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Assessment of static foot posture as an indicator of biomechanical adaptation in American football players

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Abstract

Purpose

Increased physical load on the body of American football players, especially in the lower limbs, may be associated with increased risk of foot deformities and injuries, potentially influencing players' overall fitness and performance. The aim of the study was to assess the relationship between American football training, training duration and anthropometric features, and foot posture in Polish players.

Methods

70 athletes training American football in Poland and 35 non-training. The study used a questionnaire and the Foot Posture Index -6 to assess foot shape. An analysis of the relationship between age, Body Mass Index and training experience with foot posture was conducted.

Results

The average BMI value between the studied groups of athletes and non-training was significantly different ($p<0.01$). The athletes and non-training participants showed good foot posture according to the total Foot Posture Index - 6, but a statistically significant difference between the groups was found in all partial values of the Foot Posture Index measurements from 1-6, except for Foot Posture Index 2, left foot. In the group of athletes, no statistically significant relationship was found between anthropometric parameters and Body Mass Index and Foot Posture Index - 6. In the non-training participants, a significant relationship ($p<0.02$) was found between the shape of the left foot and BMI.

Conclusions

Monitoring foot posture and BMI in athletes practicing American football may be beneficial. Based on the observed tendency toward foot pronation, football players may benefit from individually selected footwear, including anti-pronation options when indicated.

Keywords

American football, pronation, Foot Posture Index, Body Mass Index, sports biomechanics

1. Introduction

American football is a demanding team game. Training in American football increases physical fitness, endurance and body efficiency. The players' muscle training, motor coordination and overall body fitness increase [36]. This is a very positive phenomenon, but participating in regular and laborious training requires players to devote time and a lot of physical and mental commitment. Poor individual preparation of the player, poorly selected training, ruthless and hard physical work can quickly affect the athlete's health. As a result, it can lead to injuries and diseases. With the increase in the number of years of training, the frequency of dizziness attacks increases in players who have had head injuries [24]. An increase in the athlete's body weight is characteristic of this discipline, and overweight or obesity is associated with the risk of many overload diseases, including those in the feet [15]. American football players have an increased mortality rate, a higher risk of cardiovascular and neurodegenerative diseases. The high frequency of injuries and overloads carries the risk of permanent disability and elimination from the game [33], [38], [48].

In order to prevent forced breaks in sports due to health reasons, physiotherapists and coaches create injury monitoring databases, implement prophylaxis and conduct preventive tests. One of the topics important for this group of athletes is the examination of foot shape, and consequently the appropriate selection of footwear for the foot. Footwear is to ensure foot stability and mobility, protect against injury and promote the safety of the athlete and other players, e.g. by eliminating the risk of slipping. It has been confirmed that the interaction in the kinematic chain and the cooperation of the muscles and joints of the lower limbs depend to a large extent on the selected footwear [6], [17], [44]. Reports suggest that appropriately good footwear properly positions the foot and is one of the most important methods of injury prevention [6], [17], [44], [49]. There is a relationship between the kinematics of the knee and ankle joints and the type of sports footwear used, and the reaction of ground forces. [6] It has been confirmed that the range of dorsal flexion of the first metatarsophalangeal joint (1 MTP) depends on the flexibility of the shoe sole in the forefoot area [17]. Rotational movement of the ankle joints is related to the rotational stiffness of the shoe [11,39]. Poorly selected footwear can disturb the function of the Achilles tendon and lead to its damage. Achilles tendinopathy affects the function of the peroneus longus, gastrocnemius and gluteal muscles. [42].

Foot function disorders in athletes may be caused by its incorrect shape as a result of muscle strength imbalance in the lower limb, muscle failure. Factors influencing foot structure deformation include: overweight, weakening of the musculoskeletal system, chronic

overload, excessive loads, maintaining a long-term incorrect position, e.g. while standing or running, inappropriate or hard surfaces, poorly selected footwear, previous injuries, individual predispositions. As a result of foot deformations, there is often a loss of correct foot function and pain [5]. A pronated foot can lead to: internal rotation of the tibia and, as a result, to disorders of the gastrocnemius muscle and axial movement in the knee joint (valgus), Achilles tendon contracture [19], [21]. Biomechanically, the function of a flat foot is dysfunctional, and there is excessive mobility between the forefoot, midfoot, and rearfoot during walking [8], [9], [19], [26]. Such a situation may predispose to an increased number of ankle sprains and dislocations, perhaps also in American football players.

The position of the foot affects the development and efficiency of the quadriceps femoris muscle. A pronated foot causes weakness of the rectus femoris muscle and the medial head of the quadriceps femoris muscle [3]. On the other hand, a clubfoot promotes lateral ankle sprains [37]. It has been confirmed that in athletes, a supinated foot can cause knee joint pain [18] and greater activation of the biceps femoris muscle [32]. The mechanical stiffness of a clubfoot foot exposes athletes more often to ankle and foot injuries than a normal foot [12].

