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Original Article

Comparison of ankle force, mobility, flexibility, and plantar pressure values in athletes according to foot posture index

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ABSTRACT

Objectives: This study aims to compare ankle force, mobility, flexibility, and plantar pressure distribution of athletes according to foot posture index (FPI).

Patients and methods: Between September 2016 and May 2018, a total of 70 volunteer male athletes (mean age: 21.1±2.3 years; range, 18 to 25 years) were included. The athletes were divided into three groups according to their FPI as follows: having supinated feet (Group 1, n=16), neutral/normal feet (Group 2, n=36), or pronated feet (Group 3, n=18). Ankle range of motion (ROM), muscle flexibility, ankle joint strength, and plantar pressure distribution were measured.

Results: There were significant differences among the three groups in both right and left ankle dorsiflexion ROM (p=0.009 and p=0.003, respectively). Group 1 had significantly smaller dorsiflexion ROM than the other groups. Group 1 also showed significantly less flexibility in the gastrocnemius and soleus muscles than the other foot posture groups. Groups 2 and 3 exhibited significant differences in the maximum torque (p=0.018), maximum work (p=0.008), and total work (p=0.008) of the right plantar flexor muscles at 60°/sec angular velocity. Peak pressure measurements of the right foot were higher in Group 1, compared to Groups 2 and 3 (p<0.001).

Conclusion: The results of this study may help to enhance athletic performance by providing a guide for designing training programs appropriate for athletes with different foot types to address their specific muscle flexibility and strength deficiencies.

Keywords: Flexibility, foot posture index, plantar pressure, sport, strength.

The foot is among the most complex and important parts of the body in terms of mobility, as it forms the connection between body and ground. It provides ankle stability during push-off and absorbs the impact during loading response in activities, such as walking and landing from a jump.[1] A key component of the foot is the arch structure. The medial longitudinal arch is instrumental in shock absorption and its flexibility ensures proper structure and function during ambulation.[2] The foot can be categorized based on the height of the medial longitudinal arch as high (pes cavus), normal, or flat (pes planus) arch type.[3] Individuals with a low arch structure have a tendency for calcaneal eversion with greater forefoot valgus, abduction, and dorsiflexion. These alterations lead to pronation of feet with low arches. In contrast, supination is more likely in feet with high arches and calcaneal inversion.[4]

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Many factors can lead to the development of pes planus or pes cavus, including abnormalities of the foot bones, dysfunction or weakness of the foot muscles, shortened Achilles tendon, ligament laxity, and tightness or contracture of the calf muscles.[5,6] Foot and ankle muscle strength has a major role in supporting the arch structure.[7] Wang and Crompton[8] reported that a high arch reduces plantar muscle strength and power in aponeurosis. Murley et al.[6] observed more tibialis posterior and tibialis anterior muscle activity in individuals with pes planus, compared to healthy individuals. Mobility and flexibility of the ankle joint are the other main factors affecting foot posture. Many lower-extremity overuse injuries have been associated with limited ankle joint dorsiflexion.[9-11]

Information derived from the plantar pressure systems is vital in various applications, such as gait and posture research, diagnosis of foot arch problems, footwear insole design, sport biomechanics, injury prevention, and creation of patient-specific training plans. These systems enable plantar pressure distribution monitoring during normal gait and/or different tasks to provide insight into how load is transferred in different parts of the weight-bearing limb.[12] Plantar pressure is also related to lower extremity posture[13] and several studies have examined the association between plantar pressure and abnormal foot posture (e.g., hallux valgus, pes planus).[13-16] In the current literature, there are insufficient data regarding differences in ankle mobility, flexibility, strength, and plantar pressure among athletes and how these variables differ with foot arch posture (i.e., high, normal, and flat). In the present study, we hypothesized that athletes with different foot posture index (FPI) would exhibit different ankle joint strength, mobility, flexibility, and plantar pressure distribution. We, therefore, aimed to compare ankle strength, mobility, flexibility, and plantar pressure distribution in athletes with different foot arch postures. Determination of possible differences in these variables according to arch type may provide researchers and practitioners a better understanding of the effects of *(i)* abnormal plantar pressure, *(ii)* muscle strength, *(iii)* mobility, and *(iv)* flexibility on foot morphology.

