

Foot biomechanics and injury risk factors in youth football players: A cross-sectional study



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ABSTRACT

Background: Altered plantar pressure distribution and foot alignment have been suggested in previous studies to be associated with ankle instability and overuse injuries; however, evidence in youth populations remains limited.

Objectives: This study aimed to investigate foot biomechanics and potential injury risk factors in youth football players aged 5–15 years.

Methods: This study employed an analytical cross-sectional design involving 30 youth football players recruited from local football academies. Participants were categorized into three age groups: 5–9 years ($n = 10$), 10–12 years ($n = 10$), and 13–15 years ($n = 10$). Data were collected through pedobarographic plantar pressure assessment, hallux valgus angle (HVA) measurement using a goniometer, navicular drop test (NDT), and subtalar angle assessment. Statistical analyses included descriptive statistics, Shapiro–Wilk normality test, Pearson correlation, independent t-test, and one-way ANOVA with effect size (η^2). A significance level of $p \leq 0.05$ was applied.

Results: The results showed that hindfoot plantar pressure was higher than forefoot pressure in both feet, indicating a posterior loading pattern. Hallux valgus angles were within normal ranges, while subtalar angles demonstrated a tendency toward pronation. Significant differences were observed in left foot HVA and left hindfoot pressure across age groups ($p < 0.05$), with moderate effect sizes ($\eta^2 = 0.20$ – 0.21). Correlation analysis revealed moderate to strong positive relationships between subtalar pronation and HVA variables.

Conclusions: Youth football players exhibit biomechanical characteristics, such as increased hindfoot loading and subtalar pronation, that may represent adaptive responses to sport-specific demands and be associated with potential injury risk. However, given the study's cross-sectional design, these findings should be interpreted as descriptive biomechanical patterns rather than as direct predictors of injury. Early biomechanical screening and targeted preventive training may help support optimal athletic development.

Keywords: ankle instability, foot biomechanics, injury risk, plantar pressure, youth football players.

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INTRODUCTION

Foot biomechanics plays a critical role in maintaining postural stability and optimizing movement efficiency in athletes, particularly in sports such as football that involve repetitive running, cutting, and directional changes. However, abnormal plantar pressure distribution and foot alignment have been identified as potential contributors to lower extremity injuries, especially ankle instability and overuse conditions (Chow, 2025; De Ridder et al., 2012; Wang et al., 2025). Previous studies have demonstrated that athletes with altered plantar pressure patterns tend to exhibit higher lateral foot loading and impaired neuromuscular control, which increases the risk of recurrent ankle sprains and compromised performance (Wang et al., 2025). Despite growing attention to foot biomechanics, most research has primarily focused on adult or clinical populations, while evidence in youth athletes remains limited. This gap is concerning, given that early biomechanical alterations during growth and development may predispose young athletes to long-term musculoskeletal problems.

Recent studies have begun to examine the relationships among plantar pressure, foot posture, and injury risk in athletic populations. For instance, Shen et al. (2024) reported that plantar pressure distribution is significantly associated with anthropometric factors and varies across different conditions in adolescents, suggesting its role in biomechanical adaptation and potential injury mechanisms. Similarly, Chow (2025) highlighted that variations in plantar load distribution and foot posture are closely linked to structural and functional changes in the foot, influencing movement patterns and injury susceptibility. Furthermore, research in young athletes has indicated that foot morphology and intrinsic muscle function are associated with chronic ankle instability, emphasizing the importance of biomechanical assessment in injury prevention (San Antolín-Gil et al., 2026). Additional evidence suggests that young athletes often exhibit tendencies toward hallux valgus and subtalar pronation, which may increase the risk of ankle and knee injuries if left unaddressed (Seyhan & Açar, 2025).

However, previous studies have several limitations. Many investigations focus on single variables (e.g., plantar pressure or foot posture alone) rather than integrating multiple biomechanical parameters (Chow, 2025; De Ridder et al., 2012; Wang et al., 2025). In addition, limited research has specifically examined youth football players, who are exposed to unique sport-specific demands that may influence foot biomechanics differently from other athletic populations. Therefore, there remains a need for comprehensive studies that simultaneously evaluate plantar pressure distribution, foot alignment (e.g., hallux valgus angle), and structural characteristics such as navicular drop in young football players.

