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Effect of Athletic Status on Medial Longitudinal Arch (MLA) in Individuals Under 20 Years of Age

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ABSTRACT

Introduction
The medial longitudinal arch (MLA) plays a role in foot function and injury prevention, particularly during growth. Its shape could be age- and chronic athletic loading-dependent. The aim of this study was to investigate the effect of participation in sports on MLA development in participants under the age of 20 years.

Methods
A cross-sectional study on 494 subjects (256 boys and 238 girls) aged below 20 years was undertaken. Subjects were divided into four age groups and further divided into athletes and non-athletes. Foot morphology was quantified using a 3D foot scanner, and the Arch Index was calculated. Independent T-tests were run to ascertain the effect of athletic status on the Arch Index for each age group.

Results
Athletes exhibited lower Arch Index values than non-athletes in some subgroups, most significantly in boys aged 12–15 and girls aged 16–19. These differences were statistically significant in some cases ($p < 0.05$), and in others, borderline (e.g., $p = 0.05$ and $p = 0.08$). The effect size was small, and asymmetries between the right and left foot existed—greater in the left foot of boys and the right foot of girls.

Conclusion
The findings suggest the possible association of sport participation with higher MLA height during developmental years. However, due to small effect sizes and borderline statistical significance in some groups, the results need to be interpreted carefully. More prospective research is needed to establish the type, intensity, and duration of sport playing roles in MLA development.

Keywords: Words, Athletic Status, Gender, The Medial Longitudinal Arch (MLA), Age

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1- Introduction

Physical condition at early development stages profoundly influences body biomechanics and musculoskeletal adaptations [1]. Systematic reviews and meta-analyses have demonstrated that long-term physical training leads to substantial physiological and structural adaptations in many organ systems, including the musculoskeletal system and weight-bearing joints [2-5]. Among the most important manifestations of such adaptations is alterations in foot arch morphology after exercise [6]. The foot arch, or the medial longitudinal arch (MLA), absorbs force and redistributes it, as well as shock absorbency, when undertaking static and dynamic activities such as standing, walking, and running. Flatfoot, normal arch, and high arch are commonly classified and each has a unique performance and risk of injury [7-9]. Walking is a repetitive biomechanical activity where parameters such as body weight and pattern of loading can influence the MLA structure [10]. As crucial as it is to function, the foot arch is positioned centrally in terms of biomechanical economy, injury protection, and the development of overuse conditions due to abnormal pressure transmission [11-14]. Therefore, understanding the structural modifications induced by different types of physical activity throughout development is essential for the optimization of performance and prevention of injury [15]. Notably, recent evidence suggests that morphological modifications of the MLA during development have potentially persistent consequences for health [16]. Morphological changes in MLA are typically either congenital or acquired. Congenital flatfoot, occurring at birth, is typically flexible and associated with global developmental characteristics[17]. Acquired flatfoot, in contrast, is well documented in adolescent athletes and results from cumulative repetitive stress generated by high levels of physical loading[18]. Whereas congenital flatfoot is usually benign and less directly associated with the potential for injury, acquired flatfoot, particularly its association with chronic athletic use, can lead to significant biomechanical derangement and pose a predisposition for musculoskeletal damage. This current study focuses specifically on acquired flatfoot in active children and differentiates this condition from the congenital condition based on both etiology and clinical consideration.

Impact sports such as running, weightlifting, and tennis have been observed to induce significant changes in foot arch shape [19,20]. Although the MLA is a protective mechanism against repetitive load and impact, repeated stress may result in reduction or collapse of the arch, which renders a person more vulnerable to injury [21,22]. Such changes are especially frequent in athletes on long-term, high-level training [8,23]. For example, the frequency of flatfoot among distance runners [24] and sport-specific adaption in gymnastics [25] demonstrate how various types of physical activities differentially affect the development of arches. Football and basketball, which involve lateral or multi-directional movements, are placing specific mechanical demands upon the foot, and these result in changes of arch structure over time [26]. These impacts are determined not only by sport type, but also by frequency, intensity, and duration of exercise, and developmental status of the individual.

Structural modifications in the MLA, height increase or decrease, are associated with knee, ankle, and spine injuries [27,28]. The majority of these injuries are induced by abnormal plantar pressure distribution [29,30]. Changed MLA morphology individuals at risk of joint overload and ankle sprain. For example, runners have been found to have an increased lower arch, which can load the knee and hip and cause chronic overuse injuries such as patellofemoral pain syndrome [31,32]. Therefore, regular monitoring and biomechanical assessment of the MLA should be done to avoid long-term injury.

Different studies have examined the influence of sport-specific loading on foot morphology [26,33-35]. Vertical ground reaction force-high sports such as running and weightlifting were associated with MLA loss [36], while low-impact activities result in minimal change in arch shape [37-39]. Moreover, lateral or pivot activities such as football, tennis, and basketball were shown to alter transverse arch size and plantar pressure patterns [40-43]. Repetitive and asymmetrical loading during these sports has the propensity to load mechanical stresses on specific areas of the foot, leading to localized morphological adaptations [44,45]. Interestingly, these adaptations are age, gender, and involvement-level dependent, further accentuating the need for subgroup-specific analysis. This study therefore analyzes the impact of sports status on the morphology of medial longitudinal arch in individuals under 20 years of age - a phase of indispensable development with high musculoskeletal plasticity. Based on variation analysis between sporting and non-sporting adolescents at different age ranges. Sports participation, as it pertains to its type, intensity, and duration, is forecasted to have a correlation with extensive changes in the medial longitudinal arch of children and adolescents under the age of 20 years.

2- Methods

2-1- Data Collection and Inclusion/Exclusion Criteria

To ensure reliability and validity of the study results, specific inclusion and exclusion criteria were established. Participants' choice was based on their general state of health as well as their ability to stand alone during the process of 3D scanning. Participants suffering from musculoskeletal, neurological, or cardiovascular illness, or physical injury, were excluded since the mentioned conditions may alter the architecture of the foot as well as biomechanics and may lead to distortion of data [46]. Participants complaining of pain, tiredness, or who were unable to be scanned due to technical issues were also excluded from the study (Figure 1, Section A).

