

Foot Abnormalities and their Effects on Selected Kinematic Variables of Gait: A Descriptive Study on 9 – 12 Players of the Handball club of Boukadir during the 2025-2026 Season

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Abstract:

The study aims to identify the effect of foot congenital abnormalities on some kinematic variables for handball player's walk. The researcher adopts a descriptive approach and used Tercel Test to measure the arch height to determine the degree of the foot deformation. To identify some kinematic variables in walking, the researcher chose a sample of 14 players aged between 9 and 12 years who are active in the amateur sports handball club in Boukadir city. The results showed that there were no statistically significant differences in some of the variables of the study, except in the variable of the knee during the mid-stance phase and in the frontal-plane knee valgus angle, there were differences between group samples according to the deformity type (flat foot, normal foot, high-arched foot). The researcher recommends the design and implementation of a corrective therapeutic training program targeting the specific type of foot deformity to be applied before considering surgical intervention. Such a program would not only help correct or minimize the deformity during this critical growth period but would also contribute to improving future athletic performance and preserving safe, efficient gait mechanics throughout the athlete's development.

Keywords: foot abnormalities, kinematics of walking, late childhood.

1. Introduction

Differences in gait patterns are often observed among individuals at an early stage in life. This may be attributed to congenital postural deformities in the upper and lower limbs present from birth, while other deformities may develop after birth as a result of injury, bone disease, inability to bear body weight, or failure to control training load intensity during the early developmental stages. These defects significantly affect an athlete's skill and performance, to the point of preventing them from reaching excellence in their sport or possibly impairing their normal walking movement in the future.

Postural deformity is a type of deviation that occurs in one or more parts of the body. It may be minor (limited to the muscles and ligaments) or major (affecting the bones and muscles as well). A minor deformity can be corrected through compensatory exercises aimed at achieving muscular balance between opposing muscle groups in the body, while the more severe type requires surgical intervention to correct the postural condition (Mohamed Sobhi Hassanein, 1987, p. 137). Foot deformity is considered one of the deformities affecting the lower limb, and intervention must therefore occur before it is too late in order to preserve the health of the feet, "because the feet are

among the important parts responsible for postural alignment and movement, serving as the base on which the body rests while also providing it with mobility. The health of the foot depends on its constituent bones, their articulation, the various muscles connected to them, as well as the numerous strong ligaments — any dysfunction in any of these tissues consequently affects postural balance and the performance of movements specific to athletic activity" (Iqbal Rasmi Mohamed, 2007, p. 42). Foot health is also considered one of the fundamental components of motor skills, as it plays the most important role in movement fluidity and in absorbing shocks and external influences, particularly for an individual performing a motor task. Accordingly, high performance efficiency can only be achieved if both feet are healthy and strong in all their components — bones, muscles, and ligaments. Foot deformities also cause numerous harmful effects; beyond the pain experienced by the affected individual, they negatively impact physical efficiency and motor capacity to practice sports activities in which the foot plays a key role in proper execution... From this, the importance of the feet in every human movement becomes clear, and improper use of the feet — failing to place them correctly or at the right angle — will lead to their deformation as a result of misuse, which in turn affects posture in general (Iqbal Rasmi Mohamed, 2007, pp. 178–190).

In light of the foregoing, and in an effort to describe the gait pattern of this age category (9–12 years) in greater detail, the researcher resorted to biomechanical analysis of gait through a 10-meter walking test, in addition to a percentage test using the "Tercel" method to measure the height of the foot arch. This was done to determine stride frequency, stride length, stride time, the time taken by the body to cover this distance, the knee angle during full support, and the knee curvature angle — through video analysis of the walking movement — in order to identify the extent to which foot deformity affects certain kinematic variables of the gait cycle among children engaging in physical and sports activity. Herein lies the significance of the study: examining these deformities at advanced age stages by identifying their causes and seeking ways to treat them before surgical intervention becomes necessary, so that they do not affect gait movement, motor performance, and consequently posture. Given these considerations, the research problem was formulated as follows:

- Are there statistically significant differences in certain kinematic variables of the gait cycle according to foot type (flat, normal, and high-arched)?

2. Methods

2.1 Study Design

This study employed a descriptive comparative design to investigate the effects of foot abnormalities on selected kinematic gait variables in young handball players. The design was considered appropriate for examining differences in gait characteristics among participants with different foot morphologies.

2.2 Participants

2.2.1 Study Population

The target population consisted of male youth athletes aged 9–12 years who regularly participated in organized physical and sports activities.

