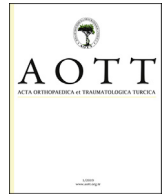




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Gender and age impact on plantar pressure distribution in early adolescence



İlksan Demirbüken^a, Bahar Özgül^a, Eren Timurtaş^{a,*}, Saadet Ufuk Yurdalan^a,
Murat Dinçer Çekin^b, Mine Gülden Polat^a

^a Marmara University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Istanbul, Turkey

^b Marmara University, Faculty of Health Sciences, Department of Health Management, Istanbul, Turkey

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ABSTRACT

Objective: The aim of the study was to investigate gender and age effect on dynamic plantar pressure distribution in early adolescence.

Methods: A total of 524 adolescents (211 women and 313 men; mean age: 12.58 ± 1.11 years (range: 11–14 years)) participated in pedobarographic measurements during gait at self-selected speed. Data of peak pressure (PP), maximum force (MaxF-Newton), body weight corrected maximum force (BW_MaxF), contact area (CA-cm²) were analyzed for total foot and four plantar regions (hindfoot, midfoot, forefoot and toes). **Results:** Higher toes PP was found in the ages of 12–14 years in females compared to males (253.79 ± 104.93 vs 216.00 ± 81.12 for the age of 12, $p = 0.011$, 264.40 ± 65.02 vs 227.21 ± 83.4 for the age of 13, $p = 0.044$, 299.75 ± 140.60 vs 238.75 ± 103.32 for the age of 14, $p = 0.005$). Females' higher MaxF especially for toes (136.24 ± 48.54 vs 115.33 ± 46.03 , $p = 0.008$) and smaller CA especially for forefoot (50.12 ± 5.79 vs 54.4893 ± 6.80 , $p = 0.001$) were considerable in the late of early adolescence. Forefoot (305.66 ± 82.14 females $p = 0.001$, 281.35 ± 79.59 males $p < 0.001$) and total foot PP (374.08 ± 113.93 females, $p = 0.035$, 338.61 ± 85.85 males $p = 0.009$) at the age of 14 was significantly higher than in younger ages in both gender groups.

Conclusion: The results indicate that especially the age of 14 years in early adolescence is a critical age for alteration in plantar pressure distribution. Interestingly females tended to increase their toe and forefoot plantar pressures compared to males by increasing age. We suggest that gender and age impact on toes plantar pressure alterations in early adolescence may be a possible risk factor for further foot impairments.

Level of Evidence: Level III, Diagnostic Study.

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Introduction

Males and females are anatomically and physiologically different in several ways.^{1,2} These differences lead to distinct rates

Abbreviations: BW_MaxF, body weight corrected maximum force; CA, contact area (cm²); MaxF, maximum force (Newton); PP, peak pressure (kPa).

* Corresponding author. Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Marmara University, Başbüyük Health Campus, Başbüyük Road No: 3, Başbüyük/Maltepe, İstanbul, Turkey. Tel.: +90 216 399 93 71; fax: +90 216 399 62 42.

E-mail addresses: ilksan_d@hotmail.com (İ. Demirbüken), fztbaharozgul@gmail.com (B. Özgül), fzteren@gmail.com (E. Timurtaş), ufukyurdalan@hotmail.com (S.U. Yurdalan), muratcekin@yahoo.com (M.D. Çekin), guldenpolat2002@yahoo.com (M.G. Polat).

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of musculoskeletal injury of lower extremity between them.³ Misalignment of the foot structure is thought to be an important factor that may cause problems at other parts of body (knee pathologies, low back pain e.t.c)⁴ and increased the risk of lower extremity deformities such as dynamic pes planus, pes cavus, restricted ankle dorsiflexion, and increased hindfoot inversion.⁵

To detect foot pathologies and evaluate foot functions, measurements of plantar foot pressure have been widely used in recent years.^{1,6} It is well documented that plantar pressure values are influenced by several determinants including anatomical structure of foot.⁷ According to forensic science studies there are anthropometric differences between the foot bones of males and females.^{8,9} Even a slight change in the foot structure alters the load distribution of the foot.¹⁰ Therefore, some researchers focused on the possible gender differences between plantar pressure distributions

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of the adult population. The methods and results of plantar pressure assessments in male and female adults reported in the literature are inconsistent with indicating no differences in plantar pressure values or different loading patterns of foot between genders.^{2,10}

