



Original Article

A Comparison of Foot Plantar Pressure in Badminton Players with Normal and High-Arched Feet during the Two-Way Lunge

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ABSTRACT

Background: Compared to the individuals with a normal arch structure, those with high or low arch can be at an increased risk of overuse injuries. The risk of overuse injury among athletes is high due, in part, to the repeated loading of the lower extremities. The current study aimed to determine if foot type (high-arched or normal) results in differences in plantar pressure during two badminton-specific movements (right-reverse lunge and right-lateral lunge).

Methods: Twenty badminton players (10 with normal feet and 10 with high-arched feet) completed five trials in both right-reverse and right-lateral lunge, while in-shoe pressure data were collected at 100 Hz. The peak pressure and mean pressure were analyzed among the subjects for five major anatomical regions of the foot, using the independent t test in SPSS version 20. The foot type was determined by the foot posture index (FPI) ($\alpha < 0.05$).

Results: Results showed that the plantar pressure characteristics of normal and high-arched feet were different; such that in high-arched feet, as compared to normal subjects, there were significantly fewer pressure strikes in the medial ($P=0.010$) and lateral ($P=0.002$) mid-foot in right-reverse lunge and this was significantly higher in forefoot ($P=0.003$) and toes ($P=0.010$). However, the peak ($P=0.157$) and mean ($P=0.104$) pressure in the heel was higher but not significant. In the right-lateral lunge, we found statistically lower peak pressure stroke for the lateral mid-foot ($P=0.010$) and forefoot ($P=0.011$); however, the mean pressure was lower in the lateral ($P=0.010$) and medial ($P=0.040$) mid-foot and forefoot ($P=0.120$), although it was not significant in the forefoot.

Conclusion: Results showed that the medial longitudinal arch of the foot might cause pressure differences in the feet among the players with normal and high-arched feet. As the results demonstrated, in high-arched feet, there are some regions where plantar pressure is higher and some where it is lower. Therefore, in order to prevent the badminton players from suffering probable foot injuries, attention should be paid to the compatibility of the insole/shoe and the medial longitudinal arch and other areas of the foot that suffer more pressures than normal subjects.

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Introduction

Physical activity is part of today's healthy lifestyle

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and sports injuries are important health issues for all, specifically for adults. Fortunately, most sports injuries can be treated effectively and most people who suffer injuries can return to a satisfying level of physical activity after an injury. Moreover, most injuries could be prevented by taking sufficient caution [1]. The risk of

lower extremity injury among young athletes is related to a variety of internal and external factors [2]. However, some deformities that increase the risk of injuries are still incurable and the risk could only be lowered by the prevention of the external factors from having an effect.

According to the experts, frequent contacts between the foot and the floor, with the reaction force exerted by the floor (ground reaction forces), may lead to injuries of the lower limbs, including stress fractures, cartilage damage, and the development of osteoarthritis [2].

Many hazardous factors have been reported for foot and ankle injuries such as age, gender, skeletal alignment, bone density, competition level, type of shoe, muscular strength, muscular imbalance, and foot morphology [3], and in sports, the risk of injury is dependent on both the sport being played as well as the player's position [3].

Meanwhile, the medial longitudinal arch of the foot plays an important role in weight transfer and shock absorption during walking and running [4]. The anatomical changes in feet, including abnormal arch structure, increase the risk of lower extremity overuse injuries two fold [2]. Previous studies showed that the type of the medial longitudinal arch of the foot is related to injuries of the lower limbs [2, 5].

A high-arched foot is related to an increased risk of multiple lower extremity injuries like the inflammation of the plantar fascia and lateral ankle sprains. Moreover, a high medial longitudinal arch may increase rigid foot mechanics that result in decreased ability to absorb shock when compared to athletes with normal arch structures [2, 6]. A high arch can change the shape of the foot, the gait, and the stability of ankle, which affect the weight-bearing and walking functions [7]. The prevalence rate of this deformity is unknown, but it is more common among athletes who engage in frequent and high impact activities [8].

