Comparative analysis of plantar pressure distribution among football players across playing positions: A cross-sectional study

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ABSTRACT

Background: Football players exhibit different muscle activation patterns during different playing activities, which can affect plantar pressure on the feet. Uneven, unbalanced plantar pressure distribution can cause muscle tension, leading to musculoskeletal injuries in the feet.

Objectives: This study aims to determine and compare plantar pressure distribution among football players based on playing position.

Methods: This study is an analytical observational study using a cross-sectional approach. The sample in this study consisted of 24 football players aged 15-18 years who met the inclusion criteria. Plantar pressure was measured using a Zebris Force Distribution Measurement (FDM) platform on the forefoot and rearfoot areas. Statistical analysis included normality tests (Shapiro-Wilk) and multivariate tests (ANOVA) according to data distribution.

Results: Differences in plantar pressure were observed between defenders, forwards, and strikers in static conditions ($p < 0.05$), but not in dynamic conditions ($p > 0.05$).

Conclusions: This study shows differences in plantar pressure distribution among football players in defender, forward, and striker positions under static conditions. However, under dynamic conditions, no significant differences were found among playing positions.

Keywords: football players, force distribution measurement (FDM), plantar pressure.

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INTRODUCTION

Football is a high-intensity sport that involves sprinting, kicking, and rapid changes of direction, which can cause injuries to the lower extremities. Uneven, unbalanced plantar pressure distribution can cause muscle tension, leading to foot injuries. Plantar pressure imbalances can lead to abnormal mechanical loading, contributing to soft-tissue degeneration and lower-extremity pain and increasing the risk of injury (Chow et al., 2022). According to Husain et al. (2020), repetitive plantar loading and uneven plantar pressure distribution significantly contribute to the development of overuse injuries. These findings are consistent with previous research by Pristianto et al. (2022), which highlights that musculoskeletal injuries during exercise often arise from improper movement patterns and biomechanical imbalances, ultimately leading to excessive mechanical stress on the lower extremities and a higher risk of injury. Muscle activation plays an important role in regulating plantar pressure distribution, especially in intrinsic and extrinsic muscles such as the gastrocnemius and tibialis anterior. Muscle activation plays an important role in regulating plantar pressure distribution, especially in intrinsic and extrinsic muscles such as the gastrocnemius and tibialis anterior, which are closely related to it (Moriguchi et al., 2018).

Previous studies have found that differences in playing positions in football, such as goalkeeper, defender, midfielder, and forward, can affect leg muscle strength due to the distinct movement requirements of each position. Goalkeepers and midfielders tend to have lower muscle strength than players in other positions because their activities focus more on defense and coordination than on strength (Śliwowski et al., 2017). Football players in defensive positions frequently engage in physical contact with opponents, run at full speed, and make sudden changes of direction, which makes them highly susceptible to musculoskeletal injuries (Hall et al., 2022).

Increased plantar pressure in certain areas, such as the medial or lateral foot, can lead to overuse injuries, including plantar fasciitis, metatarsalgia, and ankle injuries, due to impaired postural control and balance (Girard et al., 2018). According to (Azevedo et al. (2017), asymmetrical plantar pressure distribution represents a critical biomechanical risk factor that contributes to the development of overuse injuries, including stress fractures, among football players. Injuries to football players most commonly occur in the ankle, accounting for 21% of cases, followed by the knee (11.8%) and the hip (1.8%) (Atay, 2015).

Football players aged 10 to 18 are more prone to injuries because they are still developing and lack training experience (Nuraminazkiya & Pristianto, 2025). In contrast, athletes aged 20 to 30 are at the ideal age for athletes (Longo et al., 2016). Plantar pressure distribution in football players can also be influenced by various factors such as body weight, training duration, and match duration. Research by Ramadhani & Romadhoni (2024) shows that the characteristics of the foot structure, such as flatfoot, are significantly related to the distribution of plantar pressure and postural balance, so that the analysis of the pressure on the sole is an important aspect in evaluating the differences in biomechanical loads in football athletes based on their playing position.

Running activities in football include irregular patterns, such as sprints, slow jogging, jumping, and quick changes of direction, both with and without the ball. Previous studies have found differences in plantar pressure between football players and non-athletes using barapodometric mats (Hawrylak et al., 2021). In addition, most studies have not yet compared plantar pressure with playing position in football athletes.

