DOI: 10.48305/JRRS.2023.26559.0 Published by Vesnu Publications

Symmetry of Plantar Pressure Distribution and Center of Pressure Excursion Index in Active Female Adolescents with Foot Pronation: Cross-Sectional Study

Zahra Koreili[1], Ali Fatahi[2], Mohammad Ali Azarbaijany[3], Ali Sharifnezhad[4]

Original Article

Abstract

Introduction: The purpose of the present study was to compare the symmetry of the distribution of plantar pressure and the Center of Pressure Excursion Index (CPEI) in active female adolescents with and without foot pronation disorder.

Materials and Methods: This cross-sectional study was conducted on 34 physically active female adolescents with and without foot pronation aging 14 to 17 years. The participants were included through convenience sampling. Dominant leg was determined using blindfolded fall test and Waterloo dominant leg questionnaire. Brody method and foot pressure measurement system were used to measure navicular bone position and plantar pressure distribution, respectively. Data distribution was determined by Shapiro-Wilk test and between-group comparison of parameters concerning plantar pressure distribution was conducted using independent t-test at the significance level of $\alpha \leq 0.05$.

Results: There was no significant difference in the symmetry of the distribution of plantar pressure and maximal plantar pressure between two groups ($P > 0.05$); however, among the symmetry indices of decuple maximal plantar pressure zones, the maximal pressure at first metatarsus ($P = 0.04$) and the medial heel ($P = 0.05$) was significantly different between groups.

Conclusion: It seems that the symmetry at first metatarsus and medial heel was less in female adolescents with foot pronation disorders compared to that of healthy group. In addition, these girls showed higher pressures at medial heel and first metatarsus probably because of wider contact between the medial region of their foot and the ground. However, the pattern of distribution of plantar pressure and CPEI was almost the same in both groups without significant difference.

Keywords: Symmetry; Plantar pressure distribution; Center of pressure excursion index; Foot pronation; Female adolescents; Physically active

Citation: Koreili Z, Fatahi A, Azarbaijany MA, Sharifnezhad A. **Symmetry of Plantar Pressure Distribution and Center of Pressure Excursion Index in Active Female Adolescents with Foot Pronation: Cross-Sectional Study.** J Res Rehabil Sci 2021; 17: 53-61.

Received: 04.04.2021 Accepted: 17.05.2021 Published: 06.07.2021

Introduction

The foot is a complex structure responsible for absorbing force, distributing pressure, maintaining balance, and transferring driving forces (1). It undergoes more structural and functional changes than any other part of the body (2). One of its most

1- PhD Student, Department of Sports Biomechanics, School of Physical Education and Sports Sciences, Islamic Azad University, Central Tehran Branch, Tehran, Iran
2- Assistant Professor, Department of Sports Biomechanics, School of Physical Education and Sports Sciences, Islamic Azad University, Central Tehran Branch, Tehran, Iran
3- Professor, Department of Sports Physiology, School of Physical Education and Sports Sciences, Islamic Azad University, Central Tehran Branch, Tehran, Iran
4- Assistant Professor, Department of Sports Biomechanics and Technology, Sport Sciences Research Institute, Tehran, Iran
Corresponding Author: Ali Fatahi, Email: ali.fatahi@iauctb.ac.ir

important and variable structural features is the medial longitudinal arch, which decreases in height when bearing body weight (3). If this decrease is abnormal, it can cause deformity in the skeletal structure of the ankle and flat feet (3). In this condition, the head of the talus and navicular bone turn inward and downward, shifting the center of gravity inward and increasing pressure on the proximal parts of the metatarsophalangeal (MTP) and toes (4). When standing, body weight transfers through the posterior subtalar joint to the heel and through two general routes to the front of the foot (2). Most of the load applied to the heel is transferred through the talocalcaneonavicular joint (TNJ) and along the medial longitudinal arch to the first to third metatarsals before reaching the ground (5). Excessive ankle pronation during walking causes premature contact of the inner sole with the ground surface, impairing essential functions of the ankle joint (1). It affects absorption, distribution, and transmission of reaction force from the ground to the ankle, and may cause disturbance in force distribution and transmission in the ankle joint and lower limb (4).