Various characteristics of American football can affect foot posture. Specific ground reaction forces on the foot may result from dynamic play, sudden accelerations or stops, abrupt changes in direction, and contact with other players in the form of physical combat [43], [44], [49]. In addition, repetitive overloads can lead to adaptive changes in the structure and function of the foot. Furthermore, it should be taken into account that most American football players are characterized by high body weight, which can also disrupt the biomechanics of the foot. On the other hand, playing on artificial surfaces and wearing cleats limits the natural movements of the foot, which can lead to compensatory changes during foot support [17], [39], [44], [49]. The frequent occurrence of microtraumas and overloading of the ligaments and musculofascial structures of the foot can, over time, lead to weakened arch stabilization and the development of abnormal foot alignment patterns, such as excessive pronation. American football players differ in body weight, tasks on the field, movement patterns, and intensity of effort, which may influence the development of different foot posture patterns [22], [43]. Despite these important biomechanical factors, there is still a lack of research analyzing foot posture in American football players, especially using standardized clinical tools such as the FPI-6.

Other previous studies have analyzed the relationship between practicing a specific sport and foot posture, but they mainly focused on athletes training in badminton, volleyball, basketball, swimming, soccer, running, handball, and futsal [2], [12]–[14], [16], [20], [27],

[30], [31]. Among young, non-professional soccer players, no relationship was found between FPI foot posture variables and the analysis of movement quality measured by FMS. [2] In futsal players, a higher risk of ankle injury associated with foot morphology disorders was confirmed [12]. In a study by Windsor et al. [47] investigated the association between foot biomechanics and self-reported history of musculoskeletal pain or injury in American football players at the United States Naval Academy [47]. In another study, Taylor et al. [44] examined the relationship between the type of footwear (cleats, turf) and the distribution of loads in the foot in American football players, which allows for the assessment of the risk of foot injury.

The relationship between abnormal foot posture and the impact of American football training remains unclear. Furthermore, the extent of the relationship between foot posture (pronation or supination) and age, BMI, and training time has not yet been fully established. This study addresses the niche topic of foot posture assessment (FPI-6) in American football players, comparing them to a control group of non-athletes.

American football, as a demanding sport with high physical load, is associated with many health challenges, especially in the context of the musculoskeletal system [48, 49]. Increased load on the body during play, especially in the lower limbs, creates a risk of foot deformities, which can affect the overall fitness and performance of players. In addition, improper selection of sports footwear, neglect of injury prevention and incorrect foot shape can lead to permanent injuries and dysfunctions that will negatively affect the athlete's performance in the future [12, 43, 44, 48, 49]. In the context of athletes' health, it is particularly important to monitor these problems, because early detection of abnormalities in foot structure can prevent more serious injuries and improve the comfort of training and results on the pitch.

The aim of the study was to assess the relationship between foot posture and American football training, its duration, and selected anthropometric characteristics in Polish male players, and to compare these findings with those to an age matched non-athletic group.

2. Materials and methods

Study population

The study included a total of 105 people, from whom two groups were distinguished: a sports group practicing American football (SG) and a control group (CG).

The SG group consisted of 70 male athletes, with an average age of 22.6±4.1 years, an average body weight of 91.8±19.6 kg and an average height of 184±7.1 cm, who regularly trained American football at the Kraków Football Kings Club. SG recruitment took place by inviting the Club's players to the study; the players were provided with an online schedule of applications with various dates for stationary tests and at the same time were provided with information about the study.

The inclusion criteria for the study were: consent of the subject or parent/guardian to participate in the study, male gender, age between 16 and 35 years, the subject is currently able to perform functional tests, no current injury, it does not exclude him, e.g. an injury, plays American football professionally. Exclusion criteria: additionally regularly practices another sport.

The CG group consisted of 35 male students of the Faculty of Health Sciences of the Jagiellonian University Medical College, with an average age of 21.5±3.3 years, an average body weight of 72.8±10.8 kg and an average height of 179.8±4.7 cm, who did not regularly practice American football or any other high-intensity sport, for 3 hours a week or more.

Recruitment to the control group was conducted in person and included in the study were students who expressed their willingness and consent to participate in the study after obtaining prior information about it.

All participants were informed about the potential risks and benefits of the study and signed an informed consent (or parental consent has been given).

Between SG and CG for the average age of the subjects $p=0.15$, and for body height and body weight $p<0.01$.

The power estimate was performed using G Power 3.1 software, assuming a Cohen's effect size of $d=0.5$, a significance level of $\alpha=0.05$, and a statistical power of 0.8. Although the control group consisted of only 35 participants and the soccer group of 70, the unequal size of these groups slightly reduces the overall statistical power, which was estimated at approximately 0.73 for the t-test for two independent samples. Nevertheless, the larger size of the soccer player group partially compensates for the smaller control group. Therefore, the total sample size is considered sufficient to detect medium or larger effects.

