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Original Article

Influence of sport discipline on foot arching and load distribution: pilot studies

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Abstract
The main purpose of the study was to analyze the relationship between body mass index and the longitudinal foot arches and foot load distribution in athletes. The foot is an important part of the musculoskeletal system, it serves the supporting and motive functions that condition human locomotion. It has a characteristic internal and external architecture. The foot is affected by a number of factors having either a positive impact on it or contributing to the formation of defects. The research included 18 athletes participating in throwing and jumping disciplines (age 20-25). Using the body mass index, underweight, correct body weight, overweight and obesity were determined. Foot assessment was made using the Clarke method. The FDM-3 dynamo graphic platform from Zebris was used to analyze the foot load distribution. Throwing athletes (n = 10) were overweight and obese while jumping athletes (n = 8) were of correct body weight. In the whole group there were generally high longitudinal arched feet, while the foot load distribution was different ($p < 0.05$). The somatic parameters as well as the arches and foot load distribution values were different in both examined groups because due to the specificity of sport discipline, competitors own different morphological profiles. Body mass index and longitudinal arching of the feet significantly affect the distribution load of foot in throwing athletes. Such correlations were not noted in jumping disciplines athletes.
Keywords: athletics, foot, longitudinal arch, load distribution, throwing events, jumping events

Introduction

The human foot is an important element of the loco motor system, responsible for movement and plays a significant role as a static-dynamic foundation of the skeleton (Di Giovanni & Greisberg, 2007). It has to work with other body parts, because at the moment of touching the ground, its task is to evenly distribute the load over its entire structure. It is worth noting that the efficiency and proficiency of the foot depends on its morphological structure, especially on the correct shape of the longitudinal and transverse foot arches (Kirby, 2000; Sarkar & Sawhney, 2014).

It is a structure that is shaped throughout our lives. In ontogenesis process, the foot undergoes constant changes under the influence of various external factors, e.g. surfaces on which we move, and internal factors, such as metabolic, hormonal and bone disorders. On the one hand, some of them support the proper development of internal and external architecture, on the other, they can contribute to the formation of defects (Puszczalowska-Lizis, 2011; Suciati, Adnindya, Septadina & Pratiwi, 2019). Body weight, physical activity and practicing selected sport disciplines are some of the factors causing changes in foot arch and position. The condition of feet also largely depends on the weight of the load, duration and intensity of effort during sports trainings, as well as on the surface the exercises take place on. All these dependencies are of interest to many researchers (Aydog, et al., 2004; Aydog, Tetik, Demirel & Doral, 2005; Calka-Lizis, Jankowicz-Szymanska & Adamczyk, 2008; Daneshmandi, Rahnema & Mehidizadeh, 2009; Lichota, Plandowska & Mil, 2013; Lopezosa, Gijon-Nogueron, Garcia-Paya & Ortega-Awila, 2018; Pinto Ribeiro, Hanai Akashi, Camargo Neves Sacco & Pedrinelli, 2003; Yi-Liang & Shen-Feng, 2017).

Considering the sport discipline, Lopezosa et al. (2018) showed that in swimmers the foot tended to be in pronation, while in footballers it was within the correct range. Different conclusions from the research were given by Calka-Lizis et al. (2008). In boys regularly training football, a reduction of the longitudinal arch of the foot was observed (56.6% of the respondents). Pinto Robeiro et al. (2003) after examining a group of futsal players, emphasized that the players had flat feet. These changes could be determined by the presence of knee valgus.

In other sports (taekwondo, handball and volleyball, athletics (Lichota, et al., 2013); football, wrestling, weightlifting, gymnastics (Aydog, et al., 2005)), the authors showed irregularities of the longitudinal and transverse foot arches. However, there are also works in which no changes were observed between the group of basketball players and the control group (Aydog, et al., 2004; Yi-Liang & Shen-Feng, 2017).

Analyzing the influence of body weight, Daneshmandi et al. (2009) suggest that its increase can have a significant impact on the arch and load distribution of students' feet.

