HOW DOES BODY SYMMETRY INFLUENCE STANDING BALANCE?

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Original scientific paper
https://doi.org/10.26582/k.51.1.1

Abstract:

The aim of the study was to determine whether maintaining the standing balance position is influenced by athlete's symmetric morphological characteristics. Thirty-two healthy sports students participated in this study (age 19.8±1.4 years, body height 182.9±6.8 cm, body weight 79.1±8.1 kg). Morphological characteristics are represented with differences between the left and the right body side of: forearm girth, upper arm girth, calf girth, thigh girth, long shoulder height, lean mass of legs and lean mass of arms. The standing balance result was calculated as a result of factor scores for 9 measurements of 30 seconds (3 measurements of normal standing, 3 measurements of blind standing, and 3 measurements of deaf standing) collected from the pressure insoles system and the difference in ground reaction force between the left and the right leg. Results show that the asymmetric leg load in maintaining standing balance depends on the side differences in the thigh girth and upper arm girth. The greater difference in the thigh girth in favour of the left side resulted in bigger ground reaction force on the right leg compared to the left leg and the greater difference in the upper arm girth in favour of the left side resulted in bigger ground reaction force on the left leg. To avoid one side overload, it is essential for all sports activities to be performed bilaterally.

Key words: *3D scan, body asymmetry, In Body, postural stability, pressure insole*

Introduction

Horak (1987) defines balance as "the ability to maintain equilibrium in a gravitational field by keeping or returning the centre of body mass over its base of support" (p. 1881). Winter (1995) claims that balance is a general term. It describes the dynamics of body posture, which is related to the inertial forces taking effect on the body and the inertial characteristics of individual body segments.

Sensory information for postural control comes from the somatosensory system, the vestibular system and vision. The somatosensory system includes muscle proprioception, joints and cutaneous afferents (Shumway-Cook & Horak, 1986). The preferred sensory input for the control of balance for healthy adults is somatosensory information from the feet in contact with the support surface (Shumway-Cook & Horak, 1986). When standing upright and the vertical projection of the centre-of-mass to the ground does not cross borders of the base of support, the body uses two main strategies to compensate for induced unbalance. Stability can be maintained by the ankle in the front-to-back plane with the classic reflex of the stretch and when the platform moves backwards, the gastrocnemii and hamstrings have the most common response. The central nervous system (CNS) first stabilizes the joint closer to the disturbance – the ankle, and then follows the stabilization of increasingly more distant joints – the knee, hip, and spine. Such maintenance of balanced position is called the "ankle strategy". When it comes to balance disturbances in the latero-medial plane, the body responds with the "hip strategy". This induces more complex developments, particularly in hips and trunk (Winter, 1995).

Postural stability and balance represent a key function for performing daily life tasks. Aging and a number of pathologies often increase the amount of postural sway, which may lead to falls (Maffiuletti, et al., 2005). Falls frequently lead to injuries or fatalities, particularly among older adults. Approximately 30% of people over 65 years of age and living in the community fall each year (Gillespie, et al., 2012; Stevens, Corso, Finkelstein, & Miller, 2006), but research suggests that falls and fall injuries are also common among middle-aged adults (Talbot, Musiol, Witham, & Metter, 2005).

Balance is an important ability also in majority of sports. The authors claim that intense training causes an increase of muscular girth, epiphysis width and a reduction of body fat (Krawczyk, Sklad, & Majle, 1995), but the muscle power, body weight, body mass index and body fat have an important influence on maintaining body balance position (Carter, et al., 2002; Goulding, 2003; Maciaszek, 2006; Maureen & Thornby, 1995). Smith, Weiss and Lehmkuhl describe that the level of body stability depends on four distinct factors: body weight, centre of gravity height, size of the support base and location of the gravity line within this support base. According to Oliveira, Imbiriba and Garcia (2000), dislocation velocity and centre of pressure (COP) area are related with anthropometric data of individuals.

