

Laterality versus jumping performance in men and women

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Purpose: The aim of this study was to investigate relationships between functional asymmetry of lower limbs, taking into account morphological features of the feet, and jumping ability in men and women. **Methods:** The study population consisted of 56 subjects, 30 women (age: 20.29 ± 0.59 years; body mass: 58.13 ± 4.58 kg, body height: 165.60 ± 5.03 cm) and 26 men (age: 20.41 ± 0.78 years, body mass: 78.39 ± 8.42 kg, body height: 181.15 ± 6.52 cm). The measurements of longitudinal arches were performed with the plantographic method on the basis of Clarke's angle mapped on a computer foot print. The measurements of jumping performance during bilateral (two legs) and unilateral (single-leg) counter movement jump (CMJ) were done on force plate. All subjects jumped three times each type of jump (total 9 jumps): three right leg, three left leg and three two legs. We put the test results through a detailed statistical analysis with the Statistica 8.0. The *t*-test for dependent variables and the Wilcoxon signed-rank test for divergent variances of the features compared. The analysis of relationships between the chosen podometric and plantographic features and jumping performance was conducted on the basis of the Pearson product-moment correlation coefficient (for the features which presented normal distribution, according to the Shapiro–Wilk test). **Results:** The correlations between values of height of single-leg jumps (right and left) and bilateral jumps, and foot indices were found in few cases only in men who had greater values of jump height with the non-dominant limb. We did not find a significant difference in jumping ability between the dominant limb and the non-dominant limb in women. We found bilateral deficits in jumping ability in the study groups, though we did not find significant differences ($P \leq 0.05$) between the values for women (a mean of 6.5%) and for men (a mean of 8.4%). **Conclusion:** We found significant gender differences of the correlations between the values of height of jumps (single-leg and bilateral jumps) and foot indices.

Key words: limb dominance, foot structure, jumping ability, bilateral deficit, sexual dimorphism

1. Introduction

The relationships between functional asymmetry of lower limbs, taking into account morphological features of the feet, and the jumping ability measured in single-leg (right and left) and bilateral jumps are the interesting problem in sport as well as daily life activity. The manner of evaluating which upper and lower extremity is dominant is very important in research of relations between laterality and muscle function. It is

believed that human functional limb asymmetry originates, develops, and consolidates as a result of both endogenic and exogenic factors [6], [25]. The lower limb functional dominance can be determined with a number of tests [20], [21], [23]. Valdez et al. [20], for instance, determined lower limb dominance using three tasks: kicking a soccer ball, stepping on an object and smoothing out sand, the leg used to perform the task was identified as the dominant leg. Hewit et al. [12] used the balance regain test and the leg used to regain balance was identified as the dominant one.

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Sometimes in determining functional dominance the subjects' declaration is used [24], and it may be combined with motor tasks [18]. Some authors stress that declared dominance and dominance determined in motor tasks do not correlate, and therefore they recommend combining both methods [6], [10]. The following kinds of laterality can be found: homogeneous laterality, i.e., one side of the body clearly dominates over the other (e.g., right-handedness and right-footedness, or left-handedness and left-footedness); and mixed laterality (or cross-dominance), i.e., there is no distinctive dominance on one side of the body over the other (e.g., right-footedness along with left-handedness) [14]. The type of test (e.g., kicking a ball or one-leg jump) may have an impact on the determination of the dominant lower limb [14].

In our research, we chose the measurements of jumping performance during bilateral (two legs) and unilateral (single-leg) countermovement jump (CMJ) on dynamometric platform. The countermovement jump (CMJ) is a complex movement that engages lower and upper limb muscles, while jump height measures its absolute effectiveness [19]. CMJ was used in many studies. For example, Impellizzeri et al. [15] proved the significant accuracy and reliability of the vertical jump test. Paterno et al. [16] used drop vertical jump (DVJ) as a diagnostic test, on the basis of which they predicted the risk of second anterior cruciate ligament injury (either reinjury or contralateral injury) in athletes who had returned to systematic training after an endoscopic reconstruction of the ligament. In another study on second division female volleyball players, Buško et al. [5] determined correlations between jump height in CMJ and somatotype. CMJ was used in studies which aimed at determining the impact of genetic and environmental factors on the jumping ability of adolescent boys and girls [17].

