

Symmetry of lower limb loading in healthy adults during normal and abnormal stance

JACEK STODÓŁKA, MAŁGORZATA SOBERA*

University School of Physical Education, Faculty of Physical Education, Wrocław, Poland.

Purpose: The purpose of the research was twofold: (1) to describe the normal asymmetry in lower limb loading during a normal stance and during a stance with visual and vestibular disturbance relating to the lower limb dominance, (2) to assess relations of loading of both lower limbs with body weight and height (BMI) and leg functional dominance. *Methods:* The subjects of this study were 95 students. Settings of the two Kistler platforms were used to register the time series of the vertical component of the ground reaction force while the subject was standing (45 seconds) in a normal position and next with eyes covered with a band and head tilted back position with one leg placed on one platform and the other on the second platform. The symmetry index (SI) was used to describe the asymmetry of the left or right loading. *Results:* The greater loading of the left or right leg during standing was independent of the functional leg dominance. The distribution of left and right lower limb loading in both trials may suggest that a low asymmetry, less than 5%, is represented by about 30% of subjects in general. No significant correlation was found between the SI and BMI of subjects who had a normal body weight, but in the group of overweight subjects the correlation was very high ($r = 0.9$). *Conclusion:* The results show that in describing norms of asymmetry in posture control in healthy humans it is very important to compare the results to posture asymmetry in various injuries or diseases. The most important result is that the higher asymmetry of lower limb loading is associated with overweight, which implies greater risk to health of those people.

Key words: posture control, loading, BMI, symmetry index

1. Introduction

Functional dominance of the left or right side of the human body is the normal effect of postural development [20]. As a medical term, it expresses the functional dominance of one of a pair of symmetrical organs of the human body over the other although the postural asymmetry is generally considered as reflecting postural impairment [23], and it is human nature to be asymmetrical. Perfect symmetry does not exist in humans, so we expect that the fundamental human activity of posture control in a normal bipedal stance will not be symmetrical either. Anker et al. [2] reported that the effects of weight-bearing asymmetry were due to changes in the biomechanical constraints of upright standing, and they suggested that through increasing weight-bearing asymmetry the postural

instability increased by reducing the efficiency of hip load/unload mechanisms and increasing the compensatory ankle movement. These authors examined healthy adults loaded with extra body weight, but the question was whether the body weight of humans is related to symmetry in postural control. Genthon and Rougier [9] stressed that it is necessary to distinguish the influence of biomechanical constraints of natural postural asymmetry from other neurological or traumatic deficits.

Usually, very small differences between activity of the left and right lower limb are not noticed in a normal bipedal stance. Sikora [19] and Greve et al. [10] did not observe any differences in load of both lower limbs when standing, which according to them is typical of adults. More often researchers consider the asymmetry of support function in development of children [6], [20]. The asymmetry of support function

* Corresponding author: Małgorzata Sobera, University School of Physical Education, Faculty of Physical Education, Al. J.I. Paderewskiego 35, 51-612 Wrocław, Poland. Phone: 0048713473372, Mobile: +48 503 403 473, e-mail: malgorzata.sobera@awf.wroc.pl

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in adults may be related to any lower limb dysfunction, joint and muscle pain, or bad motor habits which started at a younger age [16]. Repeated asymmetry of loading both legs for hours every day can involve asymmetrical spine loading and lumbar pain [7]. This effect could be more dangerous for health in the case of overweight people. The research on lower limb symmetrical loading in a normal stance in relation to gender, body mass and height (BMI) in young healthy adults may describe normal deviation from perfect symmetry of lower limb loading that does not constitute a danger for human posture and health. Gallagher et al. [8] proposed taking into consideration a threshold of normal asymmetry as 65% of body weight loaded on one lower limb for 2 hours. The difference seems to be too great to assume that such asymmetry would be normal. Loading like this for about 12 hours a day and years of life would generate high loading on one side of the body on the major joints and spine [15], [21].