PATIENTS AND METHODS

This monocentric, cross-sectional study was conducted at Anadolu University, Faculty of Sports Sciences, between September 2016 and May 2018. A total of 70 volunteer male athletes (mean age: 21.1±2.3 years; range, 18 to 25 years) including basketball, volleyball, handball, football, rugby players, and runners were included. The athletes were divided into three groups according to their FPI as follows: Group 1, supinated feet (n=16); Group 2, neutral feet (n=36); and Group 3, pronated feet (n=18). Exclusion criteria included a history of lower-extremity surgery, major trauma, or orthopedic injury (e.g., bursitis, tendinopathy, plantar fasciitis, ligament injuries) and presence of any systemic disease that could affect plantar pressure distribution and/or the morphological and mechanical properties of the intrinsic foot muscles (e.g., diabetes, connective tissue disorders). A written informed consent was obtained from each participant. The study protocol was approved by the Eskişehir Osmangazi University Non-Invasive Clinical Research Ethics Committee (No: 80558721/G-166, Date: 12.05.2017). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Assessment of foot posture index

Foot posture during full weight-bearing was assessed using the FPI-6,[17] which was shown to have acceptable validity[18] and good intra-rater reliability.[19] The FPI-6 yields a composite score obtained by summing six sub-measurements: supra- and infra-lateral malleolar curvature, talar head palpation, calcaneal frontal plane position, talonavicular joint prominence, medial longitudinal arch height and congruence, and forefoot abduction/adduction.[20] According to the total score and reference values suggested by Redmond,[17] feet were classified as pronated (+6 to +9), neutral (0 to +5) or supinated (-1 to -4), (Figure 1).

Measurement of ankle joint range of motion (ROM)

The ankle joint ROM was measured using a manual goniometer in two axes: inversion/eversion and plantar flexion/dorsiflexion. For measurements of plantar/dorsiflexion, the goniometer pivot point was placed at the lateral malleolus and the fixed arm was kept parallel to the lateral midline of the fibula, while the movable arm was followed by the lateral midline of the fifth metatarsal bone.[21] For measurements of inversion/eversion, the pivot point of the goniometer was placed in the lateral-medial direction of the foot at the level of metatarsal heads, the fixed arm was parallel to the lateral midline of the leg, and the movable arm was parallel to the plantar face of the foot.[22]

Measurement of foot muscle flexibility

Flexibility of the muscles acting on the ankle was measured with a tape and goniometer. For tibialis

Supinated feet:	Neutral feet:	Pronated feet:
More than 3° calcaneal inversion from perpendicular; no medial bulge at talonavicular joint; high medial longitudinal arch	Calcaneus is perpendicular to ground and/or medial longitudinal arch height is normal	More than 3° calcaneal eversion from perpendicular; presence of medial bulge at talonavicular joint; low medial longitudinal arch

Figure 1. Assessment of foot posture index.

anterior flexibility, the participant sat on a platform with knees extended and was asked to perform plantar flexion as much as possible. The distance between the floor and the first toe was measured with a tape measure.[23] Soleus and gastrocnemius muscle flexibility was measured while standing, using a manual goniometer.[24] For soleus muscle flexibility, the participant was in stride standing position with no shoes. Goniometer landmarks were the inferior tip of the lateral malleolus and midline of the lateral aspect of the head of the fibula. The participant bent their knee forward in line with the second toe, until heel contact was lost or there was pain around the ankle joint. The test was repeated while maintaining knee extension throughout for gastrocnemius muscle.[24]

Measurement of ankle joint strength

Strength of the ankle dorsiflexor muscles (extensor hallucis longus, extensor digitorum longus, tibialis anterior), ankle plantar flexor

