20]. This specialization includes not only leg dominance but also handedness (preference for using one hand over the other), ocular dominance (preference for visual input from one eye), and auditory dominance (preference for auditory input in one ear) [21]. Therefore, single-leg standing is a common balance activity that challenges the body's stability with a reduced base of support and includes only one leg (dominant or non-dominant) in maintaining stability. It engages lower limb muscles, enhances proprioception, and helps maintain balance during movement. This exercise mimics real-life scenarios like stepping over obstacles, changing directions, or reaching for objects while staying stable [22].

Lower limb laterality is linked to different activities of the primary sensorimotor cortex, causing observable differences between dominant and non-dominant limbs in movement characteristics [23,24].

Lower limbs are crucial for postural support, locomotion, and coordination [16]. People prefer one side of the body in voluntary activities due to bilateral asymmetry in motor control circuits [14,25]. Dominant limb preference is based on muscle strength, functional use, or personal choice and involves tasks like balance maintenance [26]. In bilateral tasks with the movement of opposite limbs, the dominant limb focuses on the activity while the other stabilizes posture, whereas, in unilateral tasks, the dominant limb maintains balance [3].

Hart and Gabbard [26] found that the limb preferred for stabilization in bilateral tasks may differ from the one used for postural control in one-leg stances, supporting the model that the dominant leg handles more challenging motor tasks [27]. Research on lower limb dominance and balance shows mixed results [28]. Some studies [3,29] found no significant balance differences between limbs, while others [14,15] noted asymmetries, especially in dynamic tasks. Dynamic tasks refer to the way our lower limbs have to adapt to changing conditions during movement [30]. And human movement- especially in the context to walking, running or jumping- requires constant adaptation to changes in the environment. In contrast to a static task such as standing, where all forces are in balance, movement requires advanced coordination of the nervous and muscular systems. Therefore, understanding the difference between static and dynamic tasks is crucial, as the dominance of the lower limb in dynamic tasks determines the efficiency of movement in the environment and the desirability of the task [17]. Balancing on the dominant leg on unstable surfaces often results in better postural control efficiency [14].

In summary, lower limb dominance affects balance to varying degrees, depending on the nature of the task (static vs. dynamic) and conditions (stable vs. unstable surface). Assessing the relationship between limb dominance and balance symmetry is a crucial element of research on human motor skills with many practical applications. Therefore, focusing on this issue is essential for diagnosing and preventing injuries, optimizing and personalizing rehabilitation programs, and improving the effectiveness of sports training [15]. This study aimed to assess whether leg dominance influences the symmetry of body balance in standing on the right or left foot and therefore can affect body balance on one-leg standing tasks.

MATERIAL AND METHODS

Participants

Ninety-six healthy adults (59 females and 37 males) were enrolled in this study (Table 1). The sample size was set at 50 participants based on power analysis in G*Power software (Franz Faul, Kiel, Germany). This study was part of a bigger project and therefore more participants were recruited. Exclusion criteria comprised: current joint or muscle pain in the lower limb or low-back region, injuries of lower limbs during the last 6 months before the study, neurological or otorhinolaryngological diseases causing body-balance disturbances, sensory-integration disturbances, and other neurological, rheumatological or severe cardiological diseases.

Ethical Approval

The study protocol was approved by the Bioethics Committee of the Medical University of Warsaw (no. KB/217/2020). The work was carried out in accordance with the Declaration of Helsinki.

Measurement methods

All studies were performed in the Biomechanics Laboratory in the Department of Physiotherapy Fundamentals at the Medical University of Warsaw. Before the study, each participant was reviewed to verify the inclusion and exclusion criteria. All participants gave their informed consent to participate in the research. Leg dominance was defined using the Waterloo Footedness Questionnaire-Revised (WFQ-R) [17,31]. The WFQ-R assesses both foot preferences for mobilizing and stabilizing tasks, which is its main advantage. Questions 1, 3, 5, 7, and 9 measure the ability to manipulate objects with the dominant foot, whereas items 2, 4, 6, 8, and 10 measure the postural support abilities of the foot [32]. All participants had to perform each task once to answer twelve questions as „1" (right foot) or „0" (left foot). The results were summed up. If the sum was 4 or less, the

Table 1. Characteristics of the participants (mean ± standard deviation).