Measuring plantar pressure distribution is a standard method to investigate ankle abnormalities in static and dynamic conditions (6). The Center of Pressure Excursion Index (CPEI), extracted from the center of pressure trajectory during walking, is used to evaluate foot disorders, including supination and pronation (7). Ground reaction force (GRF) enters the lower surface of the heel during walking and the center of pressure quickly moves from the back of the foot to the front to reach the big toe as the stance phase continues (1, 2). During walking, the foot's pronation movement adjusts and distributes contact forces (8). Flat feet increase pronation, leading to abnormal pressure distribution (9). Investigation of foot abnormalities is essential for preventing disorders and designing appropriate medical equipment (4).

Previous research suggests that foot pronation causes early contact with the ground in the stance phase of walking. The toe-heel running pattern is better suited for people with flat feet than other running practices (10). Ankle abnormalities play a significant role in pressure distribution and transmission on the soles of the feet (11). Maximum pressure on the soles of the people with flat feet compared to healthy people is on the inner part of the heel, toes, and second and third metatarsal head (4, 12). Gender, age, and body mass affect the distribution of foot pressure, and foot superiority is ineffective in this issue (13, 14).

Research on the distribution of plantar center of pressure excursion (CPE) in adolescent age groups is currently limited and fragmented, with a predominant emphasis on symmetry and plantar pressure among athletes (14, 15). A comprehensive analysis of plantar pressure, symmetry, and CPE in both healthy individuals and those with ankle deformities can offer valuable insights into injury prevention strategies, corrective exercise programs, and appropriate medical equipment. By comparing and contrasting the differences in these factors, a better understanding of the mechanisms behind ankle deformities can be gained, leading to more effective treatment plans and improved overall health outcomes. Therefore, the purpose of the present study was to compare plantar pressure symmetry and CPEI between healthy active adolescent girls and those with plantar flatness abnormalities.

Materials and Methods

This cross-sectional study was carried out from March 2020 to July 2021 in the 6th district of Tehran, Iran. The study was approved by the Ethics Working Group of Iran Physical Education and Sports Science Research Institute, and the ethics code IR.SSRI.REC.1400.1181 was obtained and all ethical considerations were followed based on the Helsinki guidelines. The statistical population of the research was active teenage girls from 14 to 17 years old in Tehran. The study's background and sample size were established using G*Power software (G*Power 3.1.9.7 freeware, University of Düsseldorf, Düsseldorf, Germany) (power = 0.75, $\alpha = 0.05$, effect size = 0.87) (9, 14). The statistical population consisted of 34 active teenage girls, 18 of whom had flat feet, and 16 were healthy. Participants were selected based on inclusion and exclusion criteria, with a consideration of at least a 10% dropout probability.

The inclusion criterion for adolescent girls with flat feet included having a navicular bone drop of more than 10 mm (16), examined by an orthopedic doctor and corrective movement experts. Exclusion criteria included any traumatic injury, history of surgery and orthopedic problems, especially in the lower limbs, diabetes, heart problems, acute vision and hearing problems, and obesity with a body mass index (BMI) over 30 kg/m^2. Measurements were taken after the participant's parent completed an informed consent form. First, the subject's weight and height were measured using a digital scale (model Bs101, Sahand Company, Iran) with an accuracy of 0.5 kg and a triangular wall caliper (26SM, Seca Company, Germany) with an accuracy of 0.1 cm. These instruments were calibrated before conducting the research. To determine the dominant and non-dominant leg of the subjects, the fall test with eyes closed and the Waterloo superior leg questionnaire (10) were used.