Additional exclusions were based on the following reasons:

1. Inpatients with unacceptable foot position during scanning (rotation > 5°) were excluded to provide consistency and accuracy in alignment of the feet.
2. Suboptimal image quality scans, e.g., high noise or distortion which could not be removed in preprocessing, were rejected to maintain data integrity.
3. Inadequate anatomical data, such as images containing over 5% missing data points or missing necessary foot landmarks, was discarded to offer full representation of the foot structure.

These guidelines were implemented to reduce possible bias and maintain consistency of collected data [47].

Participants were categorized into two groups based on their level of physical activity in the past year, as presented in the demographic questionnaire. The categorization was informed by the conceptual model provided by Gatti [48], with a focus on frequency and intensity of physical activity among youth.

- **Physically Active Group**: The group included participants who had reported doing planned physical activity for a minimum of 150 minutes per week in the previous year. They did recreational or school sports (e.g., football, running, volleyball), but not professional or elite, at this time. They did physical activity on a regular and consistent basis to qualify as regular moderate physical activity.
- **Physically Inactive Group**: Those participants who had not engaged in any organized physical activity or formal sport over the previous year were considered to be inactive. They did not exercise at all, apart from usual, everyday movements or light activities.

This separation allowed for better differentiation between active and inactive adolescents and the ability to examine additional differences in foot arch between the levels of activity and the sexes.

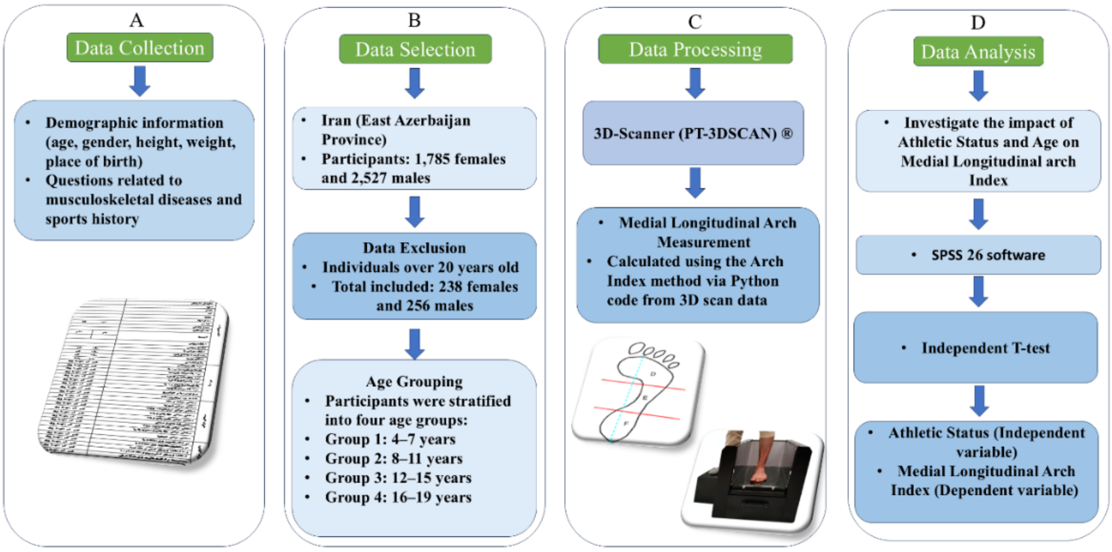

Fig. 1 Overview of the Methodology: **(A)** Collection of demographic data, including sports history, height, age, and related variables; **(B)** Selection of participants under 20 years of age; **(C)** Data acquisition using a three-dimensional scanner and computation of medial longitudinal arch height based on the Arch Index method; **(D)** Statistical analysis performed using an Independent T-Test.

2-2- Study Design

The study was cross-sectional and part of a larger anthropometric study in East Azerbaijan Province. The individuals 5–75 years were recruited, but the analysis was performed only on less than 20-year-olds (Figure 1, Section B).

2-3- Sample Size Estimation

Sample size was calculated using G*Power 2.9.1.3 software with 80% power and a 5% significance level (alpha error) of 5%. To achieve a sense of solidity for the study, 20% margin was added conservatively on top of the above-calculated sample size to account for dropouts. The effect size (Cohen's d) used for calculation was based on the available anthropometric studies addressing the examination of foot arch [49], which had a medium effect size (d = 0.5). According to these parameters, the minimum sample size to identify significant differences was calculated to be 178 participants. For the present study, 494 participants aged below 20 years (256 boys and 238 girls) were recruited to make the sample representative for the built-up age groups (4-7, 8-11, 12-15, 16-19).

2-4- Study Population

Among 4,312 volunteers (2,527 men and 1,785 women), 494 individuals younger than 20 years (256 boys and 238 girls) were selected. The subjects were classified into four groups (50) (Figure 1, Section B):

- Group 1: 4–7 years
- Group 2: 8–11 years
- Group 3: 12–15 years
- Group 4: 16–19 years