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These presented research shows that the health problems of young athletes are vital, since any change of the longitudinal and transverse foot arches is reflected in movement abilities and thus in sports achievements. Physical activity, despite its undoubtedly positive impact on health, also causes negative effects, especially in people who do sport in a competitive manner (Zlotkowska, et al., 2015). It is worth noting that qualified sport causes numerous injuries and in the later years of life even a degenerative disease (Widuchowski & Widuchowski, 2008). Therefore, caring for proper shape and load distribution and foot efficiency, preventing their deformations, takes on special significance in this aspect. In addition, it may be emphasized that not only the foot but also body posture is an important element in athletes (Barczyk-Pawelec, Giemza, Jastrzebska, Hawrylak & Kaczanowska, 2012; Grbavac, Rezic & Cerkez, 2018; Hawrylak, Wojna & Chromik, 2015; Lichota, et al., 2011; Mrozkowiak, Sokolowski & Kaiser, 2016; Opanowska & Pretkiewicz-Abacjew, 2015; Wodecki, Guigui, Hanotel, Cardinne & Deburge, 2002).

The literature on the subject also includes works describing body posture among athletes of various sport disciplines (volleyball, football, handball, judo, pole vault) (Barczyk-Pawelec, et al., 2012; Grbavac, et al., 2018; Hawrylak, et al., 2015; Lichota, et al., 2011; Mrozkowiak, et al. 2016; Opanowska & Pretkiewicz-Abacjew, 2015; Wodecki, et al., 2002). Grbavac et al. (2018)and Barczyk-Pawelec et al. (2012), examining the body posture of handball players, have found that the specificity of this sport causes scoliotic and kyphotic body postures. Other authors have observed that people training volleyball have increased spine flexibility and the range of motion of the shoulder girdle exceeding accepted norms. In players of other sports (judo, wrestling, volleyball and football, fencing, pole vault), numerous asymmetries of body posture could be noticed (Lichota, et al., 2011; Mrozkowiak, et al., 2016; Opanowska & Pretkiewicz-Abacjew, 2015; Wodecki, et al., 2002). In people practicing volleyball, torso tilts to the left, elevation of the left arm, longer left torso-brachial triangle and higher correct iliac crest are very often observed (Mrozkowiak, et al., 2016). Often, the specificity of the exercises performed during training a given sport can affect the shape of the curves of the spine. Sprinters, people practicing taekwondo, handball and volleyball have more pronounced chest kyphosis than lumbar lordosis (Lichota, et al., 2011; Opanowska & Pretkiewicz-Abacjew, 2015). Different results were obtained by Wodecki et al. (2002), who, while examining runners, observed a change in the angle of thoracic kyphosis and lumbar lordosis. The articles listed above lack information about changes of the longitudinal and transverse foot arches and foot load distribution in participants of field disciplines, like hammer throw and shot put, as well as high jump and triple jump. In the literature, the authors examining the team of young juniors training high jump, observed that most of them had the correct arch of the feet (Widuchowski & Widuchowski, 2008).

Current literature is not sufficient to describe the problem of longitudinal foot arches in athletes participating in throwing and jumping disciplines, hence the aim of the work was to investigate the relationship between body mass index and the longitudinal foot arches and their load distribution in athletes of throwing and jumping disciplines.

Material & methods

Participants

Eighteen athletes participated in this study (8 athletes participating in jumping disciplines and 10 athletes participating in throwing disciplines). Prior to participating in the study, the participants had given a written consent to participate in the observations. Table 1 shows the somatic data of the study group.

The inclusion criteria for participants were: age 20-25, athlete (throwing and jumping), written consent to participate in the study, correctly taken image of the plantar surface of the foot, training internship of 1-5 years, more than 5 trainings a week.

The exclusion criteria in this study were: an athletepracticing other sports disciplines, occurrence of orthopedic or neurological disorders, incorrect image of the foot plantogram.

Procedure/ Measure/Instruments

This study is a cross-sectional study and relationship between body mass index and foot load distribution and the longitudinal foot arches was analyzed. The somatic parameters were measured and the overall assessment of the foot arches and feet load distribution in athletes practicing throwing and jumping disciplines was made.

All participants were informed about the study and signed a consent form. All the procedures of this study were completed in accordance with the ethical standards as described in the Declaration of Helsinki.

The following somatic parameters were measured on a calibrated electronic scale with a height meter: body weight with an accuracy of 0.1 kg and body height with an accuracy of 0.5 cm. These data were used to calculate the body mass index (BMI) ("Standards body mass index," 2019).

Foot examination was performed using the plantographic method. Reflections of the plantar surface of the feet were made on a CQ System Electronic podoscope (podoscope, CQ Electronic System, Czernica Wr., Poland) ("Specialized Electronic Systems for Medicine Picture Diagnostics," 2019). Participants stood barefoot on the device while maintaining an even load on the lower limbs. After that, a computer program scanned the image of the soles of the feet. The measurement was supervised by the same physiotherapist for all competitors.