The amount of navicular bone loss in subjects with smooth and healthy soles was measured using the Bordy method (16). First, the subjects were seated with their leg in a weightless position, and the distance between the navicular bone and the ground was measured with a digital caliper (Ghamat Pooyan Company, Iran) with an accuracy of 0.01 mm (Figure 1A). Next, the subjects were asked to stand and distribute their weight equally on both legs, and the distance was measured again (Figure 1B). The difference between the two measurements was used to calculate the amount of navicular bone drop. If the difference in size between the two states is between 5 and 9 mm, the foot arch is normal. If it is 10 mm or more, the person has flat feet (16, 17). Flat feet are often associated with excessive foot eversion (2). To diagnose flat feet with more confidence, ankle pronation is investigated. In the standing position, the posterior projection of the heel bone and line with the Achilles tendon of the subjects was marked. Then, the angle between the small arm (in line with the heel) and the giant arm (in line with Achilles) was measured with a goniometer (Ghamat Pooyan Company, Iran) with an accuracy of 1 degree (2, 5) (Figure 1C). Besides, the length of the sole, from the longest toe to the end of the heel, was measured and recorded with a caliper.

The foot pressure scanner (PT-Scan4452F100 model, Payamavaran Ferdowsi Company, Iran) was used to evaluate the foot pressure distribution variables. The characteristics of this scanner are 55 × 64.5 cm^2, and the sensor's active surface is

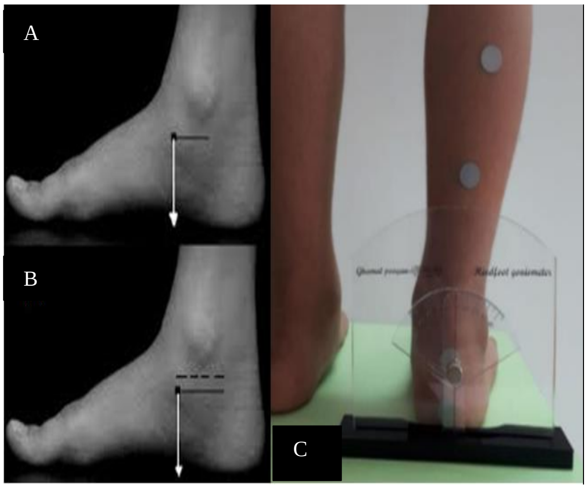

Figure 1. Navicular bone drop test (sitting or non-weight bearing position) (A); standing or weight bearing position (B); the lines used to calculate the heel valgus angle (C)

41 × 41 cm^2 with a frequency of 50 Hz, an image resolution of 0.07 cm^2, and a pressure measurement accuracy of ±10%. This device consists of a plate with a metal frame installed on the ground and flat with the surface. With the subject standing on the metal plate, the system records the pressure distribution information of the sole of the person's foot in a static state while taking a step in a dynamic form. This device has the ISO13485 standard and the IEC60601 electrical and noise safety standard, and its validity and reliability have been confirmed before (18).

The device was placed on a path of 6 meters in length to prevent the decrease or increase of acceleration at the beginning and end of the activity. First, the subjects were asked to walk the route length several times naturally and with bare feet as a test to familiarize them with the evaluation method. After starting the trial, the subject was asked to walk along the specified path at an average speed. If a person steps on the page without altering their natural walking pattern, it is recorded as a successful repetition. The plantar pressure distribution of each foot is then analyzed by dividing it into ten anatomical pressure-sensitive areas and calculating the indices of maximum pressure, contact surface, impulse, and maximum force for all ten points using the device software (Figure 2 A). Additional information on the device software can be found on the website C:\Payatek\PT-ScanSuit.

