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DOES FOOT POSTURE INFLUENCE PLANTAR PRESSURE?

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ABSTRACT

This study compared plantar pressure distribution among asymptomatic individuals with pes rectus, pes cavus and pes planus feet during walking. Feet were divided into three groups based on the arch index (AI) values: Pes cavus (n=38); Pes rectus (n=72); Pes planus (n=62). Force time integral (FTI), maximal force (MF), peak pressure(PP), pressure-time integral (PTI), contact time (CT), contact area (CA), and maximum force normalised to body weight[MF(%BW)] were evaluated for each part of the foot and total foot during barefoot walking. A one-way analysis of variance (ANOVA) was performed. Peak pressure at the 5th metatarsophalangeal joints (MTPJs) in the pes planus foot group was lower compared to the pes rectus and pes cavus foot groups. The pes planus group displayed increased MF and CA in the middle foot while walking compared to the pes rectus and pes cavus groups($p<0.05$). When compared to pes rectus and planus feet, cavus feet displayed higher pressure in the hind foot and lateral forefoot and lower PP, MF and CA in the midfoot ($p<0.05$). High and low arch structures display different plantar pressure characteristics that may be linked to lower extremity injuries. When designing a prophylactic exercise programme for asymptomatic individuals, foot types and associated pressure characteristics should be considered.

Keywords: Pes cavus; Pes planus; Pes rectus; Athletes; Injuries.

INTRODUCTION

The risks of lower extremity injuries among physically active individuals are related to internal and external factors (Carson *et al.*, 2012a). Structural foot deformities have frequently been indicated as intrinsic risk factors of lower extremity overuse injuries (Hreljac *et al.*, 2000; Bowring & Chockalingam, 2010). There are intrinsic biomechanical factors that cause stress fractures and there is the higher incidence of ankle injuries that might be related to an excessive longitudinal arch (a pes cavus foot), leg-length discrepancies and an excessive forefoot varus position (Kaufman *et al.*, 1999; Williams *et al.*, 2001, 2004). On the other hand, a pes planus foot has been associated with medial tibial stress syndrome, patellofemoral pain, tibialis posterior tendinopathy and the other injuries involving the medial soft tissue structures of the lower extremity (Williams *et al.*, 2004; Bowring & Chockalingam, 2010; Buldt *et al.*, 2018a). Buldt *et al.* (2018a) suggested that pes planus and pes cavus feet display abnormal biomechanical parameters that may predispose an individual to injury. Abnormal arch structure increases the risk of developing lower extremity overuses injuries two-fold (Kaufman *et al.*, 1999). The athletes with both high and low arches may have an increased risk of developing a lower extremity injury compared to athletes with normal arches (Kaufman *et al.*, 1999; Williams *et al.*, 2001).

Understanding the relationship between different types of the medio-longitudinal arch (MLA) and the plantar pressure distribution could be helpful to designing preventative strategies for lower extremity injuries. Plantar pressure analysis refers to the measurement of magnitude and distribution of the force that is applied to the plantar surface of the foot during walking (Landorf & Keenan, 2000; Wong *et al.*, 2007; Shu *et al.*, 2010; Buldt *et al.*, 2018a). The studies including plantar pressure analysis indicated that morphological factors (Hills *et al.*, 2001; Birtane & Tuna, 2004) and walking speed are related to plantar pressure (Rosenbaum *et al.*, 1994; Burnfield *et al.*, 2004; Pataky *et al.*, 2008). Moreover, the foot structure is associated with the plantar pressure among athletes in athletic tasks (Queen *et al.*, 2009). According to the features of sports, biological adaptive modifications can be short-term or long-term, which indicates adaptive modifications on all body levels require complicated efforts. High-level sports performance is based on the biological adaptation degree of the body (Huang *et al.*, 2019).

There is a growing body of literature suggesting that foot structure based on an arch index (AI) influences plantar pressure variables during walking (Ledoux & Hillstrom, 2002; Teyhen *et al.*, 2009; Rao *et al.*, 2011). Although loading measurements collected when healthy individuals are walking and performing various athletic tasks have been studied according to foot type, only a limited number of studies have compared pes planus, pes cavus and pes rectus (Queen *et al.*, 2009; Carson *et al.*, 2012b). Most of the studies (Williams *et al.*, 2001, 2004; Carson *et al.*, 2012a) have indicated the plantar pressure differences between arch groups, however, there is still a need for an exploration of the potential differences among asymptomatic individuals as an injury risk factor.

PURPOSE OF RESEARCH AND HYPOTHESIS

This study aimed to compare plantar pressure distribution among asymptomatic individuals with pes rectus, pes cavus, and pes planus feet during barefoot walking. It was hypothesised that pes cavus and pes planus feet would have asymmetrical plantar distribution when compared to pes rectus feet.

