

Assessment of the association between foot arch profiles and single-leg dynamic postural control in male soccer players

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Abstract

Background and Study Aim

Postural control is a fundamental skill that emerges from the interaction between the central nervous system and sensorimotor structures. It enables the maintenance of body balance and plays a critical role in both athletic performance and injury risk, particularly in sports such as soccer, where unilateral loading patterns are common. Despite the application of various assessment approaches, including static and non-task-specific methods, their effectiveness in reflecting postural control under dynamic and limb-specific conditions remains a matter of practical interest. In this context, the present study aimed to examine the relationship between foot arch profiles and single-leg dynamic postural control in soccer players.

Material and Methods

A total of 48 male university-level soccer players participated in the study. Participants were classified into three groups (high, normal, and low arch profiles) based on plantar pressure measurements. Single-leg dynamic postural control was assessed using a balance platform. Directional postural sway and the percentage of time spent within the target zone were analyzed using one-way ANOVA with post hoc comparisons.

Results

The findings revealed that foot arch structure significantly influences postural control. Athletes with normal arch profiles demonstrated superior balance performance, maintaining their position within the target zone for longer durations ($90.75 \pm 2.30\%$) compared with the high arch ($71.69 \pm 3.95\%$) and low arch groups ($77.31 \pm 2.87\%$) ($p < 0.0001$). In contrast, the high arch group exhibited a more rigid and asymmetrical control strategy, with reduced right-directed sway ($42.00 \pm 2.42\%$) and increased left-directed sway ($58.00 \pm 2.42\%$). The low arch group showed increased anterior sway ($57.88 \pm 2.00\%$) compared with the normal ($49.06 \pm 0.85\%$) and high arch groups ($47.63 \pm 1.59\%$) ($p < 0.0001$). These differences were associated with large effect sizes ($\eta^2 = 0.81-0.90$), indicating strong group effects.

Conclusions

Foot arch morphology plays a significant role in the organization of postural control strategies. A normal arch structure appears to provide advantages in terms of mechanical stability and sensory feedback. High and low arch profiles lead to distinct balance strategies. The use of a dynamic single-leg assessment provides a more task-specific perspective on postural control in soccer players. These findings suggest that evaluating foot arch structure and implementing individualized training programs may contribute to performance optimization and injury risk reduction in athletes.

Keywords:

foot arch profile, postural control, balance, soccer players, plantar pressure

Introduction

Postural control represents a complex functional ability that underpins coordinated movement and stability during physical activity. In sports contexts such as soccer, maintaining balance during dynamic and unilateral actions is essential for effective performance and safe movement execution. The mechanisms of postural control involve the integration of sensory input and biomechanical factors, where structural characteristics of the foot may influence stability and movement patterns. Variations in foot arch profiles can alter load distribution, proprioceptive feedback, and movement control, thereby contributing to

differences in balance performance under dynamic conditions.

Postural control is defined as the ability to maintain the body's center of mass within the limits of the base of support. This process is regulated through the continuous interaction between the central nervous system and peripheral sensorimotor structures [1, 2, 3]. In athletes, postural control is not merely a mechanism for maintaining balance. It is also considered a fundamental component for sustaining athletic performance and reducing injury risk [3, 4, 5]. This function becomes particularly critical in sports such as soccer, where unilateral loading patterns and limb-specific tasks are highly prevalent [6]. In such contexts, postural control strategies may vary depending on task demands and limb-specific characteristics [4].

Postural control is achieved through different motor strategies depending on task requirements [5, 6, 7]. Among these, the ankle, hip, and stepping strategies are the most commonly described. The ankle strategy plays a dominant role in controlling small-amplitude postural oscillations. The effectiveness of this strategy is closely related to the morphological characteristics of the foot-ankle complex and the quality of somatosensory input derived from the plantar surface [8, 9, 10]. Accordingly, the mechanical and sensory interactions between the plantar surface and the ground can be considered key determinants in the organization of postural control.