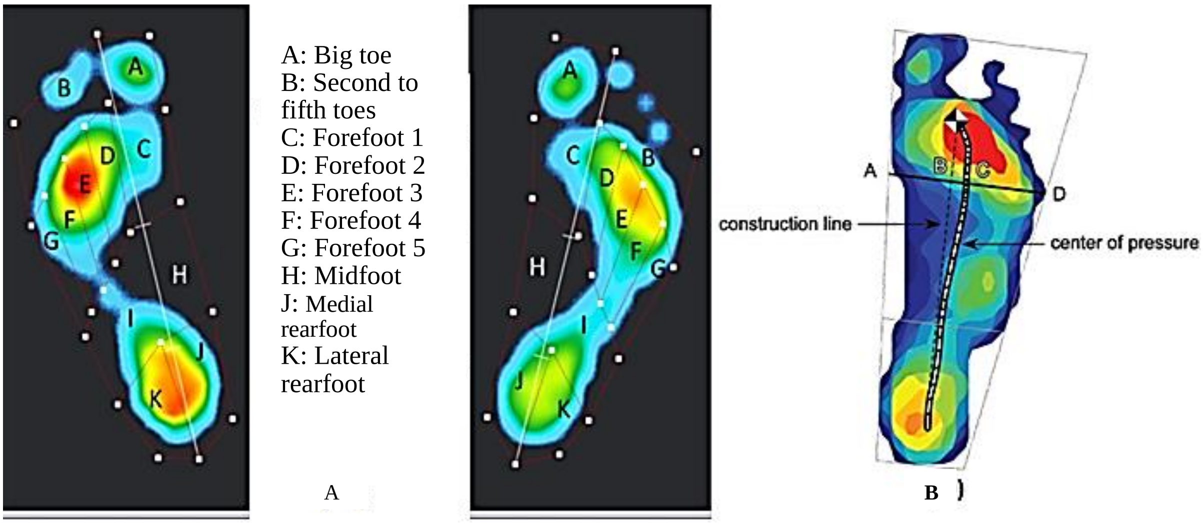

Figure 2. Areas of plantar pressure calculation (A); guidelines and indicators used in the calculation of the Center of Pressure Excursion Index (CPEI) (B)

To evaluate the CPEI, the study examined the aggregate frame that showed the plantar pressure distribution during the stance phase. PT-ScanSuit software (Payamavaran Ferdowsi, Iran) was used to draw CPE, AD line, and construction line (Figure 2 B). Point B is the intersection of AD and construction lines, and point C is the intersection of AD and CPE lines. The CPEI was calculated using equation 1 (18) after measuring the distance between points B and C.

Equation 1: Calculation of the CPEI: CPEI = BC/AD

Equation 2 checked the symmetry in selected indices between dominant and non-dominant limbs. In this regard, X2 is the dominant leg variable, and X1 is the non-dominant leg variable. The optimal symmetry between the two legs is determined using a symmetry index (SI) equal to zero; if the SI is more than 10%, it indicates asymmetry between the superior and non-superior leg variables. Moreover, a positive sign indicates that the variable is more significant in the dominant leg, and a negative sign indicates that the variable is more significant in the non-dominant leg (14, 15).

$$\text{Equation 2: SI (\%)} = 100 \times \frac{(X2-X1)}{0.5 \times (X2+X1)}$$

The data collection method involved preparing personnel in the field, conducting a detailed review of the data collection protocol at each stage, and ensuring timely implementation of all items. An independent t-test was performed on Shapiro-Wilk test data to compare plantar pressure distribution indices between two groups: healthy active adolescent girls and those with flat feet. The test was conducted in SPSS software (version 22, IBM Corporation, Armonk, NY, USA) with a significance level of 0.05.

Results

The demographic characteristics of the subjects are presented in table 1. The study included 18 active adolescent girls with flat feet and 16 healthy active adolescent girls. All participants completed the procedures. The normality of data was checked using the Shapiro-Wilk test ($P < 0.05$). No significant differences were found between the two groups ($P < 0.05$), but all girls with flat feet had a higher BMI than the healthy group.

Table 2 showed no significant difference in pressure distribution symmetry between healthy and flat feet groups during standing ($P \leq 0.05$).

No significant differences were observed in maximum plantar pressure, force, or contact surface symmetry across the entire sole (Table 3) ($P \leq 0.05$).