On the other hand, such asymmetric loading is a simple biomechanical factor that determines the time needed to initiate a subsequent lift-one-leg task for, e.g., a step [18]. Yiou and Do [23] suggest that there is a need to differentiate between asymmetry due to postural impairment and asymmetry of “normal” limb dominance. The asymmetry of lower limb support function may appear in abnormal conditions of stance, e.g., when input information is deficient in comparison to normal control of posture. Klier and Angelaki [13] reported that specific incoming sensory information from head motions was processed into appropriate outgoing motor commands that control behavior. In daily life we often raise and bend backward the head to see something above the head. The posture becomes unstable because of the abnormal head position. The vestibulo-ocular reflex generates compensatory eye movements whose goal is to maintain a clear and stable view of the environment during head movements [1]. If the postural control is disturbed by closing the eyes, the human body starts to sway in all directions more than in a normal eyes-open stance [3]. Covering the eyes completely eliminates the participation of vision input, while tilting the head interferes with the normal functioning of the labyrinthine system [13]. These interferences – covering the eyes and tilting the head backward – can highlight the asymmetry or symmetry of lower limb loading in standing position.

The purpose of the research was twofold: (1) to describe the normal asymmetry in lower limb loading during a normal stance and during a stance with visual and vestibular disturbance relating to the lower limb

dominance, (2) to assess relations of loading of both lower limbs with body weight and height (BMI) and leg functional dominance.

2. Material and method

2.1. Participants

The subjects of this study were 95 students of physical education (50 women and 45 men) aged 21.08 ± 1.08 years (body mass 68.09 ± 13.12 kg, height 172.89 ± 9.56 cm). The participants were recruited from university population. All were healthy and physically fit, but none was practicing sport professionally. All subjects signed an informed consent form. The study was approved by the Human Ethics Committee of the University School of Physical Education in Wrocław. None of the participants had any physical or physiological limitations that could have affected the experiment.

2.2. Measures

Settings of the two platforms (Kistler, Corp. type 9286AA, BioWare 4 software) were used to register the time series of the vertical component of the ground reaction force while the person examined was standing in a normal bipedal position – the first session – with one leg placed on one platform and the second one on the other. Force tracings were synchronized in time. Both platforms were checked to determine force calibration. Each subject stood on the platforms barefoot in natural bipedal stance with the feet parallel at the width of the hips (the distance between the feet was about 30 cm). They were asked to avoid movements of the body segments. The subjects looked straight ahead at a defined point in space situated at a distance of 3 m at sight level. In the first test, the participant was asked to stand relaxed, with arms at the sides, keeping their feet pointed forward and maintaining the posture for 45 seconds. They stood for about 10 seconds and then data were collected. In the second session, the participants stood on the platforms in abnormal (disturbed) stance: with eyes covered by a band and head tilted back as much as they could without changing the trunk position. The result was obtained in the form of force tracings registering changes in the curve showing values of the vertical force component of the left and right lower limb (Fig. 1).

