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COMPARATIVE ANALYSIS OF THE IMPACT OF VARIOUS FOOT ARCHES ON DYNAMIC BALANCE, SPEED PERFORMANCE AND JUMPING ABILITY AMONG SHORT-DISTANCE RUNNERS AND MIDDLE-DISTANCE RUNNERS

Original Research

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ABSTRACT

Introduction: The structural configuration of the human foot, including its longitudinal and transverse arches, plays a important role in stability, propulsion, and overall running performance. Variations in foot arches classified as low (flat), normal, and high may influence dynamic balance, sprinting ability, and jumping performance. Given the distinct biomechanical demands of short-distance and middle-distance running, understanding these influences is essential for optimizing athletic performance.

Methods: Forty-eight competitive runners were randomly assigned into short-distance (n = 24) and middle-distance (n = 24) groups. Foot arch types were determined using the Navicular Drop Test. Dynamic balance was assessed with the Star Excursion Balance Test (SEBT), speed performance with the 40-Yard Dash Test, and jumping ability with the Vertical Jump Test (VJT). Statistical significance was set at $p \leq 0.05$.

Results: Among 48 runners, low-arch athletes demonstrated the highest vertical jump height (short-distance: 52.07±0.0 cm; middle-distance: 42.02±3.97 cm), outperforming normal (45.82±7.34, 40.10±3.13) and high arches (46.07±11.60, 42.64±0.0) (p=0.001). For 40-yard dash, high-arch short-distance runners were fastest (4.81±0.01 sec), followed by normal (5.54±0.32) and low arches (6.96±0.23) (p=0.001). Middle-distance sprint times were slowest in high arches (7.52±0.0) versus low (6.37±0.47) and normal (7.09±0.52) (p=0.001). Dynamic balance was optimal in high-arch short-distance runners (right: 87.54±3.39; left: 88.14±3.37) and normal-arch middle-distance runners (right: 90.70±2.51; left: 92.27±2.42) (p=0.05).

Conclusion: Foot arch type significantly influences athletic performance. Low-arch runners demonstrated superior vertical jump height across both distances. High-arch short-distance runners excelled in speed and dynamic balance, whereas low-arch middle-distance runners achieved fastest sprint times. Normal-arch middle-distance runners showed optimal dynamic balance. These findings support personalized training interventions based on individual foot arch characteristics.

Keywords: Foot arch, dynamic balance, sprint performance, vertical jump, running biomechanics.

INTRODUCTION

Sports science has extensively studied the biomechanical properties and anatomy of the human foot, especially the differences in arch structure. The human foot is a unique and important static-dynamic component of body's mobility apparatus. It plays a crucial role in the mechanics of running since it's an essential part of human posture which keeps the body in direct contact with the ground during locomotion (1).

A human foot is divided into three sections: rearfoot, midfoot, hindfoot. The rearfoot is composed of talas, calcaneus and two tarsal bones. Midfoot is made up of five tarsal bones i.e. navicular, cuboid and medial, middle and lateral cuneiform bones. The forefoot is a composition of metatarsals and phalanges. Human foot consists of a unique external and internal architecture. The external foot architect is made up of longitudinal arches (medial and lateral) and transverse arches which act as a lever and propels body forward during movement (1).

The longitudinal arch is a complex interplay between the shape of bone, joint, ligamentous supports and acting tendons. It acts much like a spring and plays a role in shock absorbing, storing and transferring energy during locomotion. It is reported that the differences in running biomechanics can be attributed to the flexibility of different medial longitudinal arch types (2). Foot arches are classified as flat foot, normal-arch foot, and high-arch foot. Flatfoot is characterized by excessive eversion of rearfoot and forefoot abduction and presents as the collapse of medial longitudinal arch (3). In normal foot posture the heel is perpendicular to the floor and is associated with properly positioned bones. The high-arch foot is composed of excessively elevated longitudinal arch (4). It has been noted that the structural and functional aspects of different types of foot arches, play a significant role in influencing the running ability. Low-arch foot frequently has a tendency to be more be more flexible whereas high-arch foot tends to be stiffer (5).

Running is just a sequence of single-leg squats performed repeatedly. Given the flight phase, a more realistic definition may be a sequence of single leg dives (6). Events lasting longer than 400 meters are categorized as "distance" races, whereas races lasting 400 meters or less are categorized as "sprints or short distance." Running events that fall into the category of "middle distance" are those that span distances between these two disciplines, specifically >400 m and 3000 m (7).