Table 4 shows that the pressure of decagonal regions differed significantly only in the symmetry of the first tarsal bone between healthy people and those with flat feet ($P = 0.04$). The maximum pressure balance in the heel area was also significantly different ($P = 0.05$).

Table 1. Demographic characteristics of subjects in two groups of healthy active teenage girls and those with flat feet

Group	Number	Age (year)	Height (m)	Weight (kg)	BMI (kg/m^2)
Flat feet	18	17.16 ± 1.54	1.67 ± 0.02	62.38	22.17 ± 2.46
Healthy	16	16.70 ± 1.16	1.67 ± 0.02	56.30	20.67 ± 2.50
The difference value of P between the two groups		0.51	0.18	0.13	0.06

Data are presented as mean ± standard deviation (SD); BMI: Body mass index

Discussion

This research aimed to compare plantar pressure distribution and CPEI symmetry between healthy, active adolescent girls. The study found no significant difference in foot symmetry variables between healthy teenagers and those with flat feet, except for maximum pressure symmetry in certain regions. This difference is likely due to decreased navicular bone height and inward/downward rotation of the talus bone, causing gravity to shift to the inner sole and the heel to rotate outwards (1, 3).

Most researchers agree that the talus bone supports around half of the body weight when standing on two legs (3, 4). Roughly 50% of this weight is transferred to the heel via the subtalar joint, while the remaining 50% is transferred to the forefoot through two routes (1). However, different sources hold differing views regarding the pattern and distribution of plantar pressure in the standing position (2).

Changes in the absorption and distribution of pressure transfer in the sole of the foot can occur due to abnormalities and complications in the anatomical structure of the foot (6, 12).

The results of previous studies indicate that individuals with flat feet struggle to maintain proper ankle alignment during the contact phase of walking, leading to changes in plantar pressure distribution and CPE (3, 6, 9), which is consistent with the results of the present research. Additionally, research suggests that individuals with flat feet experience a faster impact of the inner sole during the stance phase of walking (11, 13).

Flat feet can cause problems in the lower limbs due to improper distribution of pressures on the soles of the feet, affecting functions such as controlled adaptation of the sole to the ground surface during walking and proper transmission of forces applied to the ankle joints. Jahani and Jalalvand observed that people with flat feet had higher ankle plantar flexion during the stance phase of walking, which is probably a compensatory mechanism to maintain balance and adjust pressure and force during walking (2, 10).

Some conditions like malformation, muscle weakness, neuromuscular disorders, or length differences in bone structure can cause systematic asymmetry leading to secondary problems in other body parts (9, 11, 19).

However, humans exhibit high asymmetry when walking in childhood, decreasing in youth and increasing in old age (2). Perttunen et al. (19) and Lythgo et al. (20) believe that walking at different speeds in healthy adolescents is entirely symmetric, but adolescents with leg length difference exhibit asymmetric plantar pressure distribution while walking. Farjad-Pezeshk et al. (14) and Memar et al. (15) found a significant difference in plantar pressure distribution between the dominant and non-dominant limbs of athletes. The dominant leg exhibited higher pressure on the thumb and last three toes, while the non-dominant leg had higher pressure on the first and second metatarsals, thumb, and third to fifth fingers. These findings contrast with the present study, which may be due to differences in age, gender, physical activity levels, and measurement tools (15, 20).

Even though in this study, there were different views and differences of opinions about plantar pressure distribution and the symmetry of related indicators, most of the studies reported insignificant differences in pressure distribution symmetry variables between people with flat feet and healthy people. Biomechanical changes, skeletal-muscular abnormalities, length differences in bone structure, and neuromuscular disorders can cause leg asymmetry (5, 14, 15).

Flat feet are often associated with excessive heel eversion, and the heel plays a significant role in bearing and transferring weight from the back to the front of the foot. Any abnormality in the anatomical structure of the ankle joints can cause improper absorption and distribution of the forces from the ground to the ankle (7, 11, 12).