Correlations between laterality and jumping ability have been studied by Challis [7], Hewit et al. [12], Valdez et al. [20], and Veligas and Bogdanis [22]. Hewit et al. [12] studied asymmetries in jumping ability in athletes, which manifested themselves both in multidirectional jumps (vertical, horizontal and lateral), and in the variables analyzed (power, force, height/length of jump). Bilateral force deficit refers to the phenomenon that maximal generated force during simultaneous bilateral muscle contractions is smaller than the sum of forces generated unilaterally [1]. An opposite phenomenon is called bilateral facilitation [1], [8]. Bilateral deficit in jumping ability appears when the sum of values of height of single-leg jumps (right and left) is greater than in bilateral jump [22], or when the value of height of single-leg jump is greater

than 50% of the value in bilateral jump [7]. It has been proved that jumping ability may also be affected by bilateral facilitation [8].

Determining the relations between both morphological and functional asymmetries of feet and jumping performance is important for sports, as well as for everyday life activities. On the basis of available literature, one can state that the height of foot arches, especially the longitudinal arch, is identified with the foot's correct function [14], [20].

The aim of this study was to investigate relationships between functional asymmetry of lower limbs, taking into account morphological features of the feet, and the jumping ability measured with height of rise of the center of body mass (jump height) in CMJ single-leg (right and left) and CMJ bilateral in men and women. We formulated the following research questions: is there a relationship between morphological asymmetry of feet and jumping ability?; Is there a relationship between functional asymmetry of lower limbs and jumping ability?; Does sexual dimorphism have impact on the values of bilateral deficit in jumping ability?

2. Materials and methods

The study population consisted of 56 subjects, 30 women (age: 20.29 ± 0.59 years; body mass: 58.13 ± 4.58 kg, body height: 165.60 ± 5.03 cm) and 26 men (age: 20.41 ± 0.78 years, body mass: 78.39 ± 8.42 kg, body height: 181.15 ± 6.52 cm). The study was approved by the Commission of Ethics of the Józef Piłsudski University of Physical Education in Warsaw. The subjects expressed informed consent to participate in the study. The assessments for upper and lower limbs were conducted on the basis of data from interviews repeated following a one-week interval, and then verified with simple motor tests that imitated characteristic function of the limbs. The questionnaire consisted of questions on subjects' own upper limb preference, i.e., on right- or left-handedness in everyday activities, and on subjects' own lower limb preference, i.e., on right- or left-footedness in a one-leg vertical jump and in kicking a ball (which limb leads, i.e., counter-movement limb, and which is the propulsive limb, i.e., take-off limb, and which limb kicks a ball, and which limb lends support, maintains posture, respectively). The tasks to test the lower limb functional preference were chosen from "The Waterloo Footedness Questionnaire" [9]. On the basis of subject answers and tests conducted, we de-

terminated the preference of limbs. Then, using letters, we established the symbol of a given asymmetry. The symbol informs which limb is preferred in a given activity. In the symbols, the first letter refers to the upper limb, and the second letter refers to the lower limb. For homogeneous laterality, we used the following symbols: R-R for right-handed right-footers, L-L for left-handed left-footers. For cross laterality (cross dominance, mixed laterality), we used the following symbols: R-L for right-handed left-footers, and L-R for left-handed right-footers. In determining the footedness of the subjects, the results of the one-leg vertical jump tests and the ball kick tests did not coincide. Therefore, we introduced three variants of classification as proposed by Ilnicka et al. [14], (for results, see Fig. 1).