METHODOLOGY

Design of study

In this research, a cross-sectional design was implemented. The dependent variables were: *Maximum force* [MF(N)]; *Maximum force normalised to body weight* [MF(%BW)]; *Force time integral* [FTI(N.s/cm^2)]; *Peak pressure* [PP(kPa)]; *Pressure time integral* [PTI(kPa.s/cm)]; *Contact time* [CT(ms)]; and *Contact area* [CA(cm^2)]. MF is defined as the maximum force on the total foot or a particular region and MF (%BW) is defined as the maximum force on the total foot or a particular region divided by total weight. FTI represents the impulse from the force-time profile for each region, while PP represents the maximum pressure value for the total foot or a particular region. PTI represents the impulse from the maximum pressure-time profile for the total foot and each region. CT indicates the stance time and CA is the maximum contact area during the stance (Giacomozzi, 2011). MF and FTI data were normalised to each subject's body weight. For each of the aforementioned parameters, the average value of all acquired frames was selected as representative of the whole trial and used for comparisons among the three arch groups. The independent variable of the study was AI groups of athletes. The calculation procedure of the AI was explained under the data processing title.

Ethical considerations

All subjects were given written information about the procedures of the study and informed consent was obtained by the declaration of Helsinki. The study was approved by the local ethics committee [80558721/175].

Patients/participants

Ninety individuals (n=90) accepted to participate in the current study. The participants were recruited from within the University and surrounding community using flyers and word of mouth. The participants were excluded if they had a history of lower extremity injuries in the past year, had an ankle and foot surgery and had a neurological and systemic disorder. Four (4) of them were excluded since they had a history of lower extremity injuries, such as chronic ankle instability, Achilles tendinopathy, ACL injury, and patellofemoral pain. Eighty-six (86) asymptomatic individuals were included in the study.

The protocol implicated by Birtane and Tuna (2004) was used in the study. Feet were divided into three groups based on the AI values (Cavanagh *et al.*, 1997). There were no significant differences between groups in terms of body mass, height and body mass index. Athletes reported that the intensity of training was four times a week and 3 to 8 hours per day.

Procedures

Foot plantar pressure was assessed using the EMED-XL plantar pressure analysis system (Novel GmbH, Munich, Germany). This system consists of a platform (platform size: 1529x504 mm²; sensor area: 1440x440 mm²) incorporating 25.344 sensors (4 sensors/cm^2) that sample at a rate of 100Hz. AI values were determined by the EMED-XL.

Before measuring plantar pressure distribution, the subjects were familiarised with the testing procedure and details of the procedure were explained. All measurements were performed barefoot. Dynamic foot-ground contact parameters were acquired by asking participants to walk at a self-selected speed over a 5m-long walkway in which the pressure platform was embedded. A five-minute acclimatisation period was allowed for participants to become comfortable with the data collection procedure. They were asked to maintain an upright posture and fix their eyes on a target on the wall they were walking toward. The five-step gait initiation protocol was used to obtain foot pressure data. Participants were asked not to look at the ground during walking trials, and in the event of targeting of the pressure plate, the trial was not analysed. Five successful trials were analysed for the foot data (Buldt *et al.*, 2018b). Novel scientific medical software, version 23 was used to build individual 'masks' to determine plantar pressures for 9 regions of the foot. The boundaries of the total foot, forefoot, and midfoot, hind foot, 1^{st}, 2^{nd}, 3^{rd}, 4^{th}, and 5^{th} metatarsophalangeal joints (MTPJ) mask areas on pressure images were determined by the Automask software (Novel-ortho, Germany). FTI(N*s), PTI(kPa*s), MF(N), PP(kPa), CA(cm^2), CT(ms) and MF(%BW) were calculated using novel scientific software.

The AI method was used to evaluate the MLA (Birtane & Tuna, 2004). AI was measured by dividing the length of the foot, without toes, into three equal parts: the forefoot, midfoot, and hindfoot. The mask of the toes was excluding and the remaining masks were calculated by the system. Arch Index was defined as the ratio of the pressure area of the midfoot to the sum of all three parts (Figure 1) (Cavanagh *et al.*, 1997). The arch indices ≥0.26 were considered low-arched (pes planus), arch indices between 0.21 and 0.26 were considered normal (pes rectus), arch indices ≤0.21 were considered high-arched (pes cavus) (Cavanagh & Rodgers, 1987).