The longitudinal arch of the foot was assessed using the Clarke angle (1959) (Clarke, 1959). It is a reliable, sensitive and practical meter (Pauk, Ihanatouski & Najafi, 2014). Figure 1 illustrates how this angle is calculated. After completing the calculation, the foot was classified as: flat (< 30°), with reduced arching (31° - 41°), correct (42° - 54°), with increased arching (> 55°).

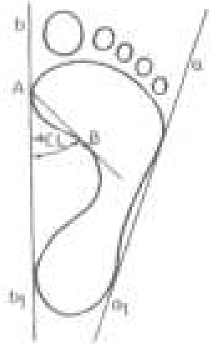

Fig. 1. Clarke angle. It is determined by the tangent (bb1- medial edge of the foot) and the segment (AB- the point of the largest depression of the foot) (source: Clarke, 1959).

The FDM-3 dynamographic platform from Zebris (FDM-3 dynamographic platform, Zebris Medical GmbH, Am Galgenbuhl, Germany) was used to assess foot load and ground pressure response. The data were evaluated using WinSpine software (Bibrowicz et al., 2018; “The Zebris FDM-3 dynamographic platform,” 2019). The participants took a natural standing position on the platform. Then, according to the methodology, load distribution for the entire foot, broken down into forefoot, backfoot and total foot, was recorded for 30 seconds. An example printout from a computer program specifying foot load is shown in Figure 2.

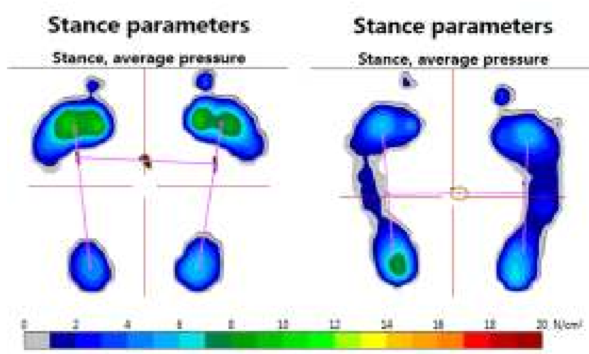

Figure 2. Foot load distribution using the Zebris FDM-3 dynamographic platform (source: Bibrowicz et al., 2018; “The Zebris FDM-3 dynamographic platform,” 2019).

Data collection and analysis / Statistical analysis

All data of the measured parameters was collected in Microsoft Excel computer program. Measures of descriptive statistics: mean (x̄), standard deviation (SD), minimum and maximum values (min-max), were calculated. The percentage and intensity of the rate of arching were presented in percentages.

The ANOVA analysis of variance test was used to check statistical significance of differences in the studied features between the groups. The normality of distribution of particular characteristics was verified by means of the Shapiro-Wilk test. In order to evaluate the correlations between the chosen characteristics of the longitudinal foot arch, load distribution and the body mass index, the rho-Spearman coefficient was employed. The significance level was set up $p < 0.05$. Statistical calculations were made in the STATISTICA 13.0 (STATISTICA 13.0, company StatSoft, Krakow, PL)

Results

Statistical analyzes of somatic parameters show that throwing athletes were characterized by statistically significantly higher average values of body weight ($p = 0.001$) and body mass index ($p = 0.001$), compared to athletes of jumping disciplines. Statistically significant differences between the all measured parameters (body mass index $p = 0.043$, body weight $p = 0.002$, body height $p = 0.001$) were also between the group of women and men. Men had higher average values of measured parameters compared to women in both throws and jumps disciplines. Based on the calculated body mass index, the subjects from the throwing group were overweight

(60%) and obese (40%) while from the jumping group athletes had correct body weight (100%). Table 1 shows the somatic data of the study group and significance of differences between the groups.

Table 1. Average values of body weight, body height and body mass index of throwing and jumping athletes.

