ANALYSIS OF LONGITUDINAL PLANTAR ARCH IN FEMALE ARTISTIC GYMNASTS

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Abstract

The aim of the study was to use plantographic measurements to analyse the condition of longitudinal plantar arch in a group of female artistic gymnasts and to find out to which characteristics of gymnasts they are related. The study group included 52 artistic gymnasts at a high performance level. Using static measurement on an Emed platform plantographs were acquired which were then evaluated by the Chippaux-Šmiřák method, the results were then scaled according to Klementa norms. In 89 measured feet out of 104 a high longitudinal foot arch was detected. Out of these 5 were slightly high, 14 were medium high and 70 were very high. The remaining 15 gymnasts had a normal longitudinal foot arch. By calculating the Pearson correlation coefficient we found out that with the duration of gymnastic practice the height of foot arch decreases (r = 0.47), these changes might also be affected by increasing BMI (r = -0.51) during growing up. Regarding the condition of preferred and non-preferred foot, no statistically significant difference was found out (p = 0.44). Based on the results we recommend compensatory exercises aiming to plantar flexors stretching to be included in artistic gymnasts' preparation.

Keywords: *Gymnastics, women, foot arch, Emed, Chippaux-Šmiřák.*

INTRODUCTION

In order to be able to compete with others at a national or international level, a gymnast should start with gymnastics at an early age. Female artistic gymnasts then perform at an elite level during adolescence. High intensity of exercise and competition loads, their amount and level of element difficulty could be in relation with the fact that there is a significant number of injuries in female high level gymnasts (Chilvers, Donahue, Nassar & Manoli, 2007). Effects of long-term specific gymnastic load on organism already from early childhood may also lead to adaptive changes in the structure of musculoskeletal system.

Despite using special mattresses, many injuries of lower extremities occur mainly during the landing phase (Mills, Pain & Yeadon, 2006, Vormittag, Calonje & Briner, 2009). Accoridng to McNitt-Gray (1991), the landings are from heights around 2 to 4 m. According to the rules, a gymnast aims to perform the landing without a loss of balance or movement of legs after the landing, while their musculoskeletal system must absorb the forces of impact. These increase the risk of ankle and feet injuries (Vormittag, Calonje & Briner, 2009).

The large forces acting on the body of the gymnast during landings in combination with high number of movement repetition are one of the main causes of injuries (Farana, Zahradník, Uchytil, & Jandačka, 2013). Caine, Russell, & Lim (2013) assume that the riskiest discipline is the floor, mainly due to the large number of take-offs and landings reflections and rebounds.

Therefore, landings are not important only as a part of gymnastic routines, but also from the point of view of injuries. Generally, stability of landing depends on balancing abilities of a gymnast and landing area characteristics. From this reason Soriano, Belloch and Alcover (2007) dealt with plantar pressure during landing and its relation to stability and perception of mattress characteristics. A statistically significant relationship between the plantar pressure and perception was found out. In the conclusion the authors summarise that even when using different types of mattresses, a high pressure repeatedly occurred on heel (785 kPa) and on a first metatarsus (352.6 kPa), approximately similar pressure on other, resting, areas (200 kPa).

Authors Slater, Campbell, Smith and Straker (2015) point out that flexion in joints of lower extremities during landings is limited by the rules of artistic gymnastics, although there are ways to decrease these forces. Using the force platform and 3D kinematic analysis of motion they measured the vertical component of force reaction of platform and angles in ankle, knee and hip joint of elite female gymnasts. Based on the results the authors suggest that the rules of artistic gymnastics should be re-evaluated as bigger flexion in joints of lower extremities during landing leads to decrease in the size of impact forces which will contribute to injury prevention.

McNitt-Gray (1991) claims that during landing are created reaction forces equivalent to ten times and more the amount of the force of gravity, which may lead to lower extremities overloading. Likewise, also Mills, Pain and Yeadon (2009) state that reaction forces of platform during landing may reach values up to 8000 N. Nevertheless, according to these authors the reduction of reaction forces of platform is not appropriate as the way of minimising the potential risk of injury because this may lead to increase of inner forces.