Foot arch structure represents a fundamental morphological feature that directly influences plantar contact area and pressure distribution [11, 12]. The height of the medial longitudinal arch determines the extent of plantar surface contact. It thereby modulates both mechanical stability and the intensity of sensory input transmitted to the central nervous system via plantar mechanoreceptors [10, 11, 12]. Although foot arch structure is generally considered a static morphological characteristic, it may indirectly influence the organization of ankle strategy during single-leg postural tasks. In this regard, the effects of foot arch profiles on postural control may become more pronounced in tasks where the ankle strategy predominates.

Most studies evaluating postural control in soccer players have relied on static stance assessments or non-sport-specific balance protocols [13, 14, 15]. However, given the nature of soccer, which frequently involves single-leg stance and unilateral loading tasks [14, 16], postural control should be assessed within a limb-specific and task-relevant framework. In addition, these approaches often fail to capture the dynamic and feedback-dependent nature of postural regulation during sport-specific activities. The relationship between foot arch profiles and single-leg postural control in task-specific and limb-specific contexts requires further clarification [10, 11, 17].

Furthermore, although foot arch structure is typically characterized using static measurements, its functional implications during dynamic single-leg postural control tasks have not yet been fully elucidated [12, 18, 19]. In particular, the role of foot arch profiles in the organization of postural control strategies during tasks requiring controlled postural sway remains a subject of ongoing debate. Moreover, it remains unclear whether different foot arch profiles lead to distinct directional control strategies under dynamic conditions. Therefore, the aim of the present study was to investigate the relationship between foot arch profiles and single-leg dynamic postural control in soccer players. Athletes with normal arch profiles were expected to demonstrate superior postural control performance.

High and low arch profiles were expected to be associated with distinct and less efficient control strategies.

Materials and Methods

Participants

The study was conducted using a convenience sampling approach. Male university-level licensed soccer players were voluntarily recruited from university teams competing in regional leagues during the 2025–2026 season. Foot arch profiles were determined after all measurements. Participants were subsequently categorized into three groups: high arch, normal arch, and low arch. To ensure numerical balance, a random selection procedure was applied to overrepresented groups. A computer-based randomization method (random number generator) was used, resulting in 16 participants in each group (total N = 48). All participants were actively training and competing soccer players. They were identified as right-foot dominant based on self-report. Dominance was defined as the preferred foot used for kicking a ball. Inclusion criteria included the absence of orthopedic or neurological conditions affecting the lower extremities. Participants also had no history of injury or medical treatment within the previous year that could influence performance. An a priori power analysis (G*Power 3.1) indicated that a minimum sample size of 42 participants was required to detect a large effect size ($f = 0.50$) with 80% power at $\alpha = 0.05$. Therefore, the sample size used in this study (N = 48) was considered sufficient.

The anthropometric characteristics of the participants are presented in Table 1.

Table 1. Anthropometric Characteristics of Participants (Mean \pm SD)

Variable	High Arch (n = 16)	Normal Arch (n = 16)	Low Arch (n = 16)
Age (years)	19.51 \pm 1.21	18.87 \pm 1.13	19.23 \pm 1.49
Height (cm)	182.0 \pm 6.59	178.11 \pm 6.28	175.6 \pm 6.80
Body mass (kg)	74.83 \pm 7.23	72.63 \pm 6.73	75.9 \pm 7.57
BMI (kg/m ²)	22.67 \pm 1.78	22.91 \pm 1.66	24.6 \pm 1.91

The study protocol was approved by the Non-Interventional Clinical Research Ethics Committee of Düzce University (Approval No: 206/116; Date: 27 February 2026). All procedures were carried out in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants prior to data collection.

Research Design

This study was designed as a cross-sectional

investigation to examine the relationship between foot arch profiles and single-leg dynamic postural control in soccer players. All measurements were conducted in a single session for each participant under standardized laboratory conditions. These conditions included identical flooring, equipment, and testing instructions. Testing was performed in a quiet indoor laboratory environment under consistent lighting conditions. All measurements were conducted at similar times of day to minimize circadian effects.