TABLE 1
Demographic and baseline characteristics of the athletes

	Group 1 Supinated (n=16)		Group 2 Neutral (n=36)		Group 3 Pronated (n=18)		
	Mean±SD	Median	Mean±SD	Median	Mean±SD	Median	*p*
Foot Posture Index							**0.001***
Right		-2.00 (-3.00 – -1.00)		2.00 (1.00 – 4.00)		6.00 (6.00 – 8.00)	
Left		-2.00 (-3.00 – -1.25)		3.00 (2.00 – 3.75)		6.50 (6.00 – 7.25)	
Age (year)	20.9±2.1		21.2±2.5		21.9±3.6		0.836
Weight (kg)	69.9±9.2		70.9±12.1		64.6±9.8		0.134
Height (cm)	1.7±0.1		1.7±0.1		1.7±0.1		0.857
BMI (kg/m²)	22.4±1.9		22.5±2.2		22.1±2.5		0.843
Experience (year)	7.4±3.3		7.7±4.6		6.4±3.6		0.559
Training frequency (week)		4.00 (3.00 – 4.75)		4.50 (3.00 – 5.75)		4.50 (3.00 – 5.25)	0.853
Training duration (h)		2.00 (1.34 – 2.00)		2.00 (1.30 – 2.00)		2.00 (2.00 – 2.00)	0.567

SD: Standard deviation; BMI: Body mass index; * All groups are different.

muscles (soleus, gastrocnemius, plantaris, tibialis posterior, peroneus longus and brevis), ankle invertor muscles (flexor hallucis longus, flexor digitorum longus, tibialis posterior and anterior), and ankle evertor muscles (peroneus longus, brevis, tertius) were measured at 60°/sec angular velocity, three repetitions submaximal and five repetitions maximal and 10 repetitions maximal at 240°/sec angular velocity using an IsoMed 2000 (D&R GmbH, Hemau, Germany) isokinetic dynamometer. There was a 30-sec rest period between maximal and submaximal repetitions.[25] The athletes included in the study were allowed to warm up on a Monark 894 E Peak Bike (Monark Exercise AB, Vansbro, Sweden) for 15 min before isokinetic strength measurement. During measurements, the athletes received continuous verbal encouragement to sustain their motivation. The data were recorded using the computer program of the isokinetic dynamometer during the measurements. Maximum torque, maximum work, and total work values (Nm) were documented for further analysis.

Measurement of plantar pressure

Plantar pressure in standing position was measured using the EMED®-XL plantar pressure system (Novel GmbH, Munich, Germany; dimensions: 1529×504 mm^2; sensor area: 1440×440 mm^2; sensor number: 25,344) at a sampling frequency of 100 Hz. Before each measurement, the system was calibrated as per manufacturer's recommendations. Familiarization protocols were conducted for static balance tests. During the static pressure test, participants performed two bilateral stances for 30 sec with 2 min resting time between trials.[26] Static standing results were averaged automatically by the EMED software. All static variables were measured for the whole foot: peak pressure (kPa), maximum force (F), contact area (cm^2), and contact time (ms).

Statistical analysis

Statistical analysis was performed using the SPSS version 23.0 software (IBM Corp., Armonk, NY, USA). Normality of data distributions was assessed using the Kolmogorov–Smirnov test. Continuous data for quantitative variables were expressed in mean ± standard deviation (SD) for normally distributed data and in median (25^{th}-75^{th} percentile) for non-normally distributed data. Categorical data were expressed in number and frequency. Comparisons between groups were performed with one-way analysis of variance (ANOVA) for normally distributed variables and Kruskal-Wallis test for non-normally distributed variables. The Tukey or Tamhane's T2 post-hoc tests were used according to the homogeneity of variances of the groups in one-way ANOVA, while the Bonferroni post-hoc method was used for multiple comparisons in Kruskal-Wallis test. A p value of <0.05 was considered statistically significant.

RESULTS

Demographic and baseline characteristics of the participants are shown in Table 1. There were no significant differences among the groups in demographic and baseline characteristics (p>0.05).

Comparison of the ankle joint ROM showed significant differences among the groups in right ankle ROM in dorsiflexion (p=0.009) and eversion (p=0.044) (Figure 2a, b). Group 1 demonstrated significantly lower left ankle ROM in dorsiflexion compared to Group 2 (Figure 2c). There was no significant difference in the other ROM measurements of both ankles among the groups.

Group 1 exhibited less flexibility than Group 2 in the right soleus muscle (p=0.014) (Figure 3a) and left soleus muscle (p=0.032) (Figure 3b). Flexibility of the left gastrocnemius muscle was higher in Group 3 than Group 1 (p=0.036) (Figure 3c). There was no significant difference in the other flexibility measurements among the groups.