As mentioned above, several authors agree on the fact that the lower extremities injuries are the most frequent among gymnasts (Mills, Pain & Yeadon, 2006, Vormittag, Calonje & Briner, 2009). They assume that the reason is the high number of landings from big heights as well as landings from flight elements with rotation. Authors Kolt and Kirkby (1999) performed a 18-month-long prospective study on Australian elite female gymnasts in which they assessed the number of injuries, their anatomical localisation and type of injury in elite female gymnasts, the data were then compared to retrospectively acquired data. The most common injuries included ankle and foot injury (31.2 %), with prevailing twisted ankle (29.7 %), then stretched ankle (23.2 %) and injury of growth plates (12.3 %).

Extreme load is related to pain which is a serious problem is artistic gymnastics as it decreases the performance of a sportsman. According to Marini, Sgambati, Barni, Piazza and Monaci (2008) the pain caused by high number of hours spent on trainings may be related to injuries which are common and serious in artistic gymnastics. In agreement with previous studies they state that the most common problems in the study group affect ankles and hips, the painfully affected area was related to the training content. The results of the study proved a positive effect of preventive-compensatory movement programme already after a short-term intervention.

Musculo-skeletal changes due to overload in ankles and feet are mainly related to the character of gymnastic movements. It has been proved that the height of plantar arch is changing with age, even without any extreme overload. Forriol and Pascual (1990) state that arch index has a value of 1 in one year (the range 0.7 – 1.35), it gradually decreases to a minimum value of around 0.6

(the range 0.3 – 0.9) at the age of 12 – 14 and then increases with age to a value of around 0.8 (the range 0.3 – 1.1). It is obvious, however, that apart from the ontogenetic changes the activity of certain feet muscles may increase the plantar arch height, the activity of other muscles decrease the height. Some authors dealt with the influence of gymnastic exercises on the changes of these structures.

The aim of the research by Aydog et al. (2005) was to evaluate the relationship between the force of muscles of ankle joint and the structure of foot in gymnasts aged 18 – 30 years. The condition of plantar arch was assessed using a podoscope, the force of plantar and dorsal flexion and inversion and eversion in ankle joint was measured using Biodex 3 dynamometer. Both arch indexes were significantly lower in gymnasts compared to the control group. Also, the measurements proved a significant correlation between the values of these indexes for the right and left foot both in gymnasts and the control group. Regarding the force characteristics, a lower force of dorsiflexion in ankle joints was found in gymnasts compared to the control group. As already mentioned above, the active performance of dorsal flexion in ankle joint is not a usual intended movement in gymnasts. Muscles participating in the flexion, i.e. musculus tibialis anterior, musculus extensor hallucis longus, musculus peroneus tertius a musculus extensor digitorum longus (Bernaciková, Kalichová & Beránková, 2010), are not exercised enough in comparison with other muscle groups. Also in a study by Aydog et al. (2005) in gymnasts a correlation between the force in ankle joint during foot eversion (with participating musculus peroneus longus, musculus peroneus brevis, musculus extensor digitorumlongus and musculus peroneus tertius) and the plantar arch height was found. Based on the results the authors recommend to perform a prospective study which would better clarify the relationship between training and adaptive changes. It would be beneficial to find out how high plantar arch and weaker dorsiflexion in ankle joint are related and how these characteristics affect foot stabilisation which is a significant factor influencing the performance. Authors summarise that foot muscles influence the development of plantar arch and therefore it can be assumed that exercising of muscles connected to ankle joint will have effect of plantar arch condition.

When comparing condition of plantar arch of gymnasts with other sportsmen, such as handball players, weightlifters, footballers and wrestlers, it was found out that gymnasts have lower values of arch indexes, i.e. higher plantar arch (Aydog, Tetik, Demirel & Doral, 2005). High plantar arch (pes cavus) as well as flat foot (pes planus) may be, according to some authors (Simkin et al., 1989, Cowan, Jones & Robinson, 1993) a cause of fractures of femur, tibia, metatarsal bones and other parts of lower extremities.

Insufficient activity of certain muscles, unbalanced exercising or stretching of given muscle groups may lead to changes in plantar arch condition. In artistic gymnastics gymnasts constantly aim to have their toes point, according to the rules, so that the aesthetics of movement is preserved. Actively performed plantar flexion by concentric activity of related muscles is a condition for a dynamic take-off from the kinesiologic point of view. Eccentric contraction of plantar flexors is necessary for stable and coordinated rebound when a gymnast places the foot from fingers to the whole sole. A direct effect of the dynamic movements as well as static positions performed within the ankle joint and foot (mainly plantar flexion) on the changes of these structures is not yet clarified, therefore we would like to contribute to knowledge in this field.