Table 2. Comparison of pressure distribution symmetry indices (contact surface and impulse) between two groups of healthy subjects and those with flat feet

Pressure variable symmetry index (percentage)	Foot sole	Group (number)	Mean ± SD	T	df	P
Contact surface	Hindfoot	Healthy (16)	1.74 ± 0.46	0.59	31	0.56
		Flatfeet (18)	-1.25 ± 0.62			
	Midfoot	Healthy (16)	-9.29 ± 2.16	-1.55	31	0.13
		Flatfeet (18)	3.49 ± 1.73			
	Forefoot	Healthy (16)	1.39 ± 0.73	1.72	30	0.09
		Flatfeet (18)	-2.50 ± 1.26			
Impulse	Hindfoot	Healthy (16)	-4.94 ± 1.16	0.83	31	0.41
		Flatfeet (18)	-10.05 ± 1.02			
	Midfoot	Healthy (16)	-0.38 ± 0.16	-0.41	30	0.60
		Flatfeet (18)	4.06 ± 1.36			
	Forefoot	Healthy (16)	2.42 ± 0.53	-0.12	32	0.91
		Flatfeet (18)	2.85 ± 1.36			

*Significant difference at $P \leq 0.05$ level
df: Degree of freedom; SD: Standard deviation

Because the movement axis of the talus tends inward and most of the applied load is transferred through the talonavicular joint and along the longitudinal-medial arch to the first to third metatarsal bones, the flat feet cause the center of gravity to incline inward and increase the maximum amount of pressure in the medial part of the forefoot (9, 12).

Limitations

One limitation of this research is the small sample size and the selection of participants from a specific treatment center, which hinders the generalization of results.

Recommendations

Future research could evaluate ankle structure, degree of deformity in each segment of ankle joints, the effect of exercise and correction programs on healthy and complicated groups, and patterns of walking and running in different age groups and people with different types of abnormalities. Measuring the electrical activity of the lower limb muscles and GRF in different types of foot models and stepping patterns will also be valuable.

Conclusion

Teenage girls with flat feet have less symmetry in the points of their first metatarsus and inside their heels compared to healthy individuals. They also experience higher pressure on the inner edge and first metatarsal due to greater contact with the ground. However, the distribution pattern of plantar pressure and CPEI is similar in both groups, and further studies are necessary to generalize and apply these results.

Acknowledgments

The authors would like to thank Dr. Amir Ali Jafarnezhadgero for his advice and sharing his experiences in the field of ankle studies.

Table 3. Comparison of maximum symmetry indices of pressure, force, and contact surface of the sole between two groups of healthy subjects and those with flat feet

Maximum variable symmetry of the entire sole (percentage)	Group (number)	Mean ± SD	T	df	P
Pressure	Healthy (16)	-2.27 ± 1.06	-0.06	29	0.95
	Flatfeet (18)	-1.75 ± 1.02			
Force	Healthy (16)	0.67 ± 0.16	-1.23	29	0.23
	Flatfeet (18)	5.57 ± 1.63			
Contact surface	Healthy (16)	-2.19 ± 1.73	-0.35	29	0.73
	Flatfeet (18)	-0.07 ± 0.26			

Significant difference at $P \leq 0.05$ level
df: Degree of freedom; SD: Standard deviation

Table 4. Comparison of maximum symmetry indices of pressure of decagonal regions between two groups of healthy subjects and those with flat feet

