JETR

JOURNAL OF
EXERCISE THERAPY
AND REHABILITATION

Journal of Exercise Therapy and Rehabilitation. 2026;13(1):40-47. DOI: 10.15437/jetr.1904937

ORIGINAL ARTICLE

Comparative analysis of foot biomechanical characteristics in adolescent football and handball players and sedentary individuals: a retrospective study

Adölesan futbol ve hentbol oyuncularında ayak biyomekanik özelliklerinin sedanter bireylerle karşılaştırılması: retrospektif çalışma

Büşra SEZER[1], Şulenur YILDIZ[1]

Abstract

Purpose: Foot structure during adolescence may vary due to growth-related changes and differences in physical activity levels. However, evidence regarding the impact of regular sports participation on foot biomechanics remains limited. This study aimed to retrospectively compare foot biomechanical characteristics between adolescents with and without regular sports participation.
Methods: Sixty healthy adolescents aged 10–18 years were classified into a sports-active group (n=30) and a non-sports group (n=30). Foot biomechanics were assessed using the Staheli Index (SI) obtained from ink footprint analysis, the Foot Posture Index (FPI), and the hallux valgus (HV) angle.
Results: A statistically significant difference in age was observed between the groups (p=0.049); however, adjustment for age did not alter the main findings. The sports-active group demonstrated significantly lower Foot Posture Index scores for both feet (p=0.005 and p=0.003) and lower Staheli Index values (p=0.003 and p=0.001). Group differences in Foot Postur Index remained significant after age adjustment (right: p=0.024; left: p=0.019). No significant differences were detected in Hallux Valgus angles (p > 0.05).
Conclusions: Adolescents who participate in sports regularly exhibit a more neutral foot posture and better preservation of the medial longitudinal arch. These findings support a potentially beneficial role of organized sports in adolescent foot development, provide a foundation for future research, and underscore the need for well-designed longitudinal studies to clarify causality.
Keywords: Sports, Posture, Foot deformities, Adolescent.

Öz

Amaç: *Ergenlik döneminde ayak yapısı, büyüme ile ilişkili değişiklikler ve fiziksel aktivite düzeylerindeki farklılıklara bağlı olarak değişiklik gösterebilir. Ancak düzenli spor yapmanın ayak biyomekaniği üzerindeki etkisine dair kanıtlar sınırlıdır. Bu çalışma, spor yapma alışkanlığı olan ve olmayan ergenlerin ayak biyomekanik özelliklerini retrospektif karşılaştırmayı amaçlamıştır.*
Yöntem: *10–18 yaş arası 60 sağlıklı ergen, spor yapan grup (n=30) ve spor yapmayan grup (n=30) olarak sınıflandırılmıştır. Ayak biyomekaniği, mürekkep taban izi analizi ile elde edilen Staheli İndeksi (Sİ), Ayak Postür İndeksi (APİ) ve halluks valgus (HV) açısı kullanılarak değerlendirilmiştir.*
Bulgular: *Gruplar arasında yaş açısından istatistiksel olarak anlamlı bir fark bulunmuştur (p=0,049); ancak yaş farkı dikkate alınarak yapılan düzeltme sonrasında temel bulgular değişmemiş ve grup farklılıkları hâlâ anlamlıdır. Spor yapan grup, her iki ayakta da ayak postür indeksi skorları açısından anlamlı şekilde daha düşük değerler göstermiştir (p=0,005 ve p=0,003) ve Staheli İndeksi değerleri daha düşük bulunmuştur (p=0,003 ve p=0,001). Yaşa göre yapılan düzeltme sonrasında Ayak postür indeksi'ndeki grup farkları anlamlılığını korumuştur (sağ: p=0,024; sol: p=0,019). Halluks valgus açılarında ise anlamlı bir fark bulunmamıştır (p > 0,05).*
Sonuçlar: *Düzenli olarak spor yapan ergenlerde ayak postürü daha nötral olup, medial longitudinal ark daha iyi korunmaktadır. Bu bulgular, organize sporların ergenlik döneminde ayak gelişimi üzerinde potansiyel olarak yararlı bir rolü olabileceğini desteklemekte, gelecekte yapılacak araştırmalar için bir temel sunmakta ve nedenselliğin açıklığa kavuşturulması amacıyla iyi tasarlanmış uzunlamasına çalışmalara duyulan ihtiyacın önemini vurgulamaktadır.*
Anahtar kelimeler: *Spor, Postür, Ayak deformiteleri, Adölesan.*

1: Hacettepe University, Faculty of Physical Therapy and Rehabilitation, Ankara, Türkiye.
Corresponding Author: Sulenur Yildiz : subasisulenur@gmail.com
ORCID IDs (order of authors): 0009-0007-7739-364; 0000-0001-7441-3463.
Received: March 9, 2026. Accepted: March 30, 2026.

