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## Is a pedometric assessment necessary for American football players? A cross-sectional study

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**Abstract:** Background: There is insufficient research on the distribution of foot pressure in American football players, categorized by player positions on the field.

Objective: To assess the impact of American football training on static foot pressure distribution during bipedal standing with eyes open and closed, comparing offensive and defensive players.

Methods: In this cross-sectional observational study, 105 men (70 American football players, 35 controls) were examined using the Zebris FDM-S podobarographic platform. Parameters related to foot pressure and postural balance were analyzed.

Results: American football players demonstrate good balance and pressure distribution in their feet during bipedal standing with open eyes. The foot pressure patterns worsen during bipedal standing with closed eyes for offensive players compared to visual control ( $p = 0.02$ ).

Conclusions: When visual input was removed, the offensive players exhibited more forefoot loading, while the defensive group showed higher hindfoot loading. A significant difference in the total load of the left foot between the attack and control groups further emphasizes the variability in the distribution of foot load within the groups, and due to the position on the field when vision is limited.

In our opinion, the greater exposure to foot load changes in offensive players provides some basis for the implementation of preventative measures for pronated feet and training aimed at strengthening the short foot muscles, stabilizing the ankle joints, and improving proprioception.

**Keywords:** American football, bipedal stance, foot loading, stabilometric parameters, static postural balance.

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## Introduction

American football (AF) is an intense sport with a high risk of injury across the entire body. Training for this discipline can lead to overloads of soft and hard tissues in the lower limbs, ultimately affecting foot loading patterns [1]. Injuries may be associated with direct physical combat between players or indirectly with poorly prepared playing surfaces, while overloads may result from individual factors such as high body weight, height, or improper BMI [2].

Regular play in AF contributes to the development of specific body posture and movement patterns in athletes, which undoubtedly can affect the feet. An important factor here is the development of good proprioception in players, which also alters the load transferred to the feet. The foot must provide a stable posture for AF players in both static and dynamic conditions. During movement, the distribution of forces on the foot primarily depends on its structure and the alignment of the entire lower limb [1, 3].

In AF, the risk of lower limb injuries is largely associated with the overload of the feet and ankle joints, but also with foot type [3, 4]. Disorders in foot structure, such as pronation or supination, affect changes in kinematics, leading to more frequent lower limb injuries [4–7]. The most common problems in AF players in the talocrural joints and feet are fractures: of the toes, metatarsal bones, Jones fracture, and Lisfranc injury, as well as plantar fasciitis, Achilles tendon injuries, and sprains in the talocrural joints [8–12]. The shaping and positioning of the foot during movement is of significant importance here [5, 6]. The maintenance of balance in the distribution of forces on the foot depends on: its structure, cushioning, adaptation to the surface, and stabilization of individual lower limb joints [5, 12]. The stiffness and lack of mobility of the foot affect the improper transfer of loads within its structures and the ankle joints [1, 5–7, 13]. In the initial support phase, relaxation of the foot structures is favored by flexion in the hip, knee, and the foot's complex pronation position, thanks to dorsiflexion in the ankle joint, combined with forefoot abduction and eversion of the heel bone. This mechanism causes: deceleration, increased foot flexibility, and cushioning when the player's foot contacts the ground. The arch-like structure of the foot supports both its elasticity and stability [14, 15]. Furthermore, the formation of the foot's arches and the fatigue of lower limb muscles influence body balance, and the way it is maintained depends on the athlete's coordination abilities. The muscles stabilizing the pelvic girdle, especially the hip joint extensors, as well as stable ankle joints, control the standing position of the body. When they are unilaterally overworked, balance weakness is observed. The reflex mechanism, i.e., the functional connections between the lower limb joints, is crucial here [3, 16]. In the case of physical contact, such as when pushing opponents, there is a risk of an uncontrolled, sudden fall, often backward. In such a moment, to prevent falling, defensive reflexes occur sequentially: unilateral flexion and extension at the hip, blocking with the foot, and stiffening in the ankle joint, which stimulates the plantar receptors of the foot through pressure and initiates joint control in the form of proprioception, with dorsiflexion of the foot. Therefore, a higher risk of falling during play is linked to balance disorders. For this reason, it is reasonable to conduct studies assessing foot function and body position stability in AF players. One of the important quantitative parameters to pay attention to is foot loading, including situational loading on the field. Both the magnitude and distribution of loads on the feet are of significant importance. Research studies have recorded that improper distribution of transferred loads on the feet may be linked to a higher frequency of overuse injuries in the lower limbs, including the feet and ankle joints [17–19].

The aim of this cross-sectional study was to assess the effect of American football training on foot loading during bipedal standing with eyes open and closed, in both offensive and defensive players. Specific objectives included evaluating differences in forefoot and hindfoot loading, as well as asymmetries between the right and left foot.

## Materials and Methods

### *Participants*

The study was conducted on a group of 70 consecutive American football (AF) players from the Krakow Football Kings Club and 35 consecutive students from the Faculty of Health Sciences Jagiellonian University Medical College, who formed the control group (CG). The AF players were selected and divided according to their position on the field: offensive (OF;  $n = 41$ ) and defensive (DF;  $n = 29$ ) (Tables 1A, 1B).

This study was a cross-sectional observational study aimed at comparing foot loading patterns during bipedal standing with eyes open and closed between American football players and a healthy control group. Data were collected at a single point in time, without follow-up.

### *Recruitment and selection*

Players from the Club were invited to participate in the study, and the purpose, procedure, and qualification criteria to them were explained. An online registration schedule with various appointment times for in-person testing to the AF players was provided.

Inclusion criteria for the study were: consent from the participant or their parent/guardian to participate in the research, male gender, age between 16 and 35 years, the ability to perform functional tests, no current injury (i.e., not excluded due to an injury), and being an active AF player. Exclusion criteria included: regularly practicing another sport.