Since the children's feet have different characteristic properties in structure and function compared to feet of adults, their plantar pressure distribution values is considered to vary from those of adults.¹¹ Liu et al found no gender differences between plantar pressure values of healthy children aged between 6 and 16 years by insole measurements.¹² Phethean et al supported the findings of the previous study by indicating no significant differences in plantar pressure between genders in 4–7 year old children.¹³ However, Bosch et al reported that males aged in 1–5 years had higher peak plantar pressures than females of the same age.⁶ Based on the literature, another study of Bosch et al suggested that gender differences may only appear in the earlier years of the life span.⁶

However adolescence is a period of development which is related with maturation and appearance of secondary sexual characteristics includes the age at onset of the menarche in female adolescents.^{14,15} Besides these differences, soft tissues are exposed to higher loading by an amplified rate of bone, ligament and tendon growth in this period. It is also important to note that static and dynamic foot functions change differently during growth and maturation. Although assessment of foot pressure distribution provides important clinical information about foot functions, plantar pressure studies in early adolescence are rare.^{12,16} The purpose of the study was to examine the possible differences in plantar pressure distributions between male and female adolescents in the ages of 11–14 during walking. Further, we also investigated the age-adjusted gender differences in plantar pressure distributions which have not been reported yet.

Methods

Participants

A total of 533 typically developed adolescents aged 11–14 years were recruited subsequent to approval from the local Ethical Committee and the local National Education Directorate. The study was performed between the years of 2012 and 2014 in three local middle schools. Adolescents' parents were informed about the study and informed consent was obtained from parents of all participants included in the study.

The adolescents who did not have any neurological and orthopedic problems were included in the study. The adolescents were excluded if they had any lower extremity asymmetry or pain, malalignment of lower extremity, gross gait abnormalities and severe postural disorders during visual inspection. The lengths of lower extremities from trochanter major to lateral malleolus were measured by a tape. The anthropometric data (age, gender, height, and weight) were recorded prior to pedobarographic analysis of 533 subjects. A total number of 524 subjects (211 female and 313 male) were included into data analysis due to a drop-out number of 9 subjects in consequences of the cases of missing values or implausible data. The mean age of subjects was 12.58 ± 1.11 years (12.38 ± 1.19 years for females, 12.72 ± 1.03 years for males). Physical characteristics are presented according to the age groups at [Table 1](#).

Plantar pressure measurement and analysis

Emed-a 50/D pedobarographic system (Novel GmbH®. Munich, Germany) was used to analyze pedobarographic data of subjects. Pressure plate size was 380 mm × 240 mm with incorporating 1760 capacitive sensors (2 sensors/cm²) sampling at a rate of 50/60 Hz with a range of 10–950 kPa.

Data were collected barefoot in mid-gait at self-selected gait speed. The trials with abnormal gait pattern as hitting the platform surface purposefully were dropped out to avoid getting incorrect data. Finally, five smooth trials were recorded for each foot.

The Research Foot software (Novel GmbH® Munich Germany) provided by Novel GmbH Munich was used to determine forces and pressures under 4 foot regions: hindfoot, midfoot, forefoot and toes following data collection. Evaluation was carried out on three of the most clinically used parameters: peak pressure (PP) kPa, contact area (CA) cm² and maximum force (MaxF) N and body weight corrected MaxF (BW_MaxF) for each foot region and total foot by the scientific analysis software.

Statistical analysis

Paired t-test was used to evaluate any plantar pressure differences between the left and right foot. Based on the findings of no differences ($p > 0.05$) and the need to meet the assumption of 'independence of observation'.¹⁷ The average data of all measured parameters of right and left foot was used for all further analyses. After testing for normality of data by using a Kolmogorov–Smirnov test all data were found to be normally distributed and independent t-tests were used to evaluate any gender differences in the plantar pressure data for each age group. One way ANOVA test was applied to compare plantar pressure data between age groups separately for pooled data and each gender group. A Bonferroni correction was used for the binary comparisons of age groups. Significant differences in plantar pressure parameters were considered as $p < 0.05$. All statistical analysis was performed using SPSS version 11.5 (Chicago, IL).

Results

Total and regional pedobarographic values of males ($n = 313$) and females ($n = 211$) according to four regions (hindfoot, midfoot, forefoot and toes) for all age groups were presented in [Table 2](#).