Group	Age [years]	Body weight [kg]	Body Height [cm]	Body Mass Index (BMI) [kg/m2]	Physical activity frequency [days / week]
Women (n = 59)	30.69 ± 11.63	63.59 ± 10.34	166 ± 6	22.99 ± 3.57	2.54 ± 1.36
Men (n = 37)	31.97 ± 10.05	81.59 ± 12.15	180 ± 9	25.18 ± 3.08	2.81 ± 1.63
All (n = 96)	31.19 ± 11.01	70.53 ± 14.10	172 ± 10	23.83 ± 3.54	2.65 ± 1.47

dominant foot was identified as left. If the sum was 8 or more, the dominant foot was identified as right. For sums between 5 and 7, foot dominance was undetermined. WFQ-R includes also 7 additional inclusion/exclusion questions, that were also taken into account.

Body balance was assessed using the Biodex Balance System (Biodex Medical Systems, Inc., NY, USA) in postural sway testing mode. This mode quantifies a person ability to maintain their center of balance. The postural stability test was performed both with (EO) and without (EC) visual control (eye contact) on a firm surface (S) while standing on the left (L) and right (R) lower limbs. On the foam surface (NS), there were performed one leg standing test only with eyes open. Therefore, there were six trials, each lasting 30 seconds, while the intervals between them were 60 seconds. In addition, each participant performed bipedal standing tests with eyes open and closed, but the results of this test were not included in the current analysis. Three indicators were obtained for each trial of one-leg standing:

$$\mathrm{APSI} = \sqrt{\frac{\sum(0-\mathrm{AP})^2}{\text{samples number}}};\ \mathrm{MLSI} = \sqrt{\frac{\sum(0-\mathrm{ML})^2}{\text{samples number}}};\ \mathrm{OSI} = \sqrt{\frac{\sum(0-\mathrm{AP})^2+\sum(0-\mathrm{ML})^2}{\text{samples number}}} \quad (1)$$

where: MLSI - a medial-lateral stability index, which represents fluctuations from the horizontal (zero point established before testing when the platform was stable) around the mediolateral axis (ML); APSI - anterior-posterior stability index, which represents fluctuations from the horizontal around the anteroposterior axis (AP); and an overall stability index (OSI), which is a composite of MLSI and APSI so it is sensitive to changes in both directions. A high score of these indexes indicates poor balance [33].

Calculation methods

Symmetry index (SI) for APSI, MLSI, and OSI were calculated using the following formula [34]:

$$SI = \frac{(L-R)}{0.5\times(R+L)} \times 100\% \quad (2)$$

where: L and R denote the APSI, MLSI, or OSI values for the left or right leg standing test, respectively. The SI = 0 means symmetry. Otherwise, it indicates asymmetry [34]. It is worth noting that in the original formula, the numerator contains the absolute value of the difference between the left and right sides. However, to directly identify which limb is causing the asymmetry, this has been modified. Thus, if the SI coefficients are negative, it will indicate that the values of APSI, MLSI, and OSI for standing on the right lower limb are higher and thus less stable.

In the first step, the Waterloo Footedness Questionnaire was used to assess how many persons perform tasks with their left or right lower limbs. Next, according to equation (2), the symmetry indices for OSI, APSI, and MLSI were calculated for the described measurement conditions. The number of positive and negative values was also counted, indicating which side of the task was less stable. In the final analysis, the symmetry indices with negative values were compared to those with positive values for the entire study group. Negative values were converted to their absolute values for this comparison. Statistical analysis was performed using Statistica Software (StartSoft, PL). The threshold for statistical significance was set at $p < 0.05$. Shapiro-Wilk's test showed that the analysed parameters had a distribution different than normal. Therefore, the comparison was made using the U Mann-Whitney test. Spearman's correlation analysis was conducted between the sum of responses for questions 1-12 of the WFQ-R test and the symmetry indices calculated for individual tests. Additionally, the summed responses for questions 5, 7, 9, 10, 11, and 12 of the WFQ-R test, which pertains to the dominance of the lower limb in force and body weight maintenance, were also correlated with the symmetry indices from the individual tests.

RESULTS

Characteristics of the study group

Following the U Mann-Whitney test, significantly (p = 0.0001) higher height, weight, and BMI values were in the male group than those recorded in the female group (Table 1). Age and weekly physical activity showed no statistically significant differences between the groups. Interestingly, analysis of responses from the Waterloo Footedness Questionnaire revealed that male and female groups had four subjects with left lower limb dominance, with the remainder showing right lower limb dominance (Table 2).

Symmetry analysis

Calculation of symmetry values for OSI, APSI, and MLSI in each condition showed significantly fewer indicators with negative values (Table 3). This means that standing on the right lower limb was significantly less stable compared to the left.

Table 2. The number of individuals in each gender group who selected the left or right lower limb in response to the Waterloo Footedness Questionnaire.