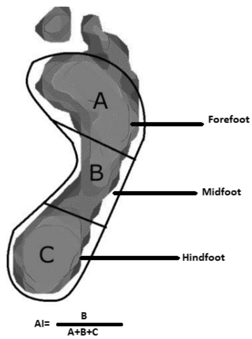


Figure 1. **PRESSURE IMAGE OF FOUR REGIONS CALLED MASKS DESIGNATED BY EMED-SF SYSTEM**

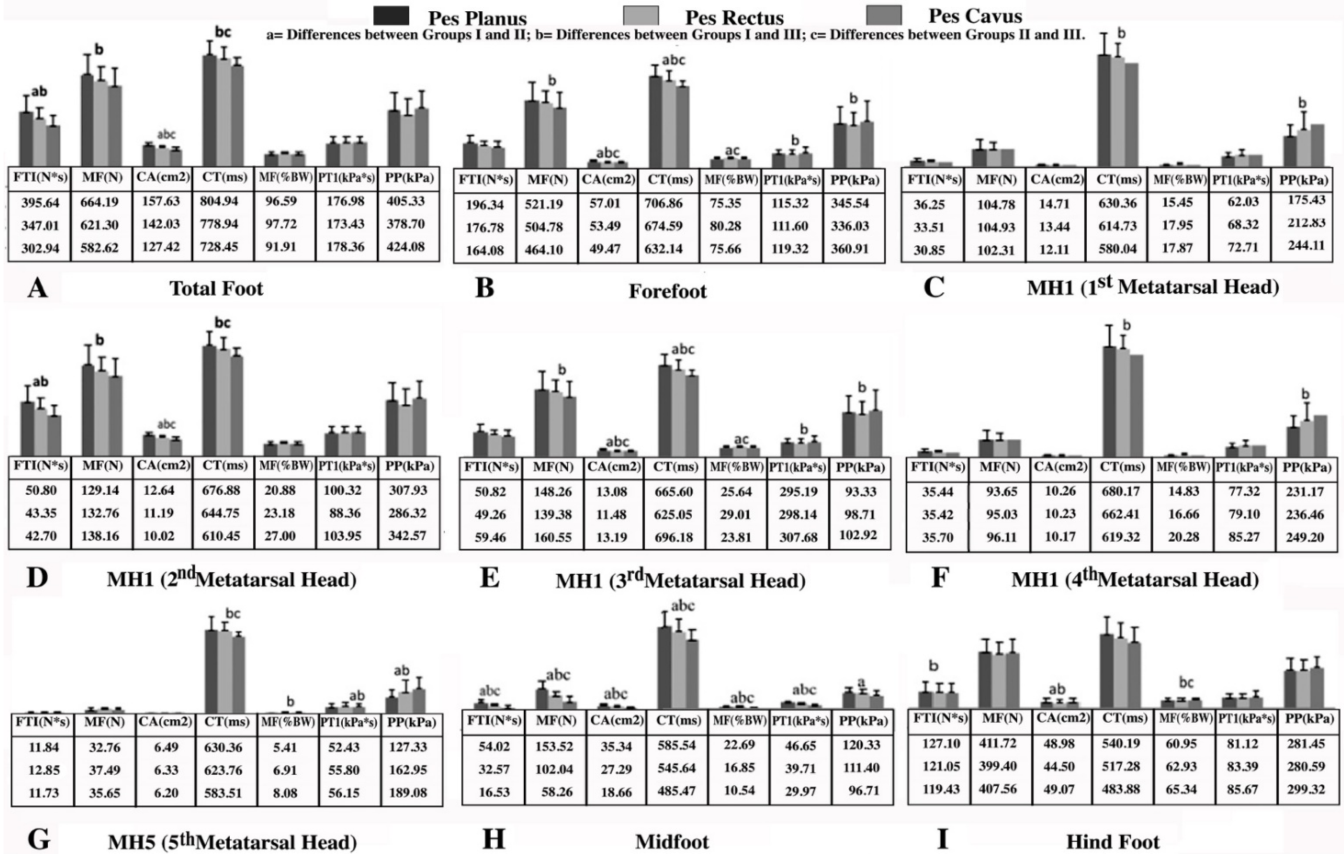
Statistical analyses

Before the statistical analysis, all measures were determined to be normally distributed based on the Shapiro-Wilk test. Means and standard deviations of the demographic characteristics of the PP, PTI, MF, FTI, CA, CT, MF (%BW) for each foot region were calculated. One-way analysis of variance (ANOVA) was performed and post hoc tests (Tukey) were used, according to Levene's homogeneity test results. For these measurements, a significance level was set as $p<0.05$. The data were analysed using SPSS Statistics 23.0 (IBM Inc., Chicago, IL).

RESULTS

Arch Index classification calculations revealed 62 feet with *pes planus* (Group I, 22.5±5.2 years; 176.7±6.0cm; BMI=26.1±6.1kg/m^2), 72 feet with *pes rectus* (Group II, 21.5±2.3 years; 177.5±4.8cm; BMI=23.3±2.2kg/m^2), and 38 feet with *pes cavus* (Group, III, 21.0±1.8 years; 175.4±3.8cm; BMI=22.0±1.6kg/m^2).

The results representing the differences of plantar pressure values between different foot arch structures of the participants are presented in Figure 2. The dynamic pedobarographic evaluation revealed that the pes planus group had the greatest FTI, MF, CA and CT values, whereas the pes cavus group had the lowest FTI, MF, CA, CT, and MF(%BW) values in the total foot mask (Figure 2A). Also, the MF (%BW) of the pes rectus group was higher than the pes planus and pes cavus group in the forefoot ($p<0.05$) (Figure 2B). FTI was the highest for the 2^{nd} MTPJ in the pes planus group compared to the pes rectus and pes cavus groups ($p<0.05$) (Figure 2C, 2G). Midfoot results showed that feet with pes planus have greater FTI, MF, CA, MF(%BW) and PTI values than feet with pes cavus and pes rectus ($p<0.05$) (Figure 2H). Pes cavus group exhibited greater CA values compared to pes planus. In addition, the pes cavus group exhibited greater MF(%BW) values compared to pes rectus group in the hindfoot ($p<0.05$) (Figure 2I).