In our research we focused only on a group of female gymnasts, as mechanical load of movement apparatus is different in men. Regarding foot, there are differences in parameters of shape and dimensions between men and women (Hong, Wang, Xu & Li, 2011), therefore it is advisable to deal with this issue for each sex separately.

The aim of the paper is to analyze the condition of longitudinal plantar arch and its characteristics, in female artistic gymnasts of high performance of Czech Republic. Based on the aim we formulated the following research questions: How is plantar arch height related to duration of gymnastic practice? How is BMI value related to condition of plantar arch? Is there a difference between preferred and non-preferred foot in condition of longitudinal plantar arch?

METHODS

Participants

With respect to the defined aim the tested group was created by an intended selection of female artistic gymnasts of various age categories, all being at a high performance level. It means that all of this group are included in the elite competition program of the Czech Republic.

As the research group included 52 artistic gymnasts with a range of age from 8 to 28 years old, we divided them according to categories in which they compete – minor: from age 8 to 12 (N = 19), junior: from age 13 to 15 (N = 18) and women: from age 16 to 28 (N = 15). The tested persons underwent the measurements at the Championship of the Czech Republic which took place in Brno in 2015, which met our requirements that the tested persons should at a high performance level. A questionnaire and basic measurements were used to acquire the overview of essential characteristics of individual gymnasts. These were processed into a table 1 according to age categories - minors, juniors and women. It is observed that with the increasing age height and weight changes. We can see that BMI increases from 15.8 in minors to 18.5 and then 21.4 in women. With increasing age also increases the duration of gymnastic practise which is understood as a period of continuous specialised gymnastic preparation during a number of years. The number of training units per week does not increase with the duration of practice, the biggest training load was found in juniors who train 21.7 hours a week in average. From the total number of tested gymnasts 29 use right leg as a preferred take-off leg, 23 use left leg as preferred.

Table 1

Basic characteristics of the research group, DTP = duration of training practice in years, T/h/t = number of training hours a week, pref. = lower extremity preferred as a take-off leg, R = right, L = left.

	age	height/m	weight/kg	BMI	DTP/years	T / h/t	pref.
Minor N = 19	10.74 ± 1.21	1.36 ± 0.10	29.43 ± 4.96	15.83 ± 0.97	5.58 ± 0.99	18.00 ± 1.30	13R : 6L
Junior N = 18	14.28 ± 0.80	1.55 ± 0.07	44.24 ± 6.49	18.46 ± 1.74	9.61 ± 1.46	21.72 ± 1.41	8R : 10L
Women N = 15	19.40 ± 3.28	1.62 ± 0.04	56.00 ± 5.87	21.39 ± 1.94	13.27 ± 2.95	20.23 ± 1.69	8R : 7L

Instruments

The emed-at system belongs to the family of Novel pedography measurement platforms. This system functions as all the scientific emed platforms with calibrated capacitive sensors. The sensor area is 360x190 mm^2, number of sensors 1377, pressure range 10 – 990 kPa, accuracy 7 % ZAS, hysteresis less than 3 %. The frame rate used was 50 Hz.

The features works with Windows 2000 and XP operating systems and measure foot pressure in static and dynamic mode accurately. The system starts recording automatically when the subject´s foot touches the platform. The emed-at software collects and displays the plantar pressure measurement from the emed-at platform. (Novel, 2008)

Procedures

The measurement itself was performed during a single day at Sokol Brno 1 in a reserved room. In order to acquire correct results, the area around the platform was levelled into the same level as the platform using accessory pads. The system enables both static and dynamic measurements, considering our topic we decided for a static mode, measurement in standing position. Right and left feet were measured individually. A proband stepped on the accessory pad with a non-measured foot and after the measurement started he stepped on the measuring platform with the second foot. The proband remains in this standing astride position with parallelly positioned feet and weight distributed equally between legs for 20 seconds. If the proband overstepped or significantly transferred weight to one foot, the measurement was repeated.

Data analysis

Data from paper questionnaires were transferred to Excel tables, BMI (body mass index) was calculated.