The novelty of the present study lies in its integrative approach to assessing multiple foot biomechanical parameters within a youth football population aged 5–15 years, combining pedobarographic analysis with clinical measurements such as HVA and NDT. By addressing this gap, the study aims to provide a more comprehensive understanding of biomechanical patterns associated with potential injury risk in young athletes. Therefore, the purpose of this study was to investigate foot biomechanics and potential injury risk factors in youth football players. The findings of this study are expected to contribute to the development of early screening strategies and targeted injury prevention programs, thereby supporting safer athletic development and long-term performance optimization.

METHODS

Study Design and Participants

This study employed an analytical cross-sectional design to examine foot biomechanics and potential injury-related risk factors in youth football players. Participants were recruited from local football training academies. The inclusion criteria were children aged 5-15 years who actively participated in organized football training. Exclusion criteria included any history of lower extremity surgery within the past year, as well as the presence of neurological or psychiatric disorders that could affect movement patterns. A total of 30 participants were included in the study and categorized into three age groups: 5–9 years ($n = 10$), 10–12 years ($n = 10$), and 13–15 years ($n = 10$).

The categorization of participants into age groups (5–9, 10–12, and 13–15 years) was based on general developmental stages and differences in growth and neuromuscular maturation commonly reported in pediatric populations. This grouping also reflects practical distinctions in youth football training levels.

Ethical approval statement

Ethical approval was obtained from the Institutional Review Board of Çankırı Karatekin University (Protocol No: October 24, 2025-15). The study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from the parents or guardians of all participants prior to data collection. All assessments were conducted in person.

Research Instruments

Sociodemographic Data

Basic demographic information, including age, height, weight, and sex, was collected using a standardized form.

Pedobarographic Plantar Pressure Assessment

Static plantar pressure distribution was assessed in a bilateral standing position using the AS Foot Scan system (Analysis System, Istanbul, Turkey) (Figure 1). The device features a sensor platform measuring 400 mm × 400 mm, equipped with 2288 sensors (1.4 sensors/cm²) and a sampling frequency of 200-400 Hz, with a delay rate below 3%. The distribution of plantar pressure was analyzed for the right and left foot, as well as the forefoot and hindfoot regions.

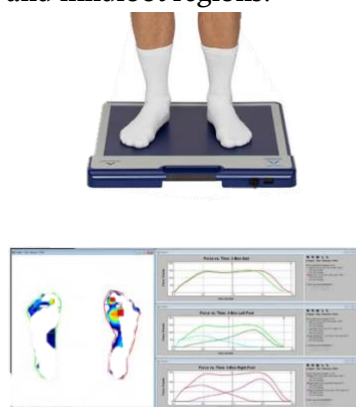


Figure 1. Representative illustration of plantar pressure assessment using a pedobarographic platform. The image is provided for illustrative purposes only and does not depict the exact device used in this study

Hallux Valgus Angle (HVA) Measurement

The hallux valgus angle was measured using a goniometer (Figure 2). The axis of the goniometer was positioned at the medial aspect of the first metatarsophalangeal joint. The stationary arm was aligned with the first metatarsal, while the movable arm followed the proximal phalanx of the hallux. The resulting angle represented the severity of hallux valgus deformity.



Figure 2. Measurement of hallux valgus angle (HVA) using a goniometer. The axis of the goniometer was positioned at the first metatarsophalangeal joint, with the stationary arm aligned along the first metatarsal and the movable arm aligned with the proximal phalanx of the hallux. (Source: [Omar et al., 2025](#))

Navicular Drop Test (NDT)

The navicular drop test was performed to evaluate medial longitudinal arch function. Participants were assessed in a weight-bearing standing position with the subtalar joint in neutral alignment. The height of the navicular tuberosity from the ground was measured, followed by a second measurement in a relaxed stance. The difference between the two measurements was recorded. Values less than 5 mm were classified as pes cavus, while values greater than 10 mm indicated pes planus.