Gender effect

Statistical analyses revealed higher total PP in females than males in the ages of 11 and 14 years ($p = 0.001$). Regional PP data showed that females had higher values than males in toes in ages from 12 to 14 years and in forefoot just for age 11 ($p < 0.05$). The only one region which male adolescents had greater PP than females was hindfoot and this difference was solely prevalent for the age of 13, not for other ages ($p = 0.010$, [Table 2](#), [Fig. 1](#)).

PP measures of females and males for midfoot did not differ remarkably across ages between 11 and 14 years ($p > 0.05$). Total MaxF of females were higher than males in the ages of 14 ($p = 0.010$). In addition, MaxF of toes of females were higher than males at the ages of 13 ($p = 0.008$) and 14 ($p = 0.010$). BW_MaxF of all regions of females were higher than males at the ages of 14 ($p < 0.05$, [Table 2](#)).

Males mostly had greater CA than females across all age groups included in the study. CA data analysis showed that males had greater CA than females in forefoot and hindfoot regions at the ages of 13 and 14 ($p < 0.05$, [Table 2](#)). Total CA of males was only significantly greater than females at 14 years ($p = 0.012$).

Age effect

Pooled pedobarographic data of both gender demonstrated that highest PP and MaxF values across all age groups were found in measures at the age of 14 years old ($p < 0.05$, [Figs. 2 and 3](#)). The subjects 13 and 14 years old had greater CA than

Table 1
Demographic data of the adolescents.

Age (Years)		Female		Male		Statistics	
		n	Mean ± SD	n	Mean ± SD	t	p
11	W (kg)	64	39.85 ± 9.81	41	36.73 ± 6.62	-1.648	0.102
	H (cm)		145.32 ± 8.72		144.21 ± 7.57	-0.668	0.506
12	W (kg)	62	42.47 ± 11.57	99	42.74 ± 9.68	0.162	0.871
	H (cm)		150.50 ± 42.47		148.16 ± 7.85	-1.767	0.079
13	W (kg)	25	44.23 ± 10.06	78	50.21 ± 14.52	1.915	0.058
	H (cm)		153.24 ± 6.92		156.67 ± 9.98	1.559	0.122
14	W (kg)	60	54.02 ± 10.32	95	54.66 ± 12.60	0.714	0.476
	H (cm)		159.88 ± 7.30		163.93 ± 8.57	2.973	0.003*
Total	W (kg)	211	45.10 ± 11.99	313	47.43 ± 13.25	2.054	0.041*
	H (cm)		151.92 ± 9.86		153.10 ± 14.30	1.826	0.068

*p < 0.05 significantly higher, Paired t-test, W = weight, H = height, n = number, SD = standard deviation.

Table 2
Gender comparison of pedobarographic data (MaxF, PP, CA) of adolescents according to age.