FTI(N*s)	MF(N)	CA(cm2)	CT(ms)	MF(%BW)	PT1(kPa*s)	PP(kPa)
395.64	664.19	157.63	804.94	96.59	176.98	405.33
347.01	621.30	142.03	778.94	97.72	173.43	378.70
302.94	582.62	127.42	728.45	91.91	178.36	424.08

A Total Foot

FTI(N*s)	MF(N)	CA(cm2)	CT(ms)	MF(%BW)	PT1(kPa*s)	PP(kPa)
196.34	521.19	57.01	706.86	75.35	115.32	345.54
176.78	504.78	53.49	674.59	80.28	111.60	336.03
164.08	464.10	49.47	632.14	75.66	119.32	360.91

B Forefoot

FTI(N*s)	MF(N)	CA(cm2)	CT(ms)	MF(%BW)	PT1(kPa*s)	PP(kPa)
36.25	104.78	14.71	630.36	15.45	62.03	175.43
33.51	104.93	13.44	614.73	17.95	68.32	212.83
30.85	102.31	12.11	580.04	17.87	72.71	244.11

C MH1 (1st Metatarsal Head)

FTI(N*s)	MF(N)	CA(cm2)	CT(ms)	MF(%BW)	PT1(kPa*s)	PP(kPa)
50.80	129.14	12.64	676.88	20.88	100.32	307.93
43.35	132.76	11.19	644.75	23.18	88.36	286.32
42.70	138.16	10.02	610.45	27.00	103.95	342.57

D MH1 (2ndMetatarsal Head)

FTI(N*s)	MF(N)	CA(cm2)	CT(ms)	MF(%BW)	PT1(kPa*s)	PP(kPa)
50.82	148.26	13.08	665.60	25.64	295.19	93.33
49.26	139.38	11.48	625.05	29.01	298.14	98.71
59.46	160.55	13.19	696.18	23.81	307.68	102.92

E MH1 (3rdMetatarsal Head)

FTI(N*s)	MF(N)	CA(cm2)	CT(ms)	MF(%BW)	PT1(kPa*s)	PP(kPa)
35.44	93.65	10.26	680.17	14.83	77.32	231.17
35.42	95.03	10.23	662.41	16.66	79.10	236.46
35.70	96.11	10.17	619.32	20.28	85.27	249.20

F MH1 (4thMetatarsal Head)

FTI(N*s)	MF(N)	CA(cm2)	CT(ms)	MF(%BW)	PT1(kPa*s)	PP(kPa)
11.84	32.76	6.49	630.36	5.41	52.43	127.33
12.85	37.49	6.33	623.76	6.91	55.80	162.95
11.73	35.65	6.20	583.51	8.08	56.15	189.08

G MH5 (5thMetatarsal Head)

FTI(N*s)	MF(N)	CA(cm2)	CT(ms)	MF(%BW)	PT1(kPa*s)	PP(kPa)
54.02	153.52	35.34	585.54	22.69	46.65	120.33
32.57	102.04	27.29	545.64	16.85	39.71	111.40
16.53	58.26	18.66	485.47	10.54	29.97	96.71

H Midfoot

FTI(N*s)	MF(N)	CA(cm2)	CT(ms)	MF(%BW)	PT1(kPa*s)	PP(kPa)
127.10	411.72	48.98	540.19	60.95	81.12	281.45
121.05	399.40	44.50	517.28	62.93	83.39	280.59
119.43	407.56	49.07	483.88	65.34	85.67	299.32

I Hind Foot

DISCUSSION

Prospective studies have found that variations in weight-bearing foot posture are associated with an increased risk of medial tibial stress syndrome in military recruits (Yates & White, 2004) and overuse leg injuries in triathletes (Burns *et al*., 2005b). These findings suggest that pes cavus and pes planus may display abnormal biomechanical parameters that predispose an individual to injury (Buldt *et al*., 2015). Studies indicate that the unbalanced plantar distribution of applied force is one of the leading factors of foot and lower extremity injuries (Orendurff *et al*., 2009; Azevedo *et al.,* 2020). Foot posture classification is a determinant factor of plantar pressure distribution (Buldt *et al.,* 2018b). Applied force loadings in some athletic movements, such as cutting, are increased on the various regions on the foot and peak pressure and pressure-time integral might reach injury leading levels for some foot structures, such as pes planus and pes cavus (Wong *et al.*, 2007).

Even though it is reported that foot postures such as pes planus or pes cavus are found to be associated with increased risk of lower limb injuries, including medial tibial stress syndrome and patellofemoral pain (Tong & Kong, 2013), there are limited studies about plantar pressure comparisons among pes planus, pes cavus, and rectus feet according to literature (Queen *et al.*, 2009; Carson *et al.*, 2012b). Three studies compared planus and normal feet (Burns *et al.*, 2005a; Rao *et al.*, 2011; Hillstrom *et al.*, 2013), three studies compared cavus to normal feet (Burns *et al.*, 2005a; Carson *et al.*, 2012b; Fernández-Seguín *et al.*, 2014) and four studies compared all three-foot postures (planus, cavus and normal) (Song & Knaap, 2004; Wong *et al.*, 2007; Rao *et al.*, 2011; Hillstrom *et al.*, 2013). This study aimed to compare plantar pressure distribution among asymptomatic individuals with pes rectus, pes cavus, and pes planus feet during walking. The results of this study showed that pes rectus, planus, and cavus foot structure groups display uniquely different plantar pressure characteristics during walking in asymptomatic individuals. Thus, the hypothesis of the study was supported.