The study was conducted under standard conditions, in accordance with the procedures applicable in scientific research. Ethical approval to conduct the study was obtained from the appropriate Bioethics Committee (nr 1072.6120.129.2018). This was a cross-sectional observational study.

Methods

In order to determine the reliability and repeatability of measurements for the study groups, the same research protocol was used, in the same way, in the same place (isolated room) and at a constant room temperature.

Survey – characteristics of the study group

At the beginning of the study, basic data on anthropometric characteristics were collected, i.e. age, height, body mass, the Body Mass Index (BMI) was calculated and the period of training experience, training frequency and additional activities were recorded. In the absence of knowledge of the subject regarding body mass and to confirm the data, the ADE BE1510 scale (ADE GmbH & Co. KG, Hamburg, Germany) with a measuring range up to 180 kg and an accuracy of 0.1 kg was used to measure.

Foot Posture Index (FPI-6)

In the next stage of the study, the Foot Posture Index (FPI-6) was used for a multi-plane, manual-visual assessment of the shape of the subjects' feet. The index assessed the feet based on six components: palpation assessment of the head of the talus (FPI 1), observation of the curvatures below and above the lateral malleolus (FPI 2) and assessment of valgus or varus of the calcaneus (FPI 3), convexity of the talo-navicular joint area (FPI 4), medial longitudinal arch of the foot (FPI 5), adduction/abduction of the forefoot in relation to the calcaneus (FPI 6). Each of the 6 test points is assessed on a scale of -2, -1, 0, +1, +2. The total FPI-6 score ranges from -12 to +12 (Table 1) [1], [14].

During the study, participants were in a standing position with both feet, barefoot, and their upper limbs were placed along their torso. Immediately before the assessment, they were asked to take a few steps in place and remain in a relaxed standing position without correcting their feet.

The detailed criteria for assessing foot posture according to the FPI-6 were based on the guidelines presented in scientific articles from previous years [14], [29], [41]. All FPI-6 assessments were conducted by a single experienced physiotherapist, who followed the standardized procedure described by Redmond et al. [41]. The second researcher recorded the data provided. This approach ensured consistency across all assessments.

Tab. 1. Classification of foot formation based on the value of the FPI-6 [26]

Total sum of FPI-6 points	Direction of foot posture

od -12 do -5	Foot in increased supination
od -4 do -1	Foot in slight supination
od 0 do +5	Neutral foot
od +6 do +9	Foot in slight pronation
od +10 do +12	Foot in increased pronation

Methods of assessing the relationship between foot posture (FPI-6) and: age, BMI and training experience

In order to assess the relationship between FPI-6 and the studied variables, age categories were created (up to 25 years – most of the respondents were students; over 25 years – most of the respondents were employed), BMI categories (BMI < 25 kg/m² – normal body weight, 25 ≤ BMI [kg/m²] <30 – overweight and BMI ≥ 30 kg/m² – obesity) and the training time categories used in the survey were used (less than 1 year; 1-3 years; 4-6 years; 7-9 years; over 9 years).

Statistical analysis

The results were developed using the Statistica 13 PL statistical program. The following tests were used: Shapiro-Wilk test to examine the normality of distribution, Mann-Whitney U test to compare variables and to check statistical significance, and the probability level (p) was determined using the Chi² test.

The data were entered into the program and grouped according to research group affiliation. Specifically, the data analysis consisted of comparing two independent groups: American football players (n=70) and a control group (n=35) in relation to selected variables. In the first step, the Shapiro-Wilk test was used to assess the normality of the distribution of each variable. Additionally, in order to assess the symmetry of the distribution, the skewness of the tested variables was determined. Homogeneity of variance (homoscedasticity) was not tested directly, as non-parametric tests were used due to the violation of the normality assumption. The assumption of independence of observations was met thanks to the study design, as each person was measured only once and the groups were independent of each other. Due to the violation of the assumption of normality of the BMI variable distribution (assessed by the Shapiro-Wilk test), the Mann-Whitney U test was used for intergroup comparison. The Foot Posture Index results were divided into foot posture categories (supination, neutral posture, pronation). Therefore, this variable was categorical, and the chi-square (Chi²) independence test was used to compare the distribution of these categories between groups.

The level of statistical significance was assumed at α=0.05.

3. Results

1. BMI

The average BMI value in SG was 27 kg/m² (SD=4.68), which indicates overweight. CG was characterized by a BMI within the norm, with an average value of 22.47 kg/m² (SD=2.8). A significant difference in values was demonstrated between the studied groups (p<0.01) (Fig. 1).