Group 3 demonstrated significantly lower maximum torque, maximum work, and total work values of the right plantar flexor muscles at 60°/sec angular velocity, compared to Group 2 (p<0.05) (Figure 4a-c). There were also significant differences between the Groups 2 and 3 in terms of total work values of the left plantar flexor muscles at 60°/sec angular velocity (p=0.045) (Figure 4d). Group 1 demonstrated significantly lower right evertor muscle strength than Group 2 for total work values at 240°/sec angular velocity (p=0.036) (Figure 4a), while Group 3 had lower total work values of the left invertor muscles at 60°/sec angular velocity compared to Group 2 (p=0.032) (Figure 4f). There was no significant difference in the other muscle strength measurements of both ankles.

Group 1 demonstrated a significantly higher peak pressure in the right foot than Groups 2 and 3 (p<0.001) (Figure 5a), while Group 3 demonstrated a significantly lower peak pressure in the left foot than Group 1 (p=0.012) (Figure 5b). There was no significant difference in the other plantar pressure measurements among the groups.

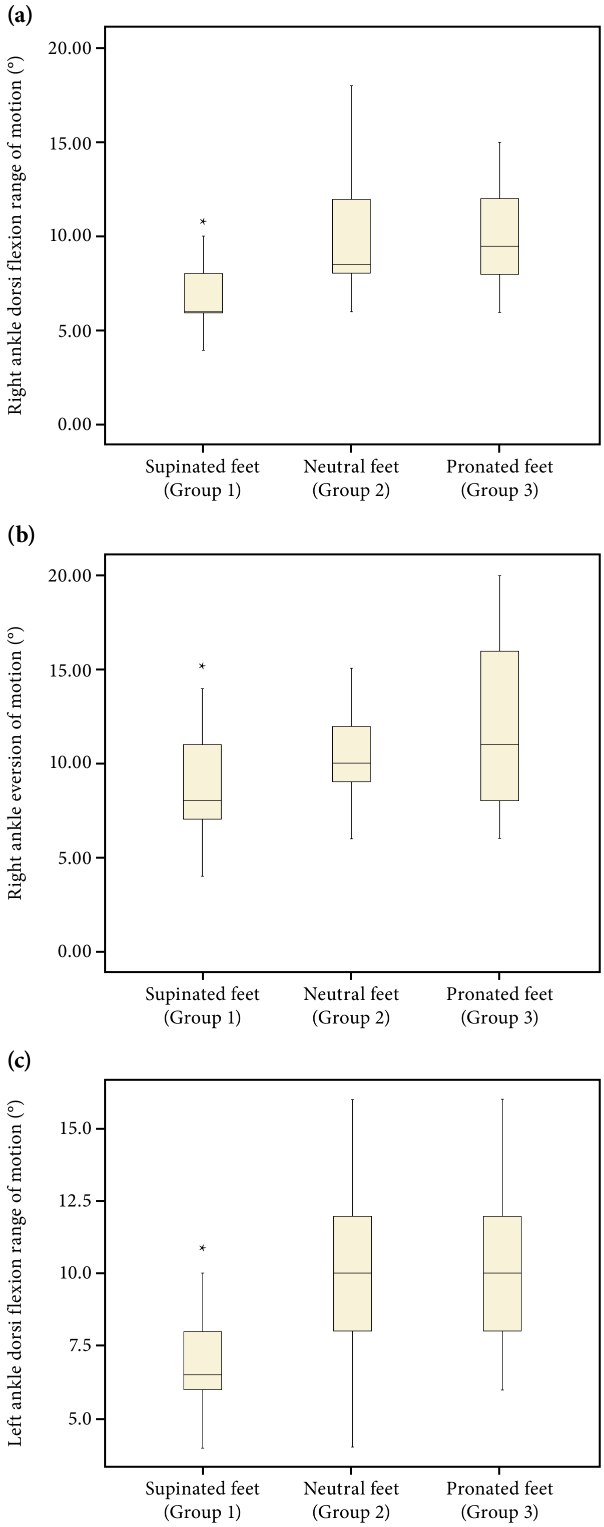

Figure 2. Comparison of ankle dorsiflexion and eversion range of motion (ROM) values of athletes in Group 1 (supinated feet), Group 2 (neutral feet), and Group 3 (pronated feet). **(a)** Right ankle dorsiflexion ROM; * $p<0.05$ Group 1 *vs.* 2, Group 1 *vs.* 3. **(b)** Right ankle eversion ROM; * $p<0.05$ Group 1 *vs.* 2. **(c)** Left ankle dorsiflexion ROM; * $p<0.05$ Group 1 *vs.* 2.