During an effective run, the foot should land as near to line of gravity as feasible. If the foot strikes ahead of line of gravity, its forward and downward forces are met with upward and backward ground reaction force, thus delaying the forward motion. However, short distance running is a series of ballistic strides propelling the body forward, these ground stresses are absorbed by foot arches (8).

Short distance runners and middle-distance runners have different physiological needs and performance requirements during races, so they were chosen as separate study groups. Short distance runners rely extensively on precise foot placement, powerful push-offs and rapid balance corrections. The ability to stabilize ones' body while moving or during change in directions is called dynamic balance. As it is important for sprinters to optimize their speed and power, they must maintain a proper running technique and form. In contrast, middle-distance runners usually manifest as a hybrid of short-distance runners and long-distance runners and demand a particular blend of speed and efficiency (7).

Having a good dynamic balance allows for this and it is measured by SEBT. The Star excursion balance test (SEBT) is a functional test that has been widely discussed in scientific literature for its ability to measure dynamic postural control of lower limbs (9). Thus, Low arch, flexible foot may stretch the soft tissues of the foot in order to adapt to ground reaction forces while running. In contrast, high-arch foot due to lack of shock absorbing capacity affects the balance and speed (5). Clinically, foot arch can be classified using navicular drop test (NDT) into flat foot, neutral foot or high-arch foot.

Speed performance is another important factor which can be affected by foot arch morphology. Speed performance is defined as the maximum velocity that an athlete can achieve in meters per second. Running velocity has been shown to be a function of force and power production. Thus given, the high-power output is associated with jumping activities. High arched (HA) feet tend to be rigid and stiff, while low arched (LA) feet are generally compliant and flexible. The structural difference between HA and LA feet have been identified to influence propulsion mechanics during jumping and running (10). The contrasting needs of short-distance runners and middle-distance runners necessitate the understanding of the effect of foot arches on performance metrics. Emphasis on dynamic balance, speed performance and jumping ability in this research represents the essential elements of running performance that are influenced by the biomechanics of the foot arch.

Limited research exists on the influence of foot arch types on dynamic balance, speed performance, and jumping ability among short-distance runners, and even fewer studies have examined these variables in middle-distance runners. Most existing evidence is derived from international athletic populations, resulting in a significant gap in understanding how foot arch variations affect performance within the Pakistani athlete community. Addressing this gap is important, as foot structure can influence running biomechanics, injury risk, and overall athletic output. Generating context-specific data on Pakistani runners may contribute to the development of targeted training interventions, more effective injury-prevention strategies, and footwear designs tailored to local needs and environmental conditions.

METHODOLOGY

This cross-sectional study was conducted at Pakistan Sports Board, Wapda Sports Complex, and Pakistan Olympic Association Department, Lahore. The study was approved by the Institutional Review Board of Shalamar Institute of Health Sciences on 11 July 2024 (Chairman: Dr M.A. Wajid). A total of 48 competitive male runners aged 18 to 30 years were recruited using a simple random sampling technique. All participants provided written informed consent prior to enrolment. After fulfilling inclusion criteria—healthy, injury-free, properly trained with healthy nutritional diet, short-distance (400 m) and middle-distance (400–3000 m) runners—participants were randomly divided into two groups (I and II) by balloting method. Runners with any co-morbidities, musculoskeletal pain, or those taking any medications were excluded from the study. Group I comprised short-distance runners (400 m) and Group II comprised middle-distance runners (400–3000 m), classified using International Association of Athletics Federations (IAAF) scores guidelines. A study proforma was used to document quantitative and qualitative parameters.

Foot arches were calculated by using navicular drop test which classified the foot under three category, low arch foot, normal arch foot and high arch foot. The Star Excursion Balance Test (SEBT) was used to measure the dynamic balance through eight-directional reach tasks with one leg while standing on the other leg and a composite score was calculated; score of less than 86.9% represented reduced stability (11). Similarly speed was assessed by 40-Yard Dash Test with each runner performing three sprints and the fastest time was recorded (12). The Vertical Jump Test (VJT) was used to measure the jump height of runners as the distance between the standing-reach height and the jumping height (13).