Data acquired by Emed system were processed as follows. In order to gain precise data, only 10s from the 20 seconds-long-recordings were used, so that it does not include data when the proband was stepping onto the platform or was balancing his position. From these 10 seconds an average plantograph was exported, average values of forces between the measured foot and platform, average plantar pressure as well as average area of contact between foot and platform. These data were exported into excel. The acquired plantographs were then processed in a graphic programme Microsoft Visio 2013 in which all necessary lines and dimensions were measured. The method Chippaux-Šmiřák was used to evaluate the data. This method is considered appropriate mainly due to a fact that other methods focus on evaluation of flat plantar arch, while Chippaux-Šmirák method differentiates among three grades of high plantar arch. The measured parameters were then evaluated according to norms according to Klementa (1987) who differentiates three grades of flat arch, three grades of normal arch and three grades of high plantar arch.

The study group in this research consisted of female gymnasts aged 8 to 28 years, therefore the lengths of feet differed also due to age differences. When determining the type of plantar arch, Chippaux-Šmiřák method is based on ratio of two dimensions, therefore different foot lengths do not influence the results. In order to be able to compare high plantar arches also with different foot lengths in gymnasts of different ages, we calculated relative sizes of gaps between the front and back parts of plantographs with regard to length of foot. As we dealt with this problem during data processing, the standard data about gymnasts´ feet length was not available. From this reason we determined foot length from plantographs, a distance from a dorsal part of heel print and a print from the area of second metatarsus was measured. Fingers could not be used for calculations as in some probands these were not printed.

Statistical analysis

The acquired data were evaluated using mathematics-statistical methods in *Microsoft Excel* and *Statistica 12* programmes. For individual variables basic statistical characteristics were calculated. The normality of acquired data was tested using Kolmogorov-Smirnov test ($p = 0.05$), therefore Person correlation coefficient ($p = 0.05$) was used for other calculations. Values of correlation coefficients were interpreted according to Gerylovová and Holčík (1990). In order to verify other relations, analysis of variance was calculated with a following post-hoc Scheffe test (p = 0.05).

RESULTS

Plantar arch height

Several data were evaluated for analysis of plantar arch. We measured the necessary dimensions of plantographs using Chippaux-Šmirák method and obtained indexes which were then evaluated according to norms by Klementa (1987). In the following tables 2, 3 and 4 are listed the measured distances between the frontal and dorsal area of foot in contact with platform (dist/cm), in normal feet also indexes calculated from the measured distances (i), for each foot therefore a single numeral data. Then, the tables include word evaluation of plantar foot arch by Klementa norms (1987) according to calculated indexes - flat foot (L), normal foot (N), slightly high foot (SH), middle high foot (MH) or very high (VH). In attempt to precisely compare condition of plantar arch among individual gymnasts, mainly in high arch, the data about the length of the gap were converted into relative distances with regard to the length of foot (length). The length of foot was measured in cm as a distance of dorsal print of heel and print of foot in area of second metatarsus.

Category of schoolgirls - minors

Table 2 shows foot parameters in schoolgirl gymnasts. For total number of 19 schoolgirls we measured 38 feet in which no flat foot (pes planus) was found, 1 foot had normal longitudinal foot arch, 37 feet had high plantar arch, out of which 5 were middle high and 32 were very high plantar arch. In high feet the average distance between the areas of contact with platform was 4.7 cm in preferred foot and 4.3 in non-preferred foot. After converting the distances to relative distances we got 0.39 for preferred foot and 0.36 for non-preferred foot. The last two columns of tables 2 - 4 include the relative length of gap, resp. distance with regard to foot length for preferred (PREF dist/length) and non-preferred foot (N PREF dist/length).

Table 2
Metric data on foot in a group of schoolgirls gymnasts - minors (average, SD, min and max are in columns listing distance included only in high feet).

MINORS (N = 19)	PREF distance [cm]	N PREF distance [cm]	PREF length [cm]	N PREF length [cm]	PREF dist/length	N PREF dist/length
average	4.656	4.305	11.779	12.005	0.391	0.357
SD	1.137	1.187	0.895	0.930	0.082	0.088
min	1.800	2.200	10.000	10.000	0.158	0.182
max	6.200	6.200	13.400	13.700	0.480	0.463

Juniors

In juniors from the total of 36 measured feet were 2 normal feet, 1 slightly high foot, 5 middle high and 28 very high plantar foot arches (tab. 3). In high feet the average distance between the areas of contact with platform was 4.2 cm in preferred foot and 4.6 in non-preferred foot. The average length of preferred and non-preferred feet was, as assumed, almost the same - 12.9 cm and 13 cm. Relative value of distance was in average 0.33 in preferred and 0.35 in non-preferred foot.