No formal sample size calculation was conducted; however, the study included approximately 65% of all eligible American football players from the Krakow Football Kings Club during the recruitment period, which supports the representativeness of the sample.

All participants were informed about the potential risks and benefits of the study and signed an informed consent (or parental consent was provided). Participants were also informed of their right to withdraw from the study at any time without providing a reason. Each participant signed a conscious and voluntary consent to participate in the research.

Before the measurements were conducted, all participants about the course of the study were informed, and demographic data such as age, height, body weight, and lower limb dominance were recorded. Participants completed an anonymous survey, which gathered essential information regarding their AF training, physical activity, health status, and previous injuries. The measurements were conducted once, between the competitive seasons, before the summer season, at the Department of Orthopedics and Physiotherapy, Jagiellonian University Medical College.

All research procedures following hygiene and safety protocols were carried out. The procedures were performed in compliance with relevant laws and institutional guidelines. The study was approved by the Ethics Committee of the Jagiellonian University.

### *Research tools*

To assess the foot parameters, a Zebris FDM-S dynamometric platform, 1.16.12 version, was used (dimensions: 69 × 40 × 2.1 cm, measurement area: 54 × 33 cm, number of sensors: 2,560, sampling frequency: 120 Hz, measurement range: 1–120 N/cm<sup>2</sup>), along with a laptop (Apple MacBook 13"3 MD760PL/A) running WinFDM software.

The platform's sensors allow for accurate analysis of force distribution density under the foot. With the results from these measurements, it was possible to assess the asymmetry of foot loading between the right and left foot, the forefoot and hindfoot, as well as the position of the resultant force projection of the foot pressure on the platform.

The system also allows for the assessment of balance based on the registration of the displacement of the point of application of the resultant force (center of pressure, COP) exerted by the feet on the ground [3, 20].

### *Determination of lower limb dominance*

Immediately before the measurements on the platform, lower limb dominance was noted. The test involved stepping onto the platform after the command "step!" and the signal of a clap. The first lower limb used was recorded as the dominant limb, while the opposite one was noted as the support (non-dominant) limb.

In the AF group, 91.4% had a dominant right lower limb, and 8.6% had a dominant left lower limb. In the CG, 97.1% showed a dominant right lower limb, and 2.9% had a dominant left lower limb.

### *Measurement procedure*

The study assessed the distribution of loads in static tests of bipedal standing with open and closed eyes between: the right and left feet, and the forefoot and hindfoot.

Two measurements on the platform were performed with open eyes (EO) and with closed eyes (EC):

- I. The first measurement involved standing naturally and freely on both feet, looking straight ahead with EO. The lower limbs were positioned at hip-width, and the upper limbs were placed along the torso.
- II. The second measurement involved standing naturally and freely on both feet, with EC. The lower limbs were positioned at hip-width, and the upper limbs were placed along the torso.

The tests were conducted three times barefoot (3 repetitions of one measurement, with stepping off and on the platform between each repetition, and equipment calibration performed between measurements). The duration of each measurement was 30 seconds. Upon stepping onto the platform, the participant focused on a reference point on the wall, which was located 6 meters away.

All measurements were conducted by the same trained examiner under standardized conditions to reduce inter-operator variability.

### *Statistical methods*

The analysis using Statistica 13 PL software was performed. The Shapiro-Wilk test was used to assess the normality of the distribution of variables. To compare variables between groups, the

independent samples *t*-test or the Mann-Whitney *U* test was used. To determine the significance of differences in variables within the same group, between lower limbs, the paired samples *t*-test was applied. The statistical significance level was set at  $\alpha = 0.05$ .

## Results

### *Participant characteristics*

The study included 70 American football (AF) players (41 offensive (OF), 29 defensive (DF)) and 35 control group (CG) participants. Detailed demographic data are presented in Table 1.

#### 1. Bipedal Standing Test with EO and EC

##### 1.1. Comparison between AF and CG

The analysis of COP values and foot loading during bipedal standing with EO and EC eyes did not show any significant differences between the AF and the CG (Tables 2, 3).

#### Open eyes

During bipedal standing with EO, the average COP ellipse area in the AF was almost 193 mm<sup>2</sup>, which was 29 mm<sup>2</sup> larger compared to the CG. On the other hand, the average COP path length was nearly 44 mm longer in the CG compared to the AF. The average COP velocity was lower in the AF by 1.71 mm/s compared to the CG. Foot loading values were slightly different between the two groups. The AF showed higher foot loading in the left and right hindfoot areas, as well as the total loading on the right foot. In contrast, the CG demonstrated higher loading in the left and right forefoot areas and the total loading on the left foot (Table 2).

#### Closed Eyes

During bipedal standing with EC, the average COP ellipse area was 4.5 mm<sup>2</sup> smaller in the AF compared to the CG. On the other hand, the average COP path length was 10.8 mm longer in the AF compared to the CG. The average COP velocity was also higher in the AF, by 0.49 mm/s, compared to the CG. Foot loading values were higher in the AF for the left and right forefoot areas, as well as the total loading on the right foot. In contrast, the CG showed higher loading in the left and right hindfoot areas, and the total loading on the left foot (Table 3).

**Table 1A.** Characteristics of participants.

Characteristics	Group		<i>p</i> -value
	AF	CG	
Age [years] Mean $\pm$ SD	22.6 $\pm$ 4.1	21.5 $\pm$ 3.33	0.15
Height [cm] Mean $\pm$ SD	184 $\pm$ 7.1	179.8 $\pm$ 4.7	<0.01**
Weight [kg] Mean $\pm$ SD	91.8 $\pm$ 19.6	72.8 $\pm$ 10.8	<0.01*

Abbreviations: AF — American football group, CG — control group, *p* < 0.05 — probability value, SD — standard deviation, \* value of the Mann-Whitney *U*-test statistic, \*\* value of the *t* Student-test statistic for independent groups.