The measurements of body build were taken with anthropometer and according to standards accepted in anthropometry. The measurements of longitudinal arches were performed with the plantographic method on the basis of Clarke's angle mapped on a computer foot print. The images were obtained from a podoscope equipped with a camera (produced by POSMED). The following measurement points and foot features (total 10) were measured in centimetres: foot length with toes (d_1), forefoot length with toes (d_2) and without toes (d_3), foot length without toes (d_4), hindfoot length (d_5), hallux length (d_6), foot height to the *sphyrionmediale* point (h_1), foot height to the *naviculare* point (h_2), foot width (s), and Clarke's angle for longitudinal arch (in degrees, based on a computer image of the foot obtained from a POSMED podoscope equipped with a camera). On the basis of the above-mentioned measurements, we calculated 7 podometric indices [-]: WD_1 – longitudinal arch index I (h_1/d_1), WD_2 – longitudinal arch index II (h_2/d_1), WD_3 – longitudinal arch index III (h_1/d_4), WD_4 – longitudinal arch index IV (h_2/d_4), WT_1 – hindfoot index I (d_5/d_1), WT_2 – hindfoot index II (d_5/d_4), WS – transversal arch Wejsflog index (d_1/s). The illustration and detailed description of the questionnaire, foot features and podometric indices were presented in the study by Ilnicka et al. [14].

The measurements of jumping performance during bilateral (two legs) and unilateral (single-leg) counter movement jump (CMJ) were done on force plate PJS-4P by JBA (Poland). The MVJ v. 3.4 software package (JBA, Poland) was used for taking the measurements. In the physical model applied, the subject body mass bouncing on the force plate was reduced to a particle affected by the vertical component of ground reaction force. The maximum height of rise of the body mass center was calculated from the registered

reaction force of the plate. All subjects jumped three times each type of jump (total 9 jumps): three right, three left leg and three two legs. The break between jumps was one minute. The task was to reach maximum height of rise of the body mass center, so called jump height. The instruction was as follows: jump as high as you can! Maximum height of rise of the body mass center reached in the best jump of each type of jumps was analysed.

The following values were calculated: the difference between the sum of values of height of single-leg jumps (right and left) and the height of bilateral jump; and the bilateral deficit ratio (BDR [%]): bilateral jump height divided by the sum of height of single-leg jumps (right and left) $\times 100$ [%]. A greater BDR value denoted a smaller difference of jump height between bilateral jump and the sum of height of single-leg jumps (right and left). In order to compare the asymmetries of various features and to assess the dimorphic differences, the asymmetry index (AI) and Mollison's index (MI) were calculated

$$AI = \frac{R - L}{(R + L)/2} \times 100 [\%] \quad (1)$$

where R denotes the value for right limb, L denotes the value for left limb.

Negative values of asymmetry index point to the dominance of the left limb in a given feature. The absolute value of the index determines the degree of diversity – the greater the value, the greater the diversity.

To assess the dimorphic differences, Mollison's index was applied

$$MI = \frac{\bar{x}_F - \bar{x}_M}{SD_M} \times 100 [\%] \quad (2)$$

where \bar{x}_F – arithmetic mean of the feature in the group of females, \bar{x}_M – arithmetic mean of the feature in the group of males, SD_M – standard deviation of the feature in the group of males.

Features considered dimorphically significant are those in which the difference of arithmetic means is greater than standard deviation (SD) for the group of males. Negative values of Mollison's index point to the dominance of the feature in men. The absolute value of the index determines the degree of diversity – the greater the value, the greater the diversity.

We put the test results through a detailed statistical analysis with the Statistica 8.0 programme by StatSoft. On the basis of the arithmetic means ($\pm SD$) of chosen features and indexes, we analysed the differences between right and left feet separately in the

group of women and in the group of men: the *t*-test for dependent variables and the Wilcoxon signed-rank test for divergent variances of the features compared. In addition, we carried out analyses of the differences between sexes and of the differences for the chosen types of laterality (the *t*-test was conducted for dependent variables; when the distribution of the features compared was at variance with the normal distribution in the Shapiro–Wilk test, we carried out the Mann–Whitney U-test). The analysis of relationships between the chosen podometric and plantographic features and the jumping performance was conducted on the basis of the Pearson product-moment correlation coefficient (for the features which presented normal distribution, according to the Shapiro–Wilk test).