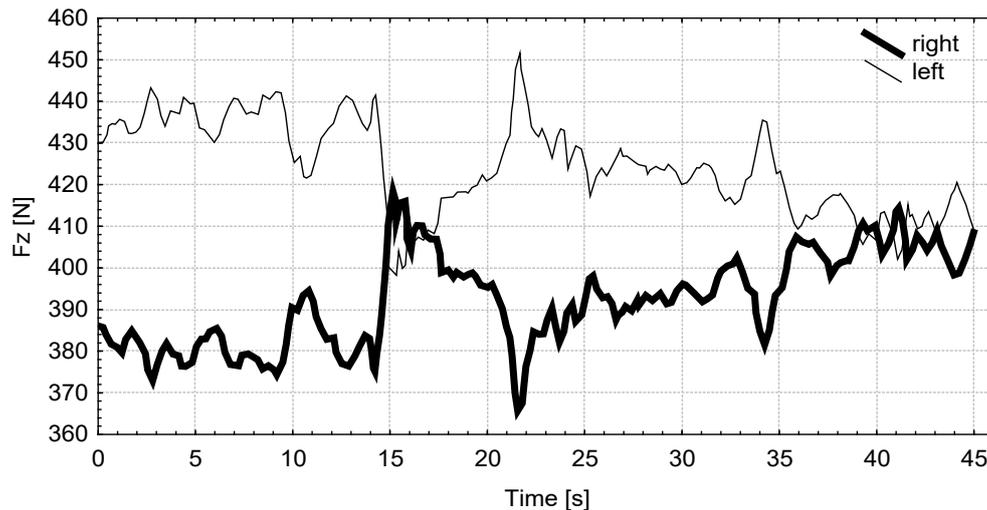


Fig. 1. Sample tracing of changes in the value of the vertical force component of pressure exerted by right and left foot over the platform

Additionally, before the experiment, participants were asked to provide information about which leg they used to perform a ball kick [11]. This question was asked in order to compare the result given in the qualitative form, which was provided by the study participants on the basis of their experience, and the result obtained from a simple test: in an upright, relaxed, standing position the participants were asked to kick a dropping paper ball. The experiment was repeated three times. The leg that performed the kick was recognized as the functionally dominant lower limb.

2.3. Procedures

The vertical component (F_z) of ground reaction forces was recorded while maintaining an upright body position in two different standing positions and then the mean value of each trial was computed. Two trial sessions of stance were performed with a sampling rate of 50 Hz. The symmetry index (SI) was used to describe the difference between the left and right loadings [4], [22].

$$SI = \frac{|FzL - FzP|}{0.5(FzL + FzP)} * 100\%$$

where FzL and FzP are the average vertical components of the ground reaction force of the left and right lower limb, respectively. A value of SI close to zero means perfect symmetry of loading of both legs, and 100% means asymmetric loading of one leg. A positive result of " $FzL - FzP$ " indicates that the left lower limb is loaded more than the right one, and a negative

result means the opposite – the right lower limb is generally loaded more than the left one. The results were divided within the male and female groups taking into account the positive and negative difference of " $FzL - FzP$ " and then the SI values were shown in percent (positive) for the two cases separately.

Finally the subjects were divided into two groups in order to find the relationship between SI and BMI as Hue et al. [12] and Ku et al. [14] found that body weight correlates with balance instability. One group included subjects with normal weight (BMI from 18.50 to 24.99 kg/m^2) and the second one included overweight participants (BMI from 25 to 29.99 kg/m^2) (categorized according to the World Health Organization) [14]. None of the subjects in this study had BMI < 18.50 kg/m^2 or BMI > 30 kg/m^2 .

2.4. Statistical analysis

The normality of data distribution was verified by the Shapiro–Wilk test taking into account the gender, leg domination and BMI factor. Not all of the data revealed a normal distribution, so we used non-parametric statistics. Descriptive statistics (medians and minimum–maximum) were calculated for all dependent variables. The SI distribution will be shown in the form of histograms for male and female groups and the figures will include the information about that which lower limb was loaded more than the other one and how many women and men loaded left/right leg. The AVOVA Kruskal–Wallis option was used to investigate the effect of gender, limb dominance and BMI on the symmetry index. Wilcoxon's test was applied to

find significant differences between the left and right loading taking into account two groups of subjects: normal and overweight participants. The relationship between BMI and the SI values in both sessions of research for both sexes was determined using Spearman's correlation. Statistical power was determined to be higher than 0.90 at the 0.05 alpha level. All the calculations were carried out using the Statistica 12.5 software.

3. Results

No effect of gender on the symmetry index was found: in normal stance: $H(1, N = 95) = 1.86, p = 0.17$ and abnormal stance $H(1, N = 95) = 0.20, p = 0.66$ as well as no effect of the lower limb dominance on the SI was found: in normal stance $H(1, N = 95) = 2.73, p = 0.10$ and in abnormal $H(1, N = 95) = 0.003, p = 0.90$. Most of the subjects in this study ($n = 84$) showed the right lower limb as functionally dominant

and only 11 persons showed the left lower limb as dominant. No effects of BMI (after the group division into normal and overweight without gender-related division) on the SI values were noticed in both sessions: in normal stance $H(1, N = 95) = 1.19, p = 0.27$ and in abnormal stance $H(1, N = 95) = 0.15, p = 0.70$.