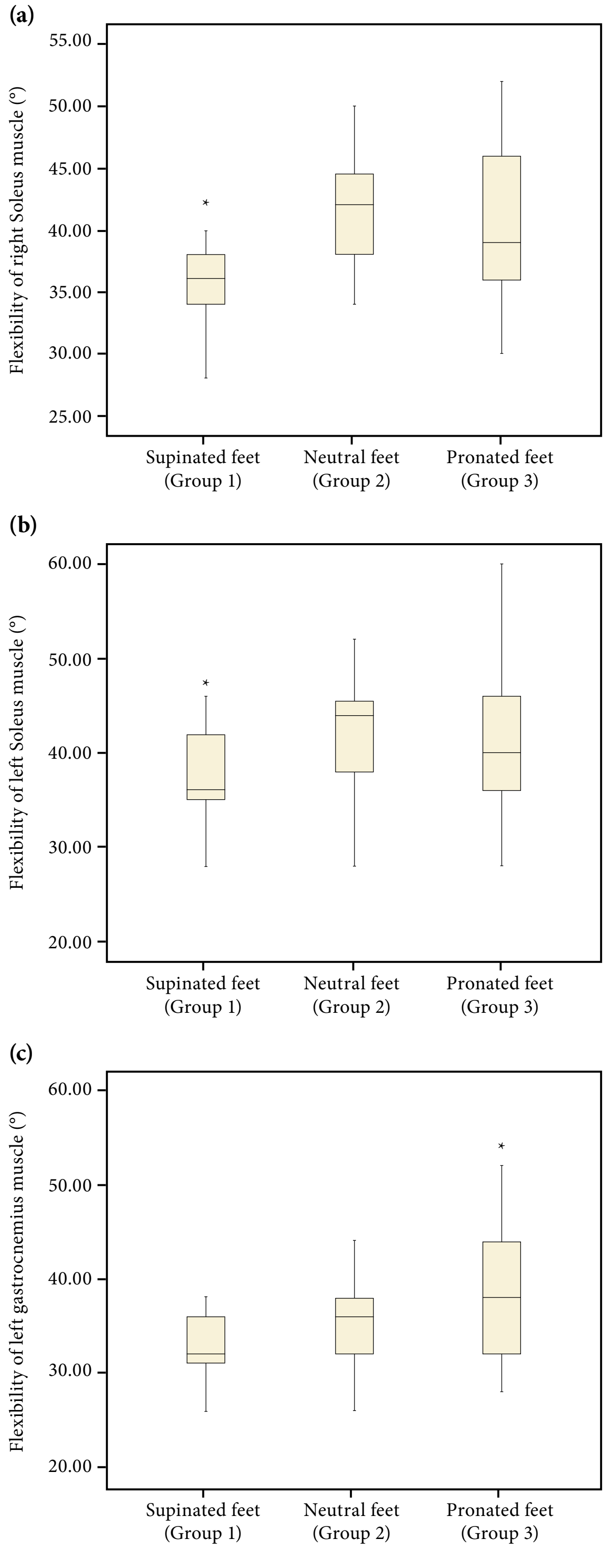

Figure 3. Comparison of the flexibility values of the athletes in Group 1 (supinated feet), Group 2 (neutral feet), and Group 3 (pronated feet). **(a)** Right soleus muscle flexibility; * $p<0.05$ Group 1 *vs.* 2. **(b)** Left soleus muscle flexibility; * $p<0.05$ Group 1 *vs.* 2. **(c)** Left gastrocnemius muscle flexibility; * $p<0.05$ Group 1 vs. 3.