Differences and correlations were considered significant at the level $P \leq 0.05$.

3. Results

Figure 1 presents classification of subjects according to their limb laterality type. In assessing footedness based on the leading limb during a one-leg vertical jump, most right-handed subjects indicated the right lower limb as the preferred one (60% women and 65.4% men, variant I – the R-R type, right-handed – right-footed).

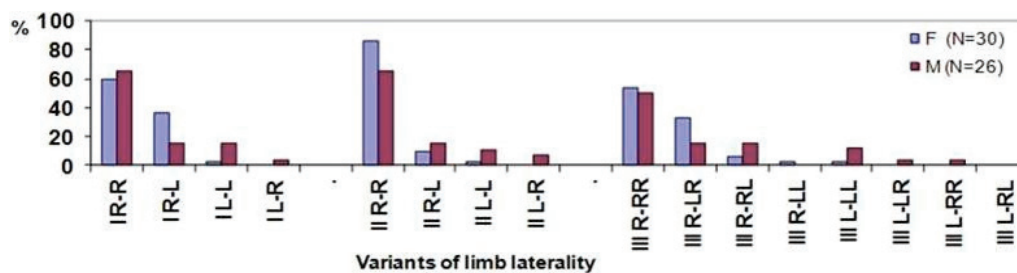


Fig. 1. Classification of subjects [%] according to their limb laterality type – three variants. Explanations: F – females, M – males, number of subjects in each group: I R-R (F = 18, M = 17), II R-R (F = 26, M = 17), III R-R (F = 16, M = 13), laterality assessments: Variant I – upper limb (the first letter in the formula): eating, writing, combing one's hair, lower limb (the second letter in the formula): in the one-leg vertical jump test – the leading limb; Variant II – upper limb (the first letter in the formula): as in variant I, lower limb (the second letter in the formula): in the ball kick test – the limbing kicking a ball; Variant III – upper limb (the first letter in the formula): as in variant I, lower limb (the second letter in the formula): in the one-leg vertical jump test – the leading limb (the third letter in the formula): in the ball kick test – the limb kicking the ball

Table 1. Mean (\pm SD) values of heights [cm] of bilateral (B) and single-leg jumps (R, L) for females (F) and males (M) for all variants of homogeneous right laterality analyzed (I R-R, II R-R, III R-RR)

Groups	R	L	B	R	L	B
	(dominant)	(non-dominant)	(bilateral)	(dominant)	(non-dominant)	(bilateral)
	F			M		
I R-R F (n = 18) M (n = 17)	14.5 \pm 2.0	14.5 \pm 1.9	26.9 \pm 3.1	21.3 \pm 3.3 ^a	22.3 \pm 3.4 ^{*a}	38.5 \pm 3.9 ^a
II R-R F (n = 26) M (n = 17)	14.1 \pm 1.6	14.3 \pm 1.5	26.4 \pm 2.8	21.6 \pm 2.6 ^a	23.0 \pm 3.0 ^{**a}	39.6 \pm 4.6 ^a
III R-RR F (n = 16) M (n = 13)	14.2 \pm 1.7	14.4 \pm 1.5	26.7 \pm 2.4	21.2 \pm 2.8 ^a	22.5 \pm 3.1 ^{*a}	38.6 \pm 4.1 ^a

Explanations: significant differences between values for lower limbs R-L set at $*P \leq 0.05$; $**P \leq 0.01$; between F and M values set at ^a $P \leq 0.001$, the description of laterality assessment variants: Variant I – upper limb (the first letter in the formula): eating, writing, combing one's hair, lower limb (the second letter in the formula): in the one-leg vertical jump test – the leading limb; Variant II – upper limb (the first letter in the formula): as in variant I, lower limb (the second letter in the formula): in the ball kick test – the limb kicking a ball; Variant III – upper limb (the first letter in the formula): as in variant I, lower limb (the second letter in the formula): in the one-leg vertical jump test – the leading limb; lower limb (the third letter in the formula): in the ball kick test – the limb kicking the ball.