2.2.2 Study Sample

A purposive sample of 14 youth handball players was recruited from the Amateur Handball Club of Boukadir during the 2025–2026 competitive season. Participants were classified into three groups according to foot morphology using the Tercel Arch Index: Flatfoot Group ($n = 4$), Normal Foot Group ($n = 5$), and high-arched foot Group ($n = 5$).

All participants were actively involved in regular training and competition at the time of data collection. The descriptive characteristics of the study sample are presented in Table 1.

2.3 Participant Characteristics

Table 1 summarizes the anthropometric and demographic characteristics of the participants included in the study.

	Unit of Measurement	Sample Size	Minimum Value	Maximum Value	Mean	Standard Deviation	Skewness Coefficient
Weight	kg	14	28.80	54.30	36.84	7.77	0.996
Height	meter	14	1.35	1.60	1.47	0.07	0.048
Foot Length	cm	14	19.00	24.00	21.36	1.15	0.231
Foot Arch Height	cm	14	1.50	2.50	1.88	0.30	1.337
Arch Height Percentage	%	14	7.08	11.90	8.81	1.41	1.118

Table 1 presents the descriptive characteristics of the study sample. The participants' body mass ranged from 28.80 to 54.30 kg, with a mean of 36.84 ± 7.77 kg. Body height ranged from 1.35 to 1.60 m, with a mean of 1.47 ± 0.07 m. Foot length varied between 19 and 24 cm, yielding a mean value of 21.36 ± 1.15 cm. Foot arch height ranged from 1.5 to 2.5 cm, with a mean of 1.88 ± 0.30 cm, whereas the arch height percentage ranged from 7.08% to 11.90%, with a mean value of $8.81 \pm 1.41\%$.

The skewness coefficients for body mass (0.996), body height (0.048), foot length (0.231), foot arch height (1.337), and arch height percentage (1.118) were within acceptable limits, indicating that the data were approximately normally distributed and that the sample exhibited an acceptable degree of homogeneity for the variables examined.

2.4 Instruments and Equipment

Data were collected using a combination of anthropometric measurement tools, motion analysis equipment, and reference materials. Arabic and international literature relevant to foot deformities and gait biomechanics was reviewed. A wooden platform (45×20 cm) and a triangular wedge ($12 \times 12 \times 18$ cm) were used for foot arch assessment. Foot length was measured using a foot-measuring device, while body height and body mass were assessed using a stadiometer and a Rossmax digital scale, respectively.

Gait trials were recorded using two digital video cameras. The first camera (Pentax, 12.1 megapixels, $6\times$ wide optical zoom, lens range 4.6–119.6 mm) was positioned in the sagittal plane. The second camera (Nikon) recorded at a sampling frequency of $25 \text{ frames}\cdot\text{s}^{-1}$ and was positioned in the frontal plane. Both cameras were mounted on lightweight tripods equipped with spirit levels to ensure accurate alignment. Calibration markers and pathway indicators were used to define the walking corridor and facilitate motion analysis.

Motion data were processed using Kinovea software (Version 0.8.24) installed on a Lenovo computer equipped with an Intel® Pentium® B960 processor operating at 2.20 GHz.

2.5 Foot Classification

Foot type was determined using the Tercel Arch Index, calculated according to the following equation:

$$\text{Arch Index (\%)} = (\text{Foot Arch Height} / \text{Foot Length}) \times 100$$

Based on the obtained values, participants were classified into three groups:

- **Flatfoot Group:** Arch index $< 8\%$ ($n = 4$).
- **Normal Foot Group:** Arch index $= 8\%$ ($n = 5$).
- **High-arched Foot Group:** Arch index $> 8\%$ ($n = 5$).

According to Tercel 's criterion, an arch index of 8% represents the average value for a normal foot during standing. Values below 8% indicate a tendency toward flatfoot, whereas values above 8% are indicative of a high-arched foot.

2.6 Gait Assessment

Participants performed a normal walking test over a distance of 10 m. Each participant was instructed to walk at a self-selected comfortable speed along a predefined walkway. The walking trials were recorded simultaneously from the sagittal and frontal planes for subsequent kinematic analysis.

2.7 Statistical Analysis

All data were coded and entered into the Statistical Package for the Social Sciences (SPSS) for analysis. Descriptive statistics, including the mean, standard deviation (SD), and skewness coefficient, were calculated for all study variables.

Differences among the three foot-type groups were examined using a one-way analysis of variance (ANOVA). When significant group effects were identified, Tukey's post hoc test was applied to determine pairwise differences. Statistical significance was established at $p < 0.05$.