Many research studies proved that in sports we could recognize the difference between the right and the left side of the body, which is defined as morphological asymmetry (Auerbach & Ruff, 2006). Krawczyk, Skład, Majle and Jackiewicz (1998) claimed that the right-left differences in anthropometric measurements are more recognized in the athletes of sports representing asymmetric movements than in the athletes of sports employing symmetric movements.

In a previous study it was found out that the body asymmetry is significant in sports which have typically unilateral muscle loading, for example handball, tennis, javelin throw, etc. (Šarabon, Košak, Fajon, & Drakslar, 2005). Furthermore, Krawczyk et al. (1998) observed 134 athletes aged 21-32 years during many different asymmetric movement sports like tennis, canoeing, kayaking and boxing in terms of the right-left differences in morphological parameters (forearm girth, upper arm girth, elbow width). In another study (Kruger, Ridder, Underhay, & Grobbelaar, 2005), the authors noticed that 19 elite international male javelin throwers (age 26.4±4.4 years) developed upper body morphological asymmetry. Thirteen out of fourteen variables had larger values on the dominant body side, especially for triceps skinfold (5.9%), half-chest girth (4.9%), forearm girth (3.9%), biceps skinfold (2.5%). Absaljamov, Zorin and Koz (1976) claimed that because of the higher mechanical load it is remarkable that hurdlers, high jumpers and pole vaulters exhibit higher muscle contractility in their swing leg than in their take-off leg. Some authors (Čuk, et al., 2012a) observed that the skittle-players had a significantly asymmetric body and asymmetric muscular efficiency. Additionally, in the research by Maughan, Abel, Watson and Weir (1986) results showed a greater proportion of muscle and smaller proportion of fat in the dominant arm than in the opposite limb in tennis players.

However, it is interesting that body asymmetry is significant not only in sports, which have typically unilateral muscle loading, but also in sports where we expect body symmetry. In the study by Čuk, Pajek, Jakše, Pajek and Peček (2012b) on a sample of 40 top-level gymnasts (average age of 23 years), who participated in the 2000 World Cup Competition in Ljubljana, the researchers found significant differences in elbow diameter, circumference of forearm, skinfold thickness of triceps and brachii biceps. Šarabon et al. (2005) claimed that repeated unilateral burdens on healthy locomotor system might lead to functional abnormalities of human posture. The deviation from perfect body symmetry is caused by a lack of development accuracy. Cronin (2010) also claimed that asymmetries between the lower limbs during athletic movements are thought to increase the risk of injury and compromise performance. Systematic sport training causes the difference in body posture because of the difference in muscular-ligament apparatus between the left and right side of torso development, which is the result of asymmetric body muscle development (Šarabon, et al., 2005).

However, according to our knowledge, there is no research, where balance abilities would be related to body morphological symmetries. Therefore, the aim of the study was to investigate if the morphological characteristics, especially bilateral asymmetry, influence human balance position. The hypothesis to be tested is (H1) that morphological bilateral asymmetries have an impact on differences in proportion of the left and right leg ground reaction force (GRF) in standing balance.

Methods

Participants

Thirty-two sports students registered in the academic 2015/2016 year at the Faculty of Sports participated in this study. Their average age was 19.8±1.4 years, their body height 182.9±6.8 cm and their body weight was 79.1±8.1 kg. Subjects had no medical conditions, none of them was a high-performance athlete, and their sports orientations were random. The institutional ethics committee approved the study and it was performed in accordance with the Declaration of Helsinki. Informed consent to study participation was given from all participants.

Measures and procedures

Our measurements were collected in two stages. In the first part, the morphological measurements were collected. For morphological measurements InBody 720 system and 3D body scanner were used. The InBody 720 bioimpedance measures each individual with high repeatability (Biospace, 2008) and measurement methods are reliable and valid. Gibson, Holmes, Desautels, Edmonds and Nuudi (2008) proved the validity of the device

InBody 720 in the study that showed a high correlation with DEXA and underwater weighing. 3D body scanner (NX-16 [TC][2], Cary, North Carolina) scans the whole body and produces a true-to-scale 3D body model. A multi-scan option with three consecutive scans was used to obtain the data. The duration of three consecutive scans lasted for 24 seconds and subjects were told to keep still as much as possible. In addition, findings of the research by Zancanaro, Milanese, Lovato, Sandri and Giachetti (2015) showed the reliability of a 3D scanner anthropometry performed by differently skilled anthropometrists.

