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An assessment of shape of the longitudinal and the transverse foot arch in male and female pole vaulters

Monika Opanowska
Department of Health Promotion and Posturology, Gdansk University of Physical Education and Sport, Poland, monika.opanowska@awf.gda.pl

Elzbieta Ptretkiewicz-Abacjew
Department of Health Promotion and Posturology, Gdansk University of Physical Education and Sport, Poland

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ORIGINAL

An assessment of shape of the longitudinal and the transverse foot arch in male and female pole vaulters

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

Monika Opanowska [ABCDEF], **Elżbieta Prętkiewicz-Abacjew** [ADEF]

Department of Health Promotion and Posturology, Gdansk University of Physical Education and Sport, Poland

abstract

Background The aim of the research was to assess the longitudinal and the transverse shape of the foot arch in male and female pole vaulters.

Material/Methods The research involved 14 women and 16 men training pole vault professionally and possessing the highest level of sport's proficiency. The assessment of the foot arch was made in static conditions, using a podoscope. The longitudinal foot arch was assessed by Clarke's method and the transverse foot arch was based on the calcaneal angle.

Results The obtained results showed that the correct and excessive foot arch occur most frequently.

Conclusions Numerous technical exercises performed by pole vaulters on the forefoot and toes strengthen the foot (shortening muscles responsible for a proper level of the longitudinal and the transverse foot arch) and result in the correct or excessive arch in the right and the left foot.

Key words foot, foot arch, pole vaulters, lower limbs

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Corresponding author: Dr Monika Opanowska, Akademia Wychowania Fizycznego i Sportu w Gdańsku, Zakład Promocji Zdrowia i Posturologii, ul. Kazimierza Górskiego 1, 80-336 Gdańsk; phone no. +48 585547266; e-mail: monkao84@wp.pl

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INTRODUCTION

Human foot plays an important role in a person's life. It is the foundation of both the static and the dynamic body posture, i.e. the main support and locomotion organ. In the ontogenetic development, the structure of the foot is undergoing constant changes which are affected by a number of factors [1, 2, 3, 4]. These are factors that, on the one hand, may influence the architecture of the foot in a stimulating way; but, on the other hand, they may cause the formation of defects. Increased physical activity and competitive sport are some of these factors. Many authors have found a clear correlation between the foot capacity and the achieved results in various sport disciplines and the development of changes in the functional effectiveness of feet as a result of increased physical activity [5, 6, 7, 8, 9, 10, 11]. The health status of feet in competitive sports takes on a particular importance, since any deviation in the shape of the foot is reflected in deterioration in the body posture and in changes in an athlete's movement capabilities. According to Starosta et al. [12], "competitive sport must not maim athletes by deforming their feet, the more so that on the very feet the athlete must not only walk along his sports path, but the path of his whole life."

In the available scientific literature, we find reports on changes in the structure of the plantar surface of the foot under the influence of training loads in male and female athletes training pole vault.

The aim of this study was to characterise the longitudinal and the transverse foot arch in male and female pole vaulters.

MATERIAL AND METHODS

The study involved 30 athletes practising pole vault: 14 women and 16 men. These athletes had the highest sport class (International Master, Master, and Sports Class I) and competed at the World, European and Polish Championships. They represented the following athletics clubs: Sopot Athletics Club, AZS AWFiS Gdansk, RKS "SKRA" Warszawa, Sporting Miedzyzdroje and Pole Vaulting Centre in Gdansk. The tested group ranged from 18 to 32 years of age, and their training experience was from 6 to 19 years. On average male and female vaulters trained 6-7 times a week for 3.5 hours a day. The subjects were selected by a special method [13]. The selection criterion was training pole vault for more than 5 years and not practising any other sport throughout the study period, while in the past only involvement in athletics was approved of.

The examined athletes were right-handed and during the vault they jumped off the left lower extremity and at the start of the approach they placed the right upper extremity higher on the pole.