**Table 1B.** Comparison of quantitative characteristics: OF vs. DF vs. CG.

Characteristic	Group		
	OF N = 41 39.05%	DF N = 29 27.62%	CG N = 35 33.3%
Age [years] Mean $\pm$ SD	22.5 $\pm$ 4.29	22.79 $\pm$ 3.99	21.46 $\pm$ 3.33
Height [m] Mean $\pm$ SD	1.8 $\pm$ 0.08	1.85 $\pm$ 0.05	1.8 $\pm$ 0.05
Weight [kg] Mean $\pm$ SD	90.9 $\pm$ 21.54	93.1 $\pm$ 16.64	72.8 $\pm$ 10.81

Abbreviations: OF — offensive group, DF — defensive group, CG — control group, N — number of subjects, SD — standard deviation.

**Table 2.** COP and foot loads — bipedal stance with EO (AF vs CG).

Parameters	AF			CG			<i>p</i>
	N	$\bar{x}$	SD	N	$\bar{x}$	SD	
Ellipse area of COP [mm <sup>2</sup> ]	70	192.7	143.4	35	163.7	92.1	0.28
Path length of COP [mm]	70	507.5	244.8	35	551.3	190.1	0.36
Average velocity of COP [mm/sec]	70	17.66	8.47	35	19.37	6.7	0.29
Left forefoot load [%]	70	43.31	9.81	35	44.29	9.59	0.63
Left backfoot load [%]	70	56.69	9.81	35	55.71	9.59	0.63
Right forefoot load [%]	70	45.37	10.86	35	45.94	10.22	0.79
Right backfoot load [%]	70	54.63	10.86	35	54.06	10.22	0.79
Total load — left foot [%]	70	50.26	3.22	35	50.94	3.08	0.3
Total load — right foot [%]	70	49.74	3.22	35	49.06	3.08	0.3

Abbreviations: COP — center of pressure, EO — eyes open, AF — American football group, CG — control group, *p* < 0.05 — probability value, N — number of subjects, SD — standard deviation, *t* Student test statistic for independent groups.

**Table 3.** COP and foot loads — bipedal stance with EC (AF vs CG).

Parameters	AF			CG			<i>p</i>
	N	$\bar{x}$	SD	N	$\bar{x}$	SD	
Ellipse area of COP [mm <sup>2</sup> ]	70	193	136	35	197.5	116.7	0.87
Path length of COP [mm]	70	598.8	263.4	35	588	177.9	0.83
Average velocity of COP [mm/sec]	70	21.09	9.07	35	20.6	6.24	0.78
Left forefoot load [%]	70	45.29	10	35	44.63	9.24	0.75
Left backfoot load [%]	70	54.71	10	35	55.37	9.24	0.75
Right forefoot load [%]	70	48.1	10.3	35	46.43	8.37	0.41

Table 3. Cont.

Parameters	AF			CG			<i>p</i>
	N	$\bar{x}$	SD	N	$\bar{x}$	SD	
Right backfoot load [%]	70	51.9	10.3	35	53.57	8.37	0.41
Total load –left foot [%]	70	49.53	4.87	35	50.97	3	0.11
Total load — right foot [%]	70	50.33	5.14	35	49.03	3	0.17

Abbreviations: COP — center of pressure, EC — eyes closed, AF — American football group, CG — control group,  $p < 0.05$  — probability value, N — number of subjects, SD — standard deviation; *t* Student test statistic for independent groups.

## 1.2. Comparison among OF, DF and CG

No significant differences were found between the OF, DF, and CG groups in the analysis of COP values and foot loading during bipedal standing with EO, as well as in COP values with EC. However, a statistically significant difference between the groups in the foot loading results during bilateral standing with EC was observed ( $p = 0.02$ ) (Tables 4, 5).

### Open eyes

During bipedal standing with EO, the largest average COP ellipse area was observed in the OF, followed by the DF, with the smallest in the CG. The average COP path length was the longest in the CG, followed by the OF, with the shortest in the DF. The average COP movement velocity was highest in the CG, then in the OF, and lowest in the DF.

Foot loading analysis showed the following patterns:

- The average left forefoot loading was greatest in the CG, and the OF had higher loading than the DF.
- The average left hindfoot loading was greatest in the DF, followed by the OF, and the lowest in the CG.
- The largest average right forefoot loading occurred in the DF, followed by the CG and then the OF.
- The average right hindfoot loading was highest in the OF, compared to the DF and CG.
- The total average left foot loading was highest in the CG, with the DF showing higher loading than the OF.
- The total average right foot loading was highest in the OF, compared to the DF and CG (Table 4).

### Closed eyes

During bipedal standing with EC, the average COP ellipse area was largest in the DF and smallest in the OF. The average COP path length was longest in the OF and shortest in the DF. The average COP movement velocity was highest in the OF and lowest in the DF.

Foot loading analysis showed the following patterns:

- The average left and right forefoot loading was highest in the OF, compared to the DF and CG.
- The average left hindfoot loading was highest in the DF, and lowest in the OF.
- The average right hindfoot loading was highest in the CG, followed by the DF, and lowest in the OF.

- The highest average total left foot loading was found in the CG, followed by the DF and then the OF. A statistically significant difference was found between the OF and CG in the average total left foot loading ( $p = 0.02$ ).
- The highest average total right foot loading was found in the OF, compared to both the DF and CG (Table 5).