The morphological variables were also measured. From InBody 720 legs lean mass and arms lean mass were taken and from 3D body scanner (according to ISO 20685:2010 norms) forearm girths, upper arm girth, calf girth, thigh girth, long shoulder height (is displayed as a vertical line from the shoulder point to the floor; the value is the height of the shoulder point above the floor) were taken.

The second part of measurements was done by body balance maintenance tests. All participants used two in-shoe insoles with pressure sensors (PedarX, Novel GmbH, Munich, Germany), feet size. Participants were not wearing shoes, but they had insoles between two socks, because shoes might change the ankle balance. The measurement system PedarX proved to be accurate and reliable and measurements were valid (Boyd, Bontrager, Mulroy, & Perry, 1997). The PedarX system was fastened with the elastic belt around subject's waist in the middle of the back and thus it was not an obstacle for the subjects and additionally it did not enforce asymmetric load on their feet. The total weight of PedarX system is 0.400 kg. Data are wirelessly transferred from the system to the computer with a built-in bluetooth module.

Participants executed three repetitions of each of three types of standing balance measurements. Each repetition was 30 s long. The first type was still-standing. All subjects were standing with their feet together, hands close to their bodies and they were looking forward. The second measurement type was blind still-standing where they were wearing dimmed glasses and nothing could be seen through them. The third measurement type was deaf still-standing where they were wearing protection earmuffs (3M™ PELTOR™ Optime™ II) with attention rating of 31 decibels (as shown in Figure 1). All measurements were randomly done and the participants had 15 s to rest between each one.

The PedarX system collected results for gravity force on the left and the right foot separately. The scanning rate was 50 Hz and time per frame was 0.02 s. Force [N] results of gravity force on the left and right foot were received every 0.02 s. The results revealed it there were differences in force

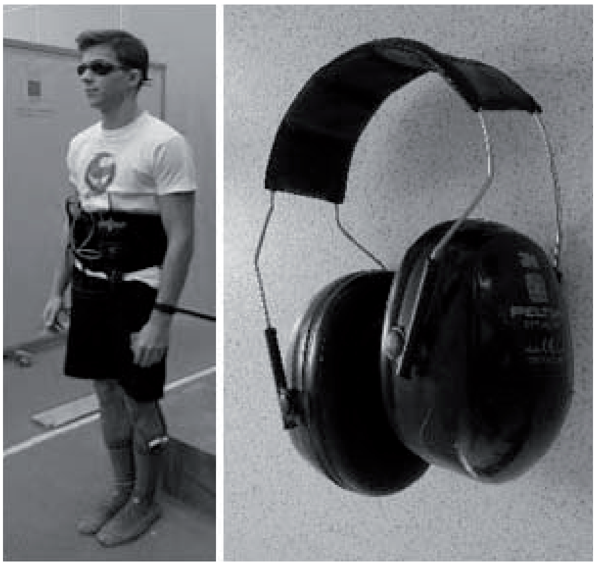

Figure 1. Blind still-standing and earmuffs.

load between the legs. We calculated the difference in force between the legs every 0.02 s and the average difference in the whole measurement. We always calculated the left leg gravity force minus the right leg gravity force. If the forces on both legs were the same, the balance was perfect.

For analysis, we used the bilateral difference in every specific morphological characteristic. Our anthropometrical variables were bilateral differences in: legs lean mass (Diff. legs lean mass), arms lean mass (Diff. arms lean mass), long shoulder height (Diff. long shoulder height), thigh girth (Diff. thigh girth), upper arm girth (Diff. upper arm girth), calf girth (Diff. calf girth) and forearm girth (Diff. forearm girth).

Statistical Analysis

All data were analysed in Microsoft Excel 2010 and statistical package SPSS 22.0. First, we did Kolmogorov-Smirnov test to verify normal distribution of variables. Pairwise t-test was used to establish differences between the left and the right side. Additionally, tests of reliability were done (factor analysis, Cronbach's alpha).

