

The effect of aging and gender on plantar pressure distribution during the gait in elderly

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Purpose: The effect of age on structural foot characteristics as well as on the plantar pressure distribution has been shown previously. However, the number of studies focused also on gender gait differences of elderly is lacking. The purpose of this study was to compare dynamic gait characteristic in younger and older elderly and to investigate the gender differences as the life-long load and footwear choice differ in males and females. *Methods:* 61 healthy elderly participants were divided by age and gender into four groups: males 60–69, males 70–79, females 60–69 and females 70–79 years old. Plantar pressures were recorded during barefoot walking at naturally chosen speed using Emed-at (Novel GmbH, Germany). Three steps of the left foot of each participant were used for further analysis, furthermore, hallux angle, foot progression angle, and arch index were calculated by the Emed software from obtained footprints. To compare the differences between the analyzed groups, effect size obtained by Cohen's *d* was used. *Results:* Comparing the two age male groups, higher mean pressure was found in the 70–79 age group in region MH4, MH5 and mid-foot, suggesting a greater lateral load and decreased longitudinal arch of the foot. Comparing female groups, the higher mean pressure was found in the older age group in region MH1. In all other regions, the mean pressures were reduced in the older groups. *Conclusions:* The results suggest that the effect of aging on plantar pressure distribution during the gait is affected by gender and should be considered when evaluating the gait of elderly.

Key words: elderly, gait, arch index, pressure distribution, foot progression angle, hallux angle

1. Introduction

Differences in fitness between younger and older elderly people were observed due to the reduction of muscle strength, endurance, flexibility and agility. These changes affect not only the physical capacity but also the gait, crucial in the independent performance of normal everyday activities. [12] Furthermore, neurologic gait abnormalities in elderly, e.g., unsteady gait, frontal, hemiparetic, neuropathic, ataxic or spastic gait, were found to be a significant predictor of the risk of non-Alzheimer's dementia development [21].

The effect of age on structural foot characteristics as well as on the plantar force and pressure distribution has been shown in previous studies. Aging affects also the risk of falling and adaptations strategies when walking [22], [23]. The analysis of different age groups revealed that the plantar pressure distribution pattern

is the most distinct in toddlers, smaller differences were found between adults and seniors [1]. Elderly people tend to have more pronated and flatter feet, reduced range of motion of the ankle and first metatarsophalangeal joint, higher prevalence of hallux valgus, toe deformities, weaken toe plantar flexors and reduced tactile sensitivity [18]. Additionally, in a study by Hessert et al. [6] weight bearing on the lateral side of the foot during heel contact and toe-off phases in elderly people was reported to possibly affect the stability during the gait [6].

Gender-specific differences in the foot shape and structure were also described in previous studies. Foot size, both in absolute and relative dimension, when the stature is considered, is smaller in females [4]. Also, the sexual dimorphism in bones of the foot, e.g., talus, calcaneus, metatarsals or phalanges, has been reported previously facilitating the gender identification in forensic cases [19], [20]. Furthermore, in males, contact

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area, force-time integral under the heel, 1st and 3rd metatarsal head and mean force under the 3rd metatarsal head were observed to be significantly larger compared to females [15]. Additionally, shoes have been identified as a main cause of forefoot disorders in females [24]. Also, during pregnancy increase in foot length, width and decrease in the height of the foot arch was observed [28]. Therefore, the life-long effect of different load (e.g., pregnancy) and footwear choice may result in plantar pressure, hallux angle, foot progression angle and arch index differences of elderly males and females. On the other hand, in a study by Murphy et al. [13] no significant difference between males and females in plantar pressure or normalized mid-foot contact area was found. However, the number of studies focused on gender differences in the gait of adults and elderly is limited. The purpose of this study was to compare dynamic gait characteristic in younger and older elderly and to investigate the gender differences in these two age groups.

2. Materials and methods

61 healthy elderly (21 men, 40 women) participated in this study and, according to age and gender, were divided into four groups: males 60–69, males

70–79, females 60–69 and females 70–79 years of age. The mean age [years], height [cm] and body mass [kg] of each group are shown in Table 1. Table 2 shows their foot characteristics: heel width, forefoot width and foot length [cm]. Inclusion criteria included independent walking and no musculoskeletal deformities affecting the gait.