**Table 4.** COP and foot loads — bipedal stance with EO (OF vs DF vs CG).

Parameters	OF			DF			CG			$p1$	$p2$	$p3$
	N	$\bar{x}$	SD	N	$\bar{x}$	SD	N	$\bar{x}$	SD			
Ellipse area of COP [mm <sup>2</sup> ]	41	196.4	166.7	29	187.4	104.4	35	163.7	92.1	0.79	0.3	0.34
Path length of COP [mm]	41	524.6	278.4	29	483.3	189.7	35	551.3	190.1	0.49	0.63	0.16
Average velocity of COP [mm/sec]	41	18.2	9.58	29	16.9	6.67	35	19.37	6.7	0.53	0.54	0.15
Left forefoot load [%]	41	43.56	9.32	29	42.97	10.62	35	44.29	9.59	0.8	0.74	0.60
Left backfoot load [%]	41	56.44	9.32	29	57.03	10.62	35	55.71	9.59	0.8	0.74	0.60
Right forefoot load [%]	41	44.95	10.71	29	45.97	11.22	35	45.94	10.22	0.7	0.68	0.99
Right backfoot load [%]	41	55.05	10.71	29	54.03	11.22	35	54.06	10.22	0.7	0.68	0.99
Total load — left foot [%]	41	49.85	3.53	29	50.83	2.7	35	50.94	3.08	0.22	0.16	0.88
Total load — right foot [%]	41	50.15	3.53	29	49.17	2.70	35	49.06	3.08	0.22	0.16	0.88

Abbreviations: COP — center of pressure, EO — eyes open, OF — offensive group, DF — defensive group, CG — control group,  $p < 0.05$  — probability value,  $p1$  — OF vs. DF,  $p2$  — OF vs. CG,  $p3$  — DF vs. CG, N — number of subjects, SD — standard deviation;  $t$  Student test statistic for independent groups.

**Table 5.** COP and foot loads -bipedal stance with EC (OF vs DF vs CG).

Parameters	OF			DF			CG			$p1$	$p2$	$p3$
	N	$\bar{x}$	SD	N	$\bar{x}$	SD	N	$\bar{x}$	SD			
Ellipse area of COP [mm <sup>2</sup> ]	41	185.8	118.8	29	203.1	158.9	35	197.5	116.7	0.6	0.67	0.87
Path length of COP [mm]	41	632.5	282.2	29	551.3	230.5	35	588	177.9	0.21	0.42	0.48
Average velocity of COP [mm/sec]	41	22.17	9.87	29	19.55	7.71	35	20.6	6.24	0.24	0.42	0.55
Left forefoot load [%]	41	46.32	10.18	29	43.83	9.73	35	44.63	9.24	0.31	0.45	0.74
Left backfoot load [%]	41	53.68	10.18	29	56.17	9.73	35	55.37	9.24	0.31	0.45	0.74
Right forefoot load [%]	41	49.05	11.01	29	46.76	9.21	35	46.43	8.37	0.36	0.25	0.88

**Table 5.** Cont.

Parameters	OF			DF			CG			p1	p2	p3
	N	$\bar{x}$	SD	N	$\bar{x}$	SD	N	$\bar{x}$	SD			
Right backfoot load [%]	41	50.95	11.01	29	53.24	9.21	35	53.57	8.37	0.36	0.25	0.88
Total load — left foot [%]	41	48.61	5.41	29	50.83	3.7	35	50.97	3	0.06	<b>0.02</b>	0.86
Totalload — rightfoot [%]	41	51.15	5.86	29	49.17	3.7	35	49.03	3	0.11	0.06	0.86

Abbreviations: COP — center of pressure, EC — eyes closed, OF — offensive group, DF — defensive group, CG — control group,  $p < 0,05$  — probability value, p1 — OF vs. DF, p2 — OF vs. CG, p3 — DF vs. CG, N — number of subjects, SD — standard deviation; *t* Student test statistic for independent groups.

**2. Comparison of total foot loading (right and left) during bipedal standing (EO and EC)**

The analysis of total foot loading for the right and left lower limbs within each group (AF, OF, DF, and CG) revealed no significant differences in total foot load, both during bipedal standing with EO and EC (Table 6).

**EO:** In the EO trial, the average total load for the right lower limb in the AF was 49.74%, and for the left lower limb, it was 50.26%. In the CG, the average total load for the right lower limb was lower (49.06%) compared to the left (50.94%) (Table 6).

**EC:** In the EC trial, the average total load for the right lower limb in the AF was 50.33%, and for the left lower limb, it was 49.53%. In the CG, the average total load for the right lower limb was lower (49.03%) compared to the left (50.97%) (Table 6).

Comparison of the right and left lower limbs:

During bipedal standing with EO and EC, the average total load on the right lower limb was higher than the left lower limb in the OF and lower than the left lower limb in the DF (Table 6).

**Table 6.** Total load on the lower limbs — bipedal stance (RLL vs LLL).

Parameters	Group	RLL			LLL			p
		N	$\bar{x}$	SD	N	$\bar{x}$	SD	
Total Load — EO [%]	AF	70	49.74	3.22	70	50.26	3.22	0.51
	CG	35	49.06	3.08	35	50.94	3.08	0.08
	OF	41	50.15	3.52	41	49.85	3.52	0.79
	DF	29	49.17	2.7	29	50.83	2.7	0.11
Total Load — EC [%]	AF	70	50.33	5.14	70	49.53	4.87	0.5
	CG	35	49.03	3	35	50.97	3	0.06
	OF	41	51.15	5.86	41	48.61	5.41	0.15
	DF	29	49.17	3.7	29	50.83	3.7	0.24

Abbreviations: RLL — right lower leg, LLL — left lower leg,  $p < 0.05$  — probability value, N — number of subjects, SD — standard deviation, EO — eyes open, EC — eyes closed, AF — American football group, OF — offensive group, DF — defensive group, CG — control group; *t* Student test statistic for dependent groups.

### 3. Comparison of total foot load in trials with EO and EC during bipedal standing

The analysis of values within each group, comparing the bipedal standing trial with EO and EC, did not show significant differences in the total load of the right and left lower limbs (Table 7).

The average total load on the right lower limb was greater during bipedal standing with EC than with EO in both the AF (by 0.59%) and the OF (by 1%). The average total load on the left lower limb was greater during bipedal standing with EO than with EC in both the AF (by 0.73%) and the OF (by 1.24%) (Table 7).