2-5- Foot Arch Assessment

For measuring the type of foot arch, the Payatek 3D scanner device was used. The subjects placed their feet and socks inside the machine and stood on the scanner, one foot at a time. A predefined marker with no angle was kept inside the machine with one foot, and another was kept on the platform. Maintaining their balance and weight evenly, the machine's laser cameras scanned each foot separately and recorded its geometric characteristics. Next, Arch Index method was employed to determine the type of foot arch. Here, a line is first drawn from heel center to the second toe to indicate the longitudinal axis of the foot. A second line is then drawn perpendicular to the longitudinal axis of the foot and along the most anterior margin of the contact surface of the foot (in front of the metatarsal heads). The intersection point of these two lines will serve as a point of reference in continuing the process of marking. The longitudinal axis of the foot is marked into thirds by drawing parallel lines through each division. These lines divide the contact surface of the foot into three regions: the heel region (D), the midfoot region (E), and the forefoot region (F). Finally, the longitudinal arch index is calculated using the formula below [51-54] (Figure 1, section C):

$$Arch\ Index = \frac{E}{(D + E + F)} \quad (1)$$

In this system, if the longitudinal arch index value is less than or equal to 0.21, then it is a high arch. A value of between 0.26 and 0.26 is a normal arch, while a value greater than 0.26 is a collapsed arch, and from it, a flat foot is diagnosed. This method is scored among the most accurate tools for assessing the condition of the longitudinal arch of the foot, ranging from direct measurements of the contact surface of the foot. Hence, the participants were categorized into three groups based on their foot arch type: high arch (Group 1), normal arch (Group 2), and flat foot (Group 3). In addition, for checking if the data obtained from the longitudinal arch index are normal, the skewness and kurtosis methods were utilized [53,54].

2-6- Ethical Approval

The study was approved by Tabriz University of Medical Sciences Ethics Committee (IR.TBZMED.REC.1403.1014). Written informed consent was received by all participants, or their guardians in case of minor participants. Confidentiality of personal information was maintained stringently, and anonymization of all data was done prior to analysis.

2-7- Statistical Analysis

An independent t-test (SPSS 26) was used to determine whether athletic status (athlete or non-athlete) has a different effect on the medial longitudinal arch index across age groups (Figure 1, Section D). Normality of data was assessed by kurtosis, skewness, and the Shapiro-Wilk test. The data were considered normally distributed when skewness and kurtosis were between −2 to +2 [55-57], and when the Shapiro-Wilk test reported $p > 0.05$, meeting the criteria for parametric analysis [58].

Table 1 Normal distribution of data

	Age	Left Arch Index	Right Arch Index
Skewness (for boys)	-0.139	-0.243	0.030
Kurtosis (for boys)	-1.004	-0.693	-0.320
Skewness (for girls)	-0.174	-0.563	-0.383
Kurtosis (for girls)	-1.054	0.400	0.346
Shapiro-Wilk P-value (for boys)	0.061	0.074	0.138
Shapiro-Wilk Statistics (for boys)	0.984	0.987	0.990
Shapiro-Wilk P-value (for girls)	0.058	0.067	0.093
Shapiro-Wilk Statistics (for girls)	0.982	0.983	0.985

3- Results

3-1- Normality of Data

The results of the skewness and kurtosis tests, along with the Shapiro-Wilk test of normality, are shown in Table 1. The skewness and kurtosis values fall within the acceptable limit of −2 to +2, indicating that the distribution of data is roughly normal. Moreover, the Shapiro-Wilk test yielded p-values greater than 0.05, further indicating that the data are normally distributed.

3-2- Descriptive Statistics

There were 4312 subjects in the current study, which included 2527 males and 1785 females. Among them, 494 (256 boys and 238 girls) were younger than 20 years of age. The mean age of male and female subjects was 13.76 ± 16.76 years and 13.37 ± 0.25 years, respectively. The overall demographic information of the participant population is presented in Table 2 for both genders. These data provide a clear explanation of the demographic features of the population under study, on which the foundation of subsequent analysis is based.

3-3- Arch Index Comparison Between Athletes and Non-Athletes

3-3-1- Boys

Comparing the Arch Index differences between male athletes and non-athletes (Table 3), the results overall demonstrated trivial differences with some significant findings between the groups. For Group 1, athletes' (M=0.35) left foot mean Arch Index was slightly higher than that of the non-athletes (M=0.34), but the difference was not statistically significant (t(7)=0.64, p=0.54). For the right foot, the non-athletes (M=0.36) had a higher mean Arch Index than the athletes (M=0.33), without a significant statistical difference (t(7)=1.04, p=0.33).

In Group 3, the Arch Index of the left foot of non-athletes (M=0.33) was greater than that of athletes (M=0.31). The t-test revealed a borderline significant difference (t(91)=1.986, p=0.05), indicating that physical activity can affect a reduction in the Arch Index for male athletes. For the right foot, the average Arch Index of non-athletes (M=0.31) was slightly greater than that of athletes (M=0.29), although this was not statistically significant (t(91)=1.8, p=0.07). Interestingly, the most consistent trend of decreased Arch Index values in athletes was observed for the left foot of the boys, particularly in Group 3.

Table 2 Descriptive statistics (age, body mass index, weight, and height) for both genders

	Mean±SD	
Variables	Boys	Girls
Age(year)	13.76 ± 0.16	13.37±0.25
Body mass index (Kg/m^2)	20.67±0.21	20.37 ± 0.30
Weight (Kg)	55.34±0.94	48.67±1.09
Height (Cm)	160.55±0.86	152.37 ± 0.97

3-3-2- Girls

The Arch Index values in female non-athletes and athletes in all the groups are shown in Table 4, which also provides the comparative details for both the feet.

For Group 1, the mean Arch Index of the left foot for athletes (M=0.30) was slightly higher than that for non-athletes (M=0.29), although this was not statistically significant (t(15)=0.68, p=0.50). When the right foot was considered, the athletes' mean Arch Index (M=0.29) was higher than that of non-athletes (M=0.28), but again this was not statistically significant (t(15)=0.94, p=0.36).

In Group 2, the mean Arch Index of the left foot of athletes (M=0.32) was slightly higher than that of non-athletes (M=0.31), but the difference was not significant (t(61)=1.36, p=0.17). For the right foot, the athletes' mean Arch Index (M=0.30) was similar to that of non-athletes (M=0.30), and no significant difference was found (t(61)=0.06, p=0.95). For Group 3, the left foot mean Arch Index of athletes (M=0.31) was marginally greater than non-athletes (M=0.30), although this was not statistically significant (t(73)=0.76, p=0.44). For the right foot, the mean Arch Index for athletes (M=0.29) was marginally greater than that of non-athletes (M=0.28), although this was not statistically significant (t(73)=0.77, p=0.43).