INTRODUCTION

Adolescence represents a developmental phase marked by rapid skeletal and muscular growth, which is associated with biomechanical changes in the body's center of mass and the forces produced during movement.[1,2] Although the World Health Organization defines adolescence as the chronological age range of 10–19 years, the timing and rate of development of bodily structures differ within this period.[3] When foot development is considered, complete ossification of the foot bones is known to occur within the first decade of life, and following the ossification process and closure of the epiphyseal plates, the feet typically attain adult dimensions between the ages of 15 and 21.[4]

Feet that exhibit pronation in childhood progressively adopt their definitive posture as maturation occurs. Throughout this developmental process, both intrinsic and extrinsic factors play a role in shaping foot development and foot posture.[5] Foot development is an important marker of the body's developmental process, with maximal increases in foot length occurring early in puberty, before peak height growth.[6,7] Foot biomechanics, which completes its development toward the end of adolescence, plays a critical role in both daily functional activities and sports participation.[8] Engagement in regular physical activity or sports at an early age may represent one of the most influential extrinsic factors affecting foot development.[8] Therefore, adolescence represents a critical period for evaluating foot structure and biomechanics due to rapid growth and ongoing physiological and anatomical changes.[9]

It is important to examine the foot biomechanical characteristics in relation to sports participation, which represents one of the extrinsic factors influencing the development of neuromuscular skills during adolescence. Although the rate of maturation related morphological changes is similar between athletes and non-athletes, evidence suggests that athletes may exhibit a higher rate of adaptation within the muscle tendon system.[10] This finding indicates that sports participation may contribute to the development of motor control in adolescents through adaptations in the muscle–tendon system. The medial longitudinal arch (MLA), which is supported by this system, plays a key role in load transfer, shock absorption, and lower-extremity alignment. Accordingly, sports participation during adolescence may exert significant effects on foot biomechanical properties via the MLA. Therefore, comparative investigation of adolescents with and without sports participation is warranted. Among the measurements commonly used to assess foot posture and arch morphology in clinical and research settings are the Foot Posture Index (FPI-6) and the Staheli Index (SI), calculated from footprint analysis.[11,12] However, studies directly comparing adolescents with and without regular exercise habits using standardized measures such as the FPI-6 and Staheli Index have not been found; the existing literature generally examines younger age groups or uses only a single measurement method.[12-15] Additionally, identifying the parameters that may have potential effects on normal foot development during adolescence facilitates understanding of important risk factors related to any misalignment of the foot and other functional disorders.[16]

This study aimed to address the lack of evidence regarding the comprehensive assessment of foot biomechanical characteristics in adolescents using standardized criteria, taking into account the natural variability of foot posture during the developmental period and the possible modifying effects of participation in sports. In this context, the primary objective of this study is to compare the foot biomechanical characteristics of adolescent football and handball players with those of sedentary adolescents in a retrospective design. By providing detailed comparisons between athletes in specific sports and sedentary peers, this study aims to contribute to the literature by clarifying how organized sports participation may influence foot structure and posture during adolescence, offering insights for clinicians and researchers interested in adolescent foot biomechanics and injury prevention.

METHODS

Retrospective observational study

Adolescents who were evaluated at at the Physical Therapy and Rehabilitation Clinics, Hacettepe University, Turkey between June

2024 and January 2025 were retrospectively reviewed in this observational study.

Participants

The study included data from healthy adolescents aged 10–18 years who participated on a voluntary basis. Individuals with diagnosed orthopedic, neurological, or rheumatologic conditions; a history of lower extremity trauma or surgery; or a body mass index exceeding 30 kg/m² were excluded. Participants in the sports group were adolescent football and handball players who had participated in structured training sessions 2–3 times per week for at least one year; they were not professional athletes. The control group consisted of sedentary adolescents who did not engage in any regular sports or physical activity but attended school and carried out routine daily activities.

Procedure

An a priori power analysis was conducted using G*Power (version 3.1.9.7) for a two-tailed independent samples t-test (α=0.05, power=0.80). Based on pilot data obtained from 20 participants per group, the effect size calculated for the right Foot Posture Index (FPI) score was Cohen's d=1.06. The analysis indicated that a minimum of 15 participants per group was required. To enhance the robustness and precision of the findings, 30 adolescents were included in each group (total n=60). The Staheli Index, Foot Posture Index (FPI-6), and hallux valgus angle were predefined as the primary outcome measures. Demographic characteristics, including age, sex, height, and body weight were extracted from the assessment records.