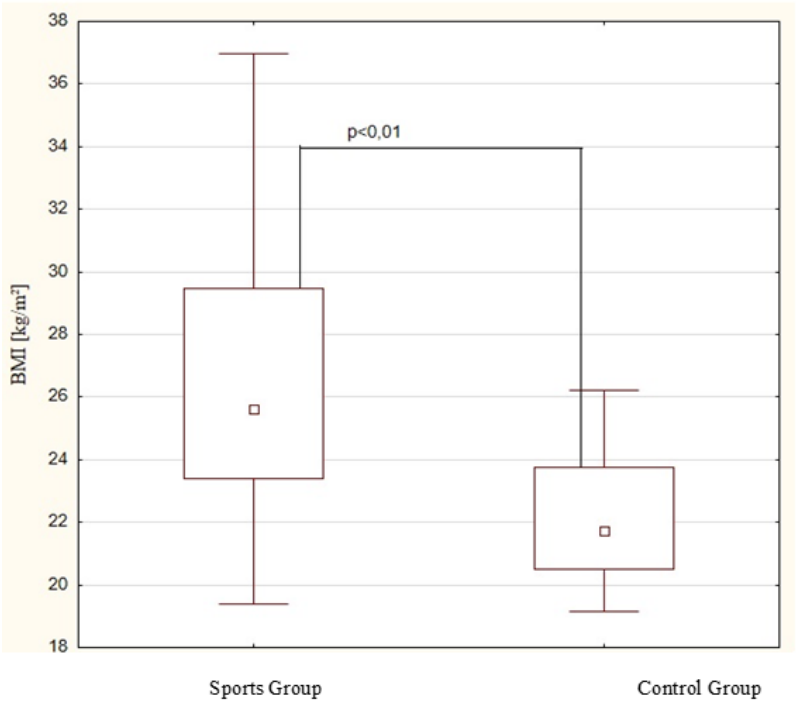

Fig. 1. The distribution of BMI in SG and CG (test U Manna-Whitneya)

2. FPI-6

Analysis of foot shape - partial assessment of FPI-6 components

In the SG and CG groups, a statistically significant difference was found in all measurement values, except for FPI 2, of the left foot (Table 2).

Tab. 2. Component values of the FPI-6 Index in SG and CG

no. FPI	FPI Scale	SG		CG		*p*
		N	%	N	%	
FPI 1 L	- 1	5	7.14	3	8.57	**0.02**
	0	31	44.29	25	71.43	
	1	34	48.57	7	20	
FPI 1P	- 1	6	5.87	3	8.57	**<0.01**
	0	28	40	25	71.43	
	1	36	51.43	7	20	
FPI 2 L	- 2	1	1.43	1	2.86	0.64
	- 1	6	8.57	1	2.86	
	0	33	47.14	18	51.43	

	1	28	40	15	42.86	
	2	2	2.86	-	-	
FPI 2 P	- 2	-	-	1	2.86	**0.01**
	- 1	6	8.57	1	2.86	
	0	45	64.29	15	42.86	
	1	16	22.86	18	51.43	
	2	3	4.29	-	-	
FPI 3 L	-1	3	4.29	1	2.86	**<0.01**
	0	26	37.14	31	88.57	
	1	35	50	2	5.71	
	2	6	8.57	1	2.86	
FPI 3 P	- 1	1	1.43	5	14.29	**<0.01**
	0	16	22.86	24	68.57	
	1	44	62.86	5	14.29	
	2	9	12.86	1	2.86	
FPI 4 L	- 1	1	1.43	3	8.57	**0.03**
	0	44	62.86	28	80	
	1	24	34.29	4	11.43	
	2	1	1.43	-	-	
FPI 4 P	- 1	2	2.86	3	8.57	**<0.01**
	0	37	52.86	28	80	
	1	29	41.43	4	11.43	
	2	2	2.86	-	-	
FPI 5 L	- 1	2	2.86	9	25.71	**<0.01**
	0	29	41.43	15	42.86	
	1	34	48.57	11	31.43	
	2	5	7.14	-	-	
FPI 5 P	- 1	2	2.86	10	28.57	**<0.01**
	0	20	28.57	15	42.86	
	1	39	55.71	9	25.71	
	2	9	12.86	1	2.86	
FPI 6 L	- 1	-	-	3	8.57	**<0.01**
	0	40	57.14	26	74.29	
	1	28	40	4	11.43	
	2	2	2.86	2	5.71	
FPI 6 P	- 1	-	-	6	17.14	**<0.01**
	0	35	50	19	54.29	
	1	29	41.43	7	20	
	2	6	8.57	3	8.57	

Total assessment of the obtained FPI-6 values

Significant intergroup differences were demonstrated between the FPI-6 index values, both for the right and left foot ($p<0.01$) (Table 3).

Analysis of the FPI-6 index results, presented in Table 4, shows that the majority of the subjects had a neutral foot position. A correctly shaped foot was present in 59 (84.3%) athletes and 30 (85.7%) people from the CG group in the left lower limb, and in the right lower limb, respectively: 57 (81.4%) and 28 (80%) (Table 3).

In the SG group, the positioning of the left and right feet towards pronation was more frequent than the positioning in supination, compared to CG. In SG, a pronation position was observed in slightly over 11% of the left foot and in almost 16% of the right foot. In CG, however, pronation of the left foot occurred in almost 3%, and of the right foot in 6%, and occurred less frequently than supination (Table 3).