Approximately 37% of the women and approximately 15% of the men indicated the left lower limb as the preferred one (variant I, R-L type; right-handed – left-footed). In assessing footedness based on the limb kicking a ball (variant II), the percentage of right-handed men in each laterality type was the same as in variant I; while the percentage of women was significantly different (86.7%). Classification of subjects according to their limb preference in variant III revealed that among the right-handed subjects, considerably fewer subjects conducted the tests (the one-leg vertical jump and kicking a ball) with the right lower limb (53.4 women and 50% men) than in variants I and II (Fig. 1). Due to the sizes of the groups, statistical analysis was only conducted for the group of right homogeneity (right-handed; right-footed) in all three variants of limb laterality type assessment (variant I R-R – 18 women and 17 men, variant II R-R – 26 and 17, variant III R-RR – 16 and 13, respectively). With the self-evident differences between sexes in terms of body height and mass, no statistically significant differences ($P \leq 0.05$) were found between arithmetic means of these features in the three variants of limb dominance analysed, neither in the group of females nor in the group of males.

Table 1 presents values of heights for single-leg jumps and bilateral jumps. In men, we found statistically significant differences for the values of single-leg jump height – they were greater for the left, i.e., the non-dominant limb, in all laterality assessment variants analyzed.

In women, we did not find significant differences between values of single-leg jump height for either limb. Women had significantly lower jump height values in all the types of jumps (Table 1). Dimorphic

differences in jump height in all the laterality assessment variants were from 6.7 to 8.8 cm greater for men, while differences in single-leg jumps for the left (non-dominant) limb were from 1.0 to 1.2 cm greater than for the right limb.

In men, values of asymmetry index (AI) were significantly greater for the left (non-dominant) limb for all laterality assessment variants (I R-R = -4.81%, II R-R = -6.1%, III R-RR = -6.2%). In women, the AI values were not significant (Fig. 2).

In women, we found a negative correlation between single-leg jump height for the dominant limb (R) or non-dominant (L) and longitudinal arch indices for both feet (for the right foot: R and WD₁, $r = -0.50$; R and WD₂, $r = -0.41$; R and WD₃, $r = -0.50$; R and WD₄, $r = -0.40$; for the left foot L and WD₁, $r = -0.49$; L and WD₂, $r = -0.43$; L and WD₃, $r = -0.40$; L and WD₄, $r = -0.45$; as well as positive correlations with foot height to the *sphyrionmediale* point for the right foot (R and h_1 , $r = 0.42$) and hind-foot length for the left foot (L and d_5 , $r = 0.36$). In women, there was a negative correlation between single-leg jump height for the non-dominant limb (L) and longitudinal arch indices for both feet (for the right foot: L and WD₁, $r = -0.46$; L and WD₃, $r = -0.38$; for the left foot L and WD₁, $r = -0.38$; L and WD₃, $r = -0.36$); as well as a positive correlation for the foot length with toes (L and d_1 , $r = 0.39$) and without toes (L and d_4 , $r = 0.32$) for the right foot, and foot length (L and d_1 , $r = 0.45$), forefoot length with toes (L and d_2 , $r = 0.33$) and without toes (L and d_3 , $r = 0.31$), foot length without toes (L and d_4 , $r = 0.46$) and hind-foot length (L and d_5 , $r = 0.35$) for the left foot. In women, there was negative correlation between bilateral jump height and longitudinal arch indices for both feet (for