Total foot

The findings of the study revealed that the pes planus group had the greatest FTI, MF, CA and CT values, whereas the pes cavus group had the lowest FTI, MF, CA, CT, and MF (%BW) values in the total foot mask. Kaufman *et al.* (1999) and Levy *et al.* (2006) suggested that the pes planus foot with higher CA was more prone to lower extremity injuries, such as stress fractures, ankle sprains, patellofemoral pain and Achilles tendinitis compared to the pes rectus foot. There was also evidence of significantly reduced CA and simultaneously increases in PTI demonstrating reduced shock attenuation in pes cavus foot types in this study (Levy *et al.* 2006). Also, previous research has shown that force and pressure values were higher in pes cavus foot types compared to the pes rectus foot (Burns *et al.*, 2005b; Teyhen *et al.*, 2009). It is assumed that PTI may play a role in the development of skin lesions (Chang *et al.*, 2014). The greater the PTI, the greater the risk for soft tissue damage (Dowling *et al.*, 2015). In the literature, a foot with pes planus is described as a better shock absorber than a foot with pes cavus (Queen *et al.*, 2009). This finding might be explained by the observation that individuals with pes cavus exhibit stiffer foot mechanics with less eversion at the ankle, rear/midfoot and mid/forefoot joints compared to individuals with pes planus during dynamic loading (Rao *et al.*, 2011).

Forefoot

Previous findings highlighted the importance of FTI measurements (Gravante *et al.*, 2005; Carson *et al.*, 2012b) that represents the time over which a force is applied during walking since it provides valuable insights into the pathomechanics associated with overuse injuries in specific foot regions. However, there was a difference among groups in FTI values. The present results showed that the forefoot was the most loaded part in the pes cavus group. Previous research has shown that the reduction of the plantar CA is associated with greater load per unit area in the forefoot and this may be a risk factor for lower-limb overload injuries (Benedetti *et al.*, 1997).

The results showed that PTI was lowest for the 5th MTPJ and highest for the 2nd MTPJ in planus feet. This finding suggests that greater stress to the 2nd MTPJ in planus feet may place this bone under risk of a stress-related injury such as stress fracture. Similar findings have also been reported by Burns *et al.* (2005a) who found higher MF in the hallux and 2nd toe and lower MF in the combined 1st, 2nd and the 5th MTPJ in planus feet compared to both the rectus and cavus feet. Moreover, Hillstrom *et al.* (2013) found higher FTI in the 5th MTPJ of cavus feet compared to rectus and planus feet. A recent study indicated that the largest differences were in the PP of 4th and 5th metatarsals between pes cavus and pes planus groups (Buldt *et al.*, 2018a). On the contrary, there were no differences among groups in terms of FTI in the 5th MTPJ. All metatarsal heads of the pes cavus group showed greater PP and MF than in pes rectus group. Due to the associated deformities, pes cavus is considered to have a smaller contact area (Benedetti *et al.*, 1997).

Midfoot

Three different foot structures exhibited significant differences in the most of the plantar pressure values for the midfoot [FTI, MF, CA, CT, MF (%BW) and PTI] in the current study. The findings of the present study showed that the feet with pes planus have greater FTI, MF, CA, MF (%BW) and PTI values than feet with pes cavus and pes rectus. The pes planus foot causes excessive stretch on the spring ligament and the tendon of the tibialis posterior to stabilize the foot while maintaining the upright stance and it may lead to greater plantar pressure values on the midfoot (Buldt *et al*., 2018b).

The pes planus foot can unlock the mid-tarsal region during ambulation due to its loose-packed characteristics allowing it to act as a shock absorber. A study has shown that pes planus foot may eventually cause mechanical problems at the lower back, hip and knee joints due to excessive calcaneal extroversion of about 2 to 3 degrees (Valmassy, 1996). Based on the plantar pressure values in the midfoot of the pes cavus group, a reduction in the CA indicates a lower plantar pressure, force and CA in the midfoot and hallux when compared to rectus and planus feet. As a result, individuals with pes cavus foot may not able to distribute the weight evenly along with the metatarsal heads and lateral side of the foot (Franco, 1987). In addition, reduction in the CA in pes cavus foot causes lower plantar sensory input (Hertel *et al*., 2002) that may link to impairment in balance performance.

The pes cavus foot is vulnerable as it may not adequately adapt to the underlying surface, increasing the demand on the surrounding musculoskeletal structures to maintain postural stability and balance due to its hypermobile midfoot (Cote *et al*., 2005). Previous studies have reported foot pain in 23% to 60% of individuals with pes cavus foot (Burns *et al.*, 2005a). Among athletes with high-arched feet, increased arch height was associated with decreased mediolateral control of single-limb stance, potentially increasing the risk of ankle injuries (Cobb *et al.*, 2014).

Hindfoot

In the current study, individuals with pes cavus exhibited greater CA and MF(%BW) values compared to pes planus and pes rectus groups in the hindfoot. According to the findings of Gravante *et al.* (2005), the individuals with pes cavus feet exhibited significantly greater CA values on the hindfoot, which is consistent with the current findings. It is accepted that smaller CA in pes cavus than pes rectus due to associated deformities (Franco, 1987; Benedetti *et al.*, 1997), and that they are more rigid and less able to absorb impact for the total foot (Williams *et al.*, 2001). But when the foot was masked and evaluated just for hindfoot, the results shows greater CA in pes cavus than pes rectus. The pes planus group demonstrated significantly higher FTI value than the pes cavus group. Consistent with these findings, the researchers observed greater PP values in the hindfoot region of individuals with pes cavus than in individuals with pes rectus (Buldt *et al.*, 2018b). This result was reflected as higher plantar pressure values in the hindfoot of the pes cavus group in the present study.

