RESEARCH ARTICLE

Effect of Medial Longitudinal Arch Height of the Foot on Static and Dynamic Balance in 7-10-Year-Old Boy Gymnasts

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Abstract

Objectives: This research aims to investigate the relationship between the height of the internal longitudinal arch of the foot and the static and dynamic balance of 7-10-year-old boy gymnasts.

Methods: This study was descriptive-correlational, and its statistical population included male gymnast students aged 7 to 10 in the city of Gouchan. These gymnasts were screened for flat feet using the Brady test. Ninety gymnasts were purposefully selected based on the Brody test to assess the arch of the foot and were divided into three groups: pronation (n=30), supination (n=30), and normal (n=30). The Flamingo test assessed static balance, and the Y Balance test assessed dynamic balance. The Shapiro-Wilk test was used to check the normality of data distribution, and a one-way analysis of variance was employed to compare the results obtained among the groups. Data analysis was performed using SPSS software (version 21).

Results: The results showed a significant difference between static and dynamic balance in male gymnasts with pronation, supination, and natural foot conditions (P=0.001 and P=0.013, respectively). The results demonstrated no significant difference in static balance between gymnastic boys with pronation and suspension (P=0.930); however, there was a significant difference in static balance between gymnastic boys with suspension and those with a natural state (P=0.0001) and between gymnastic boys with pronation and those with a natural state of the foot (P=0.001).

Conclusion: Based on the results, gymnastic boys with different arch heights (pronated, supinated, natural) showed static and dynamic balance variations. Boys with pronated or supinated feet had poorer static and dynamic balance than those with natural arches. Based on these results, coaches and corrective movement specialists can help boy gymnasts with different arch heights to optimize their balance performance and reduce the risk of injury.

Level of evidence: II

Keywords: Foot, Gymnast, Medial longitudinal arch height, Static and dynamic balance

Introduction

Balance is an inseparable factor in all human day-to-day activities, and maintaining postural control in performing all tasks is essential. However, this factor holds even greater importance in activities performed with intensity and high speed, and for achieving success and preventing injury, it should be at an optimal level.[1] Sports coaches and sports medicine specialists believe that athletes, to succeed in their respective sports, should possess good balance,[2] as balance is the most crucial part of an athlete's capability and is involved in almost all activities.[3] Studies have shown that variables such as dominant foot, joint range of motion, age, height, weight, physical activity level, and characteristics can impact an individual's balance.[2] Since balance is

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maintained in the kinetic chain and relies on the integrated feedback of the hip, knee, and ankle joint movements, any disruption in sensory information transmission or the performance of the surrounding muscles of each of these joints can compromise the mechanical integrity of other joints and, consequently, the lower limb and subsequently the body's balance.[4] There are two types of balance: static and dynamic. The ability to maintain a stable position for a specific period is called static balance, such as balancing while standing. Static balance is a fundamental characteristic of natural motor development. Most motor development tests measure static balance.[5]

Additionally, the body's ability to maintain balance during movement, such as walking, running, rising from a seated position, and agile movements, is called dynamic balance. Dynamic balance is crucial for injury prevention and enhancing athletic performance.[6] Therefore, considering that the foot is the lowest part of this kinetic chain, any change in the weight-bearing level and morphological characteristics of the foot may influence balance control.

Some of the problems related to foot abnormalities are associated with foot arches; therefore, considering the importance and role of the foot in controlling the kinetic chain of the lower limb, it is better to accurately identify changes in foot arch shapes in individuals. The delayed diagnosis not only leads to the onset of clinical symptoms in adulthood but also requires much more aggressive corrective actions and, sometimes, in severe cases, surgical interventions. Researchers have always been concerned about finding effective ways to reduce foot abnormalities and their related problems. This can only be achieved by identifying the range and extent of these abnormalities, which will provide a basis for determining whether foot arches are natural or unnatural. Standardization allows for assessment, comparison, and judgment to improve individuals' quantitative and qualitative aspects.[7,8]