In a study of the longitudinal and the transverse foot arch, the plantographic method was applied, which assesses the plantar surface of the foot with a use of a podoscope equipped with computer software (system ElPodo version 2.01, developed by a team of authors from the Cartography Department at the Warsaw University of Technology). The study was conducted in static conditions, i.e. in a standing position with an equal load on both lower limbs. In order to evaluate the longitudinal foot arch, Clarke's angle was determined (Fig. 1). To assess the value of the longitudinal foot arch, Malina's standards

were used [15]. The value of the transverse arch was established on the basis of the calcaneal angle (γ) (Fig. 2), and the assessment was conducted with a use of standards applied in the subject literature [16, 17, 18, 19], (Table 1)

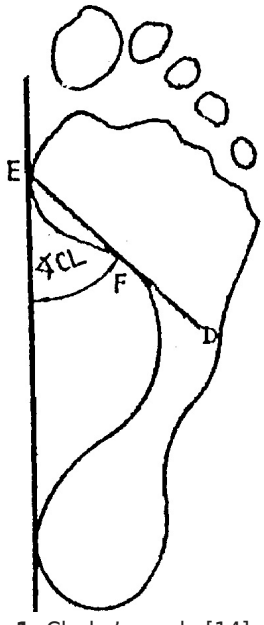

Fig 1. Clarke's angle [14]

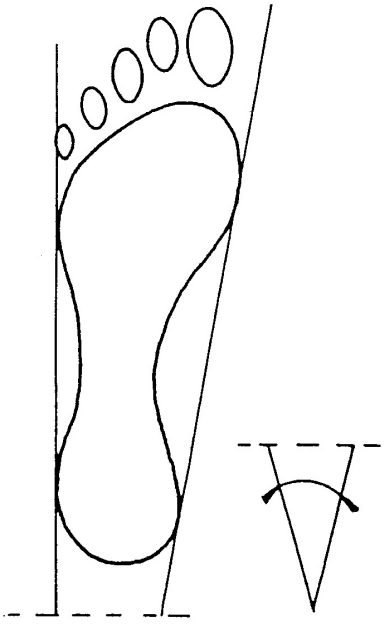

Fig 2. The calcaneal angle - (γ) [16]

Table 1. Standardization of types of foot arch

	Arch of the foot	[°]
Longitudinal	Pes excavate	above 55
	Correct	42 - 54
	Flattened	20 - 41
	Flat	below 20
Transverse	Excessively arched	below 15
	Correct	15 - 18
	Flat	above 18

The obtained results were subjected to statistical analysis with STATISTICA ver. 9 software. Basic techniques of descriptive statistics were applied ($\bar{x}$, ±SD, %). ANOVA analysis of variance test was used to check for significance of differences in the studied features between the left and the right foot, between women and men, and for the gender differences between left and right feet. In addition, the percentage list of the incidence of particular types of longitudinal and transverse foot arches in the light of the selected methods was prepared.

RESULTS

Having analysed the material concerning the value of Clarke's angle, it was found that excessively arched feet were the dominant foot type, observed in athletes left (take-off) foot 19 times (63.3%) and in the right foot 17 times (56.7%). The remaining feet were characterised by the correct longitudinal arch (11 left feet and

13 right feet). No case of a reduced architecture of the arch was observed (Tab. 2). Noteworthy is the fact that half of the female vaulters had correctly arched left and right feet. Among male vaulters excessively arched feet prevailed, and they were more often found in the left foot (75.0%) than in the right one (37.5%). In total in 14 athletes (46.7%) both feet were excessively arched and in 8 they were correct (26.7%).

Table 2. Frequency of occurrence of individual types of the longitudinal foot arch in male and female pole vaulters

Longitudinal arch		Women		Men		Total	
		n	%	n	%	n	%
Correct	L	7	50.0	4	25.0	11	36.7
	P	7	50.0	10	62.5	13	43.3
Pes excavate	L	7	50.0	12	75.0	19	63.3
	P	7	50.0	6	37.5	17	56.7

Analysing the longitudinal foot arch among male and female vaulters, it was observed that the value of the arithmetic mean of Clarke's angle for the left foot (56.16°) and the right one (56.34°) were very close and were within the range of excessively arched feet (Tab. 3). Slightly higher values were recorded in the group of men, for whom the arithmetic mean of the angle for the left foot had the value of 58.64° and for the right foot 57.93°. Analysing the mean values of Clarke's angle among female vaulters (54.32° for the left foot and 54.52° for the right foot), it is worth noting that they were on the border of the adopted qualification for feet with an excessive longitudinal foot arch.

When assessing the significance of differences between the mean values obtained in the study of male and female vaulters, statically significant differences were found only in the longitudinal foot arch of left feet ($p < 0.05$) (Table 3), and in other analysed cases statistically insignificant differences were found.