The data was entered and analyzed using SPSS 21.0 (Statistical Package for Social Science). Mean ± S.D has given for quantitative (Age, height, weight) variable. Frequencies and percentages were given for qualitative variables. Shapiro-Wilk test was used for normality of the data. Independent sample t tests was applied to observe groups mean differences of the biomechanical factors in both groups. Pearson Chi-Square test and Fisher Exact test (if cell frequency is less than 5) was applied to observe the association of foot arches and dynamic balance, speed performance and jumping ability between the two groups. A p-value of 0.05 was considered statistically significant.

RESULTS

Total 48 runners were recruited in the study. Runners with normal foot arch demonstrated significantly superior performance in vertical jump height followed by low-arch foot (p-values=0.001), indicating strong statistical significance in both running categories. The **40-yard dash test measuring speed** also demonstrated considerable differences for all arch types, with high arches performing best in short-distance sprints (p=0.001), followed by normal arches (p=0.001) and low arches (p=0.001) while all foot arch types show a consistent yet slower times in **middle-distance running**, with significant differences (p = 0.001). The most notable performance in balance for middle-distance running was seen in low and normal arches. In contrast, short distance runners with high foot arches showed the best dynamic balance, with significant differences observed compared to those with normal or low foot arches (p=0.005).

Graph: Comparison of Age, Weight and Height by Foot Arch type

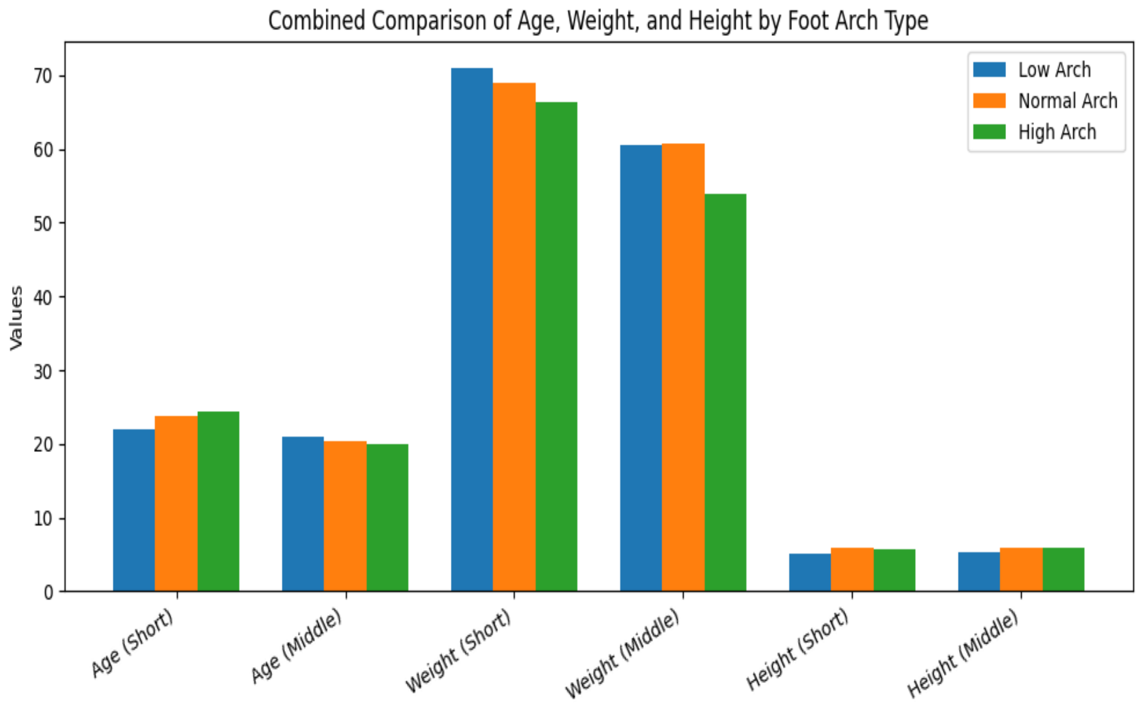

Figure 1 Combined Comparison of Age, Weight, and Height by root Arch Type

Table1: Impact of Foot Arch Type on Athletic Performance Metrics across short-distance and middle-distance running categories