Therefore, this study was conducted to determine and compare differences in plantar pressure among football players aged 15 to 18 years across playing positions using the Force Distribution Measurement tool. This study aims not only to enhance understanding of position-specific plantar pressure distribution but also to provide a more precise identification of injury risk factors based on biomechanical loading patterns. In line with this, Rahman et al. (2023) emphasized that football, a high-demand sport, is strongly associated with lower limb injuries; therefore, a comprehensive understanding of foot mechanics, including plantar pressure distribution, is essential for effective injury prevention and performance optimization.

Although previous studies have established the relevance of plantar pressure and injury risk in football players, they have predominantly focused on general comparisons or isolated determinants, with limited attention to the distinct biomechanical demands of each playing position. Moreover, existing research lacks a systematic comparative framework that integrates functional movement characteristics specific to positional roles. Consequently, this study offers a novel contribution by integrating position-specific biomechanical analysis with plantar pressure assessment, thereby addressing both methodological and contextual gaps through a targeted comparative approach in adolescent football players.

METHODS

Study Design and Participants

This study is an analytical, observational, cross-sectional design. The study population consisted of all 45 football players in the AT-Farmasi Surakarta Club. The sampling technique used in this study was purposive sampling, which involves selecting samples based on inclusion criteria in accordance with the research objectives. Inclusion criteria include football players who are active in matches or training and who participate in the study from start to finish. Exclusion criteria include players with acute lower-extremity injuries, players with a history of lower-extremity injuries that still cause discomfort, and players undergoing rehabilitation programs.

Ethical approval statement

This research has obtained ethical approval from the Faculty of Health Sciences, University of Muhammadiyah Surakarta, with No. 1648/KEPK-FIK/XI/2025. All actions involving human participants were conducted in accordance with the principles of research ethics outlined in the Declaration of Helsinki. Furthermore, the authors obtained permission from the parents of the students and teachers involved, and informed consent was obtained before the study began.

Research Instruments

The operational definition of the variable is done by measuring plantar pressure, which is the pressure generated by the sole when it comes into contact with the ground. Plantar pressure is expressed in kilopascals (kPa) or Newtons per square centimeter. Plantar pressure measurements are taken using a Force Distribution Measurement (FDM) device, which records plantar pressure in the medial, lateral, anterior, and posterior areas.

Each participant was asked to perform the stance phase by standing on the FDM platform three times for measurement. Higher values indicate greater plantar load on specific areas of the foot. The instrument has very high reliability, as indicated by Intra-class Correlation Coefficients (ICCs) of 0.916 for intrarater and 0.915 for interrater, which are considered excellent (Patel & M., 2023).

Data Analysis

The initial stage of data analysis begins with a Shapiro–Wilk normality test to ensure the data are normally distributed, enabling parametric statistical testing. Next, a descriptive analysis was conducted to characterize the sample. After that, the One-Way ANOVA test was used because this study aimed to compare plantar pressure values across more than two playing position groups in football athletes, making it the most appropriate method to assess average differences between groups. If the ANOVA results show significant differences, the analysis is continued with a post hoc test to determine which playing position group contributed to the differences.

RESULTS

Based on Table 1, the respondents were 24 athletes categorized by age, BMI, training frequency, number of matches, and playing position. Based on the age categories 10-15 and 16-19, the majority of athletes were in the 10-15 age range (14 people, 58.3%), while the rest were aged 16-19 (10 people, 41.7%).

In the BMI category, 11 people (45.8%) were underweight, 10 people (41.7%) were normal weight, and 3 people (12.5%) were obese. The Body Mass Index (BMI) category can affect plantar pressure, with excessive weight triggering musculoskeletal conditions such as plantar fasciitis or Achilles tendinopathy (Gurau et al., 2025).

The frequency of training per week was dominated by athletes who trained 2-3 times, totaling 18 people (75%), while 6 people (25%) trained 4-6 times. In the number of matches per month category, 14 athletes (58.3%) participated in 2-4 matches, and 10 athletes (41.7%) participated in 5-7 matches per month.

The playing positions show that 6 people (25%) are defenders, 7 people (29%) are midfielders, 4 people (16.67%) are goalkeepers, 4 people (16.67%) are forwards, and 3 athletes (12.5%) are strikers. This data as a whole illustrates the diverse characteristics of the respondents across demographics, physical condition, and role in the game.