Excessive subtalar joint pronation may occur alongside a flat foot.[9,10] Abnormal compensatory pronation may lead to instability and excessive movement of the foot joints.[11] The study by Binabaji et al. (2012) found that a flat foot can change the distribution of plantar pressure during walking due to changes in the activity of lower limb muscles.[12,13] Flat feet are associated with altered vertical ground reaction forces, which can lead to improper force distribution throughout the body. This misalignment can cause greater force transmission to the upper body and may result in discomfort or injury, particularly in the spine.[14]

Flat and cavus feet occur when the height of the foot's medial longitudinal arch (MLA) becomes higher than its natural limit and an elevation on the foot is developed due to structural abnormalities. Cavus foot is often associated with various neurological conditions that cause progressive deformities due to muscle imbalance and structural changes, such as those observed in cerebral palsy and spinal cord injuries.[15] Reynolds et al. (2013) showed that the pressure on the forefoot and metatarsals increases in individuals with cavus foot.[16] Cavus foot, accompanied by excessive supination of the subtalar joint, may negatively impact body posture control due to the limited weight-bearing surface of the foot compared to a natural foot.[11] On the other hand, structural abnormalities in the foot may affect an individual's performance in static and dynamic tasks, especially in body movements. Flat and cavus foot abnormalities may distort incoming environmental signals from deep sensations.[17,18] Therefore, flat and cavus feet may be unstable during weight bearing and disrupt body posture control. Studies also indicate that individuals with a natural arch in the foot can perform more physical activities and tire later.[18,19]

The results are contradictory regarding the impact of changes in the arch of the foot on balance. For instance, Cote et al. (2005), Harrison et al. (2010), Satvati et al. (2013), and Tsai et al. (2006) have reported that individuals with flat foot abnormalities have less static balance than those with normal arches.[20-23] Conversely, Moosavi and Pashnameh also indicate no significant difference in static balance between individuals with flat feet and those with normal arches.[24] Additionally, Satvati et al. found no relationship between the severity of flat feet and static balance.[22] At the same time, Harrison et al. found a direct correlation between the severity of flat feet and decreased static balance.[21]

It is worth noting that the same scenario applies to dynamic balance. Dabholkar et al. reported that individuals with flat feet have weaker performance in dynamic balance compared to individuals with normal arches,[25] while Mousavi et al. stated that an increase in the arch index led to improved dynamic balance and a decrease in this index resulted in reduced dynamic balance.[26] Moreover, Qasemi reported that individuals with flat feet and cavus have better dynamic balance in some aspects than individuals with natural arches.[4]

It has been observed that previous reports on this matter have yielded contradictory results due to various factors, such as differences in test subjects and measurement tools. Furthermore, the lack of attention to various confounding factors has made it difficult to rely on the results of previous research, practically making it impossible to come to a clear and definitive conclusion regarding the impact of foot arch height on dynamic and static balance. Additionally, the limited research in this area with gymnast participants and the lack of sample homogeneity, especially in terms of other lower limb abnormalities, such as genu varum or valgum, body mass index (BMI), lower limb length discrepancy, level of physical activity, sports history, and many other factors, has led to the inclusion of a wide range of individuals with different characteristics and the influence of various confounding factors on the research results. Therefore, this research aims to investigate the relationship between the height of the MLA of the foot and the static and dynamic balance of 7-10-year-old boy gymnasts.

Materials and Methods

This study was descriptive-correlational, and its statistical population included male students aged 7 to 10 who were engaged in gymnastics in the city of Quchan. The sample size was calculated using G*Power software (effect size=0.25, alpha error=0.05, and power=0.95) and estimated to be 252 individuals for a one-way ANOVA test. These gymnasts were screened for flat feet using the Brady test. Among gymnasts with pronation, supination, and normal foot arches, 90 individuals were selected as the sample based on inclusion and exclusion criteria and randomly divided into three groups: pronation (n=30), supination (n=30), and normal (n=30).