Age (Year)		11		12		13		14	
		F (n = 64)		M (n = 41)		F (n = 25)		M (n = 78)	
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Peak pressure (kPa)	Total	316.68 ± 94.66*	282.87 ± 66.36	333.70 ± 92.05	311.51 ± 67.96	305.80 ± 56.60	318.1 ± 72.2	374.08 ± 113.93*	338.61 ± 85.85
	Hindfoot	262.38 ± 93.90	241.34 ± 65.90	261.77 ± 91.37	260.90 ± 68.87	229.90 ± 42.84	261.05 ± 73.12*	271.71 ± 61.12	265.61 ± 78.40
	Midfoot	106.79 ± 27.01	100.37 ± 26.53	100.27 ± 29.54	103.35 ± 31.27	106.90 ± 36.73	113.84 ± 31.23	118 ± 32.76	108.52 ± 36.49
	Forefoot	253.39 ± 77.91*	221.52 ± 60.53	251.08 ± 73.36	244.04 ± 64.23	246.60 ± 55.63	255.12 ± 67.30	305.66 ± 82.14	281.35 ± 79.59
	Toes	201.05 ± 86.77	198.72 ± 69.96	253.79 ± 104.93*	216.00 ± 81.12	264.40 ± 65.02*	227.21 ± 83.4	299.75 ± 140.60*	238.75 ± 103.32
Maximum force (N)	Total	553.95 ± 279.46	574.03 ± 273.09	568.40 ± 263.76	600.94 ± 270.75	569.16 ± 223.67	546.19 ± 184.61	822.54 ± 410.28*	630.19 ± 209.49
	Hindfoot	300.80 ± 75.10	293.47 ± 68.46	307.45 ± 83.14	317.22 ± 75.44	309.35 ± 62.61	340.48 ± 94.14	386.36 ± 100.15	376.81 ± 80.50
	Midfoot	95.15 ± 62.45	81.53 ± 45.00	88.36 ± 51.37	93.08 ± 57.96	105.66 ± 61.24	104.88 ± 59.54	119.29 ± 60.16	106.48 ± 62.91
	Forefoot	359.82 ± 121.90	328.53 ± 82.13	361.15 ± 106.97	373.62 ± 106.51	372.50 ± 85.58	412.51 ± 130.89	487.54 ± 137.19	463.98 ± 98.22
	Toes	90.71 ± 36.67	96.46 ± 30.22	110.59 ± 40.70	104.73 ± 38.32	126.32 ± 27.01*	105.25 ± 37.3	136.24 ± 48.54*	115.33 ± 46.03
Maximum force (N%BW)	Total	144.43 ± 66.84	162.66 ± 76.71	140.01 ± 63.96	145.53 ± 65.30	135.17 ± 58.71	110.24 ± 27.85	156.27 ± 68.50*	116.88 ± 36.39
	Hindfoot	79.21 ± 18.49	82.63 ± 18.60	74.17 ± 19.26	78.93 ± 27.63	72.11 ± 13.20	69.36 ± 10.49	74.56 ± 14.33*	70.07 ± 12.18
	Midfoot	23.60 ± 11.80	91.17 ± 14.93	21.13 ± 11.46	21.64 ± 11.25	23.21 ± 10.77	23.16 ± 26.24	22.23 ± 8.83*	19.09 ± 9.49
	Forefoot	93.08 ± 18.00	91.17 ± 14.93	87.18 ± 16.70	88.76 ± 13.80	85.65 ± 11.62	82.19 ± 12.97	92.24 ± 17.03*	86.10 ± 9.80
	Toes	24.49 ± 10.73	27.85 ± 10.66	27.58 ± 10.68	25.80 ± 9.69	29.57 ± 7.35	24.27 ± 18.51	26.34 ± 10.33*	22.05 ± 8.57
Contact area (cm ²)	Total	117.65 ± 19.33	117.62 ± 16.19	119.86 ± 17.46	123.90 ± 21.76	125.98 ± 17.71	133.44 ± 20.54	134.15 ± 17.25	142.16 ± 20.23*
	Hindfoot	30.21 ± 3.67	29.97 ± 3.17	30.84 ± 3.52	31.66 ± 4.07	32.16 ± 2.92	34.75 ± 4.74*	33.48 ± 3.77	36.67 ± 4.04*
	Midfoot	24.24 ± 7.39	23.40 ± 7.90	23.57 ± 6.82	24.84 ± 9.08	25.42 ± 7.99	27.51 ± 8.18	27.19 ± 6.35	28.6893 ± 9.01
	Forefoot	44.83 ± 7.48	45.22 ± 6.26	45.12 ± 6.20	47.17 ± 7.47	45.79 ± 6.24	50.43 ± 8.55*	50.12 ± 5.79	54.4893 ± 6.80*
	Toes	18.29 ± 4.51	18.96 ± 3.13	20.55 ± 4.32	20.02 ± 4.16	22.05 ± 3.73	20.36 ± 4.44	22.84 ± 4.80	22.10 ± 5.63

*p < 0.05 significantly higher, Paired t-test, F = female, M = male, n = number, SD = standard deviation.

younger age groups (p < 0.05, Figs. 2 and 3). The subjects 12 and 13 years old had lower BW_MaxF than the age of 11 years old (p < 0.05, Fig. 3).

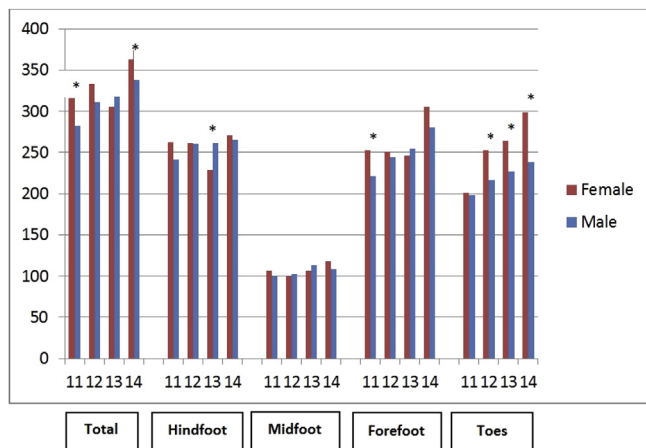


Fig. 1. Gender comparison of peak pressure data between females and males, *p < 0.05 significantly higher.