Based on the ANOVA results in Table 2, the variables tested were the distributions of plantar pressure on the right. They left feet, divided into two main segments: forefoot and backfoot, in both static and dynamic conditions. The ANOVA test was conducted to determine whether there were differences in plantar pressure distribution across athlete groups.

In static conditions, the right forefoot and right backfoot areas showed a p-value of 0.045, indicating a significant difference in plantar pressure distribution between the athlete groups ($p < 0.05$). This indicates that when athletes are stationary, the pressure on the right foot shows greater load variation by playing position. Meanwhile, the left forefoot and left backfoot areas have a p-value of 0.143, indicating no significant difference. Under dynamic conditions, the entire foot area (right/left forefoot and right/left backfoot) showed p > 0.05 (0.289–0.881), indicating no significant difference in plantar pressure distribution between groups of athletes during movement.

Overall, these results indicate that differences in plantar pressure distribution are more pronounced and easier to identify when athletes are in a static condition, especially in the right foot area. Meanwhile, under dynamic conditions, plantar pressure tends to remain stable, with little variation.

Table 1. Characteristics of the Respondents

Characteristics	n	%	Min	Median	Max	Mean	SD
a. Age							
10-15 year	14	58.3	15	15	18	16.1667	1.46456
16-19 year	10	41.7					
b. BMI							
Underweight	11	45.8	14.9	18.7	28.3	19.3542	3.32356
Normal	10	41,7					
Overweight	0	0					
Obesity	3	12.5					
c. Number of Workouts Per Week							
2 - 3	18	75	2	3	6	3.5417	1.10253
4 - 6	6	25					
d. Number of Matches per Month							
2 - 4	14	58.3	2	4	7	4.5	1.35133
5 - 7	10	41.7					
e. Playing Position							
Defender	6	25	N/A	N/A	N/A	N/A	N/A
Midfielder	7	29					
Goalkeeper	4	16.67					
Forward	4	16.67					
Striker	3	12.5					

Key: N/A: Not Available, SD: Standard Deviation
Note: Age classification based on WHO (early adolescence & late adolescence), BMI classification using WHO 2007 Growth Reference.

Table 2. ANOVA Test Results

Variable	Static			
	ANOVA*			
	df	Mean Square	f	Sig.
Fore foot (R)	4	174.052	2.991	0.045
Back foot (R)	4	174.052	2.991	0.045
Fore foot (L)	4	992.549	1.951	0.143
Back foot (L)	4	992.549	1.951	0.143
	Dynamic			
	ANOVA*			
	df	Mean Square	f	Sig.
Fore foot (R)	4	353.432	0.289	0.881
Back foot (R)	4	556.726	0.780	0.552
Fore foot (L)	4	478.778	0.487	0.745
Back foot (L)	4	623.629	0.645	0.637

**Significancy p < 0,05*

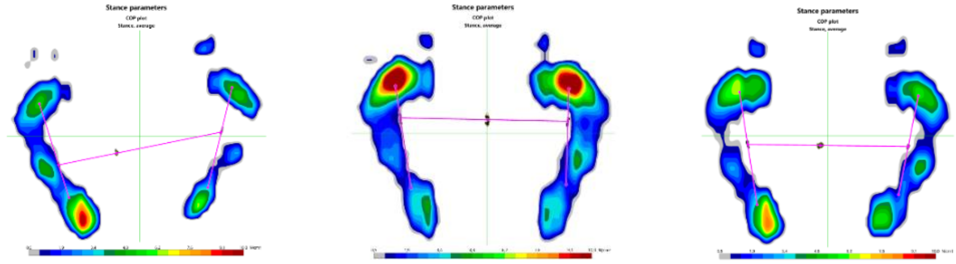
Post-hoc tests showed that most comparisons of plantar pressure between playing positions did not show significant differences in plantar pressure values, either in static or dynamic conditions (Table 3). However, there were some significant differences in static conditions. In the right forefoot area, a significant difference was found between defenders and attackers (p-value = 0.032; mean difference = 43.416). In the right backfoot, there was a significant difference between defenders and attackers with a p-value of 0.032 and a mean difference of 43.416, as well as between attackers and strikers with a p-value of 0.035 and a mean difference of -42.083.