Anthropometric Measurements

Anthropometric assessments were conducted at the beginning of the measurement session, prior to any procedures that could induce fatigue. These assessments were performed in accordance with the standards of the International Society for the Advancement of Kinanthropometry (ISAK) (Olds, 2006). Body height was measured without shoes and in an upright standing position using a portable stadiometer (SECA 213, SECA GmbH, Germany). Body mass was recorded with participants wearing light sports clothing and no shoes, using a calibrated digital scale (SECA 813, SECA GmbH, Germany). Body mass index (BMI) was calculated as body mass divided by the square of height (kg/m^2).

Determination of Foot Arch Profiles

Foot arch profiles were determined based on plantar pressure distribution measurements. Plantar pressure data were collected using the Footscan® 7 Platform System (RSscan International, Olen, Belgium), which records data at a sampling frequency of 300 Hz. Measurements were conducted with participants standing barefoot in a relaxed upright posture. Participants performed three 10-second standing trials. The first two trials were used for familiarization. The third trial was recorded for analysis. A 30-second rest interval was provided between trials. Foot placement was standardized using visual markers. Participants stood barefoot in a relaxed upright posture with their feet positioned naturally at shoulder width. Foot arch profiles were classified using the Chippaux–Smirak Index (CSI). It was defined as the ratio of the narrowest width of the midfoot region to the widest width of the forefoot. Based on CSI values, participants were categorized as high arch (≤ 0.29), normal arch (0.30–0.39), and low arch (≥ 0.40). Only dominant foot (right foot) values were used for analysis.

Single-Leg Dynamic Postural Control Assessment

Single-leg postural control was assessed using a wireless portable balance system (Sigma System Cosmo Gamma, Cosmo). Participants stood barefoot on their dominant foot, while the non-supporting foot was lifted off the ground. They were instructed to maintain their center of mass within a visual target zone for 30 seconds

using real-time feedback. Prior to data collection, participants performed two familiarization trials to ensure adequate understanding of the task and the visual feedback system. The third trial was used for analysis. A 60-second rest interval was provided between trials. The system was calibrated individually for each participant according to the manufacturer's guidelines before testing. The target zone was defined as a circular area centered on the participant's baseline center of pressure position obtained during calibration. Visual feedback was provided continuously via a monitor positioned at eye level approximately 1.5 m in front of the participant. Directional postural sway (medial, lateral, anterior, posterior) and the percentage of time spent within the target zone were recorded. These variables were used as indicators of dynamic postural control performance.

Statistical Analysis

Statistical analyses were performed using GraphPad Prism (version 10.3.1; GraphPad Software, San Diego, CA, USA). Descriptive statistics were expressed as mean \pm standard deviation ($\bar{x} \pm \text{SD}$). The normality of data distribution was assessed using skewness and kurtosis coefficients (acceptable range: ± 2). In addition, normality was visually examined using Q–Q plots. Differences between foot arch groups were analyzed using one-way analysis of variance (ANOVA). The homogeneity of variances was evaluated using the Brown–Forsythe and Bartlett tests. The results of these tests confirmed that the assumption of homogeneity of variances was satisfied. When significant differences were found, Holm–Šídák-corrected post hoc tests were applied. Effect sizes were reported using eta squared (η^2). Statistical significance was set at $p < 0.05$.

Results

Descriptive statistics and between-group comparisons of single-leg dynamic postural control parameters obtained from the dominant foot, according to foot arch profiles, are presented in Table 2. The results of pairwise post hoc comparisons are illustrated in the corresponding figures.