Tab. 3. Summary of the FPI-6 values in SG and CG

Lower Limb	FPI-6 classification	SG		CG		*p*
		N	%	N	%	
L	Foot in increased supination	-	-	-	-	**<0.01**
	Foot in slight supination	3	4.29	4	11.42	
	Neutral foot	59	84.28	30	85.71	
	Foot in slight pronation	8	11.42	1	2.86	
	Foot in increased pronation	-	-	-	-	
R	Foot in increased supination	-	-	-	-	**<0.01**
	Foot in slight supination	2	2.86	5	14.29	
	Neutral foot	57	81.43	28	80	
	Foot in slight pronation	11	15.71	2	5.71	
	Foot in increased pronation	-	-	-	-	

Abbreviations: FPI-6 - Foot Posture Index-6, **SG**- sports group, **CG –** control group**, N –** number of subjects, ***p* < 0.05 -** probability value (test Chi²), **L –** left lower leg, **R -** right lower leg

Tab. 4. The relationship between FPI-6 and the categories: BMI, age, and training experience in SG and CG

FPI-6	Group	Variable	*p*
L	SG	BMI	0.36
		Age	0.64
		Training experience	0.72
	CG	BMI	**0.02**
		Age	0.08
R	SG	BMI	0.18
		Age	0.23
		Training experience	0.26
	CG	BMI	0.27
		Age	0.29

Abbreviations: FPI-6 Index - Foot Posture Index-6, ***p* < 0.05 -** probability value (test Chi²), **L –** left lower leg, **R -** right lower leg, **SG**- sports group, **CG –** control group**, BMI –** Body Mass Index

3. Relationship between foot posture (FPI-6) and: age, BMI and training time

In the SG group, the shape of the left and right foot is not related to BMI (p=0.36 left, p=0.18 right), age (p=0.64 left, p=0.23 right) and training time (p=0.72 left, p=0.26 right).

However, in the CG, a significant relationship ($p<0.02$) was demonstrated between the shape of the left foot and BMI (Table 4).

Relationship between FPI-6 and BMI – detailed results

The mutual relationships between FPI-6 and BMI values were analyzed. The obtained values do not indicate a relationship between them in the studied SG group (Table 5).

In SG with a correct left foot position, 39% had a BMI within the norm, 27.1% were obese, and almost 34% were overweight. The shape of the left foot in slight pronation was shown by almost 63% of athletes with a BMI within the norm and 37.5% of overweight. The left foot in a supinated position was shown by almost 67% of athletes with a BMI within the norm and slightly over 33% of overweight (Table 5).

Among athletes with a neutral right foot position, almost 44% had BMI values within the norm, slightly over 26% with obese BMI, and 30% with overweight BMI. The right foot shape in slight pronation was observed in 45.5% of athletes with normal BMI and almost 55% of those with overweight BMI. The right foot in supination was observed in 50% of obese players and 50% of overweight players (Table 5).

In CG, a significant relationship between FPI-6 and BMI was found only in the left foot ($p=0.02$). The majority of people (90%) with normal BMI had both feet shaped correctly. Feet with slight supination were also observed in people with normal BMI values. On the other hand, feet with slight pronation were observed in slightly over 83% of overweight people (left and right lower limb) and in 50% of people with normal BMI (right lower limb) (Table 5).

Tab. 5. The relationship between foot formation according to FPI-6 and BMI in SG and CG

Lower Limb	Group	BMI	Slight pronation		Neutral		Slight supination		*p*
			N	%	N	%	N	%	
L	SG	Norm	5	62.5	23	38.98	2	66.67	0.36
		Overweight	3	37.5	20	33.9	1	33.33	
		Obesity	-	-	16	27.12	-	-	
	CG	Norm	-	-	27	90	4	100	**0.02**
		Overweight	1	33.33	2	6.67	-	-	
		Obesity	-	-	1	3.33	-	-	
R	SG	Norm	5	45.45	25	43.86	-	-	0.18
		Overweight	6	54.55	17	29.82	1	50	
		Obesity	-	-	15	26.32	1	50	
	CG	Norm	1	50	25	89.29	5	100	0.27
		Overweight	1	50	2	7.1	-	-	
		Obesity	-	-	1	3.6	-	-	

Abbreviations: FPI-6 - Foot Posture Index-6, **BMI –** Body Mass Index, **N –** number of subjects, ***p* < 0.05** - probability value (test Chi^2), **L –** left lower leg, **R -** right lower leg, **SG-** sports group, **CG –** control group

4. Discussion

The relationship between sport, age and BMI on foot posture

The study assessed the relationship between American football training and foot shape using the FPI-6 index. In the study groups, the occurrence of foot types was determined according to the FPI-6 classification: normal, with slight pronation and pronation, with slight supination and supination. It was observed that the total FPI-6 results for the left and right foot were statistically significantly different between SG and CG.