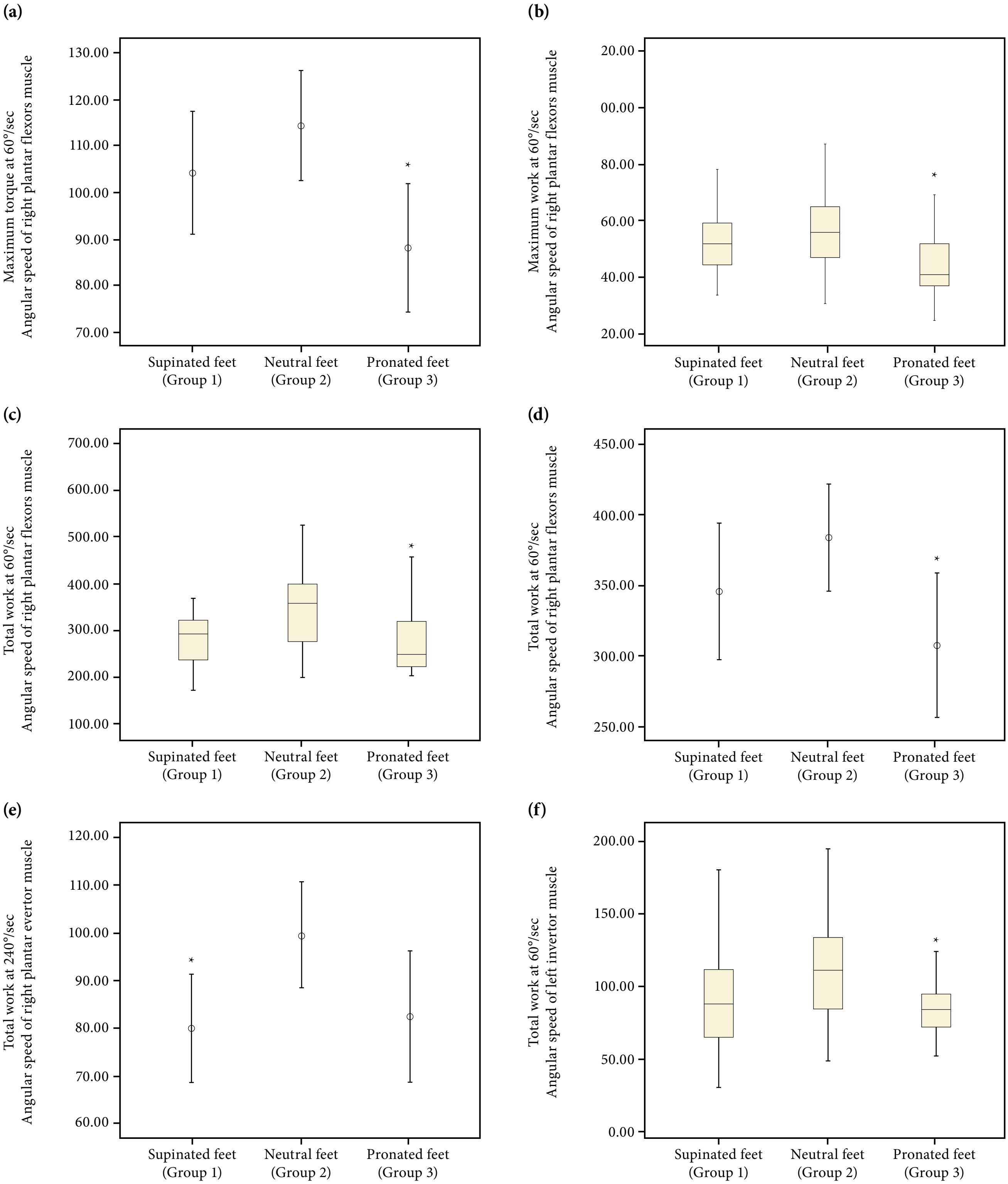

Figure 4. Comparison of muscle strength values at angular velocity of 60°/sec or 240°/sec among athletes in Group 1 (supinated feet), Group 2 (neutral feet), and Group 3 (pronated feet). **(a)** Maximum torque of right plantar flexor muscles at 60°/sec angular velocity; * $p<0.05$ Group 2 *vs.* 3. **(b)** Maximum work of right plantar flexor muscles at 60°/sec angular velocity; * $p<0.05$ Group 2 *vs.* 3. **(c)** Total work of right plantar flexor muscles at 60°/sec angular velocity; * $p<0.05$ Group 2 *vs.* 3. **(d)** Total work of left plantar flexor muscles at 60°/sec angular velocity; * $p<0.05$ Group 2 *vs.* 3. **(e)** Total work of right evertor muscles at 240°/sec angular velocity; * $p<0.05$ Group 1 *vs.* 2. **(f)** Total work of left invertor muscles at 60°/sec angular velocity; * $p<0.05$ Group 2 *vs.* 3