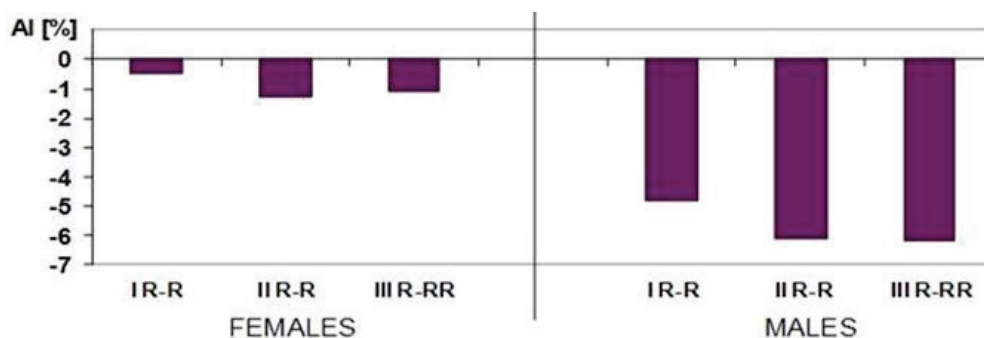


Fig. 2. Mean values of asymmetry index (AI) values for the single-leg jump heights for all the variants of homogeneous right laterality in females and males (I R-R, II R-R, III R-RR). Explanations: negative values denote higher results for the left limb; laterality assessments: Variant I – upper limb (the first letter in the formula): eating, writing, combing one’s hair, lower limb (the second letter in the formula): in the one-leg vertical jump test – the leading limb; Variant II – upper limb (the first letter in the formula): as in variant I, lower limb (the second letter in the formula): in the ball kick test – the limb kicking a ball; Variant III – upper limb (the first letter in the formula): as in variant I, lower limb (the second letter in the formula): in the one-leg vertical jump test – the leading limb, lower limb (the third letter in the formula): in the ball kick test – the limb kicking the ball; number of subjects in each group: I R-R (F = 18, M = 17), II R-R (F = 26, M = 17), III R-R (F = 16, M = 13)

the right foot, B and WD_1 , $r = -0.48$, B and WD_3 , $r = -0.46$; for the left foot, B and WD_1 , $r = -0.41$, B and WD_2 , $r = -0.40$, B and WD_3 , $r = -0.45$, B and WD_4 , $r = -0.46$), as well as foot height to the *sphyrionmediale* point for right and left feet (B and h_1 , $r = -0.43$, -0.36 , respectively) and foot height to the *naviculare* point for the left foot (B and h_2 , $r = -0.34$).

In men, statistically significant correlations between values of height of single-leg jumps (right and left) and bilateral jumps, and foot indices were found in few cases only, and they concerned: positive correlations between single-leg jump height for the left (non-dominant) limb and forefoot length without toes for the left foot (L and d_3 , $r = 0.38$); and between single-leg jump height for the right limb (R) and Clarke's angle for the left foot ($r = 0.40$); as well as negative correlations between single-leg jump height for the left limb (L) and hind-foot length for the left foot (L and d_5 , $r = -0.33$), hindfoot indices WT_1 and WT_2 for the left foot ($r = -0.48$ and $r = -0.57$, respectively); as well as between bilateral jump height (B) and hind-foot indices WT_1 and WT_2 for the left foot ($r = -0.44$ and $r = -0.43$, respectively).

Analysis of the dimorphism (MI), expressed in SD value, of the values of height of single-leg jumps (right and left) and bilateral jumps for all the variants of homogeneous right laterality assessment (I R-R, II R-R, III R-RR) revealed higher values in men (Fig. 3).

Table 2 presents bilateral deficit ratio (BDR) values in men and women in different variants of homogeneous right laterality. A greater BDR value denoted a smaller difference between the sum of values of height of single-leg jumps (right and left) and height of bilateral jump, that is a smaller deficit. The mean BDR value was 93.5% (from 1.8 to 2.1 cm) for women and 91.6% (from 3.6 to 4.1 cm) for men.