CONCLUSION

This study confirms that pes rectus, pes planus and pes cavus foot structure display uniquely different plantar pressure characteristics during walking. These differences are most evident in the midfoot of the pes planus group, and the forefoot and hindfoot of the pes cavus group. As it was indicated in a recent study (Kruger *et al*., 2019), ankle kinematics are different for foot types. Accordingly, the pes planus groups demonstrate the lowest hindfoot inversion, whereas the pes cavus group demonstrates the highest. Consistent with the kinematic findings, the participants with pes cavus showed a lower CA of the total foot and also an increase the load of bone in the forefoot. The pes cavus foot has been suggested to result in a more rigid foot that is less capable of dissipating forces related to contact with the ground.

On the other hand, it was observed that pes planus feet displayed lower PP, MF(%BW) and both PTI and FTI values for the 5th MTPJ. Structurally, it is accepted that a foot with pes planus is a better shock absorber due to the loss of the MLA of the foot, which results in relative flattening of the plantar surface. A low arch with a flexible foot has a greater ability to absorb ground reaction forces generated during activities or sports compared to a high arch with a stiffer foot. To cope with the increased ground reaction forces, low arches require greater effort to control the structures of the foot and maintain body balance, which may result in greater ankle muscle strength in low arches (Zhao *et al.*, 2017).

RECOMMENDATIONS

Previous findings suggest that the pes cavus and pes planus feet have a mechanical disadvantage when compared to a normal foot and prone to lower extremity injuries (Girard *et al.*, 2007; Öztürk *et al.*, 2019). The pes cavus feet may be related to a lateral ankle injury, stress fractures and anterior knee pain, while the pes planus foot may increase the risk of medial tibial stress syndrome, knee pain and other injuries involving the medial and soft tissue structures of the lower extremity. The important contribution of this study is to the understanding of the potential risk factors for lower extremity injuries depending on the plantar pressure characteristics of the different foot structures. Based on the results, the exercise training programmes focusing on the foot core strengthening, correcting the foot posture and enhancing the functional movement patterns are recommended for the individuals with pes planus or pes cavus feet. Also, plantar pressure analysis before and after the exercise program may be important to see the effectiveness of the program.

The findings of this study should be considered in the context of limitations. The major limitation of this study was the lack of foot structure variables (ankle mobility, flexibility, strength, etc.). As these structural factors may also be affected by gender and sports types, a more detailed understanding of gender and/or sports types-related differences in foot function could be obtained by measuring both structure and function in athletes within different sports branches. Moreover, foot posture and pressure are not always related. Future studies are needed to investigate ankle mobility, flexibility, and strength according to foot posture in individuals.

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Conflict of interest

The authors declared no conflict of interest.

REFERENCES

AZEVEDO, R.R.; NERY, S.B.; STEFANYSHYN, D.J. & CARPES, F.P. (2020). Plantar loading in the youth soccer player during common soccer movements and risk for foot injury. *Injury*, 51(8): 1905-1909.

BENEDETTI, M.G.; CATANI, F.; CECCARELLI, F.; SIMONCINI, L.; GIANNINI, S. & LEARDINI, A. (1997). Gait analysis in pes cavus. *Gait and Posture*, 5(2): 169.

BIRTANE, M. & TUNA, H. (2004). The evaluation of plantar pressure distribution in obese and non-obese adults. *Clinical Biomechanics*, 19(10): 1055-1059.

BOWRING, B. & CHOCKALINGAM, N. (2010). Conservative treatment of tibialis posterior tendon dysfunction: A review. *Foot (Edinb)*, 20(1): 39-47.

BULDT, A.K.; ALLAN, J.J.; LANDORF, K.B. & MENZ, H.B. (2018a). The relationship between foot posture and plantar pressure during walking in adults: A systematic review. *Gait and Posture*, 62(May): 56-67.

BULDT, A.K.; FORGHANY, S.; LANDORF, K.B.; LEVINGER, P.; MURLEY, G.S. & MENZ, H.B. (2018b). Foot posture is associated with plantar pressure during gait: A comparison of normal, planus and cavus feet. *Gait and posture*, 62(May): 235-240.

BULDT, A.K.; FORGHANY, S.; LANDORF, K.B.; MURLEY, G.S.; LEVINGER, P. & MENZ, H.B. (2015). Centre of pressure characteristics in normal, planus and cavus feet. *Journal of Foot and Ankle Research*, 11(February): PMC5800032.

BURNFIELD, J.M.; FEW, C.D., MOHAMED, O.S. & PERRY, J. (2004). The influence of walking speed and footwear on plantar pressures in older adults. *Clinical Biomechanics*, 19(1): 78-84.

BURNS, J.; CROSBIE, J.; HUNT, A. & OUVRIER, R. (2005a). The effect of pes cavus on foot pain and plantar pressure. *Clinical Biomechanics*, 20(9): 877-882.