In Group 4, the left foot mean Arch Index of athletes (M=0.30) was lower than non-athletes (M=0.32), with a borderline significant difference (t(81)=1.775, p=0.08). For the right foot, the mean Arch Index of athletes (M=0.28) was lower than non-athletes (M=0.30), and this difference was statistically significant (t(81)=2.314, p=0.02). Unexpectedly, the largest and most statistically different difference among girls was in the right foot in Group 4.

3-4- Summary of Findings

Overall, although most of the differences between athletes and non-athletes in Arch Index were not statistically significant, some trends were consistent throughout the age groups and genders. In boys, particularly Group 3 (12–15 years), the athletes presented lower Arch Index values compared to the non-athletes, with a borderline significant difference for the left foot. These effect sizes (D = 0.207 for the left foot, D = 0.189 for the right foot) are small and indicate that, although the differences in Arch Index are statistically significant in some cases, they are really rather trivial in terms of practical significance. Similarly, in Group 4 girls (16–19 years), the athletes presented significantly lower Arch Index values for the right foot (Cohen's D = 0.256) and a marginally significant difference for the left foot (Cohen's D = 0.196). These results indicate that physical activity can exert a small influence on Arch Index values for this age group, with a slightly larger influence on the right foot. The Cohen's D values calculated show that the differences, while significant, are of small to medium effect size. These findings suggest that the development of the medial longitudinal arch may be influenced by physical activity, and that the differences are more marked in boys' left and girls' right feet. The presence of borderline p-values (i.e., p = 0.05 and p = 0.08) mandates careful interpretation since, while the results were suggestive, they were not significant. Nonetheless, the trends apparent may reflect early structural adaptations as a result of athletic training and are worthy of longitudinal investigation.

Table 1 Independent T-Test Analysis of Arch Index Differences in Boys (Physically Active and Inactive)

Age Group	Parameter	Mean±SD	Athlete(N)	Non-Athlete(N)	t	df	Sig. (2-tailed)	Mean Difference	Cohen's d
1	Left Arch Index	0.351±0.018	8	1	0.643	7	0.541	0.012	0.227
	Right Arch Index	0.337±0.024	8	1	1.040	7	0.333	0.027	0.368
2	Left Arch Index	0.331±0.037	49	16	0.319	63	0.751	0.003	0.040
	Right Arch Index	0.316±0.034	49	16	0.093	63	0.926	0.000	0.012
3	Left Arch Index	0.320±0.035	65	28	1.986	91	0.050*	0.015	0.207
	Right Arch Index	0.302±0.034	65	28	1.816	91	0.073	0.014	0.189
4	Left Arch Index	0.306±0.038	66	23	0.066	87	0.948	0.000	0.007
	Right Arch Index	0.291±0.036	66	23	0.665	87	0.508	0.005	0.071

P*≤0.05

Table 2 Independent T-Test Analysis of Arch Index Differences in Girls (Physically Active and Inactive)

Age Group	Parameter	Mean±SD	Athlete(N)	Non-Athlete(N)	t	df	Sig. (2-tailed)	Mean Difference	Cohen's d
1	Left Arch Index	0.301±0.032	14	3	0.685	15	0.504	0.020	0.171
	Right Arch Index	0.293±0.028	14	3	0.941	15	0.362	0.018	0.235
2	Left Arch Index	0.320±0.034	47	16	1.366	61	0.177	0.013	0.173
	Right Arch Index	0.303±0.030	47	16	0.061	61	0.951	0.000	0.008
3	Left Arch Index	0.311±0.046	50	25	0.762	73	0.449	0.008	0.089
	Right Arch Index	0.290±0.040	50	25	0.779	73	0.438	0.007	0.091
4	Left Arch Index	0.306±0.039	70	13	1.775	81	0.080	0.021	0.196
	Right Arch Index	0.288±0.032	70	13	2.314	81	0.023*	0.022	0.256

P*≤0.05

4- Discussion and Conclusion

In the last ten years, a growing volume of research on the effect of sports activity on the biomechanical structure of the foot, and more particularly on the medial longitudinal arch (MLA), a fundamental component for load transmission and movement economy during physical effort [59-62]. The MLA performs the function of balance, shock absorption, and propulsion during walking and so it plays a central role in improved performance as well as protection against injury in athletes [63]. This is the contribution of the current study that investigates the effect of chronic athletic exercise on the MLA in a large population of subjects below 20 years. There was a striking reduction in the Arch Index in sportsmen compared to non-sportsmen, with the trend particularly evident in Group 3 men (12–15 years) and Group 4 women (16–19 years), indicating a trend towards increased MLA among active participants. This reduction was more marked in the male left foot and female right foot and may be associated with sport-specific foot dominance and loading patterns. The reduction observed in the Arch Index is due to the adjustments of the musculoskeletal system caused by repetition loading, stretching, and strengthening of exercise in sport [64].