In the DF, the bipedal standing trials (EO and EC) did not show any changes in the values for the right and left lower limbs. Similar results were obtained in the CG for both trials with no significant difference for the right lower limb (difference 0.03%) and the left lower limb (difference 0.03%) (Table 7).

The greatest average total load for the right lower limb was observed in the OF, both during the EO and EC trials. The greatest average total load for the left lower limb was observed in the CG, both during the EO and EC trials (Table 7).

The average total load on the right lower limb was greater in the AF, and on the left lower limb in the CG, both during bipedal standing with EO and EC (Table 7).

The average total load on the right lower limb was greater in the OF than in the DF, both during bipedal standing with EO and EC. The average total load on the left lower limb was greater in the DF than in the OF in both trials (Table 7).

**Table 7.** Total load on the lower limbs — bipedal stance (EO vs EC).

Stance parameters	Group	EO			EC			<i>p</i>
		N	$\bar{x}$	SD	N	$\bar{x}$	SD	
Total Load RLL [%]	AF	70	49.74	3.22	70	50.33	5.14	0.25
	CG	35	49.06	3.08	35	49.03	3	0.93
	OF	41	50.15	3.52	41	51.15	5.86	0.19
	DF	29	49.17	2.7	29	49.17	3.7	1
Total Load LLL [%]	AF	70	50.26	3.22	70	49.53	4.87	0.14
	CG	35	50.94	3.08	35	50.97	3	0.93
	OF	41	49.85	3.52	41	48.61	5.41	0.09
	DF	29	50.83	2.7	29	50.83	3.7	1

Abbreviations: EO — eyes open, EC — eyes closed,  $p < 0.05$  — probability value, N — number of subjects, SD — standard deviation, RLL — right lower leg, LLL — left lower leg, AF — American football group, OF — offensive group, DF — defensive group, CG — control group; *t* Student test statistic for dependent groups.

## Discussion

We found that training in American football did not affect the static parameters of foot load during bipedal standing with EO and EC to show significant differences for the entire group of players compared to healthy, non-exercising individuals. However, there were slight intergroup differences in foot area loads. During the bipedal standing test with EO, AF players showed greater total

load on the right (dominant) foot as well as both heels. The CG group exerted more load on the left limb and the forefoot of both feet. Despite these intergroup differences, the results obtained for AF players were not statistically significantly different, which suggests a normal distribution of load transfer during bipedal standing with EO when compared to the CG.

Similar studies were conducted in a group of runners [21]. Research on marathon runners showed that the sport practiced can influence the distribution of foot loads in static conditions. These athletes exhibited increased pressure in the forefoot of the dominant lower limb compared to the control group [21]. Likely, the specificity of the trained discipline affects posture, which in turn influences the area of foot load. It can be assumed that a forward-shifted center of mass (COM) during running contributes to greater load on the forefoot. The regular posture adopted during running becomes ingrained and indirectly influences the foot loading patterns. In our study, AF players showed a tendency to greater loads on the hindfoot, which may also be related to the semi-squat position assumed during preparation for an attack or block in the game. It is possible that AF players in positions requiring more running (e.g., running back) would exhibit different, individual foot load patterns. Next analysis may help reduce the risk of lower limb injury in this group of athletes. However, already based on the results from the OF group, it can be observed that the left (non-dominant) limb is less loaded than the right. The only significant difference observed was a lower total load on the left foot in the OF group ( $p=0.02$ ) compared to the CG during double-leg standing with EC. It is consistent that the dominant limb experiences greater load than the opposite limb, both in marathon runners [21] and the OF players in our study. Additionally, Aydog *et al.* [22] demonstrated that athletes (gymnasts, wrestlers, weightlifters, football and handball players) have different foot postures in the dominant limb compared to the opposite lower limb. Among young golfers ( $17 \pm 0.8$  years old), it was also observed that the total load on the dominant lower limb (left) was significantly greater than the opposite, predisposing to overuse and disturbances in foot load-bearing function [23]. This suggests that the dominant foot in AF players, especially those in offensive and running positions, may be more susceptible to structural changes, injuries, and may contribute to balance disturbances.

### **Comparison of right and left foot loads**

Rohan *et al.* [24] indicate that intense effort and the symmetrical use of lower limbs during a half-marathon run contributed to a reduction and balance of the load asymmetry between the right and left feet. After the running effort, there was an increase in load on the sole of both feet, but significantly only in the left limb, specifically in the forefoot and heel [24]. Hantke *et al.* [25] highlight that significant asymmetry in foot loads between lower limbs may be a risk factor for injuries in gymnasts.

We did not observe significant asymmetry in the total load between the right and left foot (in the standing, two-footed position) among football players. Furthermore, the EC test did not lead to significant changes in foot load within groups, compared to EO. However, it was noted that, during EO, the left foot was slightly more loaded than the right foot. In contrast, during EC, the load was slightly greater on the right foot and smaller on the left. The lack of significant asymmetry in load between the right and left foot suggests that it does not contribute to an increased risk of lower limb or foot injuries in AF players.

İlhan Odabaş *et al.* [23] showed, unlike our study, differences between the load on the right and left foot in golfers. In male golfers, the total load on the left foot was significantly higher (55%)

than on the right. It was also observed that the hindfoot of both the right and left foot were similarly loaded (28%), but the forefoot of the right foot was significantly less loaded (18%) compared to the forefoot of the left foot (26%). In both feet, a higher load was observed in the hindfoot than in the forefoot. The ratio of load between the forefoot and hindfoot was significantly higher in the right foot (18% vs 28%) compared to the left foot (26% vs 28%) [23].