Table 1. Participants' characteristics

	<i>n</i>	Age	Height	Body mass
Males 60–69	11	64.91 ± 2.17	178.27 ± 6.00	86.00 ± 15.53
Males 70–79	10	73.20 ± 3.12	175.60 ± 7.85	96.10 ± 10.71
Females 60–69	20	64.70 ± 3.40	167.10 ± 4.22	73.15 ± 9.82
Females 70–79	20	74.00 ± 2.83	164.10 ± 6.62	73.35 ± 13.02

Table 2. Foot characteristics of participants

	Heel Width	Forefoot width	Foot length
Males 60–69	6.17 ± 0.43	10.51 ± 0.65	28.29 ± 1.43
Males 70–79	6.51 ± 0.36	10.76 ± 0.54	28.09 ± 1.15
Females 60–69	5.92 ± 0.50	9.84 ± 0.43	25.98 ± 1.22
Females 70–79	5.61 ± 0.40	9.68 ± 0.59	25.15 ± 1.34

Plantar pressures were recorded during barefoot walking using the Emed-at (Novel GmbH, Germany), 50 × 145 cm platform mounted in a 4.5-meter long path allowing free gait. Participants were asked to walk at their naturally chosen gait speed, as the gait speed sig-

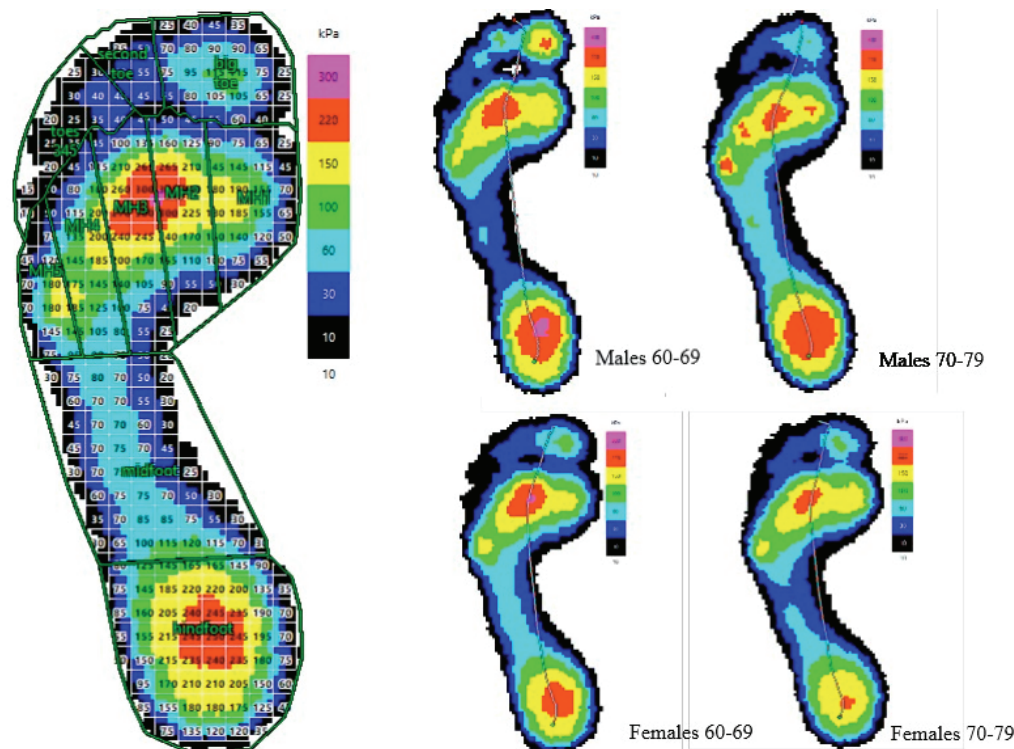


Fig. 1. Mask regions of mean pressure and an average pressure distribution picture of males 60–69, males 70–79, females 60–69, and females 70–79 groups

nificantly affect the gait pattern (e.g., Pietraszewski et al. [26]), and three trials of each participant were recorded. For further analysis, three steps of the left foot of each participant were used. Using the Emed-at software, the foot was divided into 10 regions: toe 1, 2, lesser toes, first, second, third, fourth and fifth metatarsal heads, mid-foot and heel, shown in Figure 1 together with the mean pressure distribution picture of each group. Associated variables (hallux angle, foot progression angle and arch index) were calculated subsequently by the Emed software from the obtained foot prints. Informed consent was provided by all participants prior to the data collection session. The study was approved by the local Ethical board.

Statistical analysis

To compare the differences between groups, effect size obtained by Cohen’s *d* was used. Cohen’s *d* is interpreted as ≥ 0.20 small, ≥ 0.50 medium, or clinically significant, ≥ 0.80 large effect [2].

3. Results

Table 3 and 4 shows means and standard deviations of analyzed variables for the four groups. Tables 5 and 6 show results of Cohen’s *d*.

Effect of age

The results show significant changes by effect size in plantar pressure in all foot regions, except for the heel in males and MH5 in females.

In males, the higher mean pressure was found at 70–79 age group, compared to the younger group in region MH4, MH5 and mid-foot. Similarly, the effect size analysis of arch index, which provides information about the longitudinal arch of the foot (*pes cavus* (<0.21), normal foot ($0.21–0.27$), *pes planus* (>0.27)), showed significant foot flattening with age in males. Hallux angle was observed to be significantly higher in the male 70–79 group, compared to the younger group.