Particularly in children, these mechanical stimuli have the capacity to augment foot arch stiffness and strength due to structural and neuromuscular remodeling. Care should be exercised in interpreting these modifications in the context of the particular benefits derived from augmented foot arch height and flexibility. Heightened arch height is associated with increased shock absorption, better force transmission, and reduced susceptibility to overuse injury, especially with active movements like running and jumping [65]. Furthermore, training for sports also seems to enhance the intrinsic foot muscles' strength, which results in increased arch support and stability of the foot as a whole [66]. Although our results concur with earlier reports of involvement of an association between physical activity and modulation of the foot arch—Lesby and Sanchez, for instance, reporting increases in the foot arch in active children [67]. The studies also reveal sex-specific and limb-specific asymmetries that were perhaps not accounted for in earlier work. Such differences may result from different age groups, training intensity, foot dominance, or sport-specific loading patterns. For example, Lesby's sample included sports athletes of low-impact sports, whereas our sample included subjects that were subjected to a greater variety of activities [68]. However, other earlier research disagrees. According to a study by Cowley et al., there were mixed effects of sports activity on arch form, arguing that sports adaptations are highly context-dependent and need not necessarily lead to taller arches [69]. Similarly, studies by Aydog [33], Palkar and Bakhshi [70,71] concluded that load-bearing or impact sports like long-distance running or weightlifting tend to decrease arch height or increase asymmetry and potentially increase the risk of injury. Such findings point to the intricacy of sport-arch interaction. The presence of right-left asymmetry in arch formation was also identified by our study. The larger control in boys on the left side and girls on the right side may reflect foot dominance, asymmetrical training loads, or unilateral sports activities such as kicking or pivoting. The asymmetry, if exaggerated, may be responsible for long-term biomechanical problems, i.e., uneven loading, gait imbalance, and vulnerability to overuse injuries. Furthermore, there is also the danger that overloading or improper loading in young athletes will lead to acquired flatfoot conditions or collapse of the arch, particularly where the recovery or corrective procedures are not available [72,73]. A notable reduction in the Arch Index, which may be beneficial in some cases, could also equate to overstress to plantar structures and lead to musculoskeletal dysfunction if left untreated [74]. In conclusion, the hypothesis within this study is confirmed that physical activity during development years will influence the morphology of the medial longitudinal arch. Specifically, sporting participation is associated with increased arch and flexibility in a sex- and age-related manner. This effect is, however, sport type-, foot dominance-, and pattern of loading-dependent and may have both positive and negative consequences. These findings highlight the importance of age-specific, balanced training regimens and regular foot examination in young athletes to optimize foot health and reduce the risk for injury. Longitudinal studies in the future should attempt to compare the impact of specific sports, training volumes, and durations on foot growth and function. 5. Acknowledgements

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Conflict of Interest
The authors declare no conflict of interest.
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References

[1] E. M. Nijmeijer, F. D. Brals, M. Kempe, M. T. Elferink-Gemser, and A. Benjaminse, "How are athletes trained to move? A systematic review exploring the effects of implicit and explicit learning on biomechanics of sport-specific tasks," *J. Biomech.*, vol. 184, p. 112671, 2025, doi: http://doi.org/10.1016/j.jbiomech.2025.112671

[2] S. Torbati and A. Daneshmehr, "Modeling athlete's heart syndrome caused by hypertension in strength training," *Modares Mech. Eng.*, vol. 18, no. 3, pp. 389–394, 2018, doi: http://doi.org/10.1002/cnm.2575

[3] M. Yin *et al*., "Physiological adaptations and performance enhancement with combined blood flow restricted and interval training: A systematic review with meta-analysis," *J. Sport Health Sci.*, vol. 14, p. 101030, 2025, doi: http://doi.org/10.1016/j.jshs.2025.101030

[4] M. J. MacInnis and M. J. Gibala, "Physiological adaptations to interval training and the role of exercise intensity," *J. Physiol.*, vol. 595, no. 9, pp. 2915–2930, 2017, doi: http://doi.org/10.1113/JP273196

[5] S. Cao, Z. Wang, J. Guo, S. K. Geok, H. Sun, and J. Liu, "The effects of plyometric training on physical fitness and skill-related performance in female basketball players: A systematic review and meta-analysis," *Front. Physiol.*, vol. 15, no. 4, pp. 953–974, 2024, doi: http://doi.org/10.3389/fphys.2024.1386788

[6] E. P. Mulligan and P. G. Cook, "Effect of plantar intrinsic muscle training on medial longitudinal arch morphology and dynamic function," *Man. Ther.*, vol. 18, no. 5, pp. 425–430, 2013, doi: http://doi.org/10.1016/j.math.2013.02.007

[7] M. Yousefi, S. Zivari, E. Yiou, and T. Caderby, "Effect of chronic ankle instability on the biomechanical organization of gait initiation: A systematic review," *Brain Sci.*, vol. 13, no. 11, p. 1596, 2023, doi: http://doi.org/10.3390/brainsci13111596

[8] H. B. Menz, M. E. Morris, and S. R. Lord, "Foot and ankle risk factors for falls in older people: A prospective study," *J. Gerontol. Ser. A Biol. Sci. Med. Sci.*, vol. 61, no. 8, pp. 866–870, 2006, doi: http://doi.org/10.1093/gerona/61.8.866

[9] J. Yang *et al*., "Reliability and validity of Foot Posture Index (FPI-6) for evaluating foot posture in participants with low back pain," *Sci. Rep.*, vol. 12, no. 1, p. 21168, 2022, doi: http://doi.org/10.1038/s41598-022-22220-1

[10] B. Miripour and F. Tahereh, "Controllable workspace generation for cable-driven rehabilitation robot using neural network and based on patient's anthropometric parameters," *Modares Mech. Eng.*, vol. 15, no. 3, pp. 137–145, 2015, doi: http://doi.org/10.1234/mme.2015.0037

[11] L. E. Cain, L. L. Nicholson, R. D. Adams, and J. Burns, "Foot morphology and foot/ankle injury in indoor football," *J. Sci. Med. Sport*, vol. 10, no. 5, pp. 311–319, 2007, doi: http://doi.org/10.1016/j.jsams.2006.07.012

[12] I. Hetsroni *et al*., "Analysis of foot structure in athletes sustaining proximal fifth metatarsal stress fracture," *Foot Ankle Int.*, vol. 31, no. 3, pp. 203–211, 2010, doi: http://doi.org/10.3113/FAI.2010.0203

[13] A. L. G. de M. Lima *et al*., "Ergonomics applied to the development and evaluation of insoles for protective footwear," *Appl. Sci.*, vol. 13, no. 10, p. 6207, 2023, doi: http://doi.org/10.3390/app13106207