The SI values of the left and right lower limb are shown in the form of histograms for either session within the male or female group (Figs. 2–5). The SI values, expressed percent, do not describe the greater loading of the left or right lower limb during trials. This analysis was based on the calculation of how many men and women (expressed percent) revealed the negative or positive values of the difference “FzL – FzP”, to determine the greater loading of the left or right lower limb that was marked in Figs. 2–5 as follows: “left > right” or “right > left” and “ n ” numbers were added. In both groups and both sessions, in normal and disturbed stance, almost half of the men or women showed greater loading of the left and half the right lower leg, as presented in Figs. 2–5. These figures show that about 30% of subjects revealed a slight

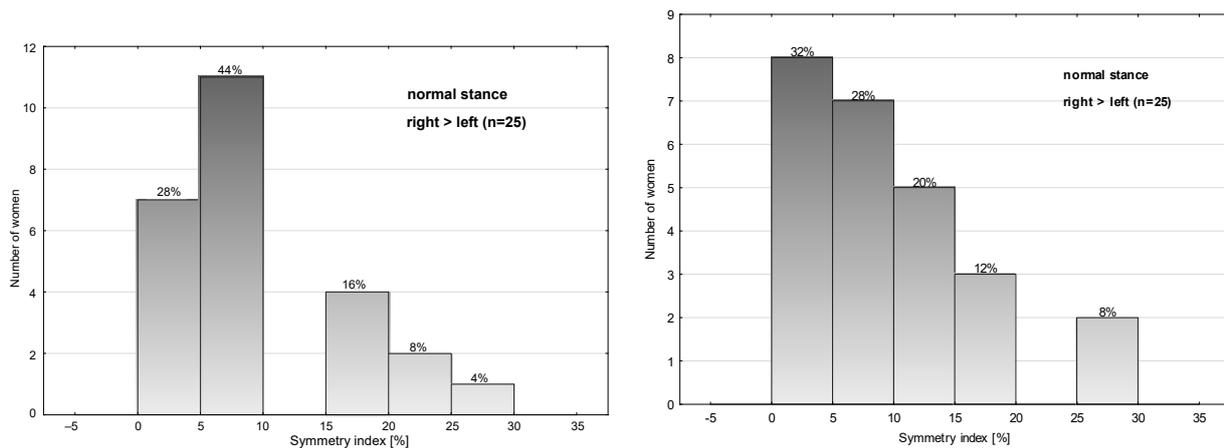


Fig. 2. Distribution of symmetry index for women in trials with eyes opened – normal stance

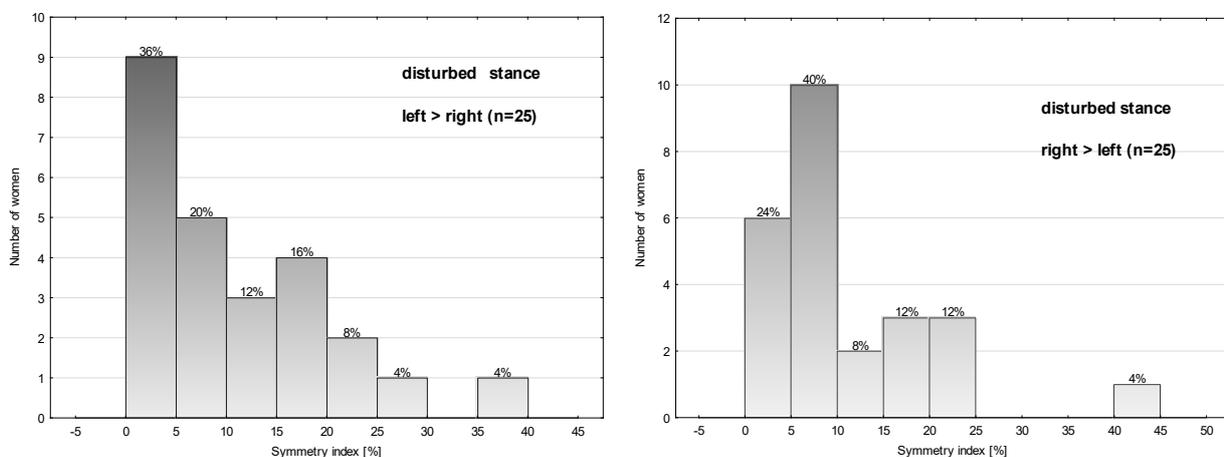


Fig. 3. Distribution of symmetry index for women in trials with eyes covered and head tilted back – abnormal, disturbed stance