Table 3. Parameters characterizing the longitudinal arch of the right and left foot

Group	Foot	$\bar{x}$	±SD	Min	Max
Women	L	54.32*	6.6	42.9	63.1
	P	54.52	5.6	48.4	69.5
Men	L	58.64*	6.2	50.0	71.0
	P	57.93	7.8	43.2	73.1
Total	L	56.16	6.8	42.9	71.0
	P	56.34	7.0	43.2	73.1

On the basis of the classification of the value of the calcaneal angle 16 cases of feet with the correct transverse foot arch (53.3%) in left (take-off) foot were found and 14 feet with the excessive foot arch (46.7%) (Table 4). Among half of the subjects (50.0%) the right foot had the correct architecture of the anterior transverse arch, among 12 people (40.0%) it was excessively arched, and among

3 people it was transversely flat (10.0%). The correct value of the calcaneal angle was observed more often among men than women. Among male vaulters the correct transverse foot arch dominated in the left foot (68.7%), while among female vaulters in the right foot (57.1%). The excessively transversely arched foot in women most often regarded the left lower extremity (64.3%), while in men the right one (50.0%). Large values of the calcaneal angle characterising transversely flat feet were found in 2 right feet among women and 1 right foot among men. In total 10 subjects (33.3%) had both feet correctly arched, while among 7 (23.3%) the transverse arch was marked by excessive foot arch.

Table 4. Frequency of occurrence of individual types of the transverse foot arch in male and female pole vaulters

Transverse arch		Women		Men		Total	
		n	%	n	%	n	%
Correct	L	5	35.7	11	68.7	16	53.3
	P	8	57.1	7	43.7	15	50.0
Flat	L	0	0.0	0	0.0	0	0.0
	P	2	14.3	1	6.3	3	10.0
Excessively arched	L	9	64.3	5	31.3	14	46.7
	P	4	28.6	8	50.00	12	40.0

The mean value of the calcaneal angle of the left foot (15.30°) and the right one (15.76°) in the whole group of subjects was similar and within the range characterising feet with the correct transverse arch (Table 5). Having divided the subjects according to their sex and the type of foot (left, right), a comparative analysis of mean values showed no statistically significant differences between male and female vaulters.

Table 5. Parameters characterizing the transverse arch of the right and the left foot

Group	Foot	$\bar{x}$	±S	Min	Max
Women	L	15.12	1.95	12.4	17.7
	P	15.87	1.78	13.7	19.2
Men	L	15.68	1.67	13.3	17.8
	P	15.66	1.61	13.4	18.3
Total	L	15.30	1.82	12.4	17.8
	P	15.76	1.67	13.7	19.2

The results of own research indicate that pole vaulter's training had no adverse effect on the morphofunctional architecture of the foot, on reducing in the longitudinal and the transverse arch. In about 2/3 of the subjects an excessive longitudinal and transverse foot arch of the right and the left foot was found, which is confirmed by high values of Clarke's angle. The transverse foot arch among more than half of male and female vaulters was mostly correct, and among the rest it was excessive. There were few cases of transversely flat right feet.

DISCUSSION

The issue related to the architecture of the longitudinal and transverse foot arch among persons engaged in various sports disciplines, including pole vault, does not have a sufficient number of scientific reports. In the available publications, many authors describe changes in the longitudinal and the transverse foot arch among athletes training, among others, team games [8, 11, 19, 20], swimming [21], combat sports [22], dance [23], and athletics, including long and high jump [24]. In literature of the subject no information on the characteristics of the foot arch among male and female athletes training pole vault was found. An available paper on vaulters' body posture [25] only discusses the shape of the spine and selected characteristics of the body posture in the frontal and the sagittal plane. Therefore, any scientific study on the shape of the foot arch among athletes of different sports can undoubtedly improve knowledge on this subject. Simultaneously, it can be a treasure trove of knowledge for coaches, showing how to introduce training loads in order not to excessively overload feet in persons involved in competitive sport.

The evaluation of the longitudinal and the transverse foot arch of the right and the left foot conducted in this study allowed determining the characteristics of the types of foot arch and the frequency of their occurrence in athletes engaged in pole vault. To assess the transverse foot arch, we used the calcaneal angle (γ), which has a direct relationship to the length of the foot and the width of its forefoot [18, 26, 27, 28], or, as Kasperczyk [16] says, components of the transverse foot arch index, the so-called Wejsflog index "W". Lizis's research results [27, 28] documented that the lower value of the calcaneal angle is conducive to the growth in the value of the transverse foot arch, thus confirming a possibility of using the calcaneal angle to assess the transverse foot arch. A comparative analysis of both methods carried out by Trzcinska et al. [18] showed no statistically significant differences between the evaluation of the transverse foot arch made by means of the Wejsflog index and the value of the calcaneal angle (γ).