Age effect according to genders

Fig. 4 shows the regional PP distribution pattern (as in toes, forefoot, midfoot and hindfoot) by increasing age according to gender. PP of forefoot at age of 14 was significantly higher than younger ages in both male and female adolescents (p < 0.05). PP distributions of midfoot did not significantly effect and hindfoot of males and females adolescents (p > 0.05).

Interesting results were observed for toes regions of adolescents. There were no significant differences in plantar pressure distribution of toes region in male adolescents between ages while female adolescents demonstrated significantly higher PP in toes at the age of 14 compared to the age of 11 (p < 0.001), and age of 12 compared to the age of 11 (p = 0.040).

Discussion

Gender effect

Total plantar pressure distribution of adolescence indicated that significant differences were observed in the age of 11 and 14 years between genders (Fig. 1). Especially at the age of 14, significant differences in MaxF and CA became relevant. Total contact area of

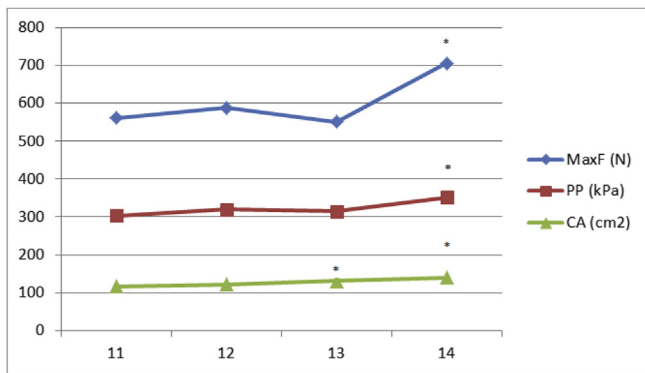


Fig. 2. Total pedobarographic data (MaxF, PP, CA) according to age groups. * $p < 0.05$ significantly higher than younger adolescents, one way ANOVA test.

males was almost same with the females at the age of 11 and males began to increase their contact area from 11 to 14 years old. This increase in CA might have caused significant differences in PP distribution for males compared to females at the age of 14. Male adults were found to have greater CA than their female counterparts due to their bigger foot size by previous studies.^{2,18}

The significant differences in PP of forefoot at the age of 11 disappeared and female's peak pressure in the toes region became higher compared to males in the following ages. Wherefore there was no gender difference for CA of foot regions, higher PP was due to higher MaxF detected for females in the late period of early adolescence. Long standing of this distribution pattern in the later years of adolescence may be a possible risk factor for toe deformities such as hallux valgus in adulthood.^{19,20} The findings of the Brain's et al partially support our comment by indicating greater plantar pressure on the front part of the foot in the individuals with hallux valgus compared to normal foot.²¹ Unfortunately we cannot speculate that female adolescents in our study are under the high risk to develop hallux valgus since we did not check the data on metatarsal pressures separately. The PP results of midfoot region showed that there is no difference in plantar pressure distribution between male and female adolescents. Plantar pressure measurements in the midfoot region provide clinically important data to

evaluate medial longitudinal arch. Development of medial longitudinal arc is a substantial process in the childhood and adolescence.²² Some researchers detected males had a greater tendency for flat foot than females in preschool-aged children²³ and schoolchildren.²² Stavlos et al indicated that foot development from the low-arched types to normal types occurs earlier in females than males.²⁴ Despite of structural gender differences according to age the prevalence of midfoot deformities such as pes planus and/or pes cavus do not vary between female and male adolescents.¹⁹ Consistent with the studies mentioned above there was no gender difference in the midfoot pressure distribution of adolescents in our study at any age groups to speculate MLA differences between genders.

There was only the age of 13 years which males had greater plantar pressure on hindfoot than females had. Male adolescents were in tendency to increase PP on hindfoot by increasing age while females decreased their PP on hindfoot at the age of 13 years old. It seems that the significantly high PP of males on the hindfoot at only this age was resulted from lower pressure values of females comparing with other age groups (Fig. 3). Relatively low number of female adolescents at 13 years old was one of the limitations to present this result.