The inclusion criteria: involved male gymnasts aged 10-7 with a navicular bone drop of 10 mm or more categorized as the pronation group, 5-9 mm as the normal group, and less than 4 mm as the supination group.

The exclusion criteria: for the present study also included a history of ankle sprain, lower limb fracture or surgery, spinal column and pelvic injuries in the past year,[27] abnormal BMI (outside the range of 18 to 25),[28] inner ear infections, uncorrected visual impairments not aided by glasses, history of brain injuries,[20,21] leg length discrepancy exceeding one centimeter,[24,29] observed patellar abnormalizes,[24,29] engagement in professional sports, a history of championship, or involvement in sports at a higher level than recreational clubs.[30] After the initial selection of samples, the parents completed a personal information recording form and an informed consent form. Then, the anthropometric characteristics of the subjects, including height, weight, scale, and BMI, were measured.

Evaluation of navicular drop: The participant was instructed to sit on a chair without shoes and place their foot on a box. The chair height was adjusted so that the thigh and knee angle would be 90 degrees. In this position, the hip joint had no adduction or abduction and was in its normal state. The examiner placed their index finger on the medial and lateral malleolus and the anterior and posterior parts of the medial and lateral sides of the navicular prominence, touching the navicular bone. The examiner slightly tilted the test subject's heel and the foot arch inward and outward until depressions under the first and second metatarsals were felt horizontally at an equal level. When the foot arch was in this position (neutral position), the location of the navicular prominence was identified and marked. Then, using a ruler, the distance from the navicular prominence to the box surface was measured in millimeters. The participant was instructed to stand with equal weight distribution on both feet. The distance from the navicular prominence to the ground surface was measured and recorded in this position. The examiner subtracted the distance from the navicular prominence to the ground in the weight-bearing position (standing) from the distance of the navicular prominence to the ground in the non-weight-bearing position (sitting on the chair), and the obtained number indicated the amount of navicular drop. The navicular drop was measured three times for each subject, and the average of the measurements was used.[31] This test is valid for assessing the amount of foot pronation. Møller et al. have reported its reliability coefficient at 85% (r=0.85).[32] In this study, considering the conditions for entry into the research, which was a grade 2 flat foot, the footprint test was used by visualizing the footprint on the mirror box and also using talcum powder to select subjects with a grade 2 flat foot based on the Denis A method [Figure 1].[33]

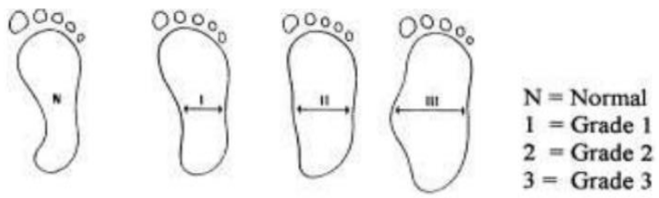
Flamingo balance test

The Flamingo balance test is a cost-effective and straightforward method that can be utilized extensively. The procedure for performing this test is as follows. The gymnast stands with shoes on a flat surface. Initially, while holding the coach's hand, they maintain their balance. During balance on the preferred foot, the free foot is bent at the knee and kept close to the buttocks. Then, the coach's hand is released. The stopwatch is started, and each time the individual loses balance, it is stopped. The number of times the person loses balance within 60 seconds is counted. If there are more than 15 falls in the first 30 seconds, the test ends, and a score of zero is considered.[34]

Balance test

Dynamic balance was measured using the Y Balance Test. If the dominant foot was the right, the test was performed counterclockwise; if it was the left, it was performed clockwise. The subject with the dominant foot (single-footed) stood on the Y-balance test platform in three directions and did not move their foot off the platform until they made a mistake. They neither supported the foot performing the reaching action nor touched the ground. They performed the reaching action with the other foot, and then returned to a normal position. The distance that the subject moved the indicator was recorded as their reaching distance. Each participant performed the Y Balance Test in three different directions. The results were then normalized to the individual's lower limb. The intratester reliability of the test was reported as 0.85, and the intertester reliability was reported as 0.99.[35]

The normality of the data distribution was checked using the Shapiro-Wilk test, and the results obtained from the different groups were compared using a one-way analysis of variance test. The analysis was conducted using SPSS software (version 19).[36]



Figures 1. Evaluation of navicular drop

Results

The results include information regarding the age, height, weight, static balance, and dynamic balance of 90 gymnasts in three groups: pronation group, supination group, and natural foot group [Table 1].