Table 3. Post-hoc Test Results

Variable	Group	Static		Dynamic	
		Mean Difference	Sig	Mean Difference	Sig
	Defender – Midfielder	- 0.666	1.0*	32.142	0.984**
	Defender – Goalkeeper	-43.416	0.972*	-34.750	0.988**
	Defender – Forward	43.416	0.032*	30.0	0.993**
	Defender – Striker	1.333	1.0*	23.333	0.998**
Fore foot (R)	Midfielder – Goalkeeper	9.50	0.978*	-66.892	0.867**
	Midfielder – Forward	-42.750	0.078*	-2.142	1.0**
	Midfielder – Striker	-0.666	1.0*	-8.809	1.0**
	Goalkeeper – Forward	-52.250	0.068*	64.750	0.918**
	Goalkeeper – Striker	-10.166	0.935*	58.083	0.957**
	Forward – Striker	42.083	0.035*	-6.666	1.0**
	Defender – Midfielder	0.666	1.0*	33.547	0.951**
	Defender – Goalkeeper	-8.833	0.972*	-54.916	0.849**
	Defender – Forward	43.416	0.032*	-25.416	0.990**
	Defender – Striker	1.333	1.0*	-9.833	1.0**
Back foot (R)	Midfielder – Goalkeeper	0.666	0.978*	-88.464	0.474**
	Midfielder – Forward	42.750	0.78*	-58.964	0.797**
	Midfielder – Striker	0.666	1.0*	-43.380	0.943**
	Goalkeeper – Forward	52.250	0.068*	29.50	0.987**
	Goalkeeper – Striker	10.166	0.935*	45.083	0.954**
	Forward – Striker	-42.083	0.035*	64.508	0.999**
	Defender – Midfielder	-2.047	1.0**	43.047	0.933**
	Defender – Goalkeeper	10.667	0.946**	-30.916	0.988**
	Defender – Forward	-30.633	0.046**	44.333	0.956**
	Defender – Striker	4.666	0.998**	3.333	1.08**
Fore foot (L)	Midfielder – Goalkeeper	12.714	0.894**	-73.964	0.756**
	Midfielder – Forward	-28.285	0.303**	1.285	1.0**
	Midfielder – Striker	6.714	0.992**	-39.714	0.976**
	Goalkeeper – Forward	-41.0	0.116**	75.250	0.817**
	Goalkeeper – Striker	-6.0	0.997**	34.250	0.991**
	Forward – Striker	35.0	0.289**	-41.0	0.982**
	Defender – Midfielder	2.047	1.0**	12.309	0.999
	Defender – Goalkeeper	-10.666	0.946**	-61.333	0.867
	Defender – Forward	30.333	0.267**	-35.583	0.979
	Defender – Striker	-4.666	0.998**	-69.833	0.850
Back foot (L)	Midfielder – Goalkeeper	-12.714	0.894**	-73.642	0.754
	Midfielder – Forward	28.285	0.303**	-47.892	0.934
	Midfielder – Striker	-6.714	0.992**	-82.142	0.745
	Goalkeeper – Forward	41.0	0.116**	25.750	0.996
	Goalkeeper – Striker	6.0	0.997**	-8.50	1.0
	Forward – Striker	-35.0	0.289**	-34.250	0.990

**Games-Howel*
***Tukey HSD*

Additionally, in the left forefoot area, a significant difference reappeared between defenders and attackers with a p-value of 0.046 and a mean difference of 30.633. In the entire plantar area during dynamic conditions, there were no significant differences, with all p-values > 0.05. Overall, the post-hoc test results show that differences in plantar pressure distribution are more common in static conditions, particularly in the right forefoot, right backfoot, and left forefoot. Meanwhile, in dynamic conditions, the differences between positions tend to be insignificant. These findings indicate that when players are stationary, position characteristics can affect plantar load, but when moving, plantar pressure patterns become more uniform between positions.



a. Defender/defensive b. Attacker c. Striker

Figure 1. Comparison of plantar pressure distribution by playing position: (a) defender, (b) attacker, and (c) striker

Greater plantar pressure in the forefoot region was observed in attacking players (Figure 1b) compared to other positions. In contrast, defenders and strikers (Figure 1a and 1c) showed a more dominant plantar pressure distribution in the rearfoot region.

DISCUSSION

The results showed that plantar pressure distribution in football players aged 15 - 18 years differed based on playing position, especially under static measurement conditions. These findings show that when athletes are standing still, plantar load is influenced by the activities of each playing position.

Plantar pressure in football players is strongly influenced by intense movements, such as sprinting, acceleration, and changes of direction, which are routinely performed during training and matches (Girard et al., 2018). The accumulation of mechanical stress over a month can alter the pressure distribution pattern on the sole and increase the risk of injury due to excessive pressure on the foot structure (Bache-Mathiesen et al., 2022).