Age effect

"Aging" in adolescence was found to be one of the influencing factors on plantar pressure distribution and its related parameters. Significant alterations in MaxF and CA at the late adolescence especially at 14 years old might be resulted from increase in the foot size and body weight of adolescents during growing (Table 1). Absence of significant differences in BW MaxF at the age of 14 compared to younger ages supported the affect at body weight on maximum force in that age. The result of studies investigated dynamic plantar pressure distribution of adults showed that males had higher maxF in the metatarsal region than females.^{2,18} It can be concluded that "age" is an important factor that have substantial influence on plantar pressure distribution. Froehle et al suggested that gait evaluations of early adolescents by using adults' normative data may bias interpretations of adolescents' gait.²⁵ We support their suggestion by our different plantar total pressure data of

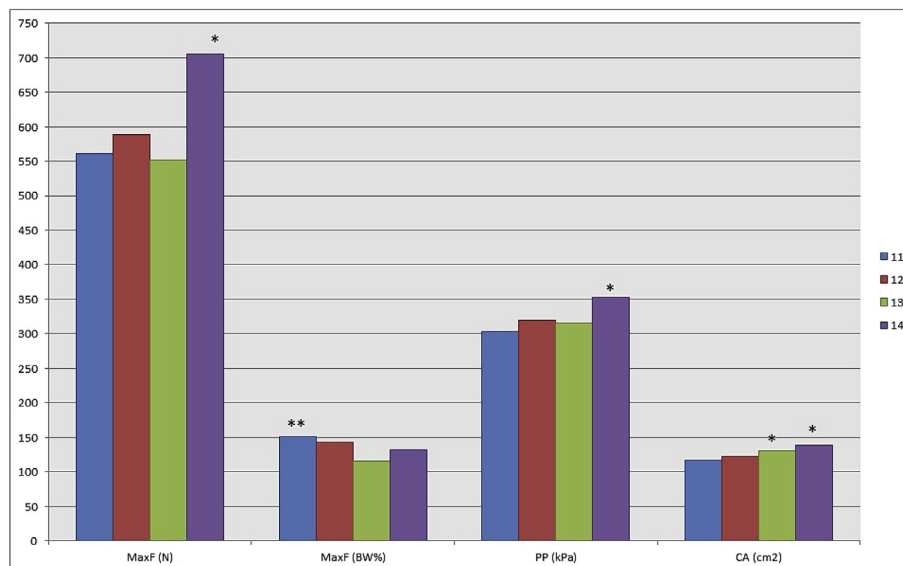


Fig. 3. Total pedobarographic data (MaxF, MaxF(BW%), PP, CA) according to age groups. * $p < 0.05$ significantly higher than younger adolescents, one way ANOVA test. ** $p < 0.05$ significantly higher than adolescents at the age of 12 and 13, one way ANOVA test.