The results of the Shapiro-Wilk test showed that all the research variables had a normal distribution. Additionally, Levene's test was used to check the homogeneity of variances of the research variables [Table 2]. According to this test, variances are equal when the p-value is greater than the critical value at a significance level of 0.05. As observed, based on the significance level, the dynamic balance variable is homogeneous, while the static balance variable is heterogeneous.

The results of a one-way analysis of variance to compare the static and dynamic balance variables in different groups are presented in [Table 3]. The results indicated a significant difference between the static and dynamic balance in male gymnasts afflicted with pronation, supination, and natural foot conditions (P=0.001 and P=0.013, respectively).

Table 1. Mean and standard deviation of age, height, weight, static balance, and dynamic balance of the research participants

Variable	Age	Height	Weight	Static balance	Dynamic balance
Supination	8.33±1.06	124.50±13.22	36.06±9.24	16.06±4.29	80.09±7.76
Pronation	8.56±1.13	126.46±10.07	38.26±9.04	15.63±4.95	80.78±7.17
Normal	8.40±1.13	126.23±12.98	37.93±8.52	7.63±3.36	85.14±5.96

Table 2. Levene's test results

Variable	Statistics	Degree of freedom 1	Degree of freedom 2	Sig
Static balance	3.39	2	87	0.038
Dynamic balance	1.58	2	87	0.211

Table 3. One-way ANOVA results for comparing static and dynamic balance variables in different groups

	Variable	Sum of Squares	Degrees of Freedom	Average of Squares	F	Sig
Static balance	*Between groups*	1353.54	2	676.54	37.35	0.0001
	within group	1575.80	87	18.11		
	Total	2928.88	89	----		
Dynamic balance	*Between groups*	450.34	2	225.17	4.58	0.013
	within group	4270.51	87	49.08		
	Total	4720.86	89	----		

Figures 2 and 3, respectively, illustrate the changes in male gymnasts' mean static and dynamic balance in the pronation, supination, and natural foot condition groups [Figure 2 and 3].

The results of the James-Howell post hoc tests for static balance and the Tukey test for dynamic balance, used for pairwise group comparisons, are presented in [Table 4].

Due to the non-homogeneity of variances in the static balance variables, the James-Howell post hoc test was used for pairwise comparisons of groups [Table 4]. The results showed no significant difference in static balance between gymnastic boys with pronation and suspension (P=0.930); however, there was a significant difference in static balance between gymnastic boys with suspension and those with a natural state (P=0.0001), and between gymnastic boys with pronation and those with a natural state of the foot (P=0.001).

The Tukey post hoc test was used to compare groups in dynamic balance. The results indicated that there was no significant difference in dynamic balance between gymnastic boys with pronation and suspension (P=0.924); however, there was a significant difference in dynamic balance between gymnastic boys with suspension and a natural position of the foot (P=0.018), and between gymnastic boys with pronation and a natural position of the foot (P=0.047).