Subtalar Angle Measurement

Subtalar alignment was assessed using a goniometer while participants stood on an elevated platform. The angle formed between the midpoint of the calcaneus and the Achilles tendon was recorded to determine pronation or supination tendencies.

All clinical measurements (hallux valgus angle, subtalar angle, and navicular drop test) were performed by a trained examiner. These methods have been previously reported to demonstrate acceptable reliability in pediatric and athletic populations ([Seyhan et al., 2024](#)). However, no intra-rater or inter-rater reliability testing was conducted within the present study.

Data Analysis

All statistical analyses were performed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were presented as mean \pm standard deviation for continuous variables. The normality of data distribution was assessed using the Shapiro–Wilk test. Based on the normality results, appropriate parametric tests were applied. To examine differences between age groups, participants were categorized into subgroups (e.g., 5–9 years, 10–12 years, and 13–15 years).

An independent-samples t-test was used for comparisons between two groups, while a one-way analysis of variance (ANOVA) was used for comparisons involving more than two groups. Pearson correlation analysis was used to evaluate the relationships between foot biomechanical parameters and anthropometric variables. Effect sizes were calculated to determine the magnitude of differences. Cohen's *d* was used for t-test comparisons, while eta squared (η^2) was reported for ANOVA. Effect

sizes were interpreted as small (0.2), medium (0.5), and large (0.8) for Cohen's *d*, and small (0.01), medium (0.06), and large (0.14) for η^2 . A significance level of $p \leq 0.05$ was considered statistically significant for all analyses.

RESULTS

Of the 30 children who participated in the study, 18 were male, and 12 were female. BMI scores were within the normal range. Sociodemographic data are presented in detail in Table 1. The Shapiro–Wilk test indicated that all variables were normally distributed ($p > 0.05$).

Table 1. Sociodemographic Data

Variable	N	Mean	SD (\pm)
Age (years)	30	8.10	2.45
Height (cm)	30	128.50	15.20
Body weight (kg)	30	29.80	10.10
BMI	30	17.45	2.95

Note: BMI: Body mass index; N: number of participants; SD: standard deviation.

Table 2. NDT Data of Youth Football Players

Variable	N	Mean	SD (\pm)
R.F NDT Weighted	30	4.15	1.30
L.F NDT Weighted	30	4.20	1.18
R.F NDT Weightless	30	5.10	1.25
L.F NDT Weightless	30	5.05	1.20

Note: NDT: Navicular Drop Test; R.F: Right Foot; L.F: Left Foot; SD: Standard Deviation.

According to the Navicular Drop Test (NDT) results (Table 2), no excessive medial longitudinal arch collapse was observed, as the difference between weight-bearing and non-weight-bearing measurements was generally less than 10 mm in both feet. These findings indicate that most participants demonstrated normal foot arch characteristics.

Table 3. Plantar Pressure Analysis Results in a Static Bipedal Position of Youth Football Players

Variable	N	Mean	SD (\pm)
L. Forefoot (%)	30	17.25	5.30
L. Hindfoot (%)	30	33.60	7.85
R. Forefoot (%)	30	16.40	5.80
R. Hindfoot (%)	30	31.10	7.10

Note: R: Right; L: Left; SD: Standard Deviation.

When plantar pressure distribution was analyzed in a static bipedal position, hindfoot pressure percentages were higher than forefoot pressure percentages in both feet (Table 3). This indicates a posterior loading pattern, which is commonly observed in young athletes.

Table 4. Subtalar Angle Data with HVA of Youth Football Players

Variable	N	Mean	SD (\pm)
R.F Subtalar pronation ($^\circ$)	30	6.70	1.55
L.F Subtalar pronation ($^\circ$)	30	6.50	1.90
R.F HVA ($^\circ$)	30	13.90	2.40
L.F HVA ($^\circ$)	30	14.20	2.10

Note: HVA: Hallux Valgus Angle; R.F: Right Foot; L.F: Left Foot; SD: Standard Deviation.