(SI less than 5%) asymmetry of lower limb loading in both groups regarding either the left or the right leg being more loaded in the trials with normal and disturbed standing. Quite a high percentage of subjects (about 70%) revealed a higher value of the symmetry index, SI above 5% up to 30–35% in both gender groups and in both trials, although most of the subjects (men and women) attained an SI value under 25% and only a few of them loaded one leg more than the other with asymmetry of about 30–40% (Figs. 2–5). It seems that the main problem is the magnitude of weight bearing asymmetry but less significant which leg is more loaded, as the results showed.

There was no clear difference between the SI distribution in the normal and disturbed stance in the female group (Fig. 2). We observed an inverted distribution of SI values in normal and disturbed trials comparing the greater loading of the left or right lower limb. In general, the greater loading of the left leg in a normal stance (Fig. 2) and the distribution of greater loading of right leg in a disturbed stance are

similar (Fig. 3), as is the right leg loading distribution in a normal stance (Fig. 2) and the greater loading of the left leg than that of the right one in the stance with disturbance (Fig. 3).

In the male group, a different distribution of SI values was observed when the left and right leg loadings were considered in a normal stance. A low SI (from 0 to 5%) was revealed in 36% of subjects in whom the left leg was loaded more than the right one (Fig. 4), but in the case of greater loading of the right leg, 35% of subjects revealed an SI value between 10% and 15% (Fig. 4). This suggests that the right lower limb is much more loaded than the left one in males during a normal stance. However, we did not observe such a phenomenon in the stance with eyes covered and head tilted back (Fig. 5). In this trial, the SI value distributions of subjects with greater loading of the left or right lower limb were quite similar independent of which leg was loaded more. A puzzling observation was the percentage of men (23%) who loaded the left leg more than the right one, with the

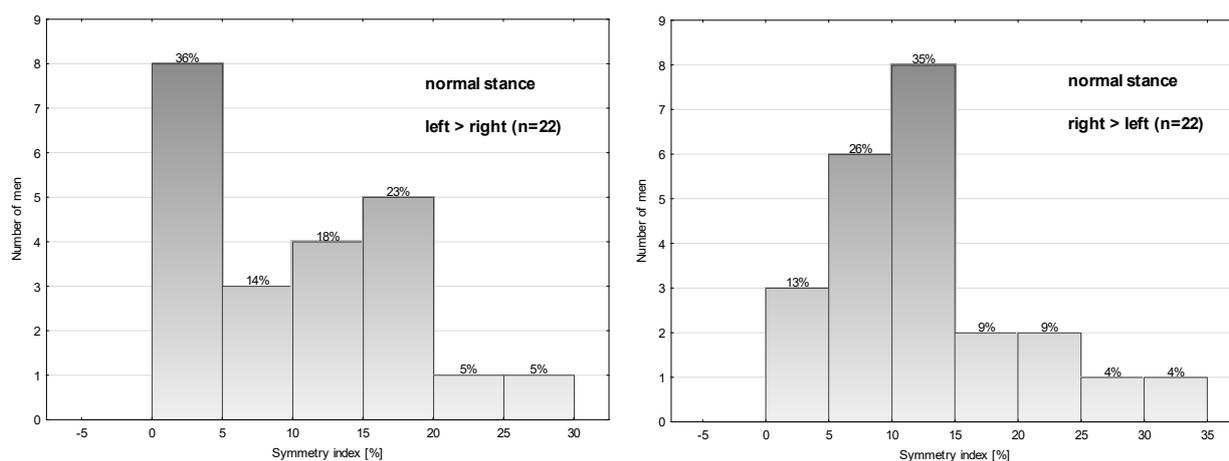


Fig. 4. Distribution of symmetry index for men in trials with eyes opened – normal stance