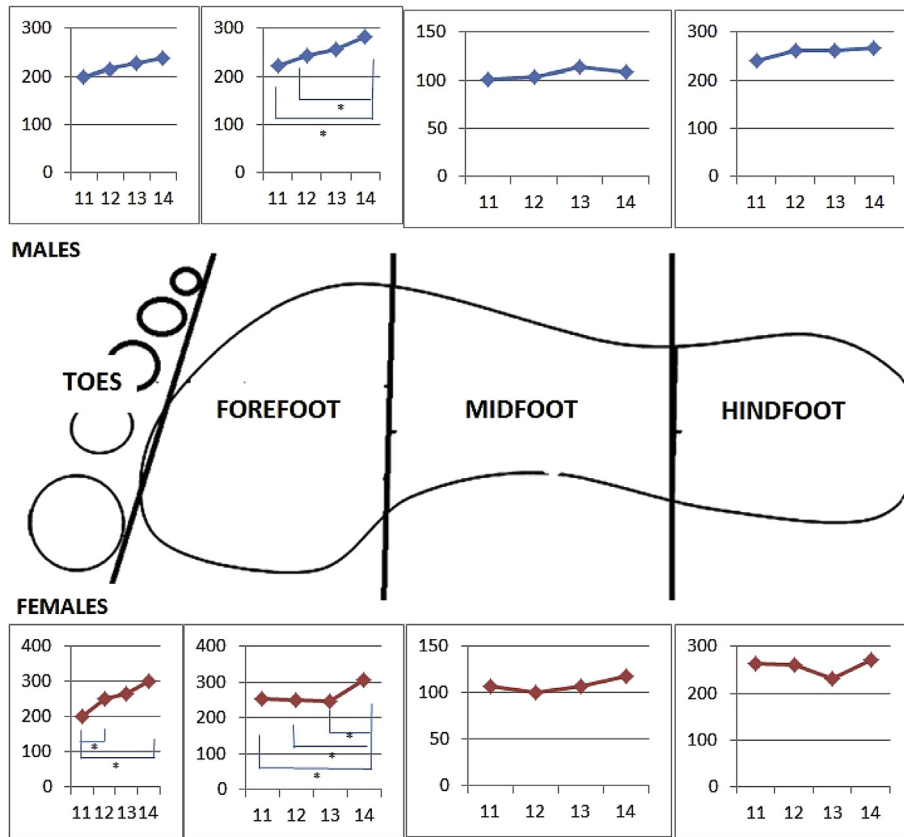


Fig. 4. Age comparison of peak pressure data of females and males separately, * $p < 0.05$ significantly higher, one way ANOVA test.

adolescence at age of 11, 12, 13 and 14 years old. Even all the evaluated subjects are at adolescent period, the age of subject should be taken into consideration during foot assessment. It is worthy to note that comparing plantar pressures of individuals at different ages regardless of gender may cause improper estimations.

The recent literature mostly focused on detailed kinematic and kinetic analyses of gait at childhood and adolescence although plantar pressure measurements at this developmental period provide valuable information about foot functions and injury risk.²⁶ Frykberg et al have indicated that high pressure values under the foot can be seen as a good indicator of potential foot damage.²⁷ An improved understanding of gender and age specific foot pressures will lead to better shoe designs that hopefully will minimize injury risk. Unfortunately similar studies performed in the late adolescence period were not found to be better interpreted of our results in the light of literature.

The reported differences in plantar pressure distribution between genders according to age are also vital for foot care of adolescents with systemic diseases such as type I diabetes mellitus. Our findings will lead to challenges in foot health approaches such as footwear modifications specific to age and gender in Foot Health Clinics. Besides, these valuable outcomes related with gender and age should be transfer into practice in foot assessment and treatment procedures by experienced clinicians.

We divided the foot into four regions by EMED automatic masking procedure which does not give information about all areas of foot especially the regions where differences were detected as forefoot divided into metatarsal heads.

As a conclusion, the results of our study demonstrated that the age of 14 years compared to earlier years, is a critical age since

alterations in plantar distribution were more apparent. Further studies can be planned with including greater range of ages between 10 and 18 years to detect development of plantar pressure patterns. The most important outcome of the present study is raising the awareness of differences between genders in plantar pressure distribution trends during gait in the early adolescence, especially at the forefoot and toes regions. We suggest that plantar pressure alterations in the region of toes according to gender and age in early adolescence may be considered a possible risk factor of foot impairments in the further ages beside other risk factors as over body weight and footwear habits by the clinicians.

Disclosure statement

None of the authors in this study have any financial and/or personal relationships with other people or organizations that could have an inappropriate impact on their work. This study was supported as a project with the number SAG-A-110412-0076 by Marmara University Commission of Scientific Research Projects (BAPKO).

References

1. Periyasamy R, Mishra A, Anand S, Ammini AC. Preliminary investigation of foot pressure distribution variation in men and women adults while standing. *Foot (Edinb)*. 2011;21(3):142–148.
2. Putti AB, Arnold GP, Abboud RJ. Foot pressure differences in men and women. *Foot Ankle Surg*. 2010;16(1):21–24.
3. Dugan SA. Sports-related knee injuries in female athletes: what gives? *Am J Phys Med Rehabil*. 2005;84(2):122–130.
4. Tong JWK, Kong PW. Association between foot type and lower extremity injuries: systematic literature review with meta-analysis. *J Orthop Sports Phys Ther*. 2013;43(10):700–714.