As shown in Table 2, significant differences were observed between foot arch profile groups across all postural control variables, with large effect sizes ($\eta^2 = 0.81$ – 0.90). The most pronounced difference was found in time spent in the target zone. The normal arch group demonstrated substantially higher values compared with both the high and low arch groups ($F(2,45) = 158.50$, $p < 0.0001$, $\eta^2 = 0.88$). Regarding directional postural sway, distinct patterns emerged across groups. The high arch group exhibited reduced right-directed sway but increased left and posterior sway. The low arch group demonstrated markedly higher anterior sway values ($F(2,45) = 204.50$, $p < 0.0001$, $\eta^2 = 0.90$). In contrast, the normal

Table 2. Single-leg dynamic postural control parameters of the dominant foot according to foot arch profiles

Parameter	High arch (n = 16)	Normal arch (n = 16)	Low arch (n = 16)	F (2,45)	p	η^2
Right-directed postural sway (%)	42.00 ± 2.42	48.63 ± 1.09	49.44 ± 1.09	96.89	<0.0001	0.81
Left-directed postural sway (%)	58.00 ± 2.42	51.38 ± 1.09	50.56 ± 1.09	96.89	<0.0001	0.81
Anterior postural sway (%)	47.63 ± 1.59	49.06 ± 0.85	57.88 ± 2.00	204.50	<0.0001	0.90
Posterior postural sway (%)	52.38 ± 1.59	50.94 ± 0.85	42.13 ± 2.00	204.50	<0.0001	0.90
Time spent in target zone (%)	71.69 ± 3.95	90.75 ± 2.30	77.31 ± 2.87	158.50	<0.0001	0.88