Maximum pressure symmetry for area (percentage)	Group (number)	Mean ± SD	T	df	P value
Tars 1	Healthy (16)	5.34 ± 1.16	2.14	31	0.04*
	Flatfeet (18)	-43.25 ± 1.02			
Tars 2-5	Healthy (16)	17.29 ± 2.16	1.34	32	0.19
	Flatfeet (18)	-20.95 ± 1.46			
Metatars 1	Healthy (16)	9.39 ± 1.73	0.90	32	0.38
	Flatfeet (18)	-9.40 ± 1.26			
Metatars 2	Healthy (16)	-15.94 ± 1.16	-1.12	32	0.27
	Flatfeet (18)	4.25 ± 1.02			
Metatars 3	Healthy (16)	0.79 ± 0.16	-1.71	32	0.10
	Flatfeet (18)	26.65 ± 1.36			
Metatars 4	Healthy (16)	1.39 ± 0.73	-0.77	32	0.45
	Flatfeet (18)	6.40 ± 1.36			
Metatars 5	Healthy (16)	10.34 ± 1.16	-0.10	32	0.92
	Flatfeet (18)	13.25 ± 1.06			
Medial part of forefoot	Healthy (16)	-14.79 ± 2.16	-1.67	32	0.11
	Flatfeet (18)	17.65 ± 2.36			
Medial side of heel	Healthy (16)	-12.39 ± 3.73	-2.01	32	0.05*
	Flatfeet (18)	6.89 ± 1.36			
Lateral side of heel	Healthy (16)	0.39 ± 1.16	0.23	32	0.82
	Flatfeet (18)	0.07 ± 0.26			

*Significant difference at $P \leq 0.05$ level
df: Degree of freedom; SD: Standard deviation

Authors' Contribution

Study design and ideation: Ali Fatahi, Zahra Koreili
Getting financial resources for the study: Zahra Koreili, Ali Fatahi
Scientific and executive support of the study: Zahra Koreili, Ali Fatahi, Mohammad Ali Azarbaijany, Ali Sharifnezhad
Data collection: Zahra Koreili
Analysis and interpretation of the results: Zahra Koreili, Ali Fatahi, Mohammad Ali Azarbaijany, Ali Sharifnezhad
Specialized statistics services: Zahra Koreili, Ali Fatahi, Mohammad Ali Azarbaijany
Manuscript preparation: Zahra Koreili, Ali Fatahi, Mohammad Ali Azarbaijany, Ali Sharifnezhad
Specialized scientific evaluation of the manuscript: Zahra Koreili, Ali Fatahi, Mohammad Ali Azarbaijany, Ali Sharifnezhad
Confirming the final manuscript to be submitted to the journal website: Zahra Koreili, Ali Fatahi, Mohammad Ali Azarbaijany, Ali Sharifnezhad
Maintaining the integrity of the study process from the beginning to the publication, and responding to the referees' comments: Zahra Koreili, Ali Fatahi, Mohammad Ali Azarbaijany, Ali Sharifnezhad

Funding

The present study is a part of the PhD dissertation by Zahra Korreili at the Department of Sports Biomechanics, School of Physical Education and Sports Sciences, Islamic Azad University, Tehran Central Branch (ethics code: IR.SSRI.REC.1400.1181) without financial support by Islamic Azad University. The university did not interfered in data collection, analysis and reporting, manuscript preparation, and final approval of the study for publication.

Conflict of Interest

The authors did not have any conflict of interest. Dr. Ali Fatahi is working since 2019 as assistant professor at the Department of Sports Biomechanics and Dr. Mohammad Ali Azarbaijany is working since 2001 as professor at the Department of Sports Physiology, Islamic Azad University, Tehran Central Branch. Dr. Ali Sharifnezhad is working since 2016 as assistant professor at Iran University of Medical Sciences, Tehran, and is the head of Physical

Education and Sport Sciences Research Center. Zahra Koreili has been studying PhD degree of Sports Biomechanics at School of Physical Education and Sports Sciences, Islamic Azad University, Tehran Central Branch since 2018.