Wojtkow *et al.* [26] observed that body weight is symmetrically distributed between the left and right feet in shooters (averaging 50% each), similarly to our findings. However, in the control group, the total load on the left foot (48%) was lower than on the right foot. The total load on the left and right feet differed significantly between the shooting group and the control group. Additionally, the patterns of load distribution between the forefoot and hindfoot varied between the studied group and the control group. The shooters had a higher average load on the hindfoot, with 54% on the right foot and 53% on the left, compared to the forefoot. In the control group, there was a greater load on the forefoot, 53% on the right foot and 51% on the left. The authors emphasize that the predominance of hindfoot load during two-legged stance in shooters results from adopting a stable and slightly kyphotic posture, which is associated with shooting technique [26].

This confirms the above-mentioned suggestions regarding the impact of sports on posture and the transferred loads to the feet. In AF players, whose starting position during a match is a half-squat, the simultaneous control before an attack or block may contribute to increased tension in the posterior fascial chain, and consequently to a tendency for higher loads on the hindfoot. In our own research, it was observed that the forefoot was less loaded than the hindfoot in both feet, with EO and EC during bipedal stance, not only in the AF group but also in the CG. This suggests that the slight predominance of hindfoot load is normal in both AF players and non-athletes.

Researchers suggest that the load distribution between the forefoot and hindfoot should be similar [26, 27]. In the group of shooters, the percentage distribution of loads in the front and rear areas of both feet was comparable. Significant differences between groups were found in the total load of the left and right feet, as well as in the forefoot and hindfoot of the right foot [26]. In our study, the differences in load between the forefoot and hindfoot of AF players were within a maximum of about 10%. The significance of the differences in load within the feet was not assessed, but when comparing AF to CG, no significant disproportions in the load distribution between the forefoot and hindfoot were observed.

Ripani *et al.* [28] observed that athletes training in rugby showed higher plantar pressures in both feet while standing on both legs, compared to the control group. The lateral edge of both feet was more heavily loaded, and the contact area of the hindfoot on both the right and left feet was significantly larger than that of the control group [28].

Chow *et al.* [29] studied over 100 rugby players, both professional and recreational. The recreational subjects showed a normal foot posture, but the elite players a lowered medial longitudinal arch. The authors observed an increase in pressures in the forefoot and lateral midfoot in professional players during the bipedal static standing test. Additionally, they noted that the heel was positioned in a varus position, and the overall load distribution resembled the pattern of a supinated foot. The increased lateral load on the forefoot and midfoot is associated with the development of a varus foot posture in rugby players, with a characteristic feature of a low longitudinal arch. These findings may reflect adaptations in professional rugby players, and excessive loading in the areas of the toes and midfoot may predispose them to injuries [29].

A specific load distribution on the feet during two-leg standing has also been presented for basketball players and runners [30, 31]. In Taiwanese male basketball players, it was observed that the relative load on both feet in the midfoot and hindfoot areas was greater, while the forefoot load was smaller in professional players compared to recreational players. There was increased pressure on the lateral edge of the foot, i.e., the lateral hindfoot and lateral longitudinal arch. Additionally, it was found that the feet of professional basketball players exhibited characteristics of supination, such as varus heel, high longitudinal arch, and a dropping cuboid bone. At the same time, the medial side of the foot (medial longitudinal arch) and lateral midfoot were less loaded. Interestingly, basketball players most commonly reported musculoskeletal pain in the lateral ankle joints and ACL area [30]. In contrast, sprinter runners showed that the lateral hindfoot and medial midfoot were more heavily loaded compared to recreational runners. The longitudinal arch of the foot, both on the lateral and medial sides, was less loaded when comparing the groups [31].

It has also been described that not only regular sports training but also the position adopted during the game or specific exercises can change the load distribution on the feet [32, 33]. Pau *et al.* [32] demonstrated an increase in forefoot loads in female basketball players associated with basketball shooting during a two-foot takeoff. A two-foot jump overburdens the front part of the foot, which can consequently lead to more frequent injuries in this area. This information may be relevant for AF players, especially wide receivers, who catch the football during a jump.

In the study by Bibro *et al.* [34], a 60-minute lower limb strength training session was applied to young men. Foot load measurements were taken during a 30-second two-foot standing test. Comparing the results before and after training, it was found that initially, the hindfoot bore more load, whereas after the exercise, the forefoot became more loaded [34]. On the other hand, Kim *et al.* [35] observed that pelvic strengthening exercises (Swiss ball) in adult men affected body posture correction and improved foot load distribution and plantar pressure. The exercises increased the foot's contact surface, reduced foot pressure, and improved the load distribution between the right and left foot [35]. The results of Bibro [34] and Kim [35] suggest that exercises can play an indirect role in reducing the risk of hindfoot overuse and improving foot load imbalances.

These studies indicate that regular participation in sports (such as running, shooting, gymnastics, golf, and rugby) can influence the foot load pattern during two-foot standing. Increased load and the varied distribution of foot pressures define the posture and function of the foot in athletes from specific sports disciplines. It has also been shown that a single training session or one-time exercises can significantly affect the loads transferred to the feet [34, 35]. The athletic position in team sports [32, 33] as well as physical characteristics [8, 36, 37] can impact the load on selected areas of the feet, which is confirmed in the case of AF players.

## Summary

The bipedal standing test with EO conducted for 30 seconds does not differentiate foot load between CG and AF players. The player's position and lower limb laterality also did not have an impact on the results of this test. Next studies should consider evaluating and controlling the distribution of loads between the forefoot and hindfoot during bipedal standing in football players, potentially over a longer duration that requires greater muscle engagement, which could influence foot posture.

Standing on both feet without visual control did not significantly differentiate the results between the AF and CG groups. It was not observed that during bipedal standing with EC, football

players (the entire study group) applied significantly different loads on their feet compared to the CG. The AF group showed a greater COP path length and velocity with EC, indicating possibly higher reliance on proprioceptive and/or other non-visual balance mechanisms. While no significant differences were found in COP values, the distribution of foot loading did differ between the OF, DF, and CG when visual input was removed. A significant difference was only noted in the reduced load on the left foot in the OF players when compared to the CG. Visual control may play a significant role in the distribution of foot loads during two-foot standing, especially considering attacking positions.