Pole vault is one of the most technically complex and the most difficult to control athletics events, requiring a competitor to have comprehensive fitness preparation as well as specific properties of the nervous system. According to Zaglaniczny [29], an athlete performing the pole vault can be compared to a sprinter during the approach, to a long jumper (triple jumper) during the take-off, in the next phases of the jump to a gymnast doing a hip pullover and a handstand, and finally to an acrobat performing complex stunts while flying over the bar and landing. The final result of the jump, i.e. the height, depends on the technique of performing individual components, including the approach and the take-off, hence on smoothly performed support and load-bearing as well as shock-absorbing functions of whole lower limbs, with particular involvement of the feet. Therefore, each training unit emphasizes exercises improving the approach and the take-off phase, during which an athlete sets feet dorsally, with a striding step, and only the forefoot and toes have contact with the ground. The process of improving the approach and the take-off includes numerous exercises performed in standing on one's forefoot and toes, which include, among others, striding runs, multiple jumps, skip A and skip C, runs with high knees, running long jumps.

These technical exercises of the lower limbs strengthen muscles (shortening them) responsible for maintaining the foot arch of the transverse and longitudinal curvature at the appropriate level; therefore, such feet gain the correct and higher foot arch. One can assume that also the type of worn shoes (athletic spikes) and an elastic and soft surface which does not burden feet during training have a beneficial impact on active and passive stabilizers of feet.

Opinions on the influence of physical activity and practising sports in the longitudinal and the transverse foot arch are divided. Some scientists believe that reducing physical activity is one of the factors conducive to lowering the foot arch [30, 31, 32], while other researchers prove in their papers that flat foot results from excessive physical activity and sports training [7, 20, 23].

Grabara and Mazurek [23] claim that excessive overloading of feet during the many hours of intensive ballet exercises, in which there are many jumps in specific poses and performing shoes with a hardened toe area, is the cause of longitudinal pes planus, but at the same time does not reduce the transverse foot arch. Grabara [7] and Całka-Lizis et al. [20] present similar observations proving that football players' foot arch is characterized by the reduction of the longitudinal and the transverse foot arch in comparison to non-training peers.

Opposing views on the effect of sports training on the foot architecture are presented by, among others, Demczuk-Włodarczyk et al. [6] Gradek et al. [24], Ślężyński and Rottermund [11], Woźniacka et al. [19], Lizis and Puszczałowska-Lizis [8]. According to the aforementioned authors, sports training is benefi-cial for the foot arch and its efficiency.

According to Ślężyński and Rottermund [11], practising competitive volleyball with many jumping exercises, especially performed on a flexible surface, is a good treatment to shape the longitudinal foot arch. Lizis and Puszczałowska-Lizis [8] support these observations in their research on basketball players. According to them, basketball strengthens active-passive stabilizers of the longitudinal foot arch and its front support zone. Also Demczuk-Włodarczyk et al. [6] attest to the positive impact on the development of the longitudinal and the transverse foot arch of a variety of sports, in this case, mountain climbing.

Results presented by Gradek et al. [24] indicated that long jump and high jump contestants were characterised by a much better longitudinal foot arch than the examined here athletes – male and female vaulters. However, noteworthy here is the fact that they were jumpers in the younger junior category. In our study excessively arched feet were by far more frequently diagnosed than the correct ones, which prevailed in Gradek's et al. [24] study.

The results of own research indicate that male and female vaulters are characterised by the correct and increased foot arch. The longitudinal and the transverse foot arch feet increases in them under the influence of specialized and appropriately intensive physical exercises. The use of appropriate training means, systematic biological regeneration, proper sports footwear and surface are all factors affecting pole vaulter's foot arch. In addition, it should be stressed that the sparsely identified transversely flat feet were found mostly in persons who in the past suffered from the ankle joint injuries – sprains and dislocations. The podoscope examination of feet included in this study also

showed that gender differences concern only the increased longitudinal foot arch of the left foot in male athletes compared to the female ones.

CONCLUSIONS

1. The longitudinal foot arch of the take-off and non-take-off limb among male and female vaulters is characterized by normal and increased foot arch.

2. The longitudinal foot arch of the take-off lower extremity (left) among male vaulters is characterized by a higher arch than among female vaulters, which may attest to better adaptive changes in men to the bear training loads.

3. The take-off foot of male and female vaulters, due to the numerous technical exercises performed in standing on the forefoot and toes which strengthen the muscles responsible for maintaining the arch at the appropriate level (by shortening), can also lead to an increased foot arch.

4. When selecting athletes to a club, coaches should pay particular attention to the young adepts' developmental age, as too soon initiated specialized training of a pole vault jumper can disturb functions of the lower extremities and cause, among others, static distortions of the feet, which, in turn, may result in premature degenerative changes of the movement apparatus.

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