5. Kaufman KR, Brodine SK, Shaffer RA, Johnson CW, Cullison TR. The effect of foot structure and range of motion on musculoskeletal overuse injuries. *Am J Sport Med.* 1999;27(5):585–593.
6. Bosch K, Gerss J, Rosenbaum D. Preliminary normative values for foot loading parameters of the developing child. *Gait Posture.* 2007;26(2):238–247.
7. Bennett PJ, Duplock LR. Pressure distribution beneath the human foot. *J Am Podiatr Med Assoc.* 1993;83(12):674–678.
8. Steele DG. The estimation of sex on the basis of the talus and calcaneus. *Am J Phys Anthropol.* 1976;45(3):581–588.
9. Smith SL. Attribution of foot bones to sex and population groups. *J Forensic Sci.* 1997;42(2):186–195.
10. Kandil OD, Aboelazm SN, Mabrouk MS. Foot biometrics: gender differences in plantar pressure distribution in standing position. *Am J Biomed Eng.* 2014;4(1): 1–9.
11. Chang JH, Wang SH, Kuo CL, Shen HC, Hong YW, Lin LC. Prevalence of flexible flatfoot in Taiwanese school-aged children in relation to obesity, gender, and age. *Eur J Pediatr.* 2010;169(4):447–452.
12. Liu XC, Lyon R, Thometz JG, Curtin B, Tarima S, Tassone C. Insole-pressure distribution for normal children in different age groups. *J Pediatr Orthop.* 2011;31(6):705–709.
13. Phethean J, Nester C. The influence of body weight, body mass index and gender on plantar pressures: results of a cross-sectional study of healthy children's feet. *Gait Posture.* 2012;36(2):287–290.
14. Matthews BL, Bennell KL, McKay HA, et al. The influence of dance training on growth and maturation of young females: a mixed longitudinal study. *Ann Hum Biol.* 2006;33(3):342–356.
15. Soliman A, De Sanctis V, Elalaily R, Bedair S. Advances in pubertal growth and factors influencing it: can we increase pubertal growth? *Indian J Endocrinol Metab.* 2014;18(Suppl 1):53.
16. Lai YC, Lin HS, Pan HF, Chang WN, Hsu CJ, Renn JH. Impact of foot progression angle on the distribution of plantar pressure in normal children. *Clin Biomech.* 2014;29(2):196–200.
17. Menz HB. Two feet, or one person? Problems associated with statistical analysis of paired data in foot and ankle medicine. *Foot (Edinb).* 2004;14(1):2–5.
18. Chung MJ, Wang MJ. Gender and walking speed effects on plantar pressure distribution for adults aged 20–60 years. *Ergonomics.* 2012; 55(2):194–200.
19. Akman MN, Ersoy Y, Ari M, Sari Z, Sari A, Tanaçan S. Postural deformities of the spine and lower extremities in school children: an epidemiologic study. *J Inonu Univ Med Fac.* 2010;2(1):49–53.
20. Ugras AA, Kaya İ, Sungur İ, et al. Screening of hand and foot anomalies in schoolchildren of Fatih District, İstanbul City. *J Curr Pediatr.* 2011;9(2):60–63.
21. Bryant A, Tinley P, Singer K. Plantar pressure distribution in normal, hallux valgus and hallux limitus feet. *Foot (Edinb).* 1999;9(3):115–119.
22. Echarri JJ, Forriol F. The development in footprint morphology in 1851 Congolese children from urban and rural areas, and the relationship between this and wearing shoes. *J Pediatr Orthop B.* 2003;12(2):141–146.
23. Pfeiffer M, Kotz R, Ledl T, Hauser G, Sluga M. Prevalence of flat foot in preschool-aged children. *Pediatrics.* 2006;118(2):634–639.
24. Stavlas P, Grivas TB, Michas C, Vasiliadis E, Polyzois V. The evolution of foot morphology in children between 6 and 17 years of age: a cross-sectional study based on footprints in a Mediterranean population. *Foot Ankle Surg.* 2005;44(6):424–428.
25. Froehle AW, Nahhas RW, Sherwood RJ, Duren DL. Age-related changes in spatiotemporal characteristics of gait accompany ongoing lower limb linear growth in late childhood and early adolescence. *Gait Posture.* 2013;38(1): 14–19.
26. Alexander IJ, Chao EY, Johnson KA. The assessment of dynamic foot-to-ground contact forces and plantar pressure distribution: a review of the evolution of current techniques and clinical applications. *Foot Ankle.* 1990;11(3):152–167.
27. Frykberg RG, Lavery LA, Pham H, Harvey C, Harkless L, Veves A. Role of neuropathy and high foot pressures in diabetic foot ulceration. *Diabetes Care.* 1998;21(10):1714–1719.