We did the evaluation of balance in two steps. In the first step, we did factor analysis (principal components) for each type of the standing types from three variables of the difference in pressure between the legs (items one to three). For the first factor, we calculated factor scores (calculated by the regression model). In the second step we continued with first factor scores for each type of stand (calculated by regression model), did a factor analysis (principal components) and calculated the factor scores for the first factor – this was used as depended variable in regression.

Regression analysis (method Enter) for dependent difference in gravity force (left/right leg) and difference of morphological characteristics (left/right side of the body) were calculated. All statistical analyse were tested at p<.05.

Results

Kolmogorov-Smirnov test showed that all variables were distributed normally except for the bilateral difference in calf and forearm girths. The dependent variable was normally distributed and therefore further multivariable analysis was allowed. The overall reliability (Cronbach's alpha) for the differences in gravity force between the legs during still-standing, blind still-standing and deaf still-standing was .917, which was in accordance with Tyson et al. (2006) and Chien et al. (2007).

In figure 2 there is an example of the subject's left and right gravity force and the difference between them. We can clearly identify the differences between legs. In this example, the difference in COP between the left and right leg is 112.31 N±22.34; however, among the tested subjects it was individually determined.

The results of regression analysis for the dependent "factor standing" and independent anthropometrical variables were significant at p<.05.

Table 1. Descriptive statistic

	Mean	Std. Deviation	K-S	Maximum	Minimum	$p_{t\text{-}test}$
Diff. calf girth [cm]	.05	.51	not	.90	-1.60	.59
Diff. upper arm girth [cm]	-.33	1.12	n	2.10	-2.70	.11
Diff. forearm girth [cm]	-.48	.81	not	2.50	-1.60	.00
Diff. thigh girth [cm]	.34	2.34	n	5.60	-4.90	.41
Diff. long shoulder height [cm]	-1.17	1.74	n	3.50	-3.70	.00
Diff. arms lean mass [kg]	-.04	.12	n	.17	-.39	.06
Diff. legs lean mass [kg]	-.04	.13	n	.39	-.22	.11
Diff. standing1 [N]	17.90	75.62	n	139.09	-137.32	.19
Diff. standing2 [N]	15.70	64.93	n	124.74	-188.60	.18
Diff. standing3 [N]	17.78	52.78	n	121.39	-83.28	.07
Diff. deaf standing1 [N]	16.53	73.61	n	142.73	-180.50	.21
Diff. deaf standing2 [N]	21.76	67.22	n	193.67	-84.22	.08
Diff. deaf standing3 [N]	16.99	55.37	n	145.80	-82.38	.09
Diff. blind standing1 [N]	5.59	69.91	n	114.40	-142.77	.65
Diff. blind standing2 [N]	4.22	55.54	n	121.65	-95.78	.67
Diff. blind standing3 [N]	19.74	64.11	n	157.23	-160.26	.09
Factor standing	.00	1.00	n	1.97	-1.98	

Note. n – normal distribution, not – not normal distribution.