For instance, badminton is a popular sport in which the foot and its movements play an important role since the sport requires jumps, lunges, and quick changes in direction. Skillful foot movements allow the badminton player to reach the shuttlecock quickly with minimum effort. It, moreover, helps players balance and control their bodies better in order to take the best positions. Therefore, it is not surprising that abnormal foot alignment may lead to many problems. High pressure is exerted in stop-and-go maneuvers and this makes the players susceptible to injuries in lower limbs, specifically during quick and frequent lunges that are considered as the most fundamental and critical maneuvers for skill proficiency and exert high pressure to the heel [9].

Previous studies have reported a significant difference in plantar pressures with respect to the type of task, the playing surface, and gender. They have shown differences between activities and competition levels [3, 10-13]. However, very few studies have investigated the effects of the type of the foot on plantar pressure [2, 3].

The most important factor in plantar pressure is the type of the foot, which is pronounced significantly in sports activities and especially, professional sports. Injury prevention necessitates the determination of

the importance of high pressure and its distribution. It, moreover, needs an investigation of the mechanism of sports-related injuries. Investigating the plantar pressure of the different lunge directions can provide us with biomechanical information on enhancing athletic performance and offer the coaches and players useful information on injury prevention during training and competitions.

Obviously, the shoe used by the player may improve his/her performance. It may absorb the shocks suitably and stabilize the movements to prevent severe and harmful pressures. It seems that preventive measures like sport-specific shoes and insoles compatible with the structure of the athlete's feet and compatible with the distribution of forces may impede injuries and their consequences. This is only possible by studying and scrutinizing the high-frequency/high-risk activities.

The purpose of current study is to compare foot plantar pressure, in badminton players with normal and high-arched feet, during the two-way lunge. This research can yield information used for providing and designing suitable in-shoe and shoe for badminton players based on their foot type. Our hypothesis states that based on foot type, the plantar pressure is different in different lunge directions.

Methods

Participants

The population of the current study, conducted in Tehran province in Iran, comprised badminton players who use their right foot dominantly. The convenient sampling method was used to select the study subjects and accordingly, 10 subjects with high-arched foot deformity and 10 subjects with normal feet (8 female and 12 male) were recruited and tested for this study. The demographic data of the subjects were recorded as follows: mean±standard deviation (SD) of age (19.3 ± 3.34 , range between 16 and 24); weight (61.5 ± 8.56); height (173.6 ± 10.83). The subjects had no history of lower extremity injuries in the past year and no history of foot and ankle surgery. The subjects were excluded if they got injured during the test procedure. All subjects signed the consent form to participate in the study. The study was approved by the ethics committee of the Kharazmi University of Tehran.

Data Collection

The feet type was determined for the players by using the Foot Posture Index (FPI) test and the players with scores 0 to 5, and 1 to 4 were considered the players with normal and high-arched foot, respectively. The reliability and validity of the FPI scale had been assessed in several studies [14-18]. The internal reliability of FPI was reported as 0.956 to 0.959 [19]. The subjects with high-arched foot deformity and normal feet in both feet were analyzed in this study. The plantar pressure characteristics were collected with the Pedar-X® system (Novel Electronics, Germany) at a frequency of 100 Hz. The instrumented insoles contained 99 capacitive pressure sensors sampled

at a rate of 200 Hz. The pressure information of each sensor was transmitted to a computer via Bluetooth wireless communication with the player unit, which was secured around the waist of the participant. The insoles were inserted in both right and left shoes during data collection, but only the data from the dominant (right) leg were collected. Before the test sessions, the insoles were calibrated according to the manufacturer guidelines. Feet-size insoles of the subjects were put in both shoes. The subjects were asked to repeat two lunge movements (right-reverse, right-lateral) (Figures 1 and 2) five times, while wearing these badminton shoes. The pressure under the right foot of the subjects was registered in the last step of the lunge. The peak pressure variables and those of the mean pressure for all areas of the feet were analyzed. Accordingly, the feet percentage mask was divided into five areas including heel, medial mid-foot, lateral mid-foot, forefeet, and toes (Figure 3)