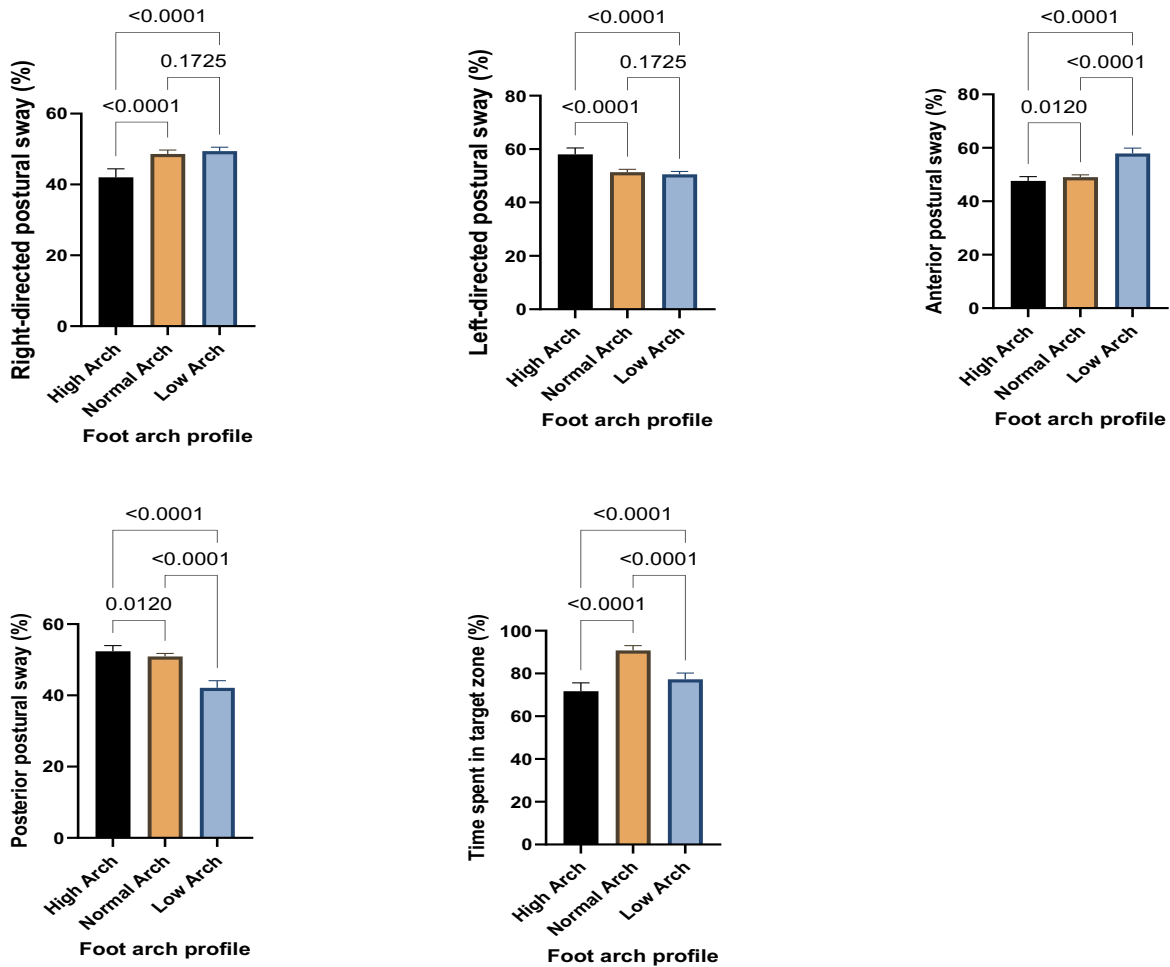


Figure 1. Post hoc comparisons of single-leg dynamic postural control parameters across foot arch profiles

arch group showed a more balanced distribution of sway across directions. This was accompanied by superior performance in maintaining position within the target zone.

The results of post hoc comparisons are presented in Figure 1.

As shown in Figure 1, post hoc analyses revealed that participants with a high arch profile exhibited significantly lower right-directed postural sway compared with both the normal arch ($p < 0.0001$) and low arch groups ($p < 0.0001$). No significant difference was observed between the normal and low arch groups ($p = 0.1725$). For left-directed postural sway, the high arch group demonstrated significantly greater sway than both the normal

arch ($p < 0.0001$) and low arch groups ($p < 0.0001$). No significant difference was observed between the normal and low arch groups ($p = 0.1725$). In terms of anterior postural sway, values were significantly higher in the low arch group compared with both the normal arch ($p < 0.0001$) and high arch groups ($p < 0.0001$). In addition, the normal arch group exhibited significantly greater anterior sway than the high arch group ($p = 0.0120$). Regarding posterior postural sway, the high arch group showed significantly greater sway than both the normal arch ($p = 0.0120$) and low arch groups ($p < 0.0001$). Furthermore, posterior sway was significantly higher in the normal arch group compared with the low arch group ($p < 0.0001$). For time spent in the

target zone, the normal arch group demonstrated significantly higher values than both the low arch ($p < 0.0001$) and high arch groups ($p < 0.0001$). In addition, the low arch group showed significantly greater time in the target zone compared with the high arch group ($p < 0.0001$).

Discussion

The aim of the present study was to investigate the relationship between foot arch profiles and single-leg dynamic postural control in soccer players. The findings demonstrated that foot arch structure significantly influences single-leg postural control performance. Large effect sizes were observed across all directional sway parameters and time spent in the target zone. These results support the notion that foot morphology plays a critical role in the organization of postural control mechanisms. They are generally consistent with previous research emphasizing the role of plantar sensory input and foot structure in balance regulation [9, 10].

One of the findings was that participants with a normal arch profile exhibited superior performance in terms of time spent within the target zone. This suggests that an optimal medial longitudinal arch height may provide advantages in both mechanical stability and plantar somatosensory feedback. Previous studies have highlighted the importance of plantar contact area and mechanoreceptor activation in the fine regulation of postural control [9, 10]. A normal arch structure may facilitate an optimal balance between rigidity and flexibility. This may enhance sensorimotor integration. However, these mechanisms were not directly measured in the present study. They are therefore interpreted based on existing theoretical frameworks. In contrast, the postural sway distribution observed in the high arch group indicated a more asymmetrical control strategy. The combination of reduced right-directed sway and increased left and posterior sway suggests that individuals with a high arch may rely on a more rigid foot structure. This may result in load transfer through a relatively limited contact area. It may lead to a more heterogeneous plantar pressure distribution and reduced quality of somatosensory input [11]. From the perspective of ankle strategy effectiveness, a high arch structure may therefore impose constraints on fine postural adjustments. These findings may reflect a shift in directional control strategy rather than a uniform reduction in stability.