Table 3
Metric data on foot in a group of junior gymnasts (average, SD, min and max are in columns listing distance included only in high feet).

JUNIORS (N = 18)	PREF distance [cm]	N PREF distance [cm]	PREF length [cm]	N PREF length [cm]	PREF dist/length	N PREF dist/length
average	4.235	4.612	12.906	12.956	0.329	0.357
SD	1.621	1.273	0.638	0.638	0.125	0.094
min	1.000	1.600	11.800	11.900	0.077	0.131
max	6.200	6.100	13.900	13.900	0.488	0.462

Category of women

Number of feet measured in this category was 30 (tab. 4). Out of the 30, 12 feet had normal arch, 4 had slightly high arch, 4 middle high and 10 very high foot arch. The relative distance in the limited number of high feet was 3.3 in preferred and 3.8 in non-preferred foot. The average length of the whole group was almost the same in preferred and non-preferred foot - 13.2 and 13.1 cm. Relative length on the gap was the same for both feet - 0.27.

Table 4
Metric data on foot in a group of gymnasts - women (average, SD, min and max are in columns listing distance included only in high feet).

WOMEN (N = 15)	PREF distance [cm]	N PREF distance [cm]	PREF length [cm]	N PREF length [cm]	PREF dist/length	N PREF dist/length
average	3.330	3.788	13.227	13.140	0.267	0.271
SD	1.095	1.355	0.584	0.448	0.092	0.094
min	1.200	1.500	11.800	12.100	0.102	0.124
max	4.800	4.900	14.100	13.900	0.384	0.386

The above listed data are supplemented with an overview table 5 with the share of individual types of plantar arches in minors, juniors and women competing is artistic gymnastics.

Table 5
Share of types of longitudinal plantar arches in individual categories of gymnasts according to Klementa norms, PREF = preffered leg, N PREF = non preffered leg, N = normal foot, SH = slightly high foot, MH = middle high foot, VH = very high foot.

	MINOR N = 19		JUNIOR N = 18		WOMEN N = 15	
	PREF/ Klem	N PREF/ Klem	PREF/ Klem	N PREF/ Klem	PREF/ Klem	N PREF/ Klem
N	1	0	1	1	5	7
SH	0	0	1	0	2	2
MH	2	3	3	2	3	1
VH	16	16	13	15	5	5

Results of static measurements

In the following part we present the results of static measurements in a standing astride position with one foot placed on a platform in which we recorded the average force by which the foot acted on a platform, average pressure and average size of area which was in contact with platform.

Table 6 presents an overview of average values and standard deviations of these parameters. This table is complemented by a graph (fig. 1) showing how increasing age, i.e. Change in category, changes the individual parameters.

Table 6
Results of statistical measurements.

		PREF F [N]	N PREF F [N]	PREF p [kPa]	N PREF p [kPa]	PREF S [cm^2]	N PREF S [cm^2]
MINOR	average	150.712	152.256	102.632	104.298	43.684	38.219
	SD	31.776	34.154	32.220	23.052	15.814	6.837
	MIN	102.933	77.500	60.000	66.667	29.500	23.333
	MAX	235.867	205.800	193.333	155.000	105.333	48.167
JUNIOR	average	251.383	241.589	155.278	164.167	51.676	49.269
	SD	44.165	38.652	40.240	49.242	9.189	7.753
	MIN	171.033	178.500	73.333	95.000	29.167	39.000
	MAX	319.433	298.200	251.667	268.333	66.000	66.833
SENIOR	average	315.198	319.284	130.778	135.444	65.733	64.055
	SD	33.215	53.790	30.562	33.602	7.762	8.673
	MIN	253.167	247.300	78.333	88.333	51.500	48.500
	MAX	363.633	449.267	205.000	206.667	77.000	80.333