### **Limitations**

A limitation of our study may be the relatively small number of AF players. However, considering the developmental stage of this sport in Poland, we believe this group still has certain representative characteristics. Potential sources of bias include the non-random selection of participants, which may limit the generalizability of the findings. However, to minimize measurement bias, all assessments were performed by a single trained examiner under standardized conditions. A strength of our research is the homogeneity of the AF group, and the fact that significant differences were observed for players in the OF position, which highlights the risk of foot overloading and the need for training focused with visual control and on proprioception during movement.

Expanding the research, including multicenter studies, addressing the aspect of visual control in AF players in various sports positions, is well justified.

### **Practical implications**

In our opinion, the increased exposure to changes in foot loading in OF players provides a basis for implementing prevention strategies for pronating feet. This should include training focused on strengthening the intrinsic foot muscles, stabilizing the ankle joints, and working on proprioception.

Such measures could help mitigate the risk of foot and ankle injuries and improve overall balance and performance on the field.

### **Conclusion**

Playing American football does not significantly affect foot loading patterns during bipedal stance with EO and EC when comparing the AF to the CG. The player's position matters. There is an indication for improving proprioception and increasing loading on the left foot during bipedal stance with EC in OF players. The distribution of left foot load suggests an increased risk of developing pronation in the left foot in OF players compared to the CG. OF players are more vulnerable to overload on the lateral side of the right hindfoot and balance disturbances, due to reduced load on the right forefoot compared to non-athletes.

### **Conflicts of interest**

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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## Authors' contributions

All authors contributed equally to the manuscript and read and approved the final version of the manuscript.

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## References

1. Carson D.W., Myer G.D., Hewett T.E., Heidt R.S. Jr., Ford K.R.: Increased plantar force and impulse in American football players with high arch compared to normal arch. *Foot (Edinb)*. 2012; 22 (4): 310–314. doi: 10.1016/j.foot.2012.09.002.
2. Spalek A., Trybulec B., Wodka-Natkaniec E., Barłowska-Trybulec M.: Causes and differentiation of injuries depending on the positions taken on the pitch among American Football players in Poland. *J Sports Med Phys Fitness*. 2021; 61 (12): 1636–1643. doi: 10.23736/S0022-4707.21.11925-5.
3. Jaszczur-Nowicki J., Bukowska J., Kruczkowski D., Spieszny M., Pieniążek M., Mańko G.: Analysis of students' foot pressure distribution on the ground, as well as their body balance before and after exercise. *Physical education of students*. 2020; 24 (4): 194–200. doi: 10.15561/20755279.2020.0402.
4. Venesky K., Docherty C.L., Dapena J., Schrader J.: Prophylactic ankle braces and knee varus-valgus and internal-external rotation torque. *J Athl Train*. 2006; 41 (3): 239–244.
5. Powell D.W., Long B., Milner C.E., Zhang S.: Frontal plane multi-segment foot kinematics in high- and low-arched females during dynamic loading tasks. *Hum Mov Sci*. 2011; 30 (1): 105–114. doi: 10.1016/j.humov.2010.08.015.
6. Buldt A.K., Murley G.S., Butterworth P., Levinger P., Menz H.B., Lendorf K.B.: The relationship between foot posture and lower limb kinematics during walking: A systematic review. *Gait Posture*. 2013; 38 (3): 363–372. doi: 10.1016/j.gaitpost.2013.01.010.
7. Buldt A.K., Forghany S., Lendorf K.B., Levinger P., Murley G.S., Menz H.B.: Foot posture is associated with plantar pressure during gait: A comparison of normal, planus and cavus feet. *Gait Posture*. 2018; 62: 235–240. doi: 10.1016/j.gaitpost.2018.03.005.
8. Wodka-Natkaniec E., Niedźwiedzki Ł., Pawłowska J., Zyznawska J., Świtoń A.: Current reports on foot and ankle injuries of American football players. *Polish Journal of Sports Medicine*. 2021; 37 (4): 207–216. doi: 10.5604/01.3001.0015.6269.
9. Chinn L., Hertel J.: Rehabilitation of ankle and foot injuries in athletes. *Clin Sports Med*. 2010; 29 (1): 157–167, table of contents. doi: 10.1016/j.csm.2009.09.006.
10. Hsu A.R., Anderson R.B.: Foot and Ankle Injuries in American Football. *Am J Orthop (Belle Mead NJ)*. 2016; 45 (6): 358–367.
11. Hsu A.R., Anderson R.B.: Foot and Ankle Injuries in American Football. *Am J Orthop (Belle Mead NJ)*. 2016; 45 (6): 358–367. PMID: 27737281.
12. Halabchi F., Hassabi M.: Acute ankle sprain in athletes: Clinical aspects and algorithmic approach. *World J Orthop*. 2020; 11 (12): 534–558. doi: 10.5312/wjo.v11.i12.534.