In our own studies, no significant disorders in the total shape of the FPI-6 feet in SG were demonstrated. The majority of athletes practicing American football (81.4% lower limb right, 84.3% lower limb left) and non-training participants with CG (80% lower limb right, 85.7% lower limb left) showed normal feet. However, differences were observed between SG and CG, indicating a more frequent occurrence of pronation in football players, almost three times more often in the right foot (15.7%:5.7%) and four times more often in the left foot (11.4%:2.9%).

Similar results were presented by Kuo et al. [30], who examined students of both sexes, practicing strenuous sports: badminton, volleyball, basketball (n=30) and leading a sedentary lifestyle (n=30). The authors also showed that the majority (80%) of student athletes and non-training students (86.7%) had correct foot posture according to the range of 0 to +5 FPI-6 points. Pronated feet were demonstrated in 20% of athletes and 6.7% of non-training students, according to the range of +6 to +9 FPI-6. The above pronation changes in foot shape between groups were statistically significant and amounted to $p=0.022$ [30]. In our own studies, pronated feet (FPI-6) were shown by slightly over 27% of football players and almost 9% of non-training participants. Similarly, pronated foot changes were significant between SG and CG ($p<0.01$).

In the group of student-athletes studied by Kuo et al. [30], no supinated foot shape was found, while in the control group it was 6.7%. In this study, however, the SG group showed a supinated position of the left foot in 4.3% and the right foot in 2.9%. However, a similar tendency of foot supination was observed as in the above studies. In CG, the supinated position of the right foot (14.3%) and left foot (11.4%) occurred much more often than in SG, which is consistent with the above results.

Lopezosa-Reca et al. [31] assessed the FPI-6 in men practicing two different sports disciplines, i.e.: 72 swimmers and 78 soccer players, with an average age of 17 years, regularly training for the last 6 years. No significant changes in foot posture were found in soccer players, and the average FPI-6 score was 2.2±1.7. A higher average FPI-6 score

(6.5±2) was observed in the swimmers group, indicating a tendency to shape the foot in the pronation direction, as well as significant concomitant valgus of the knee joints [31]. Other reports suggest that running training loads may also deepen the pronation posture of the foot [16], [20]. Escamilla-Martínez et al. [20] assessed the feet of long-distance runners (n=30) using the FPI-6. The athletes were examined immediately before and after an hour-long run, performed at a moderate speed of 3.3 m/s. The second measurement showed an increase in the FPI-6 score by 2 points, which indicated a tendency to increase foot pronation after running effort [20]. Cowley and Marsden [16] examined runners taking part in a half marathon. The first FPI-6 test was conducted a week earlier and resulted in +3 points, and the second one was conducted immediately after finishing the run. The increased positive FPI-6 values obtained in the repeated assessment confirmed the influence of running load on the tendency to increase pronation: significantly in the left foot by an average of 1.7 points and insignificantly in the right foot by an average of 0.3 points. In these studies, the authors emphasize that the difference between the limbs may result from lower muscle fatigue of the dominant lower limb – the right one [16]. In our own studies, athletes were examined before a demanding American football training, never after the training, and most of them obtained values in the range of 0 to +5 FPI-6 points, thus indicating a normal foot. However, SG players tended to pronate their feet more often than to supinate (within the study group) and in comparison to the control group.

The study of differences in foot posture of handball players, basketball players and runners was conducted by Martínez-Nova et al. [34]. The partial assessment and the total sum of FPI-6 were determined in each of the above-mentioned groups, consisting of 30 participants. The obtained mean FPI-6 results were within the norm in basketball players (3.9±4.1) and runners (2.9±2.8). However, in handball players, the frequent occurrence of supinated feet (-0.4±6.9) was found. The FPI-6 results were significant between all three groups. The FPI1 components concerning the position of the head of the talus and the FPI4 components assessing the convexity in the region of the talonavicular joint were found to be particularly different between the athletes [34]. In our own studies, the difference between the groups was significant in all the FPI-6 components, except for the FPI2 of the left foot - assessing the curvature below and above the lateral malleolus.

Researchers determined in their studies whether there is a relationship between FPI-6 and lower limb injuries. In the study by Cherati et al. [13], indoor soccer players were examined at a 6-month interval, before and after the season. In 68 male and female futsal players, no relationship between FPI-6 and the occurrence of ankle sprains was confirmed.

Also, exposure to ankle injuries was not associated with: BMI, age, body mass, height, gender, training time and dominant limb. It was confirmed that a previous ankle injury is a significant risk factor for recurrent injury [13]. Studies of over 100 players: basketball players and soccer players, also did not show a relationship between the occurrence of lateral ankle sprains (LAS) and foot posture according to FPI-6, regardless of whether or not an ankle injury was reported [27]. However, a relationship was confirmed between limited plantar flexion of the foot, weakness and laxity of the lateral ankle joint ligaments, and impaired balance in the Single Leg Balance (SLB) test, and more frequent, acute, or recurrent LAS injury [27].