References

1. Hamill J, Knutzen K, Derrick TR. Biomechanical basis of human movement. 3rd ed. Philadelphia, PA: Wolters Kluwer Health/Lippincott Williams and Wilkins; 2009. p. 311-2.
2. Oatis CA. Kinesiology: The Mechanics and Pathomechanics of Human Movement. Philadelphia, PA: Lippincott Williams and Wilkins; 2009.
3. Dehghani M, Jaafarnejad A, Azizian N, Alavi Mehr SM. Effects of walking with internal and external attention on the balance and plantar pressure pattern in patients with low back pain. J Rehab Med 2019; 8(4): 227-35. [In Persian].
4. Buldt AK, Forghany S, Landorf KB, Murley GS, Levinger P, Menz HB. Centre of pressure characteristics in normal, planus and cavus feet. J Foot Ankle Res 2018; 11: 3.
5. Stamm SE, Chiu LZ. Calcaneal plantar flexion during the stance phase of gait. J Appl Biomech 2016; 32(2): 205-9.
6. Lee SY, Hertel J. Effect of static foot alignment on plantar-pressure measures during running. J Sport Rehabil 2012; 21(2): 137-43.
7. Putti AB, Arnold GP, Cochrane LA, Abboud RJ. Normal pressure values and repeatability of the Emed ST4 system. Gait Posture 2008; 27(3): 501-5.
8. Emami A, Hadadnezhad M, Svoboda Z, Abbasi A. Effect of technique correction protocol on hamstring muscle activity following fatigue protocol in patients with pronation. Jundishapur Sci Med J 2020; 19(1): 53-68. [In Persian].
9. Golchini A, Rahnama N, Lotfi Foroushani M. Effect of corrective exercises with a new approach on the isometric strength in people with pronation distortion syndrome. Journal of Paramedical Sciences and Rehabilitation 2021; 9(4): 41-60. [In Persian].
10. Jahani MR, Jalalvand A. A study to evaluate spatial, temporal, distance running parameters in man patients of flat foot. Beyhagh 2019; 24(4): 25-35. [In Persian].
11. Jafarnezhadgero A, Ghane G, Valizadeh Orang A, Mokhtari Malek Abadi A. A comparison of planatar pressure variables during three differntrunning patterns in pronated feet individuals with and withoutlow back pain. J Anesth Pain 2020; 11(3): 77-87. [In Persian].
12. Beinabaji H, Anbarian M, Sokhangouei Y. The effect of flat foot on lower limb muscles activity pattern and plantar pressure characteristics during walking. J Res Rehabil Sci 2012; 8(8Suppl):1328-41. [In Persian].
13. Zulkifli SS, Loh WP. A state-of-the-art review of foot pressure. Foot Ankle Surg 2020; 26(1): 25-32.
14. Farjad-Pezeshk A, Sadeghi H, Farzadi M. Comparison of plantar pressure distribution and vertical ground reaction force between dominant and none-dominant limb in healthy subjects using principle component analysis (PCA) technique. J Rehab 2013; 14(1): 91-102. [In Persian].
15. Memar R, Ghasempour H, Farjad Pezeshk SA, Shirazikhah M. the symmetry in the selected plantar pressure distribution parameters of the elderly subject with lower limb discrepancy (LLD). Salmand Iran J Ageing 2012; 7(3): 38-44. [In Persian].
16. Onodera AN, Sacco IC, Morioka EH, Souza PS, de Sa MR, Amadio AC. What is the best method for child longitudinal plantar arch assessment and when does arch maturation occur? Foot (Edinb) 2008; 18(3): 142-9.
17. Nguyen AD, Shultz SJ. Sex differences in clinical measures of lower extremity alignment. J Orthop Sports Phys Ther 2007; 37(7): 389-98.
18. Tohidinezhad F, Khorsand A, Zakavi SR, Rezvani R, Zarei-Ghanavati S, Abrishami M, et al. The burden and predisposing factors of non-communicable diseases in Mashhad University of Medical Sciences personnel: A prospective 15-year organizational cohort study protocol and baseline assessment. BMC Public Health 2020; 20(1): 1637.

19. Perttunen JR, Anttila E, Sodergard J, Merikanto J, Komi PV. Gait asymmetry in patients with limb length discrepancy. Scand J Med Sci Sports 2004; 14(1): 49-56.
20. Lythgo N, Wilson C, Galea MP. Gait symmetry in school-aged children and young adults whilst walking at slow, normal and fast speeds. Proceedings of the 6th World Congress of Biomechanics (WCB 2010); 2010 Aug 1-6; Singapore.