During attacks, increased pressure was observed in the forefoot area, as shown in Figures 1a, 1b, and 1c. This finding has practical implications for training programs for players in this position, which need to emphasize strengthening the muscles that support the forefoot and the control required for quick maneuvers. Increased load on the forefoot is also associated with the risk of metatarsal stress fractures (Sun et al., 2024). Therefore, training programs that strengthen the metatarsophalangeal muscles and improve neuromuscular control of the forefoot are recommended to reduce the risk of injury and increase acceleration capacity (Tourillon et al., 2024). Conversely, in the positions of defender and striker, greater plantar pressure on the backfoot indicates a greater need for stability, making balance and postural stability training important to support their roles on the field (Petry et al., 2016).

Right Forefoot

Further test results showed significant differences in the right forefoot area between defenders and attackers. These findings indicate that the two positions have different biomechanical patterns of plantar pressure distribution. Attackers exert higher plantar pressure on the right forefoot than defenders do. Higher plantar pressure in attackers is relevant because this position requires activities such as sprinting, rapid toe pressure, and sudden acceleration, which require greater weight to be supported by the front of the foot. These findings are in line with previous studies showing that increased sprinting and repetitive acceleration movements can increase plantar load (Girard et al., 2018). In addition, the high frequency of hard contact on the anterior part of the foot among attackers can increase the risk of musculoskeletal problems, such as metatarsalgia and stress fractures (Sun et al., 2024).

In players occupying the defender position, plantar pressure in the right forefoot region tends to be lower. This finding may be attributed to the more upright postural alignment commonly adopted by defenders to maintain balance and postural stability during marking and anticipatory movement (Hall et al., 2022). Consequently, the load distribution shifts relatively away from the forefoot, resulting in lower plantar pressure in this region than in players in the attacking position.

Right Backfoot

The right backfoot area shows significant differences between defenders and attackers, and between attackers and strikers. These findings indicate that the distribution of plantar pressure on the right backfoot in static conditions is greatly influenced by the biomechanical characteristics and role requirements of each position.

The difference in plantar pressure between defenders and attackers can be explained by the fact that defenders focus more on stability, balance, and quick responses to their opponents' movements. Defenders tend to maintain a more upright posture and a more even distribution of pressure across the entire sole to maintain body control and observe opposing players (Katis et al., 2017). This is different from attackers, who are more guided by sprinting and acceleration movements.

Meanwhile, the difference between the forward and striker positions shows that plantar pressure differs between the two, with the striker focusing more on attacking. In the striker position, players tend to focus more on maintaining their position and receiving the ball, which results in leaning on the back foot to maintain balance and make quick changes in body direction (Atasever & Kiyici, 2023). Conversely, attackers are often in a fast transition phase, so their weight tends to be more on the forefoot. Other studies also support the finding that offensive players show greater plantar load on the rear of the foot during the pre-explosive movement phase (Vera-Ivars et al., 2025). This combination of differing activity demands and biomechanical adaptations causes significant differences in right backfoot plantar pressure during static conditions. Implications for performance: forefoot patterns in attackers enhance acceleration, while backfoot dominance in defenders and strikers strengthens stability and balance control, in line with the demands of their respective roles.

Left Forefoot

There is also a significant difference between the playing positions of defenders and attackers in the left forefoot area. Although the left foot is often considered the non-dominant foot for most football players, these findings show that differences in playing position still affect the distribution of plantar pressure in the left forefoot. In the attacking position, the left forefoot still plays an important role in balancing the body when sprinting and preparing the body to kick with the dominant foot.

This aligns with previous research, which explains that even though the left foot is non-dominant, it still functions because the non-dominant foot also plays an important role in maintaining postural balance during kicking or sudden acceleration movements (Sadhnani, 2024).

Thus, differences in plantar pressure in the left forefoot between defenders and attackers illustrate the biomechanical requirements of each position, even though this foot is not the dominant one. These findings also show that the non-dominant foot continues to make a significant contribution to players' performance and movement control, especially during intensive activities performed by attacking players.

Overall, these position-based differences can be explained by biomechanical load-transfer mechanisms, in which plantar pressure reflects the distribution of body weight and ground reaction forces through the foot during sport-specific movements. Football players in attacking roles, who frequently sprint, accelerate, and make rapid directional changes, tend to shift pressure toward the forefoot to facilitate propulsion. In contrast, defenders and strikers rely more on stability and postural control, leading to relatively greater or more evenly distributed loading on the rearfoot.