13. Taylor J.B., Nguyen A.D., Griffin J.R., Ford K.R.: Effects of turf and cleat footwear on plantar load distributions in adolescent American football players during resisted pushing. *Sports Biomech.* 2018; 17 (2): 227–237. doi: 10.1080/14763141.2016.1271448.
14. Menz H.B.: Biomechanics of the Ageing Foot and Ankle: A Mini-Review. *Gerontology.* 2015; 61 (4): 381–388. doi: 10.1159/000368357.
15. Dodelin D., Tourny C., L'Hermette M.: The biomechanical effects of pronated foot function on gait. An experimental study. *Scand J Med Sci Sports.* 2020; 30 (11): 2167–2177. doi: 10.1111/sms.13785.
16. Flores D.V., Mejía Gómez C., Fernández Hernando M., Davis M.A., Pathria M.N.: Adult Acquired Flat-foot Deformity: Anatomy, Biomechanics, Staging, and Imaging Findings. *Radiographics.* 2019; 39 (5): 1437–1460. doi: 10.1148/rg.2019190046.
17. Bukowska J.M., Krawczyński M., Jaszczur-Nowicki J.: Human gait structure on stable and unstable surfaces. *Journal of Kinesiology and Exercise Sciences.* 2019; 87 (29). doi: 10.5604/01.3001.0014.3308.
18. Hotfiel T., Golditz T., Wegner J., Pauser J., Brem M., Swoboda B., Carl H.D.: A cross-sectional study on foot loading patterns in elite soccer players of different ages. *J Back Musculoskelet Rehabil.* 2020; 33 (6): 939–946. doi: 10.3233/BMR-181436.
19. Pomarino D., Pomarino A.: Plantar Static Pressure Distribution in Healthy Individuals: Percentiles for the Evaluation of Forefoot Loading. *Foot Ankle Spec.* 2014; 7 (4): 293–297. doi: 10.1177/1938640014528973.
20. Yoo S.D., Kim H.S., Lee J.H., Yun D.H., Kim D.H., Chon J., et al.: Biomechanical Parameters in Plantar Fasciitis Measured by Gait Analysis System With Pressure Sensor. *Ann Rehabil Med.* 2017 Dec; 41 (6): 979–989. doi: 10.5535/arm.2017.41.6.979.
21. Hawrylak A., Matner P., Demidaś A., Barczyk-Pawelec K., Demczuk-Włodarczyk E.: Static and dynamic plantar pressure distribution in amateur marathon runners. *J Sports Med Phys Fitness.* 2019 Jan; 59 (1): 76–81. doi: 10.23736/S0022-4707.18.07964-1.
22. Aydog S.T., Tetik O., Demirel H.A., Doral M.N.: Differences in sole arch indices in various sports. *Br J Sports Med.* 2005 Feb; 39 (2): e5. doi: 10.1136/bjsm.2003.011478.
23. İlhan Odabaş H., Bulgan Ç., Bingül B.M., Sarpyener K.: The evaluation of foot pressure and postural structure of national golfers. *Acta Orthop Traumatol Turc.* 2019 Mar; 53 (2): 150–153. doi: 10.1016/j.aott.2019.02.005.
24. Rohan A., Nyc M., Rogóż A., Fugiel J.: Changes in plantar pressure distribution after long-distance running. *New Medicine.* 2017; 21 (2): 58–68. doi:10.25121/NewMed.2017.21.2.58.
25. Hantke A., Michnik R., Jurkojć J., Skubacz H., Gruszka M.: Badania stabilograficzne gimnastyczek sportowych. *Aktualne Problemy Biomechaniki.* 2012; 6: 37–42.
26. Wojtków M., Korcz K., Szotek S.: Ocena postawy ciała i symetrii obciążenia stóp u zawodników uprawiających strzelectwo sportowe. *Aktualne Problemy Biomechaniki.* 2016; 10: 91–97.
27. Morton D.J.: *The Human Foot: Its Evolution. Physiology and Functional Disorders.* New York: Columbia University Press 1935.
28. Ripani M., Ciccarelli A., Morini S., Ricciardi G., Michielon G.: Evaluation of foot support in rugby players: A baropodometric analysis. *Sport Sci Health.* 2006; 1: 104–108. doi: 10.1007/s11332-006-0018-7.
29. Chow T.H., Chen Y.S., Hsu C.C., Hsu C.H.: Characteristics of Plantar Pressure with Foot Postures and Lower Limb Pain Profiles in Taiwanese College Elite Rugby League Athletes. *Int J Environ Res Public Health.* 2022 Jan 20; 19 (3): 1158. doi: 10.3390/ijerph19031158.
30. Chow T.H., Chen Y.S., Tsai W.C., Lin M.H.: Plantar Pressure Profiles and Possible Foot Syndromes of Taiwanese College Elite Basketball Players. *J Am Podiatr Med Assoc.* 2021 Feb 1; 111 (1): Article\_5. doi: 10.7547/18-043.
31. Chow T.H., Chen Y.S., Wang J.C.: Characteristics of Plantar Pressures and Related Pain Profiles in Elite Sprinters and Recreational Runners. *J Am Podiatr Med Assoc.* 2018 Jan; 108 (1): 33–44. doi: 10.7547/15-189.
32. Pau M., Ciuti C.: Stresses in the plantar region for long- and short-range throws in women basketball players. *Eur J Sport Sci.* 2013; 13 (5): 575–581. doi: 10.1080/17461391.2012.738711.

33. Eils E., Streyl M., Linnenbecker S., Thorwesten L., Völker K., Rosenbaum D.: Characteristic plantar pressure distribution patterns during soccer-specific movements. *Am J Sports Med.* 2004 Jan–Feb; 32 (1): 140–145. doi: 10.1177/0363546503258932.
34. Bibro M., Drwal A., Jankowicz-Szymańska A.: The assessment of the effect of strength training of lower limbs on arching and forces distribution of the sole in young men. *Health Promot & Phys Act.* 2018; 3 (4): 7–11. doi: 10.5604/01.3001.0012.8372.
35. Kim T.H., Lee C.W., Kim S.G., An B.W.: The effect of a pelvis-concentrated exercise program on male college students' body alignment and foot base pressure. *J Phys Ther Sci.* 2015 Apr; 27 (4): 1165–1167. doi: 10.1589/jpts.27.1165.
36. Wodka-Natkaniec E., Niedźwiedzki L., Gaździk T., Nowobilski R.: Lower limb injuries in American football players in Poland. *J Sports Med Phys Fitness.* 2024 Oct; 64 (10): 1079–1086. doi: 10.23736/S0022-4707.24.15974-9.
37. Tuna H., Yildiz M., Celtik C., Kokino S.: Ergenlik dönemindeki çocuklarda statik ve dinamik ayak basınç değerleri [Static and dynamic plantar pressure measurements in adolescents]. *Acta Orthop Traumatol Turc.* 2004; 38 (3): 200–205.