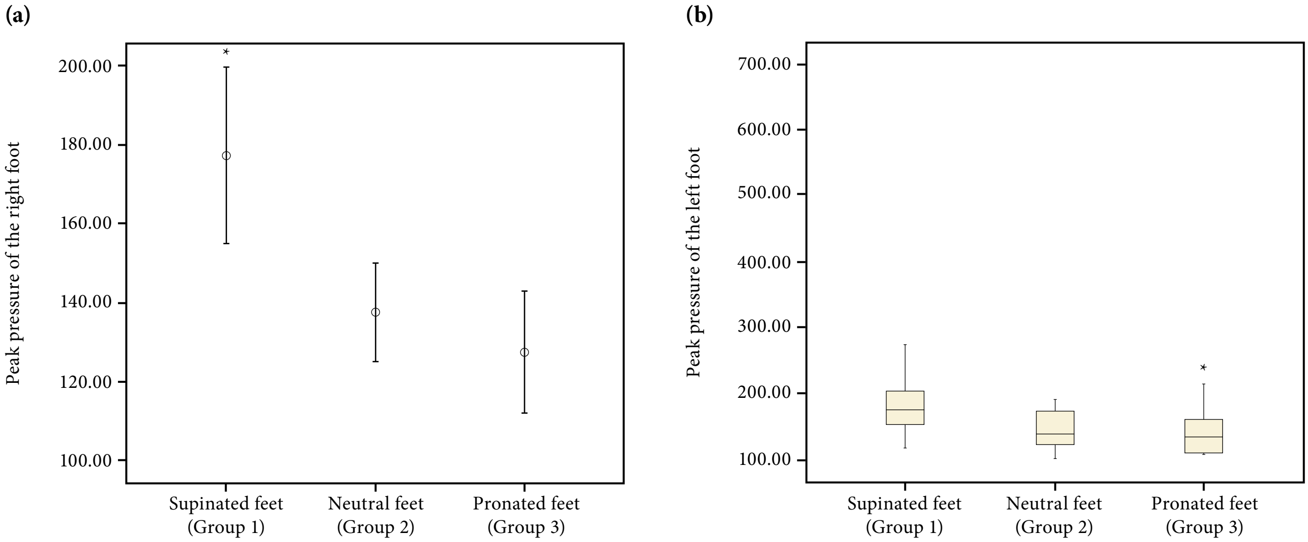

Figure 5. Comparison of the static peak plantar pressure values of athletes in Groups 1 (supinated feet), 2 (neutral feet), and 3 (pronated feet). **(a)** Static peak pressure values of the right foot; * $p<0.05$ Group 1 *vs.* 2 and Group 1 *vs.* 3. **(b)** Static peak pressure values of the left foot; * $p<0.05$ Group 1 *vs.* 3.

DISCUSSION

In this study, we compared the ankle joint ROM, strength, muscle flexibility, and plantar pressure distribution among athletes with different FPI. As hypothesized, the results showed that dorsiflexion ROM significantly differed between each of the three foot posture categories, with Group 1 (supinated feet) showing significantly less dorsiflexion ROM than the other groups. Our results are consistent with previous studies.[27] Cornwall and McPoil[27] reported that individuals with limited mediolateral or vertical mobility tended to have higher dorsal arches compared to those with more foot mobility. These findings are also consistent with previous studies reporting that individuals with flatter arches have a greater foot mobility compared to those with higher arches.[28,29] Zifchock et al.[29] showed that pes cavus feet tended to be stiffer, while pes planus feet were more flexible.