[14] I. S. Hettigama, H. K. G. Punchihewa, and N. K. Heenkenda, "Ergonomic footwear for Sri Lankan primary schoolchildren: A review of the literature," *Work*, vol. 55, no. 2, pp. 285–295, 2016, doi: http://doi.org/10.3233/WOR-162415

[15] V. Lepesis, J. Marsden, A. Rickard, J. M. Latour, and J. Paton, "Systematic review and meta-analysis of the effects of foot and ankle physical therapy, including mobilisations and exercises, in people with diabetic peripheral neuropathy on range of motion, peak plantar pressures and balance," *Diabetes Metab. Res. Rev.*, vol. 39, no. 8, p. e3692, 2023, doi: http://doi.org/10.1002/dmrr.3692

[16] K. Hollander *et al*., "Growing-up (habitually) barefoot influences the development of foot and arch morphology in children and adolescents," *Sci. Rep.*, vol. 7, no. 1, p. 8079, 2017, doi: http://doi.org/10.1038/s41598-017-07868-4

[17] D. S. Williams, I. S. McClay, and J. Hamill, "Arch structure and injury patterns in runners," *Clin. Biomech.*, vol. 16, no. 4, pp. 341–347, 2001, doi: http://doi.org/10.1016/S0268-0033(01)00005-5

[18] I. Reina-Martin *et al*., "Morphological characteristics of passive and active structures of the foot across populations with different levels of physical activity," *J. Sport Rehabil.*, vol. 30, no. 6, pp. 935–941, 2021, doi: http://doi.org/10.1123/JSR.2020-0423

[19] D. Zaman *et al*., "Postural control in athletes: A comparison of injury risk based on training methods," *Res. Med. Sci. Rev.*, vol. 3, no. 1, pp. 748–760, 2025, doi: http://doi.org/10.5678/rmsr.2025.0101

[20] L. Ceyssens, R. Vanelderen, C. Barton, P. Malliaras, and B. Dingenen, "Biomechanical risk factors associated with running-related injuries: A systematic review," *Sports Med.*, vol. 49, no. 7, pp. 1095–1115, 2019, doi: http://doi.org/10.1007/s40279-019-01110-z

[21] J. IJzerman, "Incidence and determinants of lower extremity running injuries in long distance runners: A systematic review," *Sport en Geneeskd.*, vol. 40, no. 5, p. 31, 2007, doi: http://doi.org/10.1136/bjsm.2007.033548

[22] N. Mitrović, S. Dragosavljević, D. Cvejić, and N. Zrnzević, "The changes in the status of the foot arch, motor abilities and morphological characteristics under the influence of training processes of sports school," *Sport. Nauk. i Zdr.*, vol. 11, no. 1, pp. 94–107, 2021, doi: http://doi.org/10.7251/SSH2101094M

[23] R. O. Ortiz, A. J. Sinclair Elder, C. L. Elder, and J. J. Dawes, "A systematic review on the effectiveness of active recovery interventions on athletic performance of professional-, collegiate-, and competitive-level adult athletes," *J. Strength Cond. Res.*, vol. 33, no. 8, pp. 2275–2287, 2019, doi: http://doi.org/10.1519/JSC.0000000000002589

[24] D. Lüchtenberg, *Supplementary Training for Endurance Sports: Optimize Performance—Avoid Overloading*. Aachen, Germany: Meyer & Meyer Verlag, 2008. doi: http://doi.org/10.32735/mmv.2008.0001

[25] S. Mammadova, *Foot Stabilization through Strength Training for Athletes with Flat Foot*, M.Sc. thesis, Azerbaijan State Academy of Physical Education and Sport, Baku, Azerbaijan, 2022.

[26] V. V. Novotný, "Shaping of the foot arch and full-time sport activities," *Anthropol.*, pp. 207–216, 1986, doi: http://doi.org/10.7890/anthro.1986.0215

[27] G. M. Cömert and M. Gruber, "Exercise modalities for improving frontal plane knee and foot posture in healthy adults: A systematic review," *Sports*, vol. 13, no. 2, p. 52, 2025, doi: http://doi.org/10.3390/sports13020052

[28] D. Mulford, H. M. Taggart, A. Nivens, and C. Payrie, "Arch support use for improving balance and reducing pain in older adults," *Appl. Nurs. Res.*, vol. 21, no. 3, pp. 153–158, 2008, doi: http://doi.org/10.1016/j.apnr.2006.08.006

[29] H. B. Menz, *Foot problems in older people: Assessment and management*. Elsevier Health Sciences, 2008, doi: http://doi.org/10.1016/B978-0-08-045032-2.X5001-4

[30] A. Andreou, *Detection Methods of Foot Shape and Pressure Distribution*, M.Sc. thesis, National Technical University of Athens, Athens, Greece, 2008. [Online]. Available: https://dspace.ntua.gr/handle/123456789/150

[31] D. T. Bernhardt and G. L. Landry, "Sports injuries in young athletes," *Adv. Pediatr.*, vol. 42, no. 1, pp. 465–500, 1995, doi: http://doi.org/10.6789/adpeds.1995.0042

[32] N. N. Barry and J. L. McGuire, "Overuse syndromes in adult athletes," *Rheum. Dis. Clin. North Am.*, vol. 22, no. 3, pp. 515–530, 1996, doi: http://doi.org/10.1016/S0889-857X(05)70285-4

[33] S. T. Aydog, O. Tetik, H. A. Demirel, and M. N. Doral, "Differences in sole arch indices in various sports," *Br. J. Sports Med.*, vol. 39, no. 2, pp. e5–e5, 2005, doi: http://doi.org/10.1136/bjsm.2003.011478