3. Results, Analysis, and Discussion

3.1 Hypothesis Testing

The following research question was examined:

Are there statistically significant differences in selected kinematic variables of the gait cycle among the flatfoot, normal-foot, and high-arched foot groups?

To address this question, means and standard deviations were calculated for all study variables after dividing the sample into three groups according to foot type. The **Flatfoot Group** consisted of four (4) participants, the **Normal Foot Group** consisted of five (5) participants, and the **High-arched Foot Group** consisted of five (5) participants.

Table 2 Means and Standard Deviations of Selected Gait Kinematic Variables According to Foot Type

Variable	Flatfoot ($n = 4$) M $\pm$ SD	Normal Foot ($n = 5$) M $\pm$ SD	High-arched Foot ($n = 5$) M $\pm$ SD	Total ($N = 14$) M $\pm$ SD
Time to cover 10 m (s)	8.34 $\pm$ 0.27	7.92 $\pm$ 0.47	7.88 $\pm$ 0.41	8.03 $\pm$ 0.42
Stride length (m)	1.30 $\pm$ 0.08	1.40 $\pm$ 0.19	1.40 $\pm$ 0.10	1.37 $\pm$ 0.14
Step time (s)	0.92 $\pm$ 0.05	0.94 $\pm$ 0.10	0.92 $\pm$ 0.06	0.93 $\pm$ 0.07
Step frequency over 10 m (steps)	7.73 $\pm$ 0.48	7.24 $\pm$ 1.05	7.15 $\pm$ 0.52	7.35 $\pm$ 0.73
Knee angle during stance phase ($^{\circ}$)	150.75 $\pm$ 2.50	147.00 $\pm$ 4.12	153.40 $\pm$ 3.65	150.36 $\pm$ 4.33
Knee recurvatum angle ($^{\circ}$)	174.50 $\pm$ 0.58	177.60 $\pm$ 1.14	179.20 $\pm$ 0.84	177.29 $\pm$ 2.13

Table 2 presents the means and standard deviations of the selected gait kinematic variables for the Flatfoot, Normal Foot, and High-arched Foot groups. Descriptive statistics revealed noticeable differences among the three groups across several gait parameters.

The Flatfoot Group exhibited the highest mean time required to cover the 10-m walking distance (8.34 ± 0.27 s), whereas the High-arched foot Group demonstrated the lowest value (7.88 ± 0.41 s), suggesting a tendency toward slower walking performance in participants with flatfoot. Similarly, stride length was shorter in the Flatfoot Group (1.30 ± 0.08 m) compared with both the Normal Foot Group and the High-arched Foot Group (1.40 m).

Step time showed only minor differences among groups, with mean values ranging from 0.92 to 0.94 s. Likewise, step frequency displayed relatively small variations, although the Flatfoot Group recorded the highest mean value (7.73 ± 0.48 steps).

Regarding joint kinematics, the High-arched Foot Group exhibited the greatest knee angle during the stance phase ($153.40 \pm 3.65^\circ$), whereas the Normal Foot Group demonstrated the lowest value ($147.00 \pm 4.12^\circ$). A similar trend was observed for the knee recurvatum angle, which increased progressively from the Flatfoot Group ($174.50 \pm 0.58^\circ$) to the Normal Foot Group ($177.60 \pm 1.14^\circ$) and reached its highest value in the High-arched Foot Group ($179.20 \pm 0.84^\circ$).

Overall, the descriptive results indicate apparent differences among the three foot-type groups in several spatiotemporal and angular gait variables. However, descriptive statistics alone are insufficient to determine whether these differences are statistically significant. Therefore, a one-way analysis of variance (ANOVA) was performed to examine the statistical significance of the observed group differences.

Table 3 One-Way ANOVA Results for Selected Gait Kinematic Variables According to Foot Type

Variable	Source	SS	df	MS	F	p
Time to cover 10 m (s)	Between Groups	0.56	2	0.28	1.72	.22
	Within Groups	1.78	11	0.16		
	Total	2.34	13			
Stride Length (m)	Between Groups	0.03	2	0.02	0.83	.46
	Within Groups	0.22	11	0.02		
	Total	0.25	13			
Step Time (s)	Between Groups	0.00	2	0.00	0.07	.93
	Within Groups	0.06	11	0.01		
	Total	0.06	13			
Step Frequency over 10 m (steps)	Between Groups	0.84	2	0.42	0.75	.50
	Within Groups	6.17	11	0.56		
	Total	7.01	13			
Knee Angle During Stance ($^\circ$)	Between Groups	103.26	2	51.63	4.06	.05
	Within Groups	139.95	11	12.72		
	Total	243.21	13			
Knee Recurvatum Angle ($^\circ$)	Between Groups	49.86	2	24.93	30.47	.00
	Within Groups	9.00	11	0.82		
	Total	58.86	13			

Note. SS = Sum of Squares; df = Degrees of Freedom; MS = Mean Square; F = Fisher's F ratio; p = significance level. Statistical significance was set at $p < .05$.