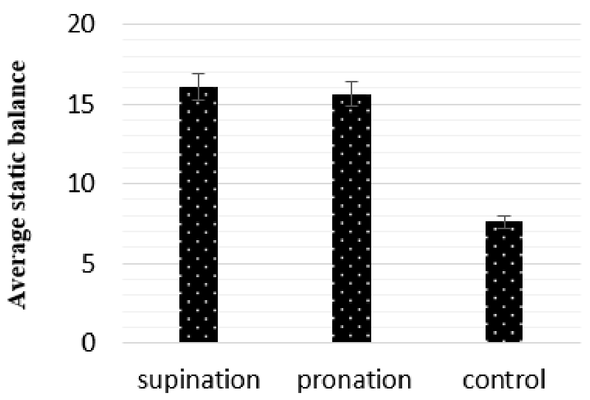


Figure 2. Variations in the average static balance

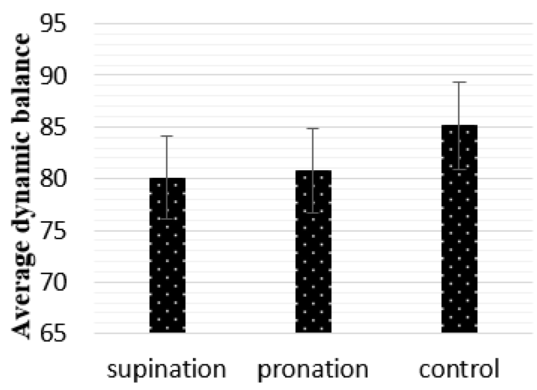


Figure 3. Variations in the average dynamic balance of gymnastic boys in the suspension, pronation, and natural foot groups groups

Table 4. Results of the James-Howell post hoc tests (static balance) and the Tukey test (dynamic balance) to examine the position of differences

	Group (I)	Group (J)	Difference of means	standard error	Sig
Static balance	***Supination***	*Pronation*	0.43	1.19	0.930
		Natural	8.43	0.99	0.0001
	Pronation	*Natural*	8.00	1.09	0.0001
Dynamic balance	***Supination***	*Pronation*	-0.68	1.80	0.924
		Natural	-5.05	1.80	0.018
	Pronation	*Natural*	-4.36	1.80	0.047

Discussion

This study examined the influence of MLA height on static and dynamic balance in 7-10-year-old male gymnasts. Our findings revealed significant static and dynamic balance variations across the three-foot types (pronated, supinated, and neutral). The results showed that gymnasts with supinated and natural feet demonstrated significant differences in balance performance compared to those with pronated feet in both static and dynamic tasks. However, no statistically significant differences were observed in balance between gymnasts with pronated and supinated feet.

The results indicated a significant difference in static balance between gymnastic boys with pronation, supination, and natural foot conditions. The James-Howell post hoc test showed no significant difference in static balance between gymnastic boys with pronation and those with suspension. However, there was a significant difference in static balance between gymnastic boys with suspension and their natural state counterparts and between gymnastic boys with pronation and the natural state ones. The results of the present study are consistent with the findings of Kordi Ashkezari et al. (2017),[37] Han et al. (2022),[38] and Faghihi and Nazari (2016).[39] These studies reported a significant relationship between MLA foot arch height and static balance, indicating that individuals with high arches (increased supination) and flat (increased pronation) feet have less balance than those with a natural foot arch.

On the other hand, the results of this study are inconsistent with the findings of Mosavi et al. (2010), who reported no significant relationship between foot arch height and static balance.[26] An explanation for the inconsistency between the results of these two studies could be attributed to the demographic differences in age groups, where the participants in the present study were 7-10-year-old gymnasts. In contrast, the participants in Mousavi et al.'s study were non-athlete adolescents aged 12-14.[26]

The reason for the reduced static balance in individuals with flat and hollow arches compared to those with a normal arch in this study can be explained as follows. In these deformities, it is likely that changes in the foot structure, the position of the foot joints, and subsequently, an increase in the longitudinal arch inside have created adverse effects on multiple joints and numerous sensory receptors in this area, leading to disturbances in the afferent pathways of the central nervous system and ultimately resulting in reduced static balance. Moreover, these changes in the upper sections have caused appropriate alignment in the foot area and, in general, the lower limb to alter. When a joint structure deviates from its ideal alignment, unnatural forces are exerted on the joint surfaces. Additionally, it leads to changes in the mechanical function of muscles and the coordinated actions of all the muscles passing through the joint, resulting in decreased neuromuscular efficiency (reference), ultimately disrupting the balance of the individuals in question (reference). On the other hand, the alterations in the movement chain of the proximal parts were not so severe to be observable. However, these minor changes in the alignment of the lower limbs have led to increased static balance in athletes with pronation and supination compared to the normal group.