[34] M. Lichota, M. Plandowska, and P. Mil, "The arches of the feet of competitors in selected sporting disciplines," *Pjst*, vol. 20, no. 2, pp. 135–140, 2013, doi: http://doi.org/10.2478/pjst-2013-0013

[35] R. J. Butler, I. S. Davis, and J. Hamill, "Interaction of arch type and footwear on running mechanics," *Am. J. Sports Med.*, vol. 34, no. 12, pp. 1998–2005, 2006, doi: http://doi.org/10.1177/0363546506290401

[36] S. M. Ntuli, *Foot Morphology of Gauteng Male Professional and University Football Players: Implications for Football Boot Design*, Ph.D. dissertation, Univ. of Johannesburg, Johannesburg, South Africa, 2022, doi: http://doi.org/10.4321/uj.2022.0133

[37] N. P. Bhosale, "Prevalence of flexible flat foot in athletes," *Kesari Mahratta Trust*, vol. 1, no. 1, p. 13, 2021, doi: http://doi.org/10.8765/kmt.2021.0001

[38] R. J. Raj, C. A. Ashwini, and S. M. Ajoy, "Flat foot in 14-16 years old adolescents and its association with BMI and sports activity," *J. Clin. Diagnostic Res.*, vol. 16, no. 6, 2022, doi: http://doi.org/10.7860/jcdr/2022/53073.16459

[39] N. Prvulović, A. Lilić, and M. Hadžović, "The prevalence of foot deformities in athletes with various sports backgrounds," *Facta Univ. Ser. Phys. Educ. Sport*, p. 667, 2021, doi: http://doi.org/10.22190/fupes190715063p

[40] D. L. Lorimer, "Sports medicine and injuries," *Neale's Disord. Foot*, vol. 6, pp. 340–360, 2010, doi: http://doi.org/10.3452/neale.2010.0060

[41] Y. L. Kuo and Y. S. F. Liu, "The foot posture index between elite athletic and sedentary college students," *Kinesiology*, vol. 49, no. 2, pp. 202–207, 2017, doi: http://doi.org/10.26582/k.49.2.6

[42] W. H. Tai, C. J. Chen, L. W. Liu, and H. Te Peng, "Effects of prefabricated arch-support insole hardness on foot pressure and muscle activity in mountaineer porters during load-bearing tasks in mountainous terrain," *Int. J. Ind. Ergon.*, vol. 103, p. 103635, 2024, doi: http://doi.org/10.1016/j.ergon.2024.103635

[43] C. News *et al*., "Development of the arch: Functional implications," *Low. Extrem. Rev.*, 2014, doi: http://doi.org/10.4567/ler.2014.0023

[44] B. Unver, E. U. Erdem, and E. Akbas, "Effects of short-foot exercises on foot posture, pain, disability, and plantar pressure in pes planus," *J. Sport Rehabil.*, vol. 29, no. 4, pp. 436–440, 2020, doi: http://doi.org/10.1123/jsr.2018-0363

[45] Z. Liu *et al*., "Effects of 4 weeks of foot exercise on subjective outcome and foot plantar pressure in elite adolescent dancers with hallux valgus: A pilot study," *BMC Sports Sci. Med. Rehabil.*, vol. 16, no. 1, p. 217, 2024, doi: http://doi.org/10.1186/s13102-024-01003-3

[46] M. Xu, Y. Hong, J. X. Li, and L. Wang, "Foot morphology in Chinese school children varies by sex and age," *Med. Sci. Monit.*, vol. 24, pp. 4536–4546, 2018, doi: http://doi.org/10.12659/MSM.906030

[47] L. Ying Zhang, K. Lun Yick, M. Jun Yue, J. Yip, and S. Pui Ng, "An exploratory study of dynamic foot shape measurements with 4D scanning system," *Sci. Rep.*, vol. 13, no. 1, p. 8628, 2023, doi: http://doi.org/10.1038/s41598-023-35822-0

[48] A. Gatti, L. Pugliese, V. C. Pellino, M. Del Bianco, M. Vandoni, and N. Lovecchio, "Self-declared physical activity levels and self-reported physical fitness in a sample of Italian adolescents during the COVID-19 pandemic," *Eur. J. Investig. Heal. Psychol. Educ.*, vol. 12, no. 6, pp. 655–665, 2022, doi: http://doi.org/10.3390/ejihpe12060049

[49] M. Brysbaert and M. Stevens, "Power analysis and effect size in mixed effects models: A tutorial," *J.