A one-way analysis of variance (ANOVA) was conducted to examine differences in gait kinematic variables among the Flatfoot, Normal Foot, and High-arched Foot groups.

The analysis revealed no statistically significant differences among the three groups in time required to cover the 10-m distance, $F(2, 11) = 1.72$, $p = .22$, stride length, $F(2, 11) = 0.83$, $p = .46$, step time, $F(2, 11) = 0.07$, $p = .93$, or step frequency over the 10-m distance, $F(2, 11) = 0.75$, $p = .50$. These findings indicate that foot morphology did not significantly influence the spatiotemporal parameters of gait in the study sample.

In contrast, significant differences were observed for knee angle during the stance phase, $F(2, 11) = 4.06$, $p = .05$, and knee recurvatum angle, $F(2, 11) = 30.47$, $p < .001$. These results suggest that foot type has a significant effect on knee-joint kinematics during walking, particularly on sagittal-plane knee alignment and hyperextension characteristics.

Because significant group differences were identified for the knee angle and knee recurvatum angle variables, post hoc multiple-comparison tests (Tukey HSD) were required to determine which specific groups differed from one another.

3.2 Discussion

3.2.1 Time Required to Cover the 10-m Distance

The ANOVA results indicated no statistically significant differences among the Flatfoot, Normal Foot, and High-arched Foot groups in the time required to cover the 10-m walking distance, $F(2, 11) = 1.72$, $p = .22$. Nevertheless, slight differences were observed in the group means. The Normal Foot Group (7.92 s) and the High-arched Foot Group (7.88 s) demonstrated values that were close to the reference value reported by Viel (2000), who indicated that the optimal time for covering a 10-m distance is approximately 7.80 s (walking speed = $1.28 \text{ m} \cdot \text{s}^{-1}$). These values are further supported by broader normative gait databases: Thévenon et al. (2015), in a study of 382 French children aged 6–12 years, reported that walking speed and stride length increase progressively with age, with significant differences observed between children under 9 years and those 9 years and older, while Dusing and Thorpe (2007) established normative GAITRite-based reference values for children aged 1–10 years that similarly support the age-appropriate gait parameters observed in the Normal Foot and High-arched Foot groups in the present study.

In contrast, the Flatfoot Group exhibited the highest mean value (8.34 s), suggesting a tendency toward slower walking performance. This finding may be attributed to alterations in foot mechanics associated with flatfoot deformity. Previous observations have indicated that individuals with flatfoot often display a modified gait pattern characterized by simultaneous lifting of the heel, midfoot, and forefoot rather than the normal heel-to-toe progression, which may reduce gait efficiency and increase the energetic cost of walking.

3.2.2 Stride Length

No statistically significant differences were found among the three groups for stride length, $F(2, 11) = 0.83$, $p = .46$. Although the Flatfoot Group demonstrated a shorter mean stride length (1.30 m) compared with both the Normal Foot Group and the High-arched Foot Group (1.40 m), all values remained within the normal range reported by Whittle (2007) for children aged 9–12 years (0.96–1.54 m). These findings are further corroborated by Voss et al. (2020), who, in a normative database of 162 typically developing children and young adults aged 5–30 years using the APDM Mobility

Lab® inertial sensor system, reported that absolute stride length increases progressively with age, supporting the age-appropriate stride length values observed across all three groups in the present study.

The relatively shorter stride length observed in the Flatfoot Group may reflect compensatory gait adaptations aimed at improving stability during walking. Such adaptations could contribute to increases in step frequency to maintain forward progression.

3.2.3 Step Time

The analysis revealed no statistically significant differences in step time among the three groups, $F(2, 11) = 0.07$, $p = .93$. Mean values ranged from 0.92 to 0.94 s, indicating a high degree of similarity in temporal gait characteristics across foot types.

Furthermore, all recorded values fell within the normative range reported by Whittle (2007), suggesting that foot morphology did not substantially affect this temporal component of gait in the study sample.