Measures

Data related to foot biomechanics were retrospectively obtained from the participants' assessment forms, including the following evaluations.

Foot posture was assessed using the Foot Posture Index (FPI).[11] The Foot Posture Index (FPI) is a six-item clinical tool designed to assess foot posture in multiple planes, classifying it as pronated, neutral, or supinated. The assessment items include palpation of the talar head, inspection of the curves above and below the lateral malleolus, calcaneal inversion/eversion, prominence of the talonavicular joint, medial longitudinal arch configuration, and forefoot abduction/adduction relative to the hindfoot. Each item is scored on a scale from -2 to +2, producing a total score between -12 and +12. Total FPI scores of 0 to +5 indicate normal foot posture, +6 to +9 indicate pronation, +10 to +12 indicate excessive pronation, -1 to -4 indicate supination, and -5 to -12 indicate excessive supination. In this evaluation, the right and left feet are assessed separately while the participant is in a standing position.

The Harris Mat was used to assess participants' medial longitudinal arches. The Staheli Index (SI) is a footprint-based metric used to quantify the height of the medial longitudinal arch and is commonly applied to identify flatfoot or high-arched feet. The SI was calculated as the ratio of the narrowest portion of the midfoot to the widest portion of the hindfoot, based on footprints obtained from an inked surface. Arch classification was defined as high (pes cavus) for ratios ≤ 0.4, normal for ratios between 0.5 and 0.7, and low (pes planus) for ratios ≥ 0.8.[12]

The hallux valgus (HV) angle, defined as the angle between the longitudinal axes of the first metatarsal and the proximal phalanx, is used to evaluate the severity of hallux valgus deformity. Bilateral measurements were performed using a universal goniometer, with angles greater than 15° considered indicative of HV.[17]

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics version 23.0 (IBM Corp., Armonk, NY, USA).[18] Data distribution was assessed using skewness and kurtosis values. Continuous variables were expressed as median (interquartile range) due to non-normal distribution. Categorical variables were presented as frequencies and percentages. Between-group comparisons were conducted using the Mann–Whitney U test. Spearman correlation analysis was used to evaluate associations between age and foot parameters. ANCOVA was performed for FPI to control for age differences between groups, with effect sizes reported as partial eta squared (η^2). A two-tailed p-value <0.05 was considered statistically significant.

RESULTS

A total of 60 adolescents were included in the analysis. The demographic and physical characteristics of the participants are presented in Table 1. Group 1 (adolescent football and handball players, n=30) and Group 2 (sedentary adolescents, n=30) were compared. The median age was 14 (IQR: 3) years in Group 1 and 12 (IQR: 4) years in Group 2, with a statistically significant difference between groups (p=0.049). No significant differences were observed between the groups in body mass index or sex distribution.

Table 1. Demographic and physical characteristics of adolescents.

	Group 1 (N=30)	Group 2 (N=30)	
	Median (IQR)	Median (IQR)	p
Age (years)	14 (3)	12 (4)	0.49
	X±SD	X±SD	
BMI (kg/m²)	19.53±2.08	19.47±3.20	0.93
Gender	n (%)	n (%)	
Female	16 (53)	15 (50)	0.79
Male	14 (47)	15 (50)	

BMI: Body Mass Index. IQR: Interquartile Range. Group 1: Adolescent football and handball players. Group 2: Sedentary adolescents not engaged in regular sports activity.

Table 2. Comparison of foot biomechanics results between groups.

	Group 1 (N=30)	Group 2 (N=30)	
	Median (IQR)	Median (IQR)	p
Foot Posture Index			
Right	2.5 (6.25)	6 (6)	0.005*
Left	3 (6.25)	6 (5.25)	0.003*
Staheli Index			
Right	0.59 (0.18)	0.70 (0.37)	0.003*
Left	0.57 (0.16)	0.69 (0.28)	0.001*
Hallux valgus a. (°)			
Right	8.15 (6)	9 (5)	0.980
Left	8 (5.5)	7.5 (5)	0.970

* p<0.05. a: angle. IQR: Interquartile Range. Group 1: Adolescent football and handball players. Group 2: Sedentary adolescents not engaged in regular sports activity.

Comparisons of foot biomechanical parameters between adolescent football and handball players and sedentary adolescents are presented in Table 2. The Foot Posture Index scores were significantly higher in sedentary adolescents for both feet (right: p=0.005; left: p=0.003). Similarly, Staheli Index values were significantly greater in the sedentary group (right: p=0.003; left: p=0.001). No significant differences were observed in hallux valgus angles (p > 0.05).