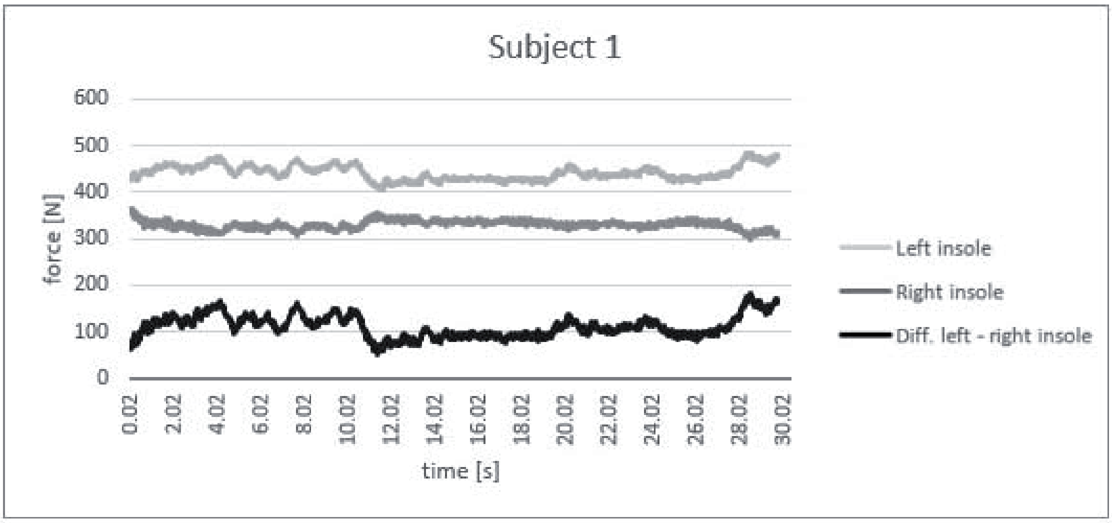

Figure 2. Example of ground reaction force for the right and left leg and difference between them while still standing.

Table 2. Results of factor analyses

	Commun-alities	Total variance explained initial eigenvalues		Component matrix	Cronbach's alpha
	Extraction	Total	Cumulative %		
1. Diff. standing1	.72	2.13	70.99	.85	.788
2. Diff. standing2	.79	.55	89.21	.89	
3. Diff. standing3	.63	.32	100.00	.79	
1. Diff. deaf standing 1	.76	2.41	80.18	.87	.868
2. Diff. deaf standing 2	.84	.36	92.09	.91	
3. Diff. deaf standing 3	.81	.24	100.00	.90	
1. Diff. blind standing 1	.76	1.73	57.60	.87	.627
2. Diff. blind standing 2	.54	.85	85.76	.74	
3. Diff. blind standing 3	.42	.43	100.00	.65	
1. Factor diff. standing	.90	2.60	86.74	.95	.923
2. Factor diff. deaf standing	.90	.29	96.27	.95	
3. Factor diff blind standing	.80	.11	100.00	.90	

Table 3. Pearson's correlation coefficients between variables

	Diff. calf girth	Diff. upper arm girth	Diff. forearm girth	Diff. thigh girth	Diff. long shoulder height	Diff. arms lean mass	Diff. legs lean mass
Diff. calf girth	1						
Diff. upper arm girth	.02	1					
Diff. forearm girth	.25	.32	1				
Diff. thigh girth	-.24	-.01	-.29	1			
Diff. long shoulder height	.07	-.34	.07	.23	1		
Diff. arms lean mass	.05	.21	.38*	-.18	.09	1	
Diff. legs lean mass	.36*	.05	-.05	.04	-.03	.00	1
Factor standing	-.11	.25	-.23	-.28	-.39*	-.26	-.13

Note. Pearson correlation coefficient, p<.05, * significant.

Table 4. Results of regression analysis; dependent variable factor scores for differences between legs load during stand balance (normal, deaf and blind) ($R=.66$, $R^2=.43$, $F=2.60$, sig $F=.04$, $df1=7$, $df2=24$)

	Beta	t	Sig.
Diff. calf girth	-.06	-.34	.74
Diff. upper arm girth	.39	2.14	.04*
Diff. forearm girth	-.36	-1.90	.07
Diff. thigh girth	-.41	-2.30	.03*
Diff. long shoulder height	-.11	-.61	.55
Diff. arms lean mass	-.26	-1.54	.14
Diff. legs lean mass	-.13	-.79	.44

Note. Dependent variable: Factor standing, p<.05, Linear regression; * significant.

Discussion and conclusion

Main finding is that morphological bilateral asymmetries have an impact on the differences between legs' GRF in standing balance. Average participants' body height was in accordance with previous findings (Popović, Bjelica, Jakšić & Hadžić, 2015) for such a generation of sports students. Paired sample T-test (Table I) showed differences in the forearm girth and long shoulder height. Because of the significant difference in the long shoulder height, we could conclude that the participants also had asymmetric body posture with a higher right arm and a lower left shoulders height; the same direction of difference is valid for the forearm girth, where the right side is dominant. The difference in arms and legs' lean mass was not significant. From these results, we can assume that the difference occurred because of fatty tissue and this is the reason for asymmetry.