No.	Questions	Women (L/R)	Men (L/R)
1	If you were asked to shoot a ball on a target, which leg would you use to shoot the ball?	2 / 57	5 / 32
2	If you had to pick up marbles while standing and put the marbles in a box, which foot would you use to pick them up?	3 / 56	7 / 30
3	When you had to trace a figure drawn on the floor, which foot would you use?	10 / 49	8 / 28
4	Which foot would you use if you had to stomp out a small fire while standing?	8 / 51	/ 29
5	If you were asked to stand on one leg, on which leg would you stand?	27 / 32	21
6	Which foot would you use to smooth sand while standing?	7 / 52	8 / 29
7	If you had to step up onto a chair, which foot would you place on the chair first?	15 / 44	13 / 24
8	Which foot would you use to stomp an insect while you were standing?	7 / 52	6 / 31
9	If you were to balance on one foot on a railway track, which foot would you use?	15 / 44	24
10	If you had to hop on one foot, which foot would you use?	10 / 49	15 / 22
11	Which foot would you use to help push a shovel into the ground while digging?	10 / 49	13 / 24
12	During relaxed standing, people initially put most of their weight on one foot, leaving the other leg slightly bent. Which foot do you put most of your weight on first?	26 / 33	13 / 24
	Summary results	4 / 55	4 / 33
13	Are you right- or left-handed?	3 / 56	6 / 31

L- left; R - right

Table 3. Number of negative and positive symmetry index values calculated for OSI, APSI, and MLSI in male and female groups across test conditions: with visual control (EO), without visual control (EC), and with visual control on foam ground (EO_NS). The second part of the table shows the number of participants whose symmetry indexes calculated for OSI, APSI, and MLSI were simultaneously negative or positive.

Condition	Visual Control (EO)			Without Visual Control (EC)			Visual Control and foam surface (EO_NS)		
Index	OSI	APSI	MLSI	OSI	APSI	MLSI	OSI	APSI	MLSI
Women(< 0 / > 0)	25 / 34	27 / 32	33 / 26	24 / 35	19 / 40	29 / 30	26 / 33	25 / 34	30 / 29
Men(< 0 / > 0)	10 / 27	8 / 29	16 / 21	14 / 23	13 / 24	15 / 22	15 / 22	17 / 20	11 / 26
All three indexes simultaneously	OSI	APSI	MLSI	OSI	APSI	MLSI	OSI	APSI	MLSI
Women(< 0 / > 0)	17 / 16			13 / 24			12 / 16		
Men(< 0 / > 0)	6 / 19			6 / 15			6 / 15		

Table 4. Mean and standard deviation symmetry index values calculated for OSI, APSI, and MLSI in the whole group across test conditions: with visual control (EO), without visual control (EC), and with visual control on foam ground (EO_NS).

Symmetry index	Negative	Positive	p-value
OSI_EO	43.24 ± 33.61	46.91 ± 35.92	p = 0.7723
APSI_EO	48.32 ± 41.82	51.85 ± 44.40	p = 0.8134
MLSI_EO	40.31 ± 31.30	45.55 ± 42.15	p = 0.9270
OSI_EC	24.97 ± 20.61	40.09 ± 28.82	p = 0.0052*
APSI_EC	35.08 ± 31.11	52.42 ± 32.19	p = 0.0072*
MLSI_EC	45.65 ± 35.72	34.48 ± 33.13	p = 0.0654
OSI_EO_NS	34.92 ± 28.97	46.53 ± 32.28	p = 0.0589
APSI_EO_NS	45.64 ± 33.14	54.92 ± 41.39	p = 0.3616
MLSI_EO_NS	42.89 ± 36.06	53.24 ± 36.48	p = 0.1445

* statistical significant differences between the negative and positive symmetry indexes.

Table 5. Spearman's correlation values (RS) between the symmetry index values calculated for OSI, APSI, and MLSI in whole group across test conditions: with visual control (EO), without visual control (EC), and with visual control on foam ground (EO_NS) and the sum of responses for questions 1 – 12 and 5, 7, 9, 10, 11, and 12 from the Waterloo Footedness Questionnaire.

Symmetry index	The summed responses for questions 1 - 12	The summed responses for questions 5, 7, 9, 10, 11, and 12
OSI_EO	R_S = -0.0847, p = 0.767	R_S = -0.1662, p = 0.612
APSI_EO	R_S = 0.031, p = 0.871	R_S = -0.0657, p = 0.862
MLSI_EO	R_S = -0.1215, p = 0.138	R_S = -0.1728, p = 0.200
OSI_EC	R_S = 0.0023, p = 0.496	R_S = 0.0053, p = 0.919
APSI_EC	R_S = -0.0144, p = 0.912	R_S = 0.0105, p = 0.693
MLSI_EC	R_S = 0.0327, p = 0.298	R_S = 0.074, p = 0.895
OSI_EO_NS	R_S = 0.1274, p = 0.812	R_S = 0.0564, p = 0.780
APSI_EO_NS	R_S = 0.0905, p = 0.753	R_S = 0.0457, p = 0.893
MLSI_EO_NS	R_S = -0.0013, p = 0.452	R_S = -0.0003, p = 0.964

R_s: Spearman's correlation values.