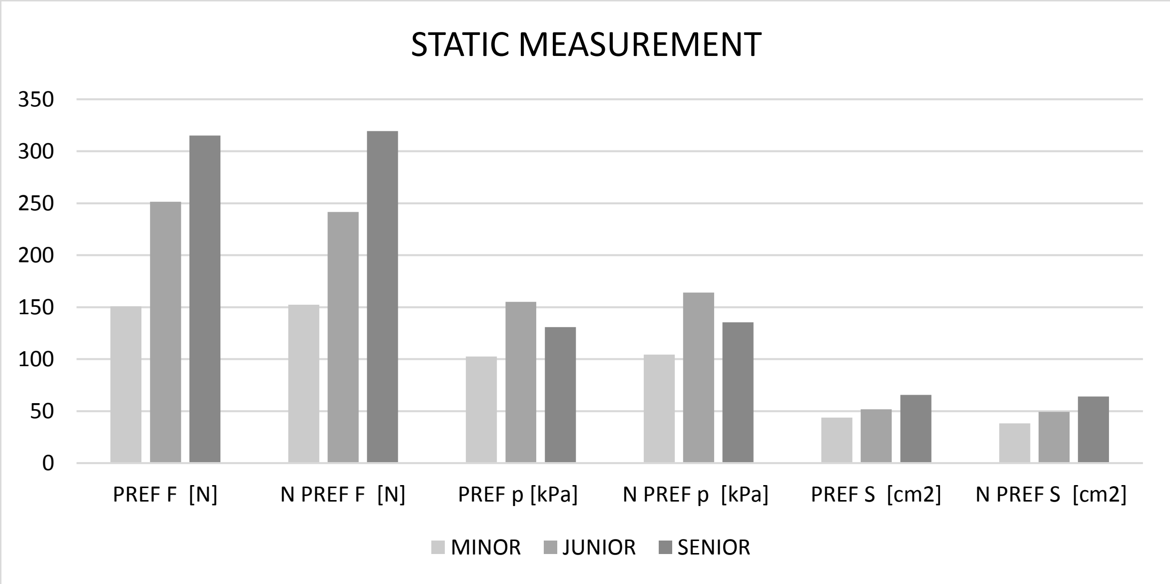

Figure 1. Comparison of results of static measurements among age groups.

With regard to measured values of force in the category of women it should be noted that with increasing forces acting on platform compared to younger categories standard deviation does not increase directly. From the point of view of this parameter women appeared as more homogeneous group. With the increasing age increases also the force acting on platform as well as size of area of foot which is in contact with platform. Different situation is with pressure which increases from minors to juniors, but decreases in women to its lowest values. From the relationship p = F / S it can be derived that if with growing force increases also area, pressure will not increase so much as the acting force is not concentrated into small area, it is dispersed. The results prove this assumption, values of pressure in women (131 kPa and 135 kPa) are lower compared to category of juniors (155 kPa and 164 kPa).

DISCUSSION

In most gymnasts, more specifically in 89 measured feet out of 104, which is in 86 %, high foot arch was found. Out of these 5 were slightly high, 14 were medium high and 70 were very high. Using Pearson correlation coefficient (p = 0.05) a statistically significant relation (r = - 0.47) was found between the length of gymnastic practice and longitudinal foot arch height, which can be interpreted as a medium dependency (Gerylovová & Holčík, 2009). This research was not conceived as a longitudinal study, therefore we don't know “departure values” for the older gymnasts. However, the statistical result points to a tendency to decrease the longitudinal foot arch height with the increasing duration of intensive regular specific exercise of lower extremities, which should be verified in further studies.

In order to clarify the calculated medium strong dependency we calculated the analysis of variance and post-hoc Scheffe test (p = 0.05) which was used to compare how big will be the difference between foot arch height among individual categories which strongly correlate with duration of gymnastic practice (r = 0.85). As shown in table 7, statistically significant difference in foot arch height was proved only between the group of minors and women (p = 0.000).

Table 7
Scheffe test for a variable "foot arch height" transformed into a scale according to Klementa.

	Scheffe test; variable:scale (group characteristics) Highlighted diferrences are significant on a level p < .050		
Prom1	{1} (M=6,790)	{2} (M=6,778)	{3} (M=5,400)
minor {1}		0.998	0.000
junior {2}	0.998		0.000
women {3}	0.000	0.000	

The results show that with the increasing duration of gymnastic practice the foot arch height decreases, these changes, however, are not too significant and rapid as significant difference was proved only between the youngest and oldest groups of gymnasts, i.e. between minors and women.