Table 2. Values of bilateral deficit ratio (BDR) of jump height for females (F) and males (M) for all analyzed variants of homogeneous right laterality (I R-R, II R-R, III R-RR)

Laterality variant	BDR [%]	
	F	M
I R-R	93.1 ± 8.9	92.1 ± 8.0
II R-R	93.5 ± 7.7	91.8 ± 8.0
III R-RR	93.9 ± 9.1	90.8 ± 7.2

Explanations: the description of laterality assessment variants:

Variant I – upper limb (the first letter in the formula):

eating, writing, combing one's hair, lower limb

(the second letter in the formula): in the one-leg vertical jump test

– the leading limb; Variant II – upper limb (the first letter

in the formula): as in variant I, lower limb (the second letter

in the formula): in the ball kick test – the limb kicking a ball;

Variant III – upper limb (the first letter in the formula):

as in variant I, lower limb (the second letter in the formula):

in the one-leg vertical jump test – the leading limb; lower limb

(the third letter in the formula): in the ball kick test – the limb

kicking the ball; for numbers of subjects in groups – I R-R

(F = 18, M = 17), II R-R (F = 26, M = 17),

III R-RR (F = 16, M = 13)

4. Discussion

Our study revealed that the right lower limb was the dominant one in over 50% of right-handed subjects; and that this dominance, depending on the sex and the assessment variant, affected from 50.0 to 86.7% of the subjects. When assessing lower limb dominance in 360 subjects of varied age (from 30 to 70 years), Hatta et al. [11] found homogeneous laterality in approximately 80% of subjects (right-handed right-footers; or left-handed left-footers).

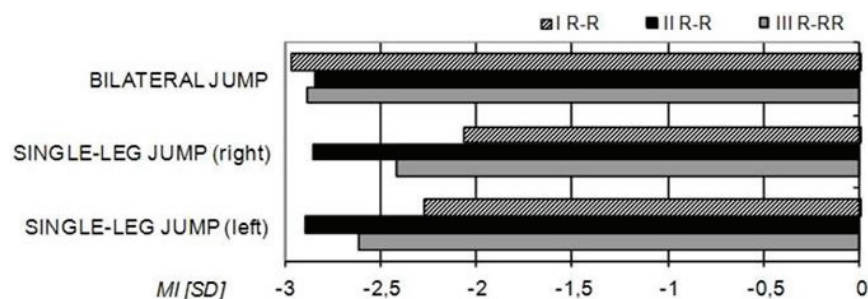


Fig. 3. Mollison's index (MI) values for heights of single-leg jumps and bilateral for all analyzed variants of homogeneous right laterality (I R-R, II R-R, III R-RR).

Explanations: MI [SD] negative values denote higher results in men; laterality assessments: Variant I – upper limb

(the first letter in the formula): eating, writing, combing one's hair, lower limb; Variant II – upper limb (the first letter in the formula):

as in variant I, lower limb (the second letter in the formula): in the ball kick test – the limb kicking a ball; Variant III – upper limb

(the first letter in the formula): as in variant I, lower limb (the second letter in the formula): in the one-leg vertical jump test

– the leading limb, lower limb (the third letter in the formula): in the ball kick test – the limb kicking the ball;

number of subjects in each group: I R-R (F = 18, M = 17), II R-R (F = 26, M = 17), III R-RR (F = 16, M = 13)