Those asymmetries are not high and in terms of normal life, they are not significant; however, they are important from the aspect of leg load. According to the differences in body posture, where the right shoulder side is higher, it is also understandable that the left leg takes more weight. As an average, this is a small amount of weight, but huge differences exist among subjects. Although Šarabon et al. (2005) claimed that only those who were doing unilateral sports had significant bilateral asymmetries, the results from this study showed that in general terms, also normal sports activities (recreational level) had emphasized bilateral asymmetries.

Reliability analysis via factor analysis, where cumulative variance explained by the first factor was from 57.60% for blind standing, through 70.99% for normal standing to 80.18% for deaf standing, demonstrated by the tests can be defined as reliable. Cronbach's alpha had even higher values (.627 for blind, .788 for normal and .868 for deaf standing). Factor analysis of factors scores for each type of standing balance measurements extracted the first factor with 86.74% of variance and Cronbach's alpha of .923. As we did the factor analysis of different standing balance protocols (normal standing with postural control from the somatosensory system, the vestibular system and vision; deaf standing and blind standing) and all types of protocols formed one unique factor, where all component matrix coefficients were very high, we can conclude that the somatosensory system according to Shumway-Cook and Horak (1986) was extracted. According to the results, we can confirm that has our set of balance tests adequate validity and reliability and the first factor scores are proper representatives of standing balance results.

Regression analysis explained 43.1% of the leg weight differences with morphological characteristics. Significant predictors were differences in the upper arm and thigh girths. The difference in the upper arm girth was positively related and the difference in the thigh girth was negatively related. Therefore, it can be concluded that a bigger value of the upper arm girth on the left side corresponds to a greater load also on the left leg. Moreover, it should be emphasized that fat on arms and legs determines the girth of the thigh.

Such results can be in the direction of Helal and El Fiky (2015) who found out that body mass index is in positive correlation with postural instability with higher values of fat mass. Alonso et al. (2015) found out that linear regression analysis on postural balance and anthropometrical variables explained much more variance of the medial-lateral postural variability (12% eyes open, 18% eyes closed) than in the anteroposterior direction (6% eyes open, 0% eyes closed); in their research body height determined variability of balance, but they did not discuss why medial-lateral postural variability is better predicted than anteroposterior. Greve, Alonso, Bordini and Camanho (2007) researched correlation between body mass index and general postural balance, the anteroposterior stability index and lateral stability index on the dominant and non-dominant legs; they concluded that the comparison of the balance indexes for the dominant and non-dominant sides showed no statistically significant differences. However, they did research load on one isolated leg at a time and with BMI only as anthropometric parameter, they could not define connections between body asymmetries and postural balance. According to our results, we can state that body symmetry is an important factor of postural balance. The limitations of this study are related to generalization of results; for generalization, further research should include more participants, both genders and a wider age span, from youth to the elderly.

The hypothesis was tested that morphological bilateral asymmetries had an impact on the differences in leg pressure in standing balance. We can conclude that:

- Among physically active sports students bilateral differences in morphological characteristics were detected.
- The significant differences were found in the forearm girth (right side prevails) and long shoulder height (right side prevails).
- Morphological bilateral differences significantly determine the differences between the legs in pressure during standing and explain 43% of it.
- The best predictors of the differences in leg pressure during standing are the bilateral differences in the upper arm girth and thigh girth.
- Bigger differences in favour of the left leg are positively related to the differences in the upper arm girth in favour of the left arm and negatively with the differences in the thigh girth in favour of the right leg.
- As the upper arm girth and thigh girth manifested no differences in lean mass, fat mass induces main relations with the standing balance differences.
- For practice it is important to balance not only lean mass but fat mass as well so that there would be no bilateral differences.

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Submitted: April 4, 2017
Accepted: September 26, 2017
Published Online First: December 5, 2018

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