Gender	Parameters		
	Throwing group		
	Body weight (kg)	Body height (cm)	BMI (kg/m^2)
	x̄±SD	x̄±SD	x̄±SD
♀ n = 5	82.6±9.72	178.9±3.85	25.8±3.25
♂ n = 5	120.7±21.6	191.3±4.4	32.5±4.8
	Jumping group		
	Body weight (kg)	Body height (cm)	BMI (kg/m^2)
	x̄±SD	x̄±SD	x̄±SD
♀ n = 6	60.3±7.8	172.0±4.2	20.3±2.1
♂ n = 2	76.9±12.0	189.5±12.0	21.2±0.7
p-value GENDER	0.002*	0.001*	0.043*
p-value COMPETITION	0.001*	0.123	0.001*

the ANOVA analysis (*$p < 0.05$)

The values of the Clarke angle, determining the arching of the feet and the load on the forefoot, backfoot and total foot of the examined athletes, are presented in Table 2. Based on the data, throwing athletes had lower average Clarke angle values, forefoot loading of the left foot and the total loading on the right foot, in comparison with athletes of jumping disciplines. The differences between the right and left foot in both groups were not statistically significant ($p < 0.05$) (Tab. 2). Subjects determined their dominant body side. The group of throws disciplines was dominated by the right arm and right leg (n = 7), followed by the right arm and left leg (n = 2) and the left arm and right leg (n = 1). In the group of jumps disciplines, on the other hand, right arm and right leg (n = 6) and right arm and left leg (n = 2)

Table 2. Average values Clarke angle and foot load distribution in throwing and jumping athletes.

Gender	Parameters							
	Throwing group							
	Clarke angle (º)		Forefoot load (N/cm^2)		Backfoot load (N/cm^2)		Total load (N/cm^2)	
	Right foot	Left foot	Right Foot	Left foot	Right foot	Left foot	Right foot	Left foot
	x̄±SD	x̄±SD	x̄±SD	x̄±SD	x̄±SD	x̄±SD	x̄±SD	x̄±SD
♀ n = 5	60.7 ± 4.4	59.5 ± 3.4	54.9 ± 10.6	48.2 ± 8.93	45.1 ± 10.6	51.8 ± 8.9	38.7 ± 10.7	61.3 ± 8.9
♂ n = 5	53.8 ± 9.0	48.4 ± 8.1	49.5 ± 5.9	48.0 ± 10.2	50.5 ± 5.9	52.0 ± 10.2	43.8 ± 7.2	56.2 ± 7.2
	Jumping group							
	Clarke angle (º)		Forefoot load (N/cm^2)		Backfoot load (N/cm^2)		Total load (N/cm^2)	
	Right foot	Left foot	Right Foot	Left foot	Right foot	Left foot	Right foot	Left foot
	x̄±SD	x̄±SD	x̄±SD	x̄±SD	x̄±SD	x̄±SD	x̄±SD	x̄±SD
♀ n = 6	60.7 ± 4.0	61.8 ± 3.7	54.8 ± 9.8	53.9 ± 15.1	45.2 ± 9.8	46.2 ± 15.1	45.0 ± 10.3	55.0 ± 10.3
♂ n = 2	63.9 ± 0.3	66.0 ± 2.4	48.8 ± 7.2	46.6 ± 1.6	51.2 ± 7.2	53.4 ± 1.6	54.6 ± 6.3	45.4 ± 6.3
p-value GENDER	0,554		0,296		0,296		0,101	
p-value COMPETITION	0,167		0,667		0,667		0,151	

ANOVA analysis (*$p < 0.05$)

The examined athletes of both throwing and jumping disciplines, mostly had feet with high longitudinal arch (80%) (Fig. 3). In the throwing group, the total of the right foot (58%) and the forefoot of the left foot (52%) were more often loaded, while in the jumps the backfoot of the right and left foot (52%, 50%) (Fig. 4).

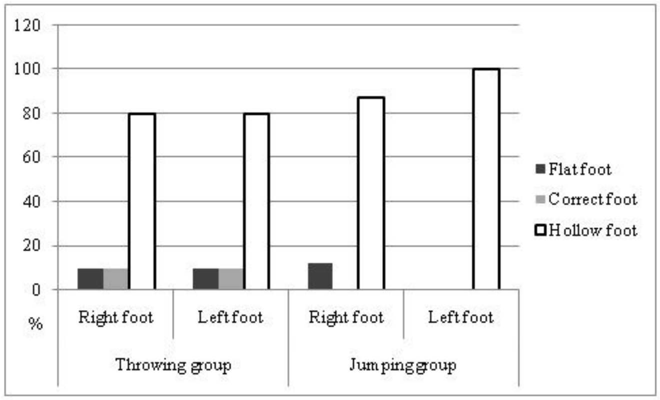

Figure 3. Frequency of occurrence types of arching among the examined athletes.