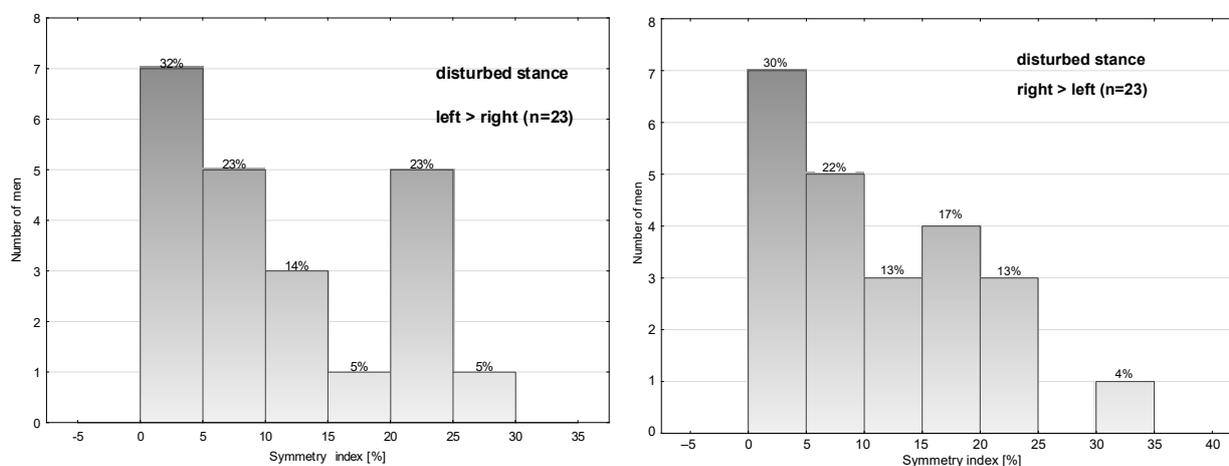


Fig. 5. Distribution of symmetry index for men in trials with eyes covered and head tilted back – abnormal, disturbed stance

symmetry index from 15 to 20% and from 20 to 25% in normal and disturbed trials, respectively (Figs. 4 and 5).

The distribution of left and right lower limb loading in both trials may suggest that a low asymmetry (independent of which leg was more loaded), under 5%, is represented by about 30% of subjects generally but the remainder reveal greater asymmetry: SI = 10% to 20% and even up to 40%. The question was: What could be the reason for the asymmetrical leg loading if the subjects were young and healthy, without a history of injuries that can involve asymmetry of leg loading? It is possible that the reason is abnormal body mass

(BMI). Therefore we decided to assess the correlation between the SI and BMI.

There was no correlation between SI and BMI taking into account all subjects in the female and male groups separately, and the correlation coefficient was very low, between 0.1 and 0.2. When we decided to omit those subjects who had an SI less than 5% (15 women in normal and disturbed stance, 11 men in normal and 14 in disturbed stance), we verified the correlation between SI values and BMI in intra-gender groups. There was no significant correlation of SI and BMI with the gender factor, so we did not di-