Regarding the second research question we investigated the relationship between BMI and longitudinal foot arch condition. Due the fact that indexes for normal and high foot arch cannot be calculated together as they depend on different dimensions, we transformed the resulting indexes Chippaux-Šmiřák into a scale norms according to Klementa. For the relationship between BMI and condition of foot arch according to the scale a correlation coefficient of r = - 0.51 was found, i.e. medium strong relation between the variables. However, the data transformation means loss of data, therefore we performed one more calculation of Pearson correlation coefficient (p = 0.05) in which only high foot arch data were included. A close relationship between BMI and relative distance in high feet arch was not proved (r = -0.3). This value is statistically significant, however, we cannot consider it explicitly conclusive from the factually-logical point of view. The results can be explained in a way that with increasing BMI foot arch is decreasing (r = -0.51), however, the relationship is not sufficiently strong, smaller differences between indexes of foot arch feet are not significant enough to correlate with BMI changes.

We were also interested in differences between parameters of preferred and non-preferred leg. As shown in Table 8, there was no statistically significant difference proved between parameters of preferred and non-preferred foot based on T test of variables (p = 0.005) either in parameter "foot arch height transformed into the scale" (p = 0.44), nor when we included only high foot arch data and compared "relative distance of areas of contact of foot with platform" (p = 0.91). The only statistically significant difference was found only in parameter "average areas of contact of foot with platform" (p = 0.03).

Table 8
Evaluation of differences between parameters of preferred and non-preferred leg.

	T-test for dependant variables (group characteristics) Highlighted parameters are significant on a level of p < ,0500									
Variable	Average	SD	N	Difference	SD of the difference	t	sv	p	Int. of reliability (-95.000%)	Int. of reliability (+95.000%)
Distance/length pref	4.364	1.406								
Distance/length non-pref	4.386	1.238	42	-0.021	1.261	-0.110	41	0.913	-0.415	0.372
Scale pref	6.423	1.017								
Scale non-pref	6.346	1.118	52	0.077	0.710	0.782	51	0.438	-0.121	0.275
Area pref	52.811	14.876								
Area non-pref	49.497	13.057	52	3.314	10.846	2.203	51	0.032	0.294	6.334

Another calculation of Pearson correlation coefficient r = 0.55 proves a medium strong relationship between area of contact of foot with platform and foot arch height expressed by scale. If we take into consideration only high foot arch data, for relationship between area of contact and relative distance of contact areas we get correlation coefficient r = - 0.31. However, as stated above, in one parameter there was a difference between preferred and non-preferred leg and in the second one there was no difference, as shown in graphs fig. 2 and fig. 3.

We performed qualitative assessment of acquired plantographs in order to find out why there is no decrease in foot arch height, or distance between contact areas, with increasing contact area in preferred legs compared to non-preferred legs. We found out that contact area in preferred legs is bigger compared to non-preferred legs mainly due to bigger contact area of fingers and wider contact area of metatarsal region. We did not observe any significant increase in contact area within longitudinal foot axis, which explains the fact that with change in size of contact area of foot the foot arch height does not proportionally change. We are of opinion that frequent use of one leg as a preferred leg results in bigger involvement of fingers participating in plantar flexion during take-off phase compared to non-preferred foot.

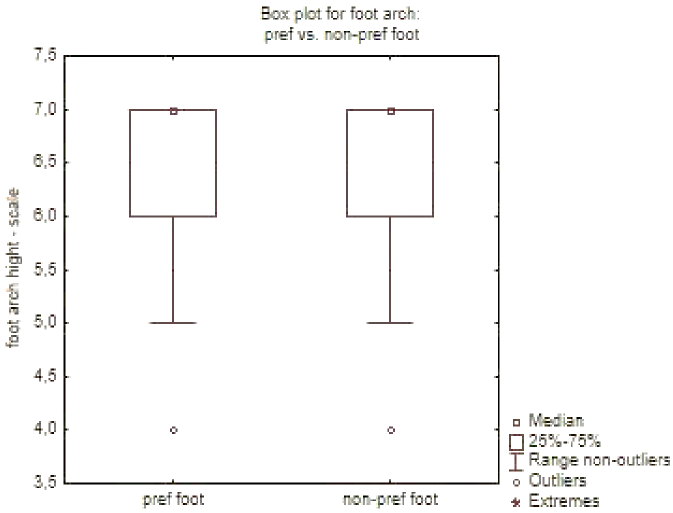

Figure 2. Box diagrams for foot arch height in preferred and non-preferred leg.