Spearman correlation analysis revealed a moderate negative association between age and FPI scores for both feet (right: ρ=-0.50, p=0.004; left: ρ=-0.49, p=0.006) (Table 3). No significant correlations were found between age and Staheli Index or hallux valgus angles (p > 0.05).

To account for the age difference between groups, an ANCOVA was performed controlling for age (Table 3). After adjustment, group differences in FPI scores remained statistically significant (right FPI: p=0.024, η^2=0.086; left FPI: p=0.019, η^2=0.093). Age was also independently associated with FPI scores (right: p=0.020, η^2=0.091; left: p=0.016, η^2=0.098), indicating moderate effect sizes.

DISCUSSION

This study examined differences in foot biomechanics between adolescents who regularly participated in organized sports (handball and football) and those without regular sports participation. The findings indicate that adolescents with regular sports habits exhibit significantly different foot biomechanical characteristics compared with their non-sporting peers. Lower Foot Posture Index and Staheli Index values observed in the physically active group suggest better maintenance of the medial longitudinal arch with a more optimal level of foot pronation. In this respect, our study is consistent with the literature suggesting that regular exercise and physical activity are associated with positive adaptations in foot biomechanics, including arch structure and postural alignment.[19-22]

As sport is considered a subcategory of physical activity, this finding is further supported by studies examining physical activity levels in relation to foot posture. Previous research comparing adolescents with

Table 3. Age-adjusted analysis and correlation results.

	Spearman ρ (Age)	p	Adjusted p (Group)	Partial η² (Group)	p (Age)	Partial η² (Age)
Foot Posture Index						
Right	-0.50	0.004	0.024	0.086	0.020	0.091
Left	-0.49	0.006	0.019	0.093	0.016	0.098
Staheli Index						
Right	-0.33	0.072				
Left	-0.26	0.16				
Hallux Valgus Angle						
Right	0.188	0.319				
Left	0.217	0.249				

Spearman correlation analysis was used to evaluate associations between age and foot parameters.
ANCOVA was performed only for FPI due to significant age association. Effect sizes are reported as partial eta squared (η²).

and without pes planus reported significantly lower physical activity levels in adolescents with pes planus, suggesting an association between reduced activity and less optimal foot posture.[23] Accordance with this evidence, the present findings suggest that regular participation inorganized sports may contribute to preserving arch structure by counteracting the tendency towards arch flattening. This assumption is supported by studies demonstrating that targeted intrinsic foot muscle training leads to improvements in medial longitudinal arch morphology and function, highlighting the role of repetitive muscular loading in arch support.[20,24] Accordingly, repetitive sport-specific loading may act as an indirect intrinsic muscle training, enhancing muscular support and neuromuscular control of the medial longitudinal arch. In addition, previous research has reported more physiological plantar load distribution in physically active individuals, whereas inactive individuals tend to exhibit greater rearfoot loading, suggesting a potential role of regular mechanical loading in foot biomechanics.[25] Interestingly, a randomized clinical trial comparing short foot exercise with a non-biomechanical function exercise reported no significant between group differences in Foot Posture Index or navicular drop, although both groups demonstrated improvements from baseline.[26] This finding suggests that even nonspecific or low intensity foot related exercises may induce better postural adaptations, potentially through increased neuromuscular activation or general mechanical loading. Similarly, Eldemir et al. (2025) reported greater navicular height in physically active university students, supporting the notion that repeated and structured mechanical loading promotes optimal arch morphology.[27] With all these information, our study supports the association between regular participation in organized sports and favorable foot structural characteristics. However, longitudinal research is still necessary to determine the long-term persistence of these adaptations and their underlying biomechanical mechanisms. In this context, Bukowska et al. (2021) reported that arch length tended to flatten with increasing age in young male athletes undergoing football training. These findings indicate that while sports participation may influence arch characteristics, age-related maturation and sport-specific loading patterns may simultaneously contribute to structural adaptations.[28]

In our study, age also emerged as an important factor. It differed significantly between groups and showed a moderate negative association with FPI scores, consistent with the natural maturation of the medial longitudinal arch during adolescence. After adjusting for age using ANCOVA, group differences in FPI scores remained statistically significant, indicating that these differences cannot be explained solely by age-related development. Together, these findings suggest that although growth and maturation influence foot posture, regular sports participation may exert an additional independent effect.