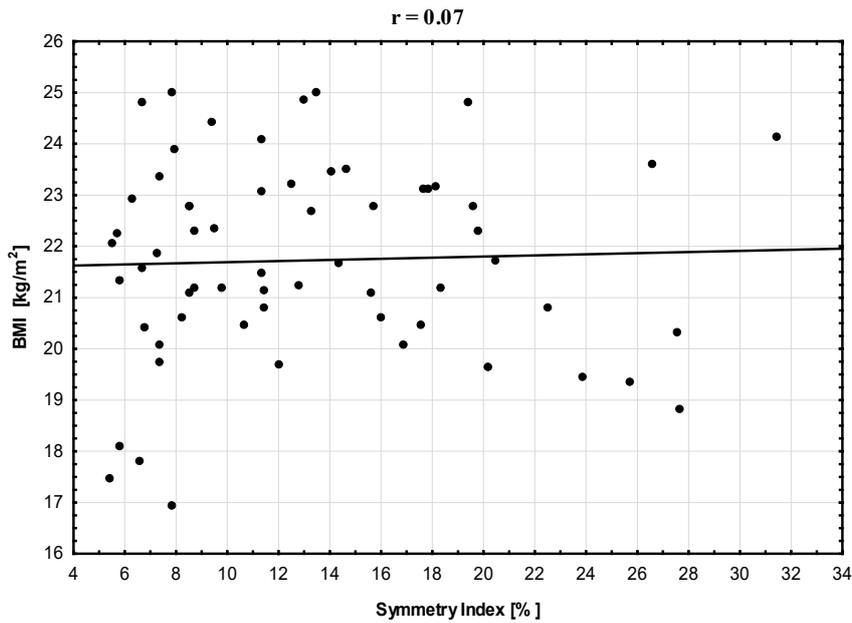


Fig. 6. Correlation between SI and BMI in the normal stance trial for the subjects with values BMI < 25 kg/m² (n = 62)

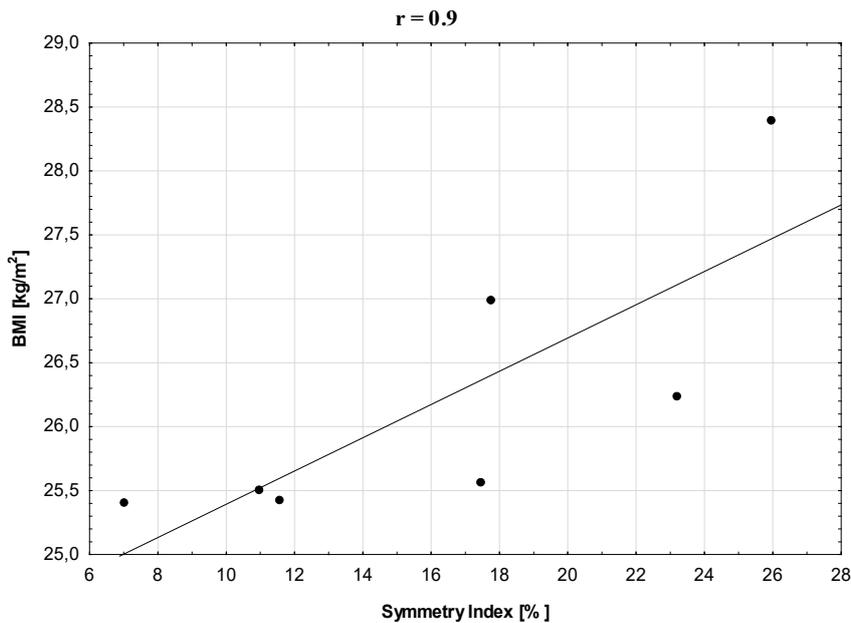


Fig. 7. Correlation between SI and BMI in the normal stance trial for the subjects with BMI ≥ 25 kg/m² (n = 7)

vide the subjects into gender groups next. We assessed the correlation of SI and BMI in the two categories BMI < 25 kg/m² ($n = 62$) and BMI \geq 25 kg/m² ($n = 7$) according to the definitions of normal and overweight.

No significant correlation was found between the symmetry index and BMI of subjects who had a normal body weight ($r = 0.07$) either in the natural stance (Fig. 6) or in the disturbed stance ($r = -0.06$). However, in the group of subjects with overweight (BMI \geq 25 kg/m²) the correlation was very high ($r = 0.9$) and significant (Fig. 7), although there were only 7 persons with overweight. Such a correlation was not found in the trial with visual and vestibular disturbance.

It is necessary to note that if we applied the cut-off value of SI < 15%, according to the threshold suggested by Gallagher et al. [8], from the total number of subjects, we would obtain a very high correlation ($r = 0.8$) between BMI and SI in the normal stance trial, as well.