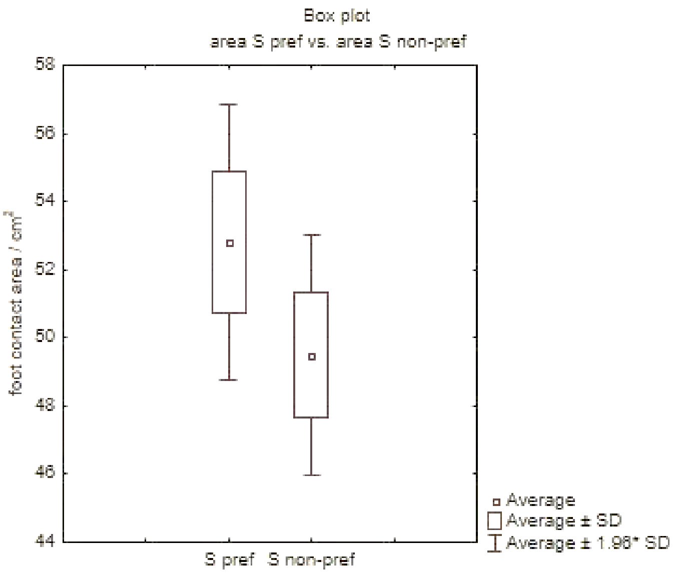

Figure 3. Box diagrams for contact area in preferred and non-preferred leg.

The results show that female gymnasts mostly have high longitudinal foot arch. This finding is in agreement with the results of previous studies (Aydog et al., 2005; Aydog, Tetik, Demirel & Doral, 2005) in which the authors found out that foot arch height in gymnasts is significantly higher compared to the control group which included handballer players, weightlifters, football players and wrestlers. It seems that high foot arch is formed already during childhood based on gymnastic load of lower extremities as it can be observed already in the youngest age category. Forriol a Pascual (1990) state that in normal population aged 12 - 14 foot arch is at its highest, then its height decreases. This decrease can be observed also in our research group when with increase in BMI during adolescence foot arch height decreases. Regarding the fact that the work was not framed as an experiment, we can state that it is the influence of gymnastic training and BMI changes that influences changes of foot arch. Changes in foot arch condition can be observed also in normal population without any extreme load (Forriol & Pascual, 1990). However, we can state that high foot arch is a frequent condition in female artistic gymnasts.

Similarly as Aydog et al. (2005) state that foot muscles affect development of foot arch, also we think that frequently actively performed plantar flexion within gymnastic exercises influence musculoskeletal structure of foot. As obvious, muscles performing plantar flexion are considered muscles that are responsible for foot arch support. As stated in Čihák (2001), these are muscles supporting longitudinal foot arch: musculus tibialis posterior which supports the heighest place of arch, musculus flexor digitorum longus, musculus flexor hallucis longus and superficial short muscles of foot. There is also superficial ligamentous layer of a tendinous character (aponeurosis plantaris), which is grown into musculus flexor digitorum brevis, and a tendinous stirrup which is used by musculus tibialis anterior to strain the edge of foot upwards. It should be noted that during normal load (standing, walking) these muscles are not activated, they are activated and contracted during load other than walking, as shown by electromyographic studies (Dylevský, 2003). We think that load acting on foot during gymnastic exercise, mainly during landing (Soriano, Belloch & Alcover, 2007), have sufficient intensity to activate muscles supporting foot arch, which leads to high foot arch condition in gymnasts. Similarly as flat foot, also high foot may be a reason of injury, mainly fractures of lower extremities (Cowan, Jones & Robinson, 1993; Simkin et al., 1989). Exercise for both flat and high foot are based on stretching and strengthening of long extrinsic muscles and short intrinsic muscles (Rose, 1992). Therefore it is advisable to include also compensatory stretching exercises of overloaded foot arch muscles into gymnastic preparation, which may act as a prevention of injury of lower extremities which are very frequent in artistic gymnastics (Mills, Pain & Yeadon, 2006; Vormittag, Calonje & Briner, 2009 and other).

CONCLUSIONS

The results of our research has shown that the high foot arch - either of mild or severe level - was present in 86% of measured gymnasts. We suppose that this finding in measured group is important for both sport persons and their coaches, despite we have seen no statistically important dependencies between variables according to our measurements. We suggest to include a stretching of plantar flexors of foot into the training practice. These compensatory exercises should serve among other purposes also as a prevention of injury of lower extremities.

We suggest to perform also a longitudinal study, in which repeated measurements would be performed over time in order to measure foot arch in gymnasts and control group to prove the influence of gymnastic load on these musculoskeletal changes. These measurements could also be performed in younger gymnasts, because our youngest tested gymnasts - juniors already have very high foot arch.

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