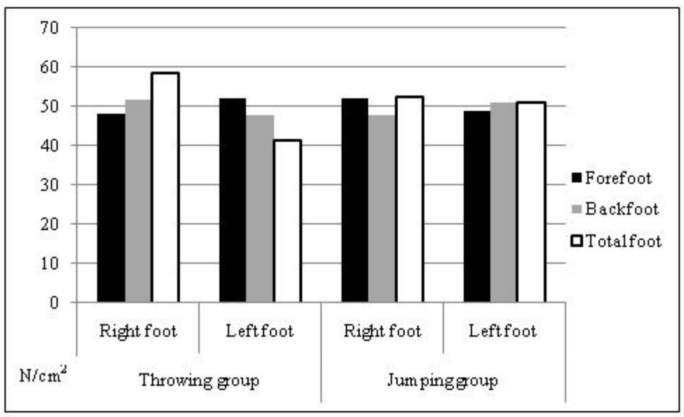

Figure 4. Frequency of foot load among athletes in throwing and jumping disciplines.

In table 3 shows statistically significant dependencies between the measured parameters. There was a correlation between the body mass index and the total load of the right and left foot in girls, and the load forefoot and backfoot of the left foot in boys in the group of throws. Such relationships were not observed among athletes of jumping disciplines (Tab. 3).

Analyzing the impact of the longitudinal arch of the foot (Clarke angle) on the degree of load distribution of its individual zones, statistically significant relationships were found between total load in the left foot and arching of the left foot in the athletes throwing disciplines. Such relationships were not observed among athletes of jumping disciplines (Tab.3).

Table 3. Correlations between the measured parameters in the athletes throwing disciplines.

	Throwing group					
	Body mass index		Clarke angle right foot		Clarke angle left foot	
	rho	rho	rho	rho	rho	rho
	♀	♂	♀	♂	♀	♂
Forefoot force- right foot	0.600	-0.700	0.300	-0.400	0.300	0.100
Backfoot force- right foot	-0.600	0.700	-0.300	0.400	-0.300	-0.100
Total force- right foot	-0.900*	-0.300	0.200	0.600	0.500	0.600
Clarke angle- right foot	0.100	0.100				
Forefoot force- left foot	-0.300	0.900*	-0.500	-0.300	0.100	0.700
Backfoot force- left foot	0.300	-0.900*	0.500	0.300	-0.100	0.700
Total force- left foot	0.900*	0.300	-0.200	-0.600	-0.500	-0.900*
Clarke angle- left foot	-0.100	0.300				

rho- Spearman correlation (*$p < 0.05$)

Discussion

The aim of this study was to examine correlation between the body mass index, the longitudinal foot arches and their load distribution in athletes of throwing and jumping disciplines. The authors confirmed the aim of this study

In our own research, it was observed that both the somatic parameters as well as the longitudinal arching of the feet and foot load distribution values were different in both examined groups because due to the specificity of sport discipline, competitors own different morphological profiles. The surveyed participants of throwing disciplines mostly had feet with a high longitudinal arch. In this group, the right total foot and the left forefoot were more often loaded. On the other hand, the athletes participating in jumping disciplines also mostly had high longitudinal arch. However, in most cases the load was on the backfoot of the right and left foot. The differences in load distribution between the right and left foot may be due to the different domination of the body side of the competitors. After a subjective assessment by the study participants, the majority of them dominate the right arm and right leg (n = 13), then the right arm and left leg (n = 4) and the left arm and right leg (n = 1).

In the available literature on the subject there are no works in which the relationship between body weight and longitudinal arching of the feet, and their load distribution in throwing (hammer throw, shot put) and jumping (high jump, triple jump) athletics disciplines are examined.