BURNS, J.; KEENAN, A-M & REDMOND, A. (2005b). Foot type and overuse injury in triathletes. *Journal of American Podiatric Medical Association*, 95(3): 235-241.

CARSON, D.W.; MYER, G.D.; HEWETT, T.E.; HEIDT, R.S. & FORD, K.R. (2012a). Increased plantar force and impulse in American football players with high arch compared to the normal arch. *Foot*, 22(4): 310-314.

CARSON, D.W.; MYER, G.D.; HEWETT, T.E.; HEIDT, R.S. & FORD, K.R. (2012b). Increased plantar force and impulse in American football players with high arch compared to the normal arch. *Foot*, 22(4): 310-314.

CAVANAGH, P.R.; MORAG, E.; BOULTON, A.J.M.; YOUNG, M.J.; DEFFNER, K.T. & PAMMER, S.E. (1997). The relationship of static foot structure to dynamic foot function. *Journal of Biomechanics*, 30(3): 243-250.

CAVANAGH, P.R. & RODGERS, M.M. (1987). The arch index: A useful measure from footprints. *Journal of Biomechanics*, 20(5): 547-551.

CHANG, H.W.; CHIEH, H.F.; LIN, C.J.; SU, F.C.; TSAI, M.J. & MILANESE, S. (2014). The relationships between foot arch volumes and dynamic plantar pressure during midstance of walking in preschool children. *PLoS ONE*, 9(4): Article 94535.

COBB, S.C.; BAZETT-JONES, D.M.; JOSHI, M.N.; EARL-BOEHM, J.E. & JAMES, C.R. (2014). The relationship among foot posture, core and lower extremity muscle function, and postural stability. *Journal of Athletic Training*, 49(2): 173-180.

COTE, K.P.; BRUNET, M.E.; GANSNEDER, B.M. & SHULTZ, S.J. (2005). Effects of pronated and supinated foot postures on static and dynamic postural stability. *Journal of Athletic Training*, 40(1): 41-46.

DOWLING, G.J.; MURLEY, G.S.; MUNTEANU, S.E.; FRANETTOVICH SMITH, M.M.; NEAL, B.S.; GRIFFITHS, I.B.; BARTON, C.J. & COLLINS, N.J. (2015). Dynamic foot function as a risk factor for lower limb overuse injury: A systematic review. *Journal of Foot and Ankle Research*, 7(December): 55-68.

FERNÁNDEZ-SEGUÍN, L.M.; DIAZ MANCHA, J.A.; SÁNCHEZ RODRÍGUEZ, R.; ESCAMILLA MARTÍNEZ, E.; GÓMEZ MARTÍN, B. & RAMOS ORTEGA, J. (2014). Comparison of plantar pressures and contact area between normal and cavus foot. *Gait and Posture*, 39(2): 789-792.

FRANCO, A.H. (1987). Pes cavus and pes planus: Analyses and treatment. *Physical Therapy*, 67(5): 688-694.

GIACOMOZZI, C. (2011). Potentialities and criticalities of plantar pressure measurements in the study of foot biomechanics: Devices, methodologies and applications. In Václav Klika (Ed.), *Biomechanics in Applications* (pp. 249-274). London, UK: InTech Open books.

GIRARD, O.; EICHER, F.; FOURCHET, F.; MICALLEF, J.P. & MILLET, G.P. (2007). Effects of the playing surface on plantar pressures and potential injuries in tennis. *British Journal of Sports Medicine*, 41(11): 733-738.

GRAVANTE, G.; POMARA, F.; RUSSO, G.; AMATO, G.; CAPPELLO, F. & RIDOLA, C. (2005). Plantar pressure distribution analysis in normal weight young women and men with normal and claw feet: A cross-sectional study. *Clinical Anatomy*, 18(4): 245-250.

HERTEL, J.; GAY, M.R. & DENEGAR, C.R. (2002). Differences in postural control during single-leg stance among healthy individuals with different foot types. *Journal of Athletic Training*, 37(12): 129-132.

HILLS, A.; HENNIG, E.; MCDONALD, M. & BAR-OR, O. (2001). Plantar pressure differences between obese and non-obese adults: A biomechanical analysis. *International Journal of Obesity*, 25(11): 1674-1679.

HILLSTROM, H.J.; SONG, J.; KRASZEWSKI, A.P.; HAFER, J.F.; MOOTANAH, R.; DUFOUR, A.B.; COUW, B.S. & DELAND, J.T. (2013). Foot type biomechanics part 1: Structure and function of the asymptomatic foot. *Gait and Posture*, 37(3): 445-451.

HRELJAC, A.; MARSHALL, R.N. & HUME, P. A. (2000). Evaluation of lower extremity overuse injury potential in runners. *Medicine and Science in Sports and Exercise*, 32(9): 1635-1641.

HUANG, P.; LIANG, M. & REN, F. (2019). *Assessment of long-term badminton experience on foot posture index and plantar pressure distribution*, *Applied Bionics and Biomechanics,* 2019(January): Article 8082967. doi.org/10.1155/2019/8082967.

KAUFMAN, K.R.; BRODINE, S.K.; SHAFFER, R.A.; JOHNSON, C.W. & CULLISON, T.R. (1999). The effect of foot structure and range of motion on musculoskeletal overuse injuries. *American Journal of Sports Medicine*, 27(5): 585-593.