Based on the results presented above, the authors indicate different development of lower limb muscle activity, and consequently foot posture, depending on the given sports discipline, environment, and type of exercise [31]. These data can be considered consistent when comparing the FPI-6 results of this study with the above studies. Football players show mainly correct foot posture in the overall FPI-6 result. However, when looking at individual FPI-6 components, they differ mostly from the control group, which may indicate a tendency for the feet to shape towards pronation specific to American football.

Relationship between foot shape and individual characteristics

A number of studies present the relationship between static foot posture and gender, age, muscle tissue content and BMI [1], [10], [25]. In our own studies, a group of only men was deliberately included to exclude the influence of gender on the results.

In the examined SG, it was shown that the feet were most often within the norm or to a lesser extent in slight pronation, least often in supination. Age or BMI in SG were not found to affect foot posture according to FPI-6 (summed score).

Redmond et al. [40] demonstrated in their studies a relationship between FPI-6 and age. In children, adolescents and the elderly, the occurrence of a foot with a tendency to be set in pronation was found [40], [46]. In school-age children (6-9 years), a higher FPI-6 score corresponded with lower values of the Clark angle typical of flat feet [23]. Similarly, a lower Clark angle value was observed in the group of adolescents (n=148) aged 11-13 years with increased fat tissue content [50]. The observations of Villarroy et al. [46] confirm that excessive body weight, high fat tissue content, in children and adolescents aged 9 to 16.5 years, promotes longitudinal flat feet.

It was found that overweight/obesity in children may remain unchanged or intensify in adulthood, thus causing excessive musculoskeletal overload of the feet. [50] Gonçalves et al. [25] noticed a negative correlation for BMI with FPI-6, indicating that the more the BMI

increased in adolescents (10-14 years), the lower the FPI-6 result. Despite the correlation between BMI and FPI-6, the authors did not confirm that the BMI index is significantly associated with the position of the foot in pronation [25]. Different results were presented by Aurichio et al. [4] and Butterworth et al. [10], who observed a deepening of flat feet (especially in women) and pronated foot posture (especially in men) in obese adults (average age 52 years) and older subjects. Jankowicz-Szymańska et al. [28] noted significant correlations between the pronated position of the head of the talus (FPI1) and a reduced height of the medial longitudinal arch (FPI5) and an increase in BMI in 20-year-old male and female students. However, the authors did not demonstrate a correlation between the total FPI-6 score and BMI [28], similarly to the results of the SG in their own studies. On the other hand, one component of the assessment – FPI1, was significantly different depending on the sex of the students (R=0.38). In young men, the head of the talus was more medially rotated, in the direction of pronation [28]. In our own studies, SG players were overweight, and the FPI1 component was also clearly more frequent in the pronation direction than in CG. A significant relationship between FPI-6 and BMI was demonstrated only in non-training individuals (CG) and only for the left foot. The obtained result may indicate that BMI values have a lesser effect on athletes, and more pronounced on non-training individuals. Perhaps overweight in non-training individuals is associated with a higher content of adipose tissue, and in SG players with additionally developed muscle mass, and its effect on foot posture is compensated by training-related exercise.

It should be noted that almost 63% of SG players with a normal BMI had their left foot in pronation, and their right foot over 45%. This may suggest that individual characteristics, e.g. gender or lower limb injuries, or specific American football training in the SG group, influence the FPI-6 of the left foot in the direction of pronation more than BMI. The relationship between gender and foot laterality and FPI-6 was also confirmed in the above-described studies by Gonçalves et al. [25], which could be consistent with the above-mentioned suggestions. However, this thesis should be tested in future studies to be certain about the reasons for more frequent pronation in the left foot in American football in players with a normal BMI. On the other hand, in players with a BMI indicating overweight, 54.5% had their right foot in pronation, and 37.5% of the left foot. This means that in football players, 92% of feet in pronation are related to excessive body weight, which affects one of the feet more. Moreover, practically about 30% of American football players who are overweight or obese showed correct foot posture according to FPI-6. It should be emphasized that no significant relationships were found between BMI and foot shape in the study group.

Analyzing the research, in students and adults practicing various sports, i.e. recreational running, half marathons, swimming, football, basketball, volleyball, badminton, the influence of sport on the formation of the pronation posture of the foot was observed [20], [30], [31]. In our own studies, it was found that American football affects FPI components from 1-6, showing a greater tendency to pronation of the feet of athletes than in non-training subjects. However, the overall FPI-6 result did not indicate that the majority of American football SG players had pronated feet, but correct ones, comparable to the control. The relationship between age, BMI and FPI-6 was not confirmed in our own studies either. However, it was shown that the pronated foot posture occurred more often in the SG subjects than in the CG, regardless of age, BMI and training time.