In the final analysis, the symmetry indices with negative values were compared to those with positive values for the entire study group. Negative values were converted to their absolute values for this comparison. It was found that for the OSI symmetry index in tests without visual control, the mean absolute value of the negative symmetry coefficients was 24.97 ± 20.61. This was significantly lower (p = 0.0052) than the mean positive symmetry values, which were 40.09 ± 28.82. A similar pattern was observed for the APSI

SI under the same conditions, with mean absolute negative values at 35.08 ± 31.11 and positive values at 52.42 ± 32.19 (p = 0.0072) (Table 4). This indicates that APSI was a decisive factor in the significance shown for OSI SI. Other symmetry index absolute values were statistically non-significant, which indicates that symmetry of standing on the left or right foot is similar in different people despite which leg is better.

The results of the Spearman correlation between the symmetry index values and the sum of responses were low and not statistically significant (Table 5).

DISCUSSION

This study aimed to investigate how leg dominance influences symmetry of the body balance in one-leg standing. It was hypothesized that leg dominance, particularly the preference of using one leg as a supporting limb can affect body balance on one-leg standing tasks The analysis showed that each participant had better test results for one leg compared to the other, and for most participants and test conditions, the more stable lower limb was the right one (positive SI values). No significant correlations were found when Waterloo Footedness Questionnaire-Revised results were confronted with balance test results. Overall, the above-described results showed no influence of leg dominance on the symmetry of body balance in one-leg standing.

Aoki, et al. [29] also showed no differences between the results of left or right-leg standing, but they calculated no symmetry indices and included only right-foot dominant participants. An important result was that laterality was also not found in the dynamic balance test. Alonso, et al. [3] confirmed no differences in one-leg standing regarding the leg dominance determined as a ball-kicking leg. This study was performed on a non-stable platform and therefore required more engagement from the postural control system.

In the last years, Promsri, et al. [16] showed that leg dominance effects were visible only when using a non-linear variable (sample entropy) to assess postural control in one-leg standing in different (stable and unstable conditions). Their study included only right-foot dominant people, which limits the interpretation of the results. In their previous study, Promsri, et al. [15] confirmed asymmetries in one-leg standing. However, they found no differences in the coordinative structure of the postural movements between the dominant and non-dominant leg. The results of their study partly confirm our results, but also show some differences when analysing dynamic or static leg preference. Also, Kiyota and Fujiwara [13] confirmed differences between non-dominant and dominant legs during dynamic testing. Importantly in their study, leg dominance was defined on the basis of the WFQ-R.

In most studies, the dominant leg is defined as the preferred leg for kicking a ball [28]. Simultaneously, leg dominance seems to be a more complicated problem than hand dominance. This comes from two different purposes we use the lower limb [26,35]. The first one is voluntary (mobilizing) motor control like kicking the ball, stomping an insect, etc. which is included in the WFQ-R and represented in six questions (1-4, 6, and 8). The other one is the supporting and force-generating function, which is represented also by 6 questions in WFQ-R (5,7,9-12) [17,35]. However, analysis of the results obtained in this study did not show a correlation between right/left leg standing symmetry and WFQ-R scores from questions on lower limb support function. This corroborates, that leg dominance probably does not show the real functional abilities of the lower limb. However, Promsri, et al. [36] suggested that leg dominance affects sensorimotor control, especially coordination of postural movements. Nevertheless, this does not affect the ability to maintain balance in one-leg standing test.

This study has some limitations. First of all the number of participants having left foot dominant was relatively low, which can influence the results. In future studies, group-oriented selection should be applied to balance the number of left- and right-foot dominant participants. Secondly, it would be worthwhile to include dynamic balance tests such as limits of stability in future studies. Thirdly, this analysis was based only on three balance parameters generated by the Biodex Balance system, which limits the possibilities of analysis. Raw data from balance tests would be more useful to analyse also other aspects of body balance and posture like non-linear variables [14].

CONCLUSION

In summary, leg dominance does not seem to affect the ability to maintain body balance on one leg standing on a stable or foam surface. Nevertheless, some asymmetry between right and left leg standing is visible in healthy adults.

Funding Statement: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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