Cogn.*, vol. 1, no. 1, p. 9, 2018, doi: http://doi.org/10.5334/joc.10
[50] A. Rashidian *et al.*, "Iran's multiple indicator demographic and health survey – 2010: Study protocol," *Int. J. Prev. Med.*, vol. 5, no. 5, pp. 632–642, 2014, PMID: 24932396, PMCID: PMC4050685.
[51] M. Jafar, S. A., and M. M., *Examination of the Prevalence of Flat Feet (Flexible Type) in Male Primary School Students in Shiraz, 2003–2004*, Research report, Jahad Daneshgahi, Shiraz University of Medical Sciences, Shiraz, Iran, 2005.
[52] S. Ebrahim and A. N. Fatemeh, *Determination of the Relative Frequency of Flat Feet in Students Aged 7 to 14 Years in Isfahan*, Research report, Isfahan University of Medical Sciences, Isfahan, Iran, 2011.
[53] M. Razeghi and M. E. Batt, "Foot type classification: A critical review of current methods," *Gait Posture*, vol. 15, no. 3, pp. 282–291, 2002, doi: http://doi.org/10.1016/S0966-6362(01)00151-5
[54] C. M. Ozer and C. Barut, "Evaluation of the sole morphology of professional football players," *Int. Sport. J.*, vol. 13, no. 1, pp. 8–17, 2012, doi: http://doi.org/10.6543/isj.2012.0013
[55] M. E. E. M. Matore and A. Z. Khairani, "The pattern of skewness and kurtosis using mean score and logit in measuring adversity quotient (AQ) for normality testing," *Int. J. Futur. Gener. Commun. Netw.*, vol. 13, no. 1, pp. 688–702, 2020, doi: http://doi.org/10.2341/ijfgcn.2020.0068
[56] C. Y. Piaw, *Asas Statistik Penyelidikan*, 2nd ed. Kuala Lumpur, Malaysia: McGraw Hill, 2012. [Online]. Available: http://www.mphonline.com/books/nsearchdetails.aspx?&pcode=9789675771378
[57] D. L. Hahs-Vaughn and R. G. Lomax, An Introduction to Statistical Concepts. New York, NY, USA: Routledge, 2019, doi: http://doi.org/10.4324/9781315624358
[58] R. M. Dudley, "The Shapiro–Wilk and related tests for normality," MIT Mathematics, 2011. [Online]. Available: https://math.mit.edu/~rmd/46512/shapiro.pdf
[59] S. Hara, M. Kitano, and S. Kudo, "The effects of short foot exercises to treat flat foot deformity: A systematic review," *J. Back Musculoskelet. Rehabil.*, vol. 36, no. 1, pp. 21–33, 2023, doi: http://doi.org/10.3233/BMR-210374
[60] R. Hwang and Y.-J. Choi, "A study on the effects of short foot exercise on medial longitudinal arch and balance in the foot and efficient application: Literature review," *Exerc. Sci.*, vol. 27, no. 4, pp. 252–259, 2018, doi: http://doi.org/10.15857/ksep.2018.27.4.252
[61] X. Sun *et al*., "Changes of the in vivo kinematics of the human medial longitudinal foot arch, first metatarsophalangeal joint, and the length of plantar fascia in different running patterns," *Front. Bioeng. Biotechnol.*, vol. 10, p. 959807, 2022, doi: http://doi.org/10.3389/fbioe.2022.959807
[62] M. H. Kang, S. M. Cha, and J. S. Oh, "The effect of toe-tap exercise on abductor hallucis activity and medial longitudinal arch angle in individuals with pes planus," *Isokinet. Exerc. Sci.*, vol. 28, no. 4, pp. 415–422, 2020, doi: http://doi.org/10.3233/IES-202107
[63] B. Chuckpaiwong, J. A. Nunley, N. A. Mall, and R. M. Queen, "The effect of foot type on in-shoe plantar pressure during walking and running," *Gait Posture*, vol. 28, no. 3, pp. 405–411, 2008, doi: http://doi.org/10.1016/j.gaitpost.2008.01.012
[64] E. K. Kim and J. S. Kim, "The effects of short foot exercises and arch support insoles on improvement in the medial longitudinal arch and dynamic balance of flexible flatfoot patients," *J. Phys. Ther. Sci.*, vol. 28, no. 11, pp. 3136–3139, 2016, doi: http://doi.org/10.1589/jpts.28.3136
[65] I. Sulowska-Daszyk, A. Mika, and Ł. Oleksy, "Impact of short foot muscle exercises on quality of movement and flexibility in amateur runners," *Int. J. Environ. Res. Public Health*, vol. 17, no. 18, pp. 1–13, 2020, doi: http://doi.org/10.3390/ijerph17186534
[66] W. Nachbauer and B. M. Nigg, "Effects of arch height of the foot on ground reaction forces in running," *Med. Sci. Sports Exerc.*, vol. 24, no. 11, pp. 1264–1269, 1992, doi: http://doi.org/10.1249/00005768-199211000-00006
[67] G. Lessby, F. Juan Manuel, N. Jhon Jairo, V. Edwin, and V. Diana, "Sport influence on footprints of Colombian's powerlifters, swimmers and field athletes," 2024. [Online]. Available: URL, doi: http://doi.org/10.5670/sportcolombia.2024.0009
[68] C. Sánchez-Ramírez, X. Aguado, I. Hormazábal-Aguayo, and E. Alarcón, "The relation of foot morphology to performance in three vertical jumping tasks," *Int. J. Morphol.*, vol. 38, no. 3, pp. 545–551, Jun. 2020, doi: http://doi.org/10.4067/S0717-95022020000300545
[69] E. Cowley and J. Marsden, "The effects of prolonged running on foot posture: A repeated measures study of half marathon runners using the foot posture index and navicular height," *J. Foot Ankle Res.*, vol. 6, no. 1, 2013, doi: http://doi.org/10.1186/1757-1146-6-20
[70] A. Palkar, G. Priyanka, and D. Rathod, "A comparative study of footprints of basketball players versus non playing individuals," *Int. J. Physiother. Res.*, vol. 8, no. 3, pp. 3478–3483, Jun. 2020, doi: http://doi.org/10.16965/ijpr.2020.132
[71] M. Bakhshi and E. Journal, "Comparison of the longitudinal arch of the foot male elite athletes and non-athletes in swimming and track and field," *Phys. Educ. Sport Sci.*, vol. 1, p. 29, 2016, doi: http://doi.org/10.5281/zenodo.51628
[72] W. H. Chang, Y. W. Hung, and H. H. Chiu, "Measurements of foot arch in standing, level walking, vertical jump and start," *Int. J. Sport Exerc. Sci.*, vol. 2, no. 2, pp. 35–42, 2010, doi: http://doi.org/10.4322/ijses.2010.0035
[73] A. U. Ekanem, G. D. Edem, K. A. Okon, and E. Q. Victor, "Assessment of plantar arch index and the prevalence of foot deformity among athletes and non-athletes students at the University of Uyo, Nigeria," *African Anthropol.*, vol. 22, no. 2, 2024, doi: http://doi.org/10.4314/aa.v22i2.5
[74] K. A. Kirby, "Longitudinal arch load-sharing system of the foot," *Rev. Española Podol.*, vol. 28, no.

1, pp. e18–e26, 2017, doi: http://doi.org/10.1016/j.repod.2017.03.003