Previous studies, conducted among players of various sports competitions, confirm that the morphological structure of the feet and its arching is associated with a specific sport discipline (Aydog, et al., 2005; Calvo, Fernandez, Camacho, Sanz & Pellico, 2003; Gradek, Mleczko & Bora, 2004; Korpelainen, Orava, Karpakka, Sura & Hulkko, 2001;Lizis & Puszczalowska-Lizis, 2008; Peterson & Renstrom, 2001). Repeated and cyclical overloading of the feet in football players, swordsmen, weightlifters, wrestlers, contributes to the appearance and fixation of flat feet (Calvo, et al., 2001; Peterson & Renstrom, 2001). Studies by Korpelainen et al. (2001) show that feet arching causes injury in runners. The examined group of athletes had feet with a high longitudinal arch and their incorrect loading. The sport competitions mentioned earlier have a negative effect on the arching of the foot. However, it seems reasonable to say that the sports in which jumping exercises are performed have a positive impact on the foot architecture. It has been proven by the research by Aydog et al. (2005), which confirms that gymnasts had properly arched feet. Lizis and Puszczalowska-Lizis (2008), while examining a group of basketball players, also observed in them the correct foot arch. It is assumed that moderate physical activity has a beneficial effect on the arching of the feet. However, excessive physical activity and feet overload during trainings can be detrimental to the structure of the foot and its proper functioning (Furgal & Adamczyk, 2009; Gradek, et al., 2004; Lichota, et al., 2013; Lizis & Puszczalowska-Lizis, 2008). Activities that will prevent excessive load distribution on the foot and its arching may be: maintaining proper weight, wearing proper shoes during training and sports games that will ensure proper cushioning, performing exercises under the control of a physiotherapist, who, knowing the morphological profile of the competitors, will adjust the appropriate set of movements.

Analyzing the impact of the longitudinal arch of the foot on the load distribution of its individual zones, statistically significant relationships were found between total load in the left foot and the arch of the left foot in athletes of throwing disciplines. Rohan, Nyc, Rogoz and Fugiel (2017), examining sprinters before the run, observed an uneven distribution of load distribution on both feet. After the run, this distribution in the right foot did not change significantly, while in the left foot there was an increase in forefoot, backfoot and total load. At the same time, these changes influenced the typology of the foot, manifesting themselves in raising of the longitudinal arch of the examined players. Thus, we can conclude that the characteristics of the arching of the feet affects the distribution of foot load.

In both examined groups the left foot was loaded more often than the right one, which may indicate that the reflective foot in both athletes representing throwing and jumping disciplines is the lower left limb. It probably depends on the technique of the sport. It is believed that the ability to maintain a vertical position and functional privilege of the right upper limb is the basis for more frequent use in the support functions of the left lower limb. This limb more often than the right limb also maintains a reflecting function during jumping, because it performs supporting and reflecting functions (Malinowski, 2004). In the study of Rohan et al. (2017) they showed that in the competitors after a long-distance run, some of the load was transferred to the right foot, due to the nature of the symmetrical activities of this sport. However, the difference in load distribution between the feet was present.

Based on the literature review, it has been shown that not only there are relationships between the longitudinal arching of the feet and their load distribution but also between body weight and foot load distribution. In the tests we have conducted, statistically significant relationships were obtained between body mass index and total load on the right and left total in girls, and the load of left forefoot and left backfoot in boys only in the group of throws. Such relationships were not observed at jumping athletes. This may be due to the fact that overweight and obesity occur in athletes of throwing disciplines. Such relationships confirm our research. Other tests carried out by Furgal and Adamczyk (2009) confirm that higher rates of foot load distribution occurred in people who are overweight and obese. Thus, we can conclude that body weight affects the distribution of weight in individual parts of the plantar pressure of the foot.

The limitation of the conducted research was the small number of participants in both groups. It is worth undertaking research in the future together with the increased number of athletes in the throwing and jumping athletics disciplines in order to reduce the error of the analyzed parameters. Perhaps this will allow for greater diversity in the occurrence of irregularities in the arching of the feet and the distribution of their loads. The recommendation of future research may be to unify the groups examined. To obtain more specific results, only athletes of high jump and hammer throw disciplines should be examined.

The recommendation of future research may be also the division of athletes into vertical and distance jumping disciplines. Different forces acting on the foot result from different bounce direction therefore, we can receive other characteristics of the longitudinal arch and foot load distribution of the tested competitors.

Conclusion

Noting that this is a pilot study, the following results seem reasonable:

(1) According to the standards developed by Clarke, athletes of throwing and jumping disciplines most often owned arching of the feet with high longitudinal arches.

(2) In the throwing group, the right totaland the left forefoot were more often loaded, while in the jumping group the right and left backfoot probably because due to the specificity of sport discipline, competitors own different morphological profiles or different domination of body parts.

(3) Body mass index and longitudinal arching of the feet significantly affect the distribution load of foot in throwing athletes probably because in this group overweight and obesity were observed.

Conflict of interest: Authors have declared that no competing interest exists.

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