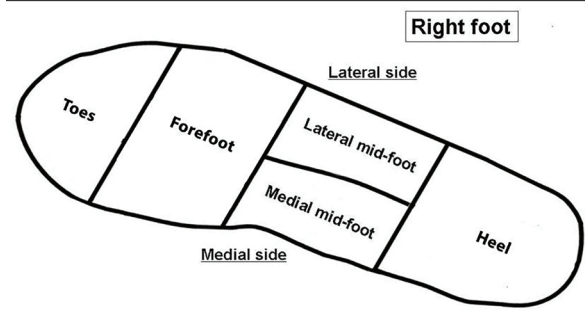


Figure 3: Regions of the foot

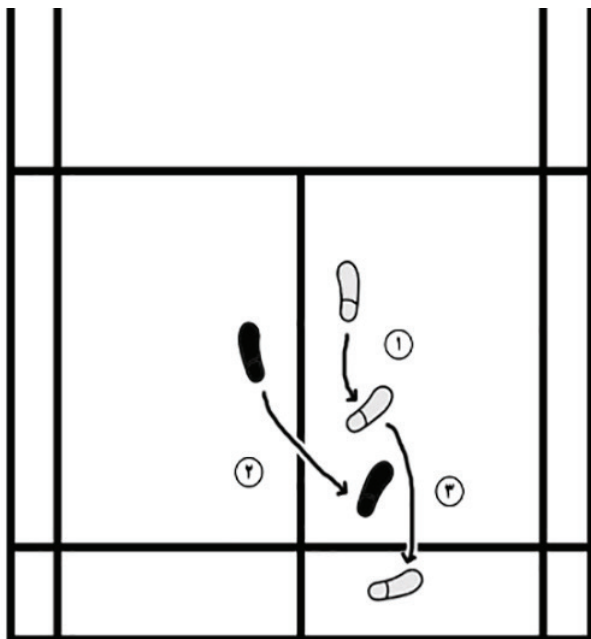


Figure 1: Right-reverse lunge

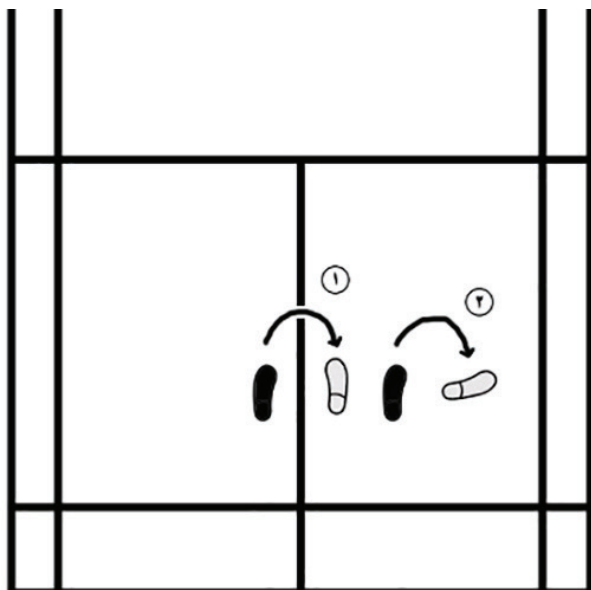


Figure 2: Right-lateral lunge

Statistical Analysis

To compare the two types of plantar feet (normal and high-arched foot), the Shapiro-Wilk test was used to investigate the normality of data and the results indicated a normal distribution among all the studied variables ($P > 0.05$). To compare the quantitative indicators in the two groups of normal and high-arched feet, the independent t-test was used. The data analyses were carried out with the software SPSS version 20 (IBM SPSS, Chicago, Ill); $P < 0.05$ was considered as the level of significance. In addition, the Cohen d statistic was calculated for each variable in order to determine the effect size. A Cohen's d value of 0.2 or less is considered to have a small effect size, a Cohen's d value of 0.5 or less is considered to have a moderate effect size, and a Cohen's d value of 0.8 or greater is considered to have a large effect size.