On the one hand, it was found that the American football players and the control group had mostly normal feet. On the other hand, however, the total result of the foot shape according to FPI-6 differed statistically significantly between the SG and CG groups, indicating more frequent foot pronation in American football players. The pronated position for both feet together concerned 27.1% of SG players and 8.6% of non-training players. Comparing the feet individually, the American football players had the right foot in pronation more often than the left. Foot supination occurred much more often in the CG than in the tested athletes. Practicing the sport was associated with differences in foot posture, which may affect the values of foot loads.

It seems essential in the future to assess the feet of team sport athletes in relation to specific positions on the field. Players in different positions perform differently in matches compared to their opponents. To meet the particular physical demands of matches, players should undergo comprehensive testing [35].

Training experience

Properly shaped feet allow for the proper distribution of transferred loads [7], and sports training is often associated with the development of a pronated foot posture [20], [30], [31]. It was found that regular practice of a sports discipline for 6 years is a sufficient period to demonstrate the effect of sports on the player's feet [45]. In our own studies, only about 16% of players trained American football for more than 6 years. The largest number of people, almost 39%, trained for 1 to 3 years, and almost 26% for less than a year. This is related to the fact that American football is a relatively young discipline in Poland. In turn, longer playing experience, 4 to 6 years, was demonstrated by 20% of players. The number of years of training is probably important for determining changes in foot posture in American football players. Perhaps too few players training for more than 6 years did not allow for full

identification of players with a changed foot shape and exposed to injuries. Future studies should examine the relationship between training experience and FPI-6 (total score) in a larger population of SG players who have been training for over 6 years.

Despite the lack of a statistically significant relationship between the shape of the left and right foot and body mass index (BMI), age, and training duration ($p > 0.05$), the results obtained have some practical significance. The lack of detected correlations may indicate that the foot posture in the studied population of American football players is not significantly modified by basic anthropometric characteristics or training duration. This suggests a relative stability of foot structure characteristics, which may be determined to a greater extent by, for example, individual biomechanical patterns and specific training, also due to the positions of players on the field. Raymond et al. [40] confirmed in their studies that people under the age of 18 and over the age of 60 tend to have a more pronated foot position.

Perhaps studies conducted exclusively on young soccer players under the age of 18 or exclusively on older players over the age of 60 would show a correlation between age and foot shape, but this needs to be verified. From a clinical and sports practice perspective, the results obtained may provide a basis for individualized assessment and planning of physiotherapy interventions—without assuming that players with a higher BMI, middle age, or longer training experience will have a specific foot type. Additionally, the lack of a relationship between the analyzed variables may suggest that structural adaptations within the foot may occur independently of these parameters and require analysis of other potential factors, such as overload, muscle endurance and strength, joint mobility, functional asymmetries, and external factors (previous collisions, falls, combat sports, footwear, etc.).

The results obtained are partially consistent with some of the earlier reports mentioned above, which also did not show clear correlations between foot shape and demographic and anthropometric characteristics. However, this requires further research involving larger and more diverse samples, taking into account additional functional, dynamic, or positional variables.

It is possible that the level of athletic experience and number of years of training may differentiate the results within a group of athletes in a homogeneously selected group with longer training experience. Perhaps studies in a group of American football players who have been training for over 6 years, constituting nearly 100% of the study participants, would show different results than those obtained. The regularity or intensity of training may also affect adaptations in the musculoskeletal system in the long term. In addition, the individual

characteristics of players in different positions may be relevant here. In future studies, it is worth considering these variables as control factors.

Limitations

American football is still a young discipline when compared to the experience of this game in Poland and the United States, therefore, taking into account the stage of development of this sport in Poland, we believe that the studied group, although relatively small, retains some representative features. It is also a statistically quite large group of feet examined directly in the player-researcher contact, which is a plus of the research. The homogeneity of the group is also a positive aspect here, because the difference in the influence of gender is excluded here. Due to the cross-sectional nature of the study, causal relationships cannot be established.

To sum up, the FPI-6 index is a quick, cost-effective diagnostic tool used directly to assess foot posture and indirectly to examine associations between training and foot posture. Additionally, it provides information about areas of overload in the feet and the risk of foot injury, highlighting the need for preventive measures [34]. Preventive research and interventions aimed at reducing foot injuries are particularly important in sports associated with pronated foot positioning [33], including American football. In future research, it is worth considering a more detailed analysis of training intensity and the specificity of the discipline or position on the pitch, which could provide different conclusions.

5. Conclusion

Playing American football is associated with differences in foot shape compared to non-training individuals. Athletes were shown to have more frequent foot pronation than supination compared to the control group.

No significant association was found between training duration and foot posture in the studied group of American football players.

Practical implications. These findings highlight the importance of monitoring foot posture and BMI in athletes practicing American football. Given the higher prevalence of pronated foot posture in athletes, individualized footwear assessment may be beneficial.

Competing interests

The authors declares that they have no competing interests.

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