	Foot arch type	Short distance running	Middle distance running	p-value
Age	Low foot arch	22.00±0	20.91±1.04	
	Normal foot arch	23.75±4.3	20.42±0.5	
	High foot arch	24.33±0.5	20±0.0	
Weight	Low foot arch	71.00±0	60.45±7.36	
	Normal foot arch	69.08±7.96	60.67±8.23	
	High foot arch	66.33±4.77	54.00±0.0	
Height	Low foot arch	5.11±0	5.37±0.29	
	Normal foot arch	5.89±0.21	5.91±0.15	
	High foot arch	5.70±0.22	5.80±0.00	
Vertical jump test (Average jump height)	Low foot arch	52.07± 0.0	42.02±3.97	0.001
	Normal foot arch	45.82±7.34	40.10±3.13	0.001
	High foot arch	46.07±11.60	42.64±0	0.001

	Foot arch type	Short distance running	Middle distance running	p-value
40 Yard dash test (Average speed)	Low foot arch	6.96±0.23	6.37±0.47	0.001
	Normal foot arch	5.54±0.32	7.09±0.52	0.001
	High foot arch	4.81±0.01	7.52±0.0	0.001
Star excursion balance test- Dynamic Balance (right leg)	Low foot arch	70.20±0.00	81.41±4.37	0.05
	Normal foot arch	77.42±3.80	90.70±2.51	0.05
	High foot arch	87.54±3.39	85.20±0.0	0.05
Star excursion balance test- Dynamic Balance (left leg)	Low foot arch	75.94±0.00	80.81±4.34	0.05
	Normal foot arch	80.60±2.63	92.27±2.42	0.05
	High foot arch	88.14±3.37	88.92±0.00	0.05

DISCUSSIONS

The present study was conducted to examine the influence of low, normal, and high foot arches on dynamic balance, speed performance, and vertical jump height among short-distance and middle-distance runners. A total of 48 participants were equally divided into two groups based on running category, and foot arches were classified using the navicular drop test. Performance metrics were assessed using the Star Excursion Balance Test, the 40-yard dash test, and the vertical jump test. This investigation contributes to the expanding body of literature regarding the biomechanical role of foot architecture in athletic populations while addressing a notable gap in research concerning middle-distance runners and the comparative influence of arch types across distinct running distances.

The most unexpected finding pertained to vertical jump performance. Contrary to prevailing assumptions and several previously published reports, runners with low foot arches demonstrated the highest vertical jump heights in both short-distance (52.07±0.0 cm) and middle-distance (42.02±3.97 cm) categories, whereas normal-arch runners exhibited the lowest vertical jump values (45.82±7.34 cm and 40.10±3.13 cm, respectively). These findings diverge from those reported by Selvaganapathy et al. (14), who observed reduced vertical jump heights among individuals with flat arches compared to those with normal arches. Similarly, Fu et al. (15) concluded that normal arch morphology confers superior jumping capability due to favourable ankle kinematics during plantar flexion and external rotation. The present findings also contrast with those of Gazbare et al. (16), who reported that low arches provide enhanced shock absorption but do not surpass normal arches in jump height. One possible explanation for this discrepancy is that the flexible nature of low-arch feet may facilitate greater energy storage and return during the stretch-shortening cycle inherent in vertical jumping, particularly when lower limb musculature is adequately conditioned. Moreover, previous studies have predominantly examined recreationally active individuals or heterogeneous athletic samples, whereas the present cohort comprised exclusively competitive runners, which may have influenced the observed outcomes. It is also plausible that the relationship between arch height and jump performance is non-linear and moderated by factors such as ankle stiffness, proprioceptive acuity, and training history, which have not been uniformly controlled across studies.

With respect to speed performance, high-arch short-distance runners recorded the fastest 40-yard dash times (4.81±0.01 sec), followed by normal-arch (5.54±0.32 sec) and low-arch runners (6.96±0.23 sec). Among middle-distance runners, however, low-arch athletes demonstrated superior sprint times (6.37±0.47 sec) compared to their normal-arch (7.09±0.52 sec) and high-arch counterparts (7.52±0.0 sec). These findings partially align with the work of Sudhakar et al. (8) and Sharma and Upadhyaya (19), who reported that high-arch feet confer mechanical advantages during explosive short sprints due to increased midfoot rigidity and efficient force transmission. Conversely, the present data contradict the conclusions of Temur et al. (20), who identified a significant negative correlation between arch height and running performance across both sprint and middle distances, with high arches associated with slower times. This divergence may be attributable to differences in participant characteristics, surface type, sprint protocol, or training status. Importantly, the present study challenges the assumption that arch-related performance effects are uniform across running distances. Among middle-

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distance runners, low arches appeared to offer a biomechanical advantage not evident in shorter sprints. This may relate to favourable lower limb alignment, reduced impact peak forces, or enhanced pronation control during repeated foot strikes over extended distances. The observation that all arch types performed with relatively slower times in middle-distance running compared to short-distance sprinting reflects the differing physiological demands of each event, wherein explosive power is prioritised in sprints and energy conservation becomes paramount over longer distances.