KRUGER, K.M.; GRAF, A.; FLANAGAN, A.; MCHENRY, B.D.; ALTIOK, H.; SMITH, P.A.; Harris, G.F. & KRZAK, J.J. (2019). Segmental foot and ankle kinematic differences between rectus, planus, and cavus foot types. *Journal of Biomechanics*, 94(July): 180-186.

LANDORF, K. & KEENAN, A. (2000). Efficacy of foot orthoses: What does the literature tell us? *Journal of American Podiatric Medical Association*, 90(3): 149-158.

LEDOUX, W.R. & HILLSTROM, H.J. (2002). The distributed plantar vertical force of neutrally aligned and pes planus feet. *Gait and Posture*, 15(1): 1-9.

LEVY, J.C.; MIZEL, M.S.; WILSON, L.S.; FOX, W.; MCHALE, K.; TAYLOR, D.C. & TEMPLE, H.T. (2006). Incidence of foot and ankle injuries in west point cadets with pes planus compared to the general cadet population. *Foot and Ankle International*, 27(12): 1060-1064.

ORENDURFF, M.S.; ROHR, E.; SEGAL, A.D.; MEDLEY, J.W.; GREEN, J.R. & KADEL, N.J. (2009). Biomechanical analysis of stresses to the fifth metatarsal bone during sports maneuvers: Implications for fifth metatarsal fractures. *Physician and Sports Medicine,* 37(2): 87-92.

ÖZTÜRK, O.; KURU ÇOLAK, T.; TÜRKOĞLU, M.A.; SARI, Z. & POLAT, G. (2019). Evaluation of foot postures of assistant referees in the regional football league. *Journal of Exercise Therapy and Rehabilitation,* 6(1): 42-48.

PATAKY, T.C.; CARAVAGGI, P.; SAVAGE, R.; PARKER, D.; GOULERMAS, J.Y.; SELLERS, W.I. & CROMPTON, R.H. (2008). New insights into the plantar pressure correlates of walking speed using pedobarographic statistical parametric mapping (pSPM). *Journal of Biomechanics*, 41(9): 1987-1994.

QUEEN, R.M.; MALL, N.A.; NUNLEY, J.A. & CHUCKPAIWONG, B. (2009). Differences in plantar loading between flat and normal feet during different athletic tasks. *Gait and Posture*, 29(4): 582-586.

RAO, S.; SONG, J.; KRASZEWSKI, A.; BACKUS, S.; ELLIS, S.J.; DELAND, J.T. & HILLSTROM, H.J. (2011). The effect of foot structure on 1st metatarsophalangeal joint flexibility and hallucal loading. *Gait and Posture*, 34(1): 131-137.

ROSENBAUM, D.; HAUTMANN, S.; GOLD, M. & CLAES, L. (1994). Effects of walking speed on plantar pressure patterns and hind foot angular motion. *Gait and Posture*, 2(3): 191-197.

SHU, L.; HUA, T.; WANG, Y.; LI, Q.; FENG, D.D. & TAO, X. (2010). In-shoe plantar pressure measurement and analysis system based on fabric pressure sensing array. *IEEE Transactions on Information Technology in Biomedicine*, 14(3): 767-775.

SONG, Y. & KNAAP, G.J. (2004). Measuring urban form: Is Portland winning the war on sprawl? *Journal of American Planning Association*, 70(2): 210-225.

TEYHEN, D.S.; STOLTENBERG, B.E.; COLLINSWORTH, K.M.; GIESEL, C.L.; WILLIAMS, D.G.; KARDOUNI, C.H.; MOLLOY, J.M.; GOFFAR, S.L.; CHRISTIE, D.S. & MCPOIL, T. (2009). Dynamic plantar pressure parameters associated with static arch height index during gait. *Clinical Biomechanics*, 24(4): 391-396.

VALMASSY, R. (1996). *Clinical Biomechanics of the Lower Extremities* (1st ed.). St Louis, MO: Mosby.

YATES, B. & WHITE, S. (2004). The incidence and risk factors in the development of medial tibial stress syndrome among naval recruits. A*merican Journal of Sports Medicine*, 32(3): 772-780.

WILLIAMS, D.S.; DAVIS, I.M.; SCHOLZ, J.P., HAMILL, J. & BUCHANAN, T.S. (2004). High-arched runners exhibit increased leg stiffness compared to low-arched runners. *Gait and Posture*, 19(3): 263-269.

WILLIAMS, D.S.; MCCLAY, I.S.; HAMILL, J. & BUCHANAN, T.S. (2001). Lower extremity kinematic and kinetic differences in runners with high and low arches. *Journal of Applied Biomechanics*, 17(2): 153-163.

WONG, P.L.; CHAMARI, K.; MAO, D.W.; WISLOFF, U. & HONG, Y. (2007). Higher plantar pressure on the medial side in four soccer-related movements. *British Journal of Sports Medicine*, 41(2): 93-100.

ZHAO, X.; TSUJIMOTO, T.; KIM, B. & TANAKA, K. (2017). Association of arch height with ankle muscle strength and physical performance in adult men. *Biology of Sport*, 34(2): 119-126.

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