Analysis of hallux valgus angles indicated values within the normal range in both feet (Table 4). However, subtalar angles demonstrated a tendency toward pronation. These findings suggest potential biomechanical adaptations associated with injury risk in youth football players.

Table 5. Correlation Analysis Between HVA and Subtalar Angles in Youth Football Players

	L.F Subtalar pronation (°)	R.F Subtalar pronation (°)	L.F HVA (°)	R.F HVA (°)
L.F Subtalar pronation (°)	-			
R.F Subtalar pronation (°)	.521*	-		
L.F HVA (°)	.482*	.538*	-	
R.F HVA (°)	.505*	.559*	.781*	-

Note: r = Pearson correlation coefficient; * $p < 0.05$; L.F = Left Foot; R.F = Right Foot; HVA = Hallux Valgus Angle

Table 6. Comparison of Foot Biomechanical Parameters Across Age Groups

Variable	5–9 years (Mean ± SD)	10–12 years (Mean ± SD)	13–15 years (Mean ± SD)	F	p-value	η^2
R.F HVA (°)	13.10 ± 2.10	13.95 ± 2.20	14.70 ± 2.30	3.21	0.056	0.19
L.F HVA (°)	13.40 ± 2.00	14.10 ± 2.10	14.90 ± 2.25	3.45	0.047*	0.20
R.F NDT Weighted (mm)	3.90 ± 1.10	4.20 ± 1.25	4.50 ± 1.30	2.88	0.073	0.17
L.F NDT Weighted (mm)	4.00 ± 1.05	4.25 ± 1.20	4.55 ± 1.25	2.76	0.081	0.16
R. Hindfoot (%)	29.20 ± 6.80	31.30 ± 7.20	32.80 ± 7.40	3.02	0.065	0.18
L. Hindfoot (%)	30.50 ± 7.00	33.40 ± 7.60	34.90 ± 8.10	3.68	0.038*	0.21

Note: R.F: Right Foot; L.F: Left Foot; HVA: Hallux Valgus Angle; NDT: Navicular Drop Test; η^2 : eta squared. *Significant at $p < 0.05$

One-way ANOVA was conducted to examine differences in biomechanical parameters across age groups (Table 6). A significant difference was observed in left foot HVA and left hindfoot plantar pressure ($p < 0.05$), with moderate effect sizes ($\eta^2 = 0.20$ and $\eta^2 = 0.21$, respectively). Older participants (13–15 years) tended to show higher values than younger participants.

No statistically significant differences were found for other variables ($p > 0.05$), although a trend toward increased values with age was observed. Findings with borderline statistical significance should be interpreted cautiously, particularly given the relatively small sample size and multiple comparisons conducted in this study.

DISCUSSION

The present study aimed to investigate foot biomechanics and potential injury risk factors in youth football players. The findings revealed that hindfoot plantar pressure was higher than forefoot pressure, and hallux valgus angles were within normal ranges. Given the cross-sectional nature of this study, the findings should be interpreted with caution. The observed biomechanical characteristics cannot be considered causal factors or direct predictors of injury, but rather as features that may be associated with injury risk based on previous literature. No injury data or longitudinal follow-up was included in this study.

The observed increase in hindfoot loading and HVA with age may indicate biomechanical adaptations that could increase the risk of lower extremity injuries in youth football players. These findings are consistent with previous studies suggesting that altered plantar pressure distribution and foot alignment may be associated with increased susceptibility and overuse injuries in young athletes (De Ridder et al., 2012; Wan et al., 2023; Wang et al., 2025).

In addition, certain biomechanical patterns observed in this study, such as increased hindfoot loading, may also reflect normal developmental or sport-specific adaptations in youth athletes. Therefore, these findings should not be interpreted

solely as pathological indicators but rather as characteristics that may have functional relevance in different contexts.