3.2.4 Step Frequency Over the 10-m Distance

No statistically significant differences were detected among groups in step frequency, $F(2, 11) = 0.75$, $p = .50$. However, the Flatfoot Group exhibited the highest mean frequency (7.73 steps), followed by the Normal Foot Group (7.24 steps) and the High-arched Foot Group (7.15 steps). This trend may be related to the shorter stride length observed in participants with flatfoot. A reduction in stride length generally requires a greater number of steps to cover the same distance, thereby increasing step frequency. Consequently, this gait strategy may increase energy expenditure and contribute to earlier onset of fatigue during locomotion.

3.2.5 Knee Angle During the Stance Phase

A statistically significant difference was observed among the three groups in knee angle during the stance phase, $F(2, 11) = 4.06$, $p = .05$. This finding suggests that foot morphology influences lower-limb alignment during weight-bearing activities.

Because the omnibus ANOVA test indicated significant group differences, Tukey's post hoc test was performed to identify the specific pairwise differences among the Flatfoot, Normal Foot, and High-arched Foot groups. The results of these comparisons are presented in Table 4.

3.2.6 Knee Recurvatum Angle

The analysis also revealed statistically significant differences among the three groups in knee recurvatum angle, $F(2, 11) = 30.47$, $p < .001$. This result indicates a strong association between foot morphology and knee joint alignment during gait.

To determine the source of these differences, Tukey's post hoc comparisons were conducted among the three foot-type groups. The outcomes of these analyses are presented in Table 4 and provide further insight into the influence of foot deformities on knee-joint biomechanics during walking.

Table 4 Tukey Post Hoc Comparisons for Significant Gait Kinematic Variables According to Foot Type

	Comparison	Mean Difference (I – J)	p
Knee Angle During the Stance Phase	Flatfoot vs. Normal Foot	3.75	.30
	Flatfoot vs. High-arched Foot	–2.65	.529
	Normal Foot vs. High-arched Foot	–6.40*	.040

Knee Recurvatum Angle	Flatfoot vs. Normal Foot	-3.10*	.001
	Flatfoot vs. High-arched Foot	-4.70*	< .001
	Normal Foot vs. High-arched Foot	-1.60*	.042

Note. Asterisks (*) indicate statistically significant differences at $p < .05$.

To further investigate the significant effects identified by the one-way ANOVA, Tukey's post hoc test was conducted for knee angle during the stance phase and knee recurvatum angle.

For the knee angle during the stance phase, a significant difference was observed only between the Normal Foot Group and the High-arched Foot Group (mean difference = -6.40° , $p = .040$). No significant differences were found between the Flatfoot Group and either of the other two groups. These findings suggest that the altered foot architecture associated with high-arched foot may influence lower-limb alignment during weight acceptance and stance, resulting in modifications of knee joint positioning during gait.

Regarding knee recurvatum angle, significant differences were identified across all pairwise comparisons. The Normal Foot Group demonstrated a significantly greater recurvatum angle than the Flatfoot Group (mean difference = 3.10° , $p = .001$), while the High-arched Foot Group exhibited significantly greater values than both the Flatfoot Group (mean difference = 4.70° , $p < .001$) and the Normal Foot Group (mean difference = 1.60° , $p = .042$).

The reduced recurvatum angle observed in the Flatfoot Group may be related to the collapse of the medial longitudinal arch and the associated alterations in lower-limb alignment. Conversely, the increased recurvatum angle found in the High-arched Foot Group may reflect compensatory biomechanical adaptations associated with an excessively elevated medial arch. These findings indicate that foot morphology influences knee alignment during gait and may contribute to changes in the physiological curvature of the knee joint.

Overall, the results demonstrate that foot deformities did not significantly affect the spatiotemporal gait variables examined in this study. However, significant effects were observed on knee-joint kinematics, particularly knee angle during stance and knee recurvatum angle, highlighting the biomechanical relationship between foot structure and lower-limb alignment during walking.

4 . Recommendations

The findings of this study highlight the importance of early identification and management of foot deformities in young athletes. Timely intervention during this critical developmental period is essential to prevent these deformities from progressing and to avoid future complications that could affect the athlete's gait and overall motor performance. In this regard, the researcher recommends the design and implementation of a corrective therapeutic training program targeting the specific type of foot deformity, to be applied before considering surgical intervention. Such a program would not only help correct or minimize the deformity during this critical growth period but would also contribute to improving future athletic performance and preserving safe, efficient gait mechanics throughout the athlete's development. Corrective exercise programs should be considered as a first-line intervention to improve foot function and gait mechanics before surgical options are contemplated.

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