Left Backfoot

There was no significant difference in plantar pressure on the left backfoot between playing positions. This finding indicates that the use of the backfoot and sole in static conditions is relatively uniform between positions. The backfoot functions as an area of stabilization and maintains body balance, so that, even though players' activities differ between positions, in static conditions, the left backfoot still produces a similar pressure pattern. Previous studies have also shown that backfoot pressure is more often influenced by postural control strategies (Fujishita et al., 2023). Therefore, the absence of differences in the left backfoot area is reasonable and consistent with previous literature.

Plantar Pressure in Dynamic Conditions

In dynamic conditions, this study found no significant differences in plantar pressure distribution across football players' playing positions. These findings indicate that when moving, plantar pressure patterns tend to be uniform across player positions. The results of this study are in line with previous studies reporting that plantar pressure measurements using baropodometry during dynamic measurements tend to show a more stable pattern than during static measurements (Gurau et al., 2025). Other studies also report that plantar pressure distribution in football players under dynamic conditions does not show significant differences, as the distribution pattern during movement is relatively uniform among athletes (Hawrylak et al., 2021).

However, in a study by Vera-Ivars et al. (2025), plantar pressure was observed in adolescent football players during dynamic conditions, with higher pressure in the forefoot region, especially during the acceleration phase and during fast running. The study also emphasized that foot morphology factors, such as foot arch, contributed to variations in plantar pressure. Haryoko (2023) shows that measurements of structural parameters of the foot, such as the Arch Height Index and the results of the Foot Print Test, can reflect the characteristics of the arch of the foot that play a role in the load distribution pattern on the sole, which is relevant to understanding variations in plantar pressure among individuals with different foot function profiles.

The findings of this study still have specific implications for physiotherapy and injury-prevention programs for football players. Biomechanical analysis is important for understanding motor adaptations involving the foot's structure and the function of the lower joints during the stabilization phase of movement in athletes (Susilo et al., 2025). Differences in plantar pressure distribution across playing positions indicate that each position imposes distinct biomechanical demands, consistent with Hawrylak et al. (2021), who found that movement demands and field role influence plantar pressure variation in athletes. Information on the specific plantar pressure patterns for each position can help physical therapists develop more targeted injury-prevention programs (Al Attar et al., 2022). Training dynamic balance, core control, and improved landing strategy are highly relevant interventions, as they differentiate the focus of the exercises and modify the exercise load based on the area of the foot that receives the most pressure (Dunsky et al., 2017).

Limitations of the study

This study has several limitations: the small sample size and single-club recruitment limit generalizability. The cross-sectional design precludes causal inference. Plantar pressure assessment was conducted under controlled static and dynamic conditions, which may not fully reflect the demands of real matches. Key influencing factors such as foot morphology, muscle strength, fatigue, and footwear were not controlled. Additionally, although training and match frequency were reported, the total duration of training and match exposure was not quantified, which may affect the interpretation of plantar loading patterns and injury risk.

CONCLUSION

The results of this study show that, in static conditions, the distribution of plantar pressure differs across defenders, forwards, and strikers; in dynamic conditions, it remains stable, with no significant differences across positions. These findings emphasize the importance of considering playing position characteristics in injury prevention and performance optimization efforts.

Practical implications from this study suggest that football players should adopt position-specific conditioning strategies, prioritizing forefoot loading capacity in attacking roles and postural stability in defensive roles, and should use systematic load monitoring. Coaches should implement position-tailored training and rigorous load management that incorporates both training and match exposure. Physical therapists are encouraged to integrate plantar pressure screening into routine evaluation and deliver targeted, individualized interventions. Future research should employ longitudinal, multi-center designs with larger samples and incorporate ecologically valid, sport-specific assessments alongside comprehensive variables, including foot morphology, fatigue, footwear, and precise quantification of training and match loads.

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AI DISCLOSURE STATEMENT

During the preparation of this manuscript, the authors used DeepL Translate in combination with Google Translate and Grammarly to support translation, grammar checking, and language refinement. All generated outputs were carefully reviewed and edited by the authors to ensure accuracy, clarity, and adherence to academic standards. The authors take full responsibility for the content of this manuscript.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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CONFLICT OF INTEREST

The authors hereby declares that this research is free from conflicts of interest with any party.

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