The observed biomechanical patterns in this study may be explained by age-related neuromuscular and structural adaptations in young athletes. As children grow and are increasingly exposed to repetitive football-specific activities such as running, cutting, and kicking, progressive changes in foot loading patterns and alignment may occur (Mikolajczyk et al., 2018). Increased training intensity and cumulative mechanical stress can lead to gradual shifts in plantar pressure distribution, particularly toward the hindfoot region, as a compensatory strategy to maintain stability during dynamic movements. Previous studies have shown that foot loading patterns are highly influenced by both maturation and sport-specific demands, potentially altering biomechanical efficiency over time (Wang et al., 2025).

From a biomechanical perspective, altered plantar pressure distribution and foot alignment can increase the risk of ankle instability through several mechanisms (Wittwer, 2012). Abnormal loading patterns, particularly increased lateral or posterior pressure, can disrupt the normal center of pressure (COP) trajectory and impair postural control (Gao et al., 2019; Kasahara et al., 2015; Li et al., 2020). This may reduce the neuromuscular system's ability to stabilize the ankle joint during dynamic tasks, increasing the risk of inversion injuries. Furthermore, individuals with altered plantar pressure patterns often demonstrate deficits in proprioception and delayed muscle activation, especially in the peroneal muscles, which are critical for ankle stabilization. These factors contribute to chronic ankle instability and increase the likelihood of recurrent sprains and overuse injuries (Wang et al., 2025).

To reduce the risk of such injuries, targeted intervention strategies are recommended. Neuromuscular training programs focusing on balance, proprioception, and ankle stability have been shown to improve postural control and reduce injury risk in young athletes (Fort-Vanmeerhaeghe, Romero-Rodriguez, Lloyd, et al., 2016; Fort-Vanmeerhaeghe, Romero-Rodriguez, Montalvo, et al., 2016; Sañudo et al., 2019). Additionally, strengthening exercises for intrinsic foot muscles and ankle stabilizers, particularly the peroneal muscles, can help optimize foot mechanics and load distribution. Gait retraining and functional movement correction may also be beneficial in addressing abnormal plantar pressure patterns. Previous research suggests that combined training approaches incorporating proprioceptive exercises and muscle strengthening can significantly enhance neuromuscular control and reduce the risk of ankle injuries (Wang et al., 2025).

The findings of this study have important practical implications for injury prevention in youth football. Early identification of abnormal plantar pressure distribution and foot alignment may serve as a valuable screening tool for detecting potential injury risk. Coaches, clinicians, and sports scientists can use these findings to design individualized training and prevention programs to optimize biomechanical function. Early intervention strategies may help reduce the incidence of ankle injuries and improve long-term athletic performance.

Limitations of the study

However, several limitations should be considered when interpreting the results of this study. First, the relatively small sample size may limit the generalizability of the findings. Second, the cross-sectional design does not allow for causal inference regarding the relationship between biomechanical variables and injury risk. Third, plantar pressure measurements were performed under static conditions, which may

not fully reflect dynamic movements commonly performed in football. Future studies should incorporate larger sample sizes, longitudinal designs, and dynamic assessments to better understand the relationship between foot biomechanics and injury risk in youth athletes.

CONCLUSIONS

This study demonstrated that youth football players exhibit biomechanical characteristics, including increased hindfoot loading and subtalar pronation, which increase with age. These findings may reflect adaptive responses to sport-specific demands and may be associated with increased injury risk; however, they should not be interpreted as direct predictors of injury given the cross-sectional design. Therefore, early biomechanical screening may be useful for identifying movement patterns that warrant further monitoring or targeted intervention.

AI DISCLOSURE STATEMENT

During the preparation of this manuscript, the authors used Grammarly and DeepL Translate to assist with grammar checking, language editing, translation, and improving academic English writing. All outputs generated by these tools were carefully reviewed, verified, and revised by the authors to ensure the accuracy, clarity, and appropriateness of the content. The authors take full responsibility for the integrity, originality, and final content of this manuscript.

DATA AVAILABILITY

The data supporting this study's findings are available on request from the corresponding author. The data are not publicly available because they contain information that could compromise the privacy of research participants

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CONFLICT OF INTEREST

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

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