4. Discussion

4.1. Asymmetry of lower limb loading

The assessment of asymmetry of body weight distribution is a theme explored by several authors [2], [9], [17], mainly in order to study mechanisms of weight-bearing in pathologic states of the human body, e.g., stroke, leg amputation or hemiparetic patients. However, it was hard to find data regarding the normal asymmetry of leg loading in healthy humans. It is still unclear what degree of asymmetry is normal and what is abnormal, too high, and dangerous to hips and spine loading. Certainly, it is quite easy to assess the asymmetry in posture and the asymmetry of weight-bearing in unhealthy humans [5]. Perhaps, even a low degree of asymmetry of weight-bearing repeated every day for years could be the cause of low back pain or problems with hip joints.

In this study, we tried to verify the presumption that if the symmetry index (which allows one to assess the percentage of greater loading of one lower limb than the other in healthy young adults) was between zero and 5% as the normal error in research, this would be the lowest asymmetry which we could accept as normal, but when the SI > 5% it would mean an increased asymmetry of one leg loading. This cannot be established explicitly on the basis of the present study, but these results show that about 30% of all subjects did not exceed the level of SI = 5% indicating

asymmetry of one leg loading in both conditions of trials, independent of which leg, left or right, was loaded more during the trials. Five percent asymmetry means that one lower limb was loaded with 5% more than half of the body mass, so it is approximately 4.0 kg for one lower limb in a man/woman of body weight, e.g., 80 kg. It seems to be not much greater loading relative to the whole body mass for a prolonged period than in daily life conditions of standing (45 seconds) in normal or disturbed conditions. It seems to be normal to load one lower limb during a standing position independently of the leg dominance. Most of the subjects (84) in this study showed the right lower limb as functionally dominant and only 11 persons showed the left lower limb as dominant, but the leg dominance was not a significant factor that influences asymmetry of leg loading. It turned out in this study that the left leg as well as the right one were loaded almost fifty-fifty in both gender groups, and no effect of leg dominance was found. Hoffman et al. [11] and Greve et al. [10] also found no difference in unilateral postural stability between the functionally dominant and non-dominant lower limbs in a healthy population of young adults. Sobera et al. [20] reported that the lateralization in support function of lower limbs was finished in 7-year-old children, so it was possible that the young adults were not asymmetrical in the support function any more.

4.2. Correlation between SI and BMI

The correlation between SI and BMI in all subjects was very low (0.1–0.2) unless the subjects with the symmetry index less than 5% were rejected from the computation and the remainder were divided into 2 groups: normal BMI and overweight. Then, a very high and significant correlation was found between SI and BMI in overweight subjects but not in those with normal BMI, although the latter was a numerous group ($n = 62$) relative to those with higher BMI ($n = 7$). It is suggested that the higher BMI influences the asymmetry of leg loading very strongly, which seems to be confirmed by the results of other authors Błaszczyk et al. [3] found that increased body weight may be a disadvantageous determinant of dynamic stability, so this may explain a significant correlation of lower limb loading asymmetry in subjects with overweight in this study. It was stated, too, that an increased body weight tends to improve postural stability [24] but only in a static state, not a dynamic one as reported by Błaszczyk et al. [3]. As found in this study, the weight-bearing in subjects with over-

weight is not symmetrical for both lower limbs, particularly during a prolonged normal stance when everybody sways naturally [8]. This can be dangerous for joints and spine health, as reported by Theilmeyer et al. [21], particularly for overweight people.

5. Conclusion

Unfortunately, we cannot specify precisely the magnitude of lower limb loading asymmetry that can be accepted as normal. This study should be considered as highlighting the problem yet to be solved, but probably more data and a greater number of subjects with overweight and underweight are necessary for that purpose. Still, we believe that the results show that in describing norms of asymmetry in posture control in healthy humans it is very important to compare the results to posture asymmetry in various injuries or diseases. The most important result is that the higher asymmetry of lower limb loading is associated with overweight, which implies greater risk to health of those people beside physiological diseases.

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