Despite these favorable findings, evidence regarding the possible effects of sports participation on foot posture remains inconsistent. For example, a study comparing elite collegiate athletes participating in high-impact sports with sedentary students reported significantly higher Foot Posture Index scores in the athletic group, indicating a greater tendency towards foot pronation despite regular sports participation.[14] Similarly, Spiteri (2024) reported a high prevalence of pronated foot posture among children attending a national sports school.[29] In addition, children participating in artistic and rhythmic gymnastics have been shown to exhibit a tendency toward pronation, characterised by increased hindfoot loading under static conditions.[30] In addition, a posturographic study examining the effects of long-term sports participation reported that athletic training may be associated with subtle alterations in plantar pressure distribution and postural control rather than uniformly favourable adaptations. In that study, athletes exhibited greater asymmetry in foot-loading patterns and increased anteroposterior centre of pressure displacement compared with non-athletes, suggesting sport-specific postural adaptations shaped by training intensity and the specific mechanical demands of the sport.[31] Supporting this interpretation, footprint-based research by Kulthanan et al. demonstrated distinct plantar imprint patterns in athletes compared with non-athletic individuals, indicating that long-term sports participation may influence arch characteristics and plantar loading through mechanical adaptation rather than consistent structural improvement.[32] Collectively, these findings indicate that variations in sport type and training programs may lead to different foot postural adaptations. Supporting this variability, Zhang et al. (2022) highlight that foot morphology is dynamic and adapts to repetitive loading, indicating that sport-specific postural adaptations arise from complex interactions between mechanical demands and individual musculoskeletal characteristics.[33]

In addition to structural and postural adaptations, sport-related foot characteristics may also be reflected in functional performance outcomes. Research conducted in professional football players reported significant associations between Foot Posture Index scores, plantar pressure distribution, and measures of static and dynamic balance, suggesting that long-term sports participation may influence not only foot posture but also postural control strategies.[34] These findings suggest that sport-related foot adaptations in adolescents can be considered not only in terms of isolated structural changes, but also within a broader biomechanical and functional context.

Within this context, the present study adds to the existing evidence by demonstrating that regular participation in organized sports during adolescence is associated with measurable differences in foot biomechanical characteristics. Our findings suggest that athletic adolescents tend to maintain more resilient and optimal arch profiles compared with their sedentary peers, who may lack sufficient repetitive mechanical loading to support arch integrity. However, it should also be considered that foot posture is a multifactorial characteristic influenced not only by current sports participation but also by previous physical activity habits and developmental factors during childhood. Therefore, the observed differences cannot be attributed solely to participation in football and handball.

Overall, these findings suggest that participation in organized sports during adolescence may play a meaningful role in supporting the development of the foot arch and postural alignment, thereby contributing to the existing literature on adolescent foot biomechanics.

Limitations

The findings of this study should be interpreted considering several limitations. First, the inclusion of specific sports branches, namely football and handball, as well as variability in training duration within the sports group, may have affected foot biomechanics outcomes. This may limit the generalizability of the results to other athletic disciplines. Additionally, sports history and training intensity were based on self-reported data, introducing the possibility of recall bias. Furthermore, foot posture may also have been influenced by prior physical activity habits and developmental characteristics during childhood, which were not controlled for in this study.

Future studies including a broader range of sports and adopting longitudinal designs that follow adolescents through skeletal maturation would provide more comprehensive insights into the development of these structural adaptations.

Conclusion

This study demonstrates that regular participation in organized sports during adolescence is associated with a more neutral foot posture and better preservation of the medial longitudinal arch. Our findings suggest that regular sports participation may serve as a protective factor against age-related arch flattening by promoting beneficial biomechanical adaptations during critical growth periods. Although changes in foot structure due to growth are inevitable, structured sports participation appears to support the structural integrity of the developing foot. From a clinical and preventive perspective, encouraging sports participation during adolescence may play an important role in promoting long-term foot health and reducing the risk of biomechanical dysfunction in later life. While these findings suggest a positive association between sports participation and foot health, longitudinal studies are needed to clarify the long-term effects of specific sporting disciplines on foot development and musculoskeletal outcomes.

Acknowledgement: *None*

Authors' Contributions: **BS:** Study conception and design, data collection, analysis and interpretation of results and draft manuscript preparation; **SY:** Study conception and design, analysis and interpretation of results and draft manuscript preparation.

Funding: *None*

Conflicts of Interest: *None*

Ethical Approval: Ethical approval for the study was granted by the Ethics Committee of the Department of Physical Therapy and Rehabilitation, Hacettepe University, Turkey on January 23, 2025 (Approval No. FTREK 24/138).

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