Results

The subjects consisted of 10 players with normal arch in both feet in the control group and 10 players with high-arched foot deformity in both feet in the experimental group. No significant difference was observed in the demographic variables of age, weight, and height between the groups (Table 1). During the right-reverse lunge, players with high-arched feet demonstrated a significantly lower peak pressure in the medial and lateral mid-foot (with moderate ES) and higher mean pressure in the forefoot (with moderate ES) and toes (with large ES) than the subjects with normal feet. Moreover, the peak and mean pressures were higher in the heel region, but not significant. During the right-lateral lunge, high-arched feet rather than normal feet demonstrated a significantly lower peak pressure in the lateral mid-foot (with large ES) and forefoot (with moderate ES) and lower mean pressure in the lateral (with large ES) and medial (with moderate ES) mid-foot. Moreover the mean pressure was lower in the forefoot region but insignificant (Table 2, 3).

Discussion

The purpose of this study was to determine the effect of foot type on plantar pressure characteristics in two basic badminton movements. The results of the current study showed that the plantar pressure characteristics were affected by the foot type and the differences depended on the direction of the movements. As in all foot types,

Table 1: A comparison of the participants' demographic characteristics between the two groups

	Age(year)	Height (cm)	Weight (kg)
Normal foot (n.10)	20.25±3.49	170±12.3	63±12.74
High arched foot (n.10)	18.7±3.18	176±9.29	60.5±4.15
P value	0.530	0.080	0.418

Values are mean±SD

Table 2: A comparison of plantar pressure in different foot regions between the two groups during the right-reverse lunge

		Group		P value	ES
		Normal foot n.10	High-arched foot n.10		
Peak pressure (kPa)	Heel (hind foot)	150.78±75.32	186.34±58.63	0.157	0.254
	Medial mid-foot	38.44±4.74	26.74±16.63	0.010*	.431
	Lateral mid-foot	106.66±16.97	82.07±20.66	0.002*	0.545
	Forefoot	173.33±52.36	155.69±56.73	0.397	0.159
	Toes	246.45±64.03	256.11±73.26	0.713	-0.070
Mean pressure (KPa)	Heel (hind foot)	70.07±33.85	89.79±29.86	0.104	0.295
	Medial mid-foot	8.92±1.84	11.01±10.68	0.513	0.135
	Lateral mid-foot	49.04±8.97	41.89±13.77	0.096	0.294
	Forefoot	77.21±16.17	59.16±5.56	0.003*	0.598
	Toes	55.00±11.44	89.08±13.86	0.010*	0.801

Values are mean±SD; *P<0.05

Table 3: A comparison of plantar pressure in different foot regions between the two groups during the right-lateral lunge

		Group		P value	ES
		Normal foot n.10	High-arched foot n.10		
Peak pressure (KPa)	Heel (hind foot)	339.72±111.49	251.71±120.13	0.078	0.354
	Medial mid-foot	41.04±19.51	27.06±3.50	0.064	0.446
	Lateral mid-foot	168.75±33.05	93.96±23.29	0.010*	0.794
	Forefoot	180.27±17.37	153.52±26.55	0.011*	0.512
	Toes	681.77±386.00	201.88±36.94	0.442	0.658
Mean pressure (KPa)	Heel (hind foot)	151.99±34.59	120.43±49.71	0.068	0.345
	Medial mid-foot	16.38±14.32	4.66±1.76	0.040*	0.498
	Lateral mid-foot	76.61±16.37	39.37±7.73	0.010*	0.824
	Forefoot	79.86±12.59	67.54±21.03	0.120	0.334
	Toes	68.69±26.16	57.61±12.79	0.257	0.259

Values are mean±SD; *P<0.05

the pressure imposed on one area of the foot is changing; these changes are not similar in different directions. These findings supported our hypothesis that plantar pressure is different, based on foot type, in different lunge directions. As described in the previous studies, the plantar pressure characteristics in various sports movements and different directions of a lunge changes in normal subjects [2, 3, 9, 11].