Dynamic balance, assessed via the Star Excursion Balance Test, revealed distinct arch-related patterns according to running distance. Among short-distance runners, those with high foot arches attained the highest composite reach scores on both right (87.54±3.39) and left limbs (88.14±3.37), outperforming normal-arch and low-arch counterparts. In contrast, middle-distance runners with normal arches demonstrated optimal dynamic balance (right: 90.70±2.51; left: 92.27±2.42), whereas low-arch runners exhibited the poorest balance performance within this group. These findings are consistent with the work of Abhilash et al. (17), who reported superior dynamic balance among individuals with supinated foot postures, and Sudhakar et al. (8), who proposed that the rigid lever characteristics of high-arched feet enhance postural control during tasks requiring rapid directional changes. The present results extend these observations by demonstrating that the balance advantages conferred by arch type are distance-dependent. Among middle-distance runners, normal arches may provide an optimal compromise between flexibility and stability, facilitating controlled reach excursions without compromising base of support. The comparatively poorer balance exhibited by low-arch middle-distance runners may be attributable to excessive subtalar joint mobility and delayed neuromuscular response to postural perturbations. These findings underscore the importance of considering both arch morphology and event-specific demands when evaluating dynamic postural control in athletes.

Several strengths of the present study warrant acknowledgment. The investigation employed a comparatively homogeneous sample of competitive male runners, thereby reducing confounding related to sex, age, and training background. The use of validated field-based performance tests and a standardised clinical assessment for arch classification enhanced the reproducibility and practical applicability of the findings. Additionally, the inclusion of both short-distance and middle-distance runners within a single comparative framework permitted novel insights into distance-specific effects of foot architecture. Nevertheless, certain limitations must be considered when interpreting the results. The cross-sectional design precluded causal inference regarding the longitudinal effects of arch type on performance development. The sample size, while adequate for detecting large effects, may have limited statistical power for subgroup analyses, particularly within arch-type categories. Foot posture was assessed using the navicular drop test, a clinical tool with established reliability, although static measures do not fully capture dynamic foot function during running. Furthermore, the absence of three-dimensional motion analysis or plantar pressure measurement restricted the biomechanical depth of the investigation. Potential confounding variables such as lower limb strength, flexibility, and previous injury history were not exhaustively controlled. Future research should incorporate larger and more diverse samples, including female athletes, and employ longitudinal designs to examine whether arch-specific performance characteristics are modifiable through targeted intervention. The integration of dynamic foot function assessment and musculoskeletal imaging would further elucidate the mechanical pathways underpinning the observed associations. Despite these constraints, the present study provides robust evidence that foot arch morphology exerts a significant and distance-dependent influence on multiple domains of athletic performance, thereby supporting the integration of arch-type profiling into routine sports screening and individualised training prescription.

CONCLUSIONS

Foot arch type significantly influences athletic performance. Low-arch runners demonstrated superior vertical jump height across both distances. High-arch short-distance runners excelled in speed and dynamic balance, while low-arch middle-distance runners achieved fastest sprint times. Normal-arch middle-distance runners showed optimal dynamic balance. These findings support personalized training interventions based on individual foot arch characteristics.

AUTHOR CONTRIBUTIONS

Author	**Contribution**
Ezzah Shakeel*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Muhammad Usman Nazir	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Iman Fatima	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Muhammad Haseeb	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Mehreen	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Mehreen	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published
Faima Iqbal	Contributed to study concept and Data collection Has given Final Approval of the version to be published
Mubeeh Jamshad	Writing - Review & Editing, Assistance with Data Curation
Bilal Ahmad	Writing - Review & Editing, Assistance with Data Curation
Mariya Tariq	Writing - Review & Editing, Assistance with Data Curation

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