The low arch group, on the other hand, exhibited increased anterior postural sway, indicating a different control pattern. Although a lower medial longitudinal arch increases plantar contact area, this broader contact does not necessarily translate into improved stability. Instead, it may reduce the precision of postural control. The increased sway in the anterior-posterior plane may reflect

greater reliance on compensatory muscular and passive structures around the ankle joint. This may result in a more reactive control strategy. Previous studies have reported that alterations in plantar contact characteristics and pressure distribution may influence postural control [12, 17]. This may be related to the patterns observed in the present study. When directional postural sway parameters are considered collectively, the findings suggest that foot arch profiles influence not only the level of postural stability but also the organization of postural control strategies. A more rigid and constrained strategy appears to characterize the high arch group. The low arch group demonstrates a wider but less controlled sway pattern. In contrast, the normal arch group exhibits a more balanced and optimized control strategy. These findings support the notion that the effectiveness of the ankle strategy is sensitive to foot morphology, particularly in single-leg tasks where ankle-based control predominates [7, 8]. Importantly, this suggests that foot morphology may influence how postural adjustments are distributed across movement directions. It does not only affect overall stability magnitude.

The present study contributes to the literature by moving beyond traditional static balance assessments and employing a dynamic task involving visual feedback. This approach more closely reflects the functional demands of soccer, where unilateral loading conditions are frequently encountered. Accordingly, the findings provide a more ecologically valid perspective on the role of foot arch morphology in sport-specific postural control. Previous studies in soccer players have predominantly relied on static or non-specific balance assessments [13, 14]. These approaches may not fully capture task-dependent postural strategies. However, it remains unclear whether the observed differences represent fundamentally distinct control mechanisms or task-specific adaptations. This warrants further investigation. From an applied perspective, these results highlight the importance of including foot arch assessment in athlete screening protocols. Furthermore, for athletes with high or low arch profiles, targeted interventions such as proprioceptive training, balance exercises, and individualized conditioning programs may be beneficial for performance optimization and injury risk reduction. More specifically, interventions may be tailored according to direction-specific deficits, such as anterior-posterior control in low arch profiles and symmetry and load distribution in high arch profiles.

Limitations of the Study and Future Research Directions

Several limitations of this study should be acknowledged. Due to the cross-sectional design,

causal relationships between foot arch profiles and postural control cannot be established. The sample consisted exclusively of male university-level soccer players. This may limit the generalizability of the findings to other populations, including female athletes, different age groups, and other sports disciplines. Foot arch profiles were determined using static plantar pressure measurements. Potential changes in arch behavior under dynamic loading conditions were not assessed. This limitation may have restricted the ability to fully capture functional foot behavior during dynamic tasks. Postural control was evaluated using a single task and only on the dominant limb. This may limit the generalizability of the findings across different task conditions and bilateral performance. No direct biomechanical or neuromuscular measurements were included. Therefore, mechanistic interpretations should be considered with caution.

Future research should consider incorporating multiple task conditions, bilateral assessments, and longitudinal or experimental designs to further elucidate the relationship between foot arch structure and postural control. Expanding the sample to include different populations may also provide deeper insight into the underlying mechanisms. Integrating biomechanical and neuromuscular analyses may further enhance this understanding. In particular, combining plantar pressure, kinematic, and electromyographic

analyses may allow for a more direct examination of the mechanisms underlying arch-related differences in postural control.

Conclusions

This study demonstrated that foot arch profiles have a significant impact on single-leg dynamic postural control in soccer players. Athletes with a normal arch profile exhibited superior postural control performance. High and low arch profiles were associated with distinct postural control strategies. These findings indicate that foot arch morphology is an important factor influencing the organization of postural control, particularly in tasks where the ankle strategy predominates. The findings suggest that foot arch structure influences not only the magnitude of postural stability but also the directional characteristics of postural control. Accordingly, the assessment of foot arch structure and the implementation of individualized training programs based on morphological characteristics may play a key role in optimizing performance and reducing injury risk in athletes. Integrating arch-specific assessments into performance evaluation may further enhance individualized training approaches.

Conflict of Interest

The authors declare no conflict of interest.

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