Our study found a correlation between lower limb asymmetry and jumping ability only in the group of men who had significantly greater values of height of single-leg jumps for the functionally non-dominant limb. We did not find a significant difference in jumping ability between the dominant limb and the non-dominant limb in women, and neither had other authors [8], [12], [18]. In their study that involved both athletes and non-athletes, Valdez et al. [20] proved that there was no significant asymmetry between the dominant and the non-dominant limb in flexibility, stability, power, strength and muscle endurance. Similarly, Hatta et al. [11], who measured muscle strength of lower limbs in subjects of different age, did not find significant differences between the dominant and the non-dominant limb. In young males, no differences between the dominant and the non-dominant limb was found in the values of unilateral squat jump performance [18]. Eben et al. [8] in tests of single-leg vertical jump and bilateral vertical jump, done by both male and female athletes, found no differences between the dominant and the non-dominant limbs in the values of jump height, reactive strength index, and time to stabilization. On the basis of measurements of bioelectric activity and triceps surae strength, a slight asymmetry was found between lower limbs in sprint and vertical jumps [2], as well as in plyometric bounce drop jumps from height of 0.4 m [3]. In assessments of lower limb asymmetries in athletes in multidirectional jump tasks (vertical, horizontal and lateral), Hewit et al. [12] proved that mean asymmetry values were: 6.7, 8.0, 8.4%, respectively, and that they were similar to the asymmetries in power and maximal force and height/length: 10.2, 6.6 and 6.2%, respectively. A greater difference in muscle strength between limbs increases the risk of injury; therefore it has to be minimized in both sport and rehabilitation [12]. Some authors [23] believe that the functionally non-dominant limb develops a more efficient defence mechanism, which, combined with the common greater muscle strength, decreases the injury risk of this limb.

Our study found bilateral deficit in both sexes, while there were no significant differences between values in women (a mean of 6.5%) and men (a mean of 8.4%). Similar values of bilateral deficit during submaximal and maximal isometric knee extensions (from 5.6 to 18.5%) in young athletic males were reported by Kuruganti and Murphy [13]. In their study on 172 boys and girls aged 10–12 years, Veligeakas and Bogdanis [22] did not find bilateral deficit in jumping ability, though girls' results pointed at a certain tendency towards this phenomenon. In his study

on female basketball players, Challis [7], who proved that single-leg jump height (for the dominant limb) was 58.1% of the bilateral jump height, stated that an important cause for bilateral deficit is the fact that for locomotion, humans use one leg at a time for propelling the body mass. In vertical jump, depending on the parameters analyzed, both bilateral deficit (e.g., in time to stabilization), and bilateral facilitation (e.g., in jump height and reactive strength index) [8] can be found. Myoelectric signal data (from vastuslateralis, vastusmedialis, rectus femoris) showed that there were differences between bilateral and the total unilateral isometric knee extension regardless of the percent maximal voluntary contraction and this suggests that the bilateral deficit may be due to neural mechanisms [13]. Bobbert et al. [4], based on complex biomechanical studies (including mathematic modeling) of maximum-height squat jumps using either two legs or only the right leg for take-off, did not agree with such an interpretation of bilateral deficit in jumping ability. They [4] believed that the main cause for bilateral deficit is the force–velocity relationship, different in each the bilateral and single-leg jumps. They proved that the velocity of muscle contraction in the take-off phase is greater in the bilateral jump, which leads to smaller values of the generated force and work performed. Bilateral deficit in proximal muscles of upper limb was found to be greater than in distal muscles [1]. In the vertical jump, bilateral deficit influences the knee and hip joint angles, angular velocities and resultant joint torques, which are different in the same limb depending on whether the jump performed is bilateral or single-leg [7].

5. Conclusions

We found significant gender differences of the correlations between the values of height of jumps (single-leg and bilateral jumps) and foot indices. The correlation between the morphological asymmetry of the feet and the jumping ability was more significant in women than in men. In women, we found a negative correlation between the heights of single-leg jumps for the dominant and for the non-dominant limb, and longitudinal arch indices for both feet, which means that a higher foot had weaker jumping ability. In men, we found a negative correlation between the height of single-leg jump for the non-dominant leg, and the hind-foot indices, which means that a greater hind-foot length resulted in weaker jumping ability. We found a correlation between

lower limb asymmetry and jumping ability only in men who had significantly greater values of height in single-leg jumps for the functionally non-dominant limb. We found bilateral deficit in the groups studied, though we did not find significant differences between men and women.

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