In the current study, our results also demonstrated a significant difference in gastrocnemius and soleus muscle flexibility among the groups, further supporting our study hypothesis. Group 1 showed significantly less flexibility of the gastrocnemius and soleus muscles than the other foot posture groups. The gastrocnemius and soleus muscles of athletes with supinated foot posture are less flexible than athletes with normal and pronated foot posture, which may explain the lower ankle dorsiflexion ROM. Our results support the findings of Rowlett et al.,[30] who also suggested that greater flexibility of the gastrocnemius and soleus muscles increased dorsiflexion ROM. Furthermore, our results have several similarities with those of Justine et al.,[31] who observed that dorsiflexion was more limited in individuals with supinated feet than individuals with normal and pronated feet. The results of this study and more recent evidence suggest that insufficient dorsiflexion ROM may be a contributing factor in ankle and foot injuries.[32] In addition, several studies have suggested that decreased lower extremity flexibility in runners may be associated with higher risk of Achilles tendon injuries.[33,34] Based on our results, we believe that athletes with supinated feet should perform exercises to increase foot mobility and flexibility of the gastrocnemius and soleus muscles.

Our results highlighted that plantar flexor and invertor muscle strength significantly differed between neutral and pronated feet. Plantar flexor and invertor muscle strength was lower in the pronated feet than the other foot postures. This finding may be responsible for the reduced medial arch height in foot pronation. Considering studies on the role of muscles in arch height, Morita et al.[35] reported that a lower arch was detrimental to both intrinsic and extrinsic foot muscles, including the abductor hallucis and posterior tibial muscles. Our findings showed lower plantar flexor muscle strength in Group 3 than Group 1. These values are consistent with those reported by Snook[36] in a study demonstrating a relationship between medial longitudinal arch and plantar flexor torque. Our results indicated that the plantar flexors of pronated feet had a lower concentric force compared to the neutral feet. This supports the biomechanical theory that hyperpronated feet are disadvantageous in terms of the lever arm of the Achilles tendon and plantar flexors.[37] In addition, in the present study, the pronated group demonstrated significantly lower maximum torque, maximum work, and total work values than the neutral group for the right plantar flexor muscles at an angular velocity of 60°/sec. Furthermore, significant differences were noted between Groups 2 and 3 in terms of the total work values of the left plantar flexors muscle at 60°/sec. On the other hand, the total work values of the right ankle evertor muscles at 240°/sec were significantly lower in Group 1 than Group 2. These results suggest that athletes with pronated feet could benefit from performing exercises designed to increase the strength of the plantar flexor and invertor muscles.

Cobb et al.[38] found that a high arch and increased invertor muscle strength could lead to decreased mediolateral postural stability. The results of the present study indicate that supinated feet exhibit higher peak pressures for the total foot during static bilateral standing. There are several possible explanations for this observation. To illustrate, the plantar tissues may stiffen in adult athletes, leading to increased plantar pressure. An alternative explanation is that limited dorsiflexion and eversion ROM may cause stiffness and increased plantar pressure in the supinated foot, as described previously.[16,39] Han et al.[16] found that the plantar pressure values of individuals with low arch foot posture were lower than in individuals with neutral foot posture. The findings of the present study also corroborate with the results reported by Williams et al.[40] in runners with high arches.

The main limitation of the present study is that the sample group comprised male athletes only. The use of convenience sampling may be a source of bias in the results. Another limitation is that only plantar pressure data of whole feet were measured. To gain a better understanding of the influence of foot posture, future research should concentrate on foot masking (forefoot, midfoot, lateral, and medial foot); in addition, the plantar pressure should be evaluated during dynamic tasks. Finally, in this study, simultaneous kinematic and electromyographic data were unable to be collected during plantar pressure data collection; therefore, no conclusions can be drawn regarding interactions between foot posture and foot biomechanics.

In conclusion, our study results show that foot posture is associated with differences in ankle dorsiflexion and eversion ROM, flexibility of the gastrocnemius and soleus muscles, strength of the plantar flexor, invertor, and evertor muscles, and peak pressure distribution. Based on these results, athletes with supinated feet are encouraged to perform exercises to increase foot mobility, evertor muscle strength, and gastrocnemius and soleus muscle flexibility. On the other hand, athletes with pronated feet should do exercises to increase the strength of the plantar flexor and invertor muscles. Increasing the strength of the muscles acting on the ankle would reduce the risk of injury and enhance performance in athletes. This study may contribute to the rehabilitation of athletes with foot deformities by identifying biomechanical variations in specific foot posture index. It may also guide training programs for amateur sportspersons by raising awareness of the necessity of the development and usage of proper insoles. Finally, the results may be beneficial both in designing insoles or sports footwear for athletes and creating individual-based training plans.

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Declaration of conflicting interests

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