Generally, among the subjects of this study, the mean and peak pressure imposed under the mid-foot region was lower in the subjects with high-arched foot deformity compared with the ones with normal foot in the typical lunge maneuver implemented in two directions; however, the mean pressure under the forefoot was less in a right-lateral lunge and higher in the right-reverse lunge for the players with high-arched feet. The mean pressure under the toes was higher for the players with high-arched feet than those with normal feet when performing the right-reverse lunge. Moreover, the peak and mean pressure under the heels of the players with high-arched feet was higher than those with normal feet in both lunge movements, although this difference was not statistically significant.

The results reflecting lower peak and mean pressure imposed on mid-foot and higher peak and mean pressure on heels in people with high-arched foot deformity compared with the ones with normal feet were consistent with those of a study conducted by Burns et al. (2005) [20]. The results obtained regarding the lower mean pressure imposed on forefoot and higher peak and mean pressure on heels were consistent with the results of Carson et al. (2012) and Habibi et al. (2013) [2, 21].

The results of previous studies on the effect of foot type on the risk of injury and its mechanics were contradictory and it is still unclear which type of foot increases the risk of injury [3, 22-25]. In badminton, the high frequency of execution of the lunge step might be considered as the main risk factor which results in injuries of the lower limb [9].

According to the results of the study, it can be concluded that the foot arch height as well as the kind and orientation of the activities are the factors that influence the imposed pressures in the plantar area and other areas under pressure. Hence, considering proper cushioning in the shoe is a significant strategy for absorbing high

and repetitive loading, especially over the heel impact of the lunge movements [9]. The structural properties and footwear material could be modified to attenuate the external impact forces [26, 27], and decrease the frequency of injuries caused by overuse [9].

Research has shown that some structures like Achilles tendon, plantar fascia, anterior talo-fibular ligament of the specific musculo-tendon, and ligamentous structures are more vulnerable to damage in badminton, in comparison with other sports, due to the specificity and the repetitive manner of the tasks that occur through a badminton game, in general, and the high frequency stop-and-go maneuvers in particular [9, 28-30]. The significant potential mechanical risk factors responsible for joint tissue injuries and loading stress on fractures and micro-damage in cartilage include repetitive and excessive external pressure that arise from badminton maneuvers. Moreover, a rupture of Achilles tendon may result from the repetitive lunge steps.

To the authors' best knowledge, the current study was the first one to investigate the plantar pressure characteristics in special movements of a specific sport, emphasizing the foot type of the players.

The way of determining the foot type and grouping the subjects is a factor that should be considered while comparing different studies. In previous studies, the type of foot or the medial longitudinal arch height of the foot was defined by using clinical tests and footprint analyses. Some studies defined foot type only based on one parameter [3, 31, 32]. However, the current study attempted to prevent errors as much as possible. We used the FPI test based on six different anatomic parameters. Previous studies showed that the instrument used, measuring repetitions, the subjects' shoes, the speed of movement, the type of foot, and the underlying floor surface can influence the amount of pressure; therefore, the data comparison regarding the plantar pressure characteristics beneath the foot should be done carefully [3, 33, 34]. The present study tried to reduce the differences between the study samples in terms of history of injury, foot and ankle pain, and the use of the badminton shoes.

This study had certain limitations; for example, it was conducted under laboratory conditions and the subjects had their own shoes on. Another limitation was the inability to estimate the shear forces to the feet. Therefore, further research on sport-specific shoes designed with fewer restrictions, the measurement of forces incurred, and moreover, the pressures imposed on feet with a focus on lower limb abnormalities can be conducted in the future.

Conclusion

Results showed that the medial longitudinal arch of the foot might cause pressure differences in the feet among the players with normal and high-arched feet. As the results demonstrated, in high-arched feet, there are some regions where plantar pressure is higher and some where it is lower. Therefore, in order to prevent the badminton

players from suffering probable foot injuries, attention should be paid to the compatibility of the insole/shoe and the medial longitudinal arch and other areas of the foot that suffer more pressures than normal subjects. In summary, an evidence-based testing protocol is the prerequisite for an objective and reliable evaluation of athletic and sports gear performance.

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