The results showed a significant difference in dynamic balance between gymnastic boys with pronation, supination, and natural foot conditions. The Tukey post hoc test indicated no significant difference in dynamic balance between gymnastic boys with pronation and those with suspension. However, there was a significant difference in dynamic balance between gymnastic boys with suspension and their natural state counterparts and between gymnastic boys with pronation and the natural state ones. The present research results are consistent with the findings of the study by Mousavi et al. (2010), indicating a significant relationship between the level of the foot arch and dynamic balance.[26] On the other hand, the results of the current study are inconsistent with the findings of the research by Kordi Ashkezari et al. (2017),[37] Hanet al. (2022),[38] and Faghihi and Nazari (2016),[39] who reported that there was no significant relationship between the level of the arch of the foot and dynamic balance. Qasemi et al. (2011) conducted a study titled "Comparison of dynamic balance in men with different foot arches." The results showed that individuals with flat feet exerted greater pressure on the foot's outer side, leading to the assumption that the stability range on the outer side was larger. Conversely, individuals with high arches exerted greater pressure on the foot's inner side. Therefore, they concluded that the anatomical structure of the foot affects dynamic balance.[40] Hence, it appears that the MLA of the foot has a significant relationship with the dynamic performance of individuals, and apart from the depth of the sensory receptors of the foot, the foot's surface also affects dynamic posture control; thus, based on the results, there is a connection between the MLA of the foot and maintaining body balance.[26]

Some of the limitations of this study include the lack of a comprehensive sampling of the entire population and the necessity of controlling peripheral variables, such as gender, activity level, and body weight. Practical recommendations for future research include conducting similar studies on gymnasts from different age groups and developing educational programs and specific exercises to reduce the longitudinal arch of the foot and improve balance.

Conclusion

The study revealed that athletes with increased foot pronation and supination showed lower static balance than those with a normal arch. However, there was no significant difference in dynamic balance between the groups using the Y Balance Test. As a result, it is recommended to emphasize static balance exercise programs in corrective, rehabilitative, and exercise regimens for individuals with MLA foot variations. Additionally, future research should focus on other potential factors affecting dynamic balance, such as muscular strength, endurance, range of motion, and concentration, and consider using high-precision laboratory equipment to compare athletes' dynamic balance levels with field tests like the Y Balance test. The study emphasizes the relationship between MLA foot variations and balance, suggesting that addressing foot positional abnormalities before sports activities can significantly impact an individual's physical condition. Corrective exercise coaches and sports science specialists can utilize these findings to screen individuals before sports participation and address physical condition problems, ultimately encouraging participation in sports activities by enhancing and modifying individuals' lifestyles.

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Authors Contribution: SH and KK contributed to the study conception and design, and SH performed clinical examination and data collection. MS and KK participated in the methodological development and design of the statistical analysis. MS and FK wrote the first draft of the manuscript and contributed to the comments and suggestions that significantly improved the manuscript. Finally, all the authors revised it critically for important intellectual content, agreed with the content, contributed to the current study's refinement, and approved the final manuscript.

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Declaration of Ethical Approval for Study: The Human Ethics Research Committee approved this study of the Sport Sciences Research Institute of Iran according to compliance with the Ethical Standards in Research of the Ministry of Science, Research and Technology, with the code SSRI.REC-2405-2748, as well as operating under the Declaration of Helsinki.

Declaration of Informed Consent: Informed consent was obtained from the parents, legal guardians, or next of kin for participating minors under the age of 16. The parents or legal guardians were fully informed about the nature of the study and their consent was obtained before any involvement of the minors in the research.

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