In females, the higher mean pressure was found at 70–79 age group, compared to the younger group in region MH1. In all other regions, the mean pressures were reduced despite the similar body mass in both female groups. For hallux angle, no significant difference between the 60–69 and 70–79 female age groups was observed. Foot progression angle increased significantly with age in the female group. The arch index was observed to be significantly lower in the older female group.

Effect of gender

Hallux valgus prevalence increases with age, observed by increased hallux angle in the male 70–79

Table 3. Means and standard deviations (SD) of the mean pressure of analyzed foot regions

		Mean pressure									
		Toe 1	Toe 2	Toes 3&4	MH1	MH2	MH3	MH4	MH5	Midfoot	Heel
Males 60–69	Mean	109.45	62.56	44.70	111.48	145.94	142.21	118.31	90.45	49.56	160.06
	SD	46.71	23.38	22.81	33.19	28.62	35.13	31.22	35.61	20.99	23.84
Males 70–79	Mean	68.71	39.71	29.74	103.26	133.04	130.65	127.42	116.83	70.39	157.93
	SD	28.47	13.69	15.45	33.71	34.78	19.31	36.44	35.84	13.27	18.49
Females 60–69	Mean	81.38	53.55	42.27	101.88	160.71	156.10	122.08	99.23	66.03	147.71
	SD	23.44	24.66	20.75	34.81	43.88	30.32	34.30	46.74	26.03	22.87
Females 70–79	Mean	71.01	41.39	33.37	125.62	136.96	137.90	106.79	90.95	54.03	130.37
	SD	36.44	19.25	15.40	50.52	39.22	35.93	28.90	47.09	22.81	17.64

Table 4. Means and standard deviations (SD) of analyzed variables

		Hallux angle	Foot progression angle	Arch index
Males 60–69	Mean	3.42	9.82	0.21
	SD	8.77	5.68	0.08
Males 70–79	Mean	8.88	10.57	0.27
	SD	5.01	7.97	0.03
Females 60–69	Mean	9.57	7.78	0.25
	SD	7.31	5.20	0.05
Females 70–79	Mean	9.83	11.62	0.23
	SD	12.41	6.07	0.07

group in this study. Comparing the younger male and female group, significantly higher hallux angle was observed in females. In the older groups, no significant difference between males and females was found. On the other hand, foot progression angle increased significantly with age in the female group. Therefore, the gender differences in foot progression angle were observed between the younger elderly only. Gender differences in the arch index were observed in both age groups. The results indicate that greater gender differences may be observed in the younger elderly

Table 5. Results of Cohen's *d* and confidence intervals (CI) of mean pressures in analyzed foot regions

		Males 60–69 × males 70–79	Females 60–69 × females 70–79
Toe 1	Cohen's <i>d</i>	1.07	0.35
	CI	–26.53; 18.72	–9.93; 16.32
Toe 2	Cohen's <i>d</i>	1.22	0.55
	CI	–12.60; 9.70	–10.25; 8.99
Toe 345	Cohen's <i>d</i>	0.77	0.49
	CI	–12.71; 10.35	–8.60; 7.24
MH1	Cohen's <i>d</i>	0.25	–0.56
	CI	–19.37; 21.14	–15.81; 21.58
MH2	Cohen's <i>d</i>	0.41	0.57
	CI	–16.50; 21.97	–18.66; 17.76
MH3	Cohen's <i>d</i>	0.42	0.55
	CI	–20.34; 12.39	–12.74; 16.30
MH4	Cohen's <i>d</i>	–0.27	0.48
	CI	–18.72; 22.31	–14.55; 13.15
MH5	Cohen's <i>d</i>	–0.74	0.18
	CI	–21.78; 21.47	–20.31; 20.81
Midfoot	Cohen's <i>d</i>	–1.20	0.49
	CI	–13.61; 7.02	–10.92; 10.49
Heel	Cohen's <i>d</i>	0.10	0.86
	CI	–13.99; 11.56	–9.17; 8.59

Table 6. Results of Cohen's *d* and confidence intervals (CI) of hallux angle, foot progression angle and arch index

	Hallux angle		Foot progression angle		Arch index	
	Cohen's <i>d</i>	CI	Cohen's <i>d</i>	CI	Cohen's <i>d</i>	CI
Males 60–69 × males 70–79	–0.78	–5.96; 2.32	–0.11	–3.47; 4.83	–1.07	–1.11; –1.05
Females 60–69 × females 70–79	–0.03	–3.23; 5.41	–0.68	–2.96; 1.98	0.33	0.31; 0.36
Males 60–69 × females 60–69	–0.79	–5.97; 2.42	0.38	–2.98; 2.66	–0.66	–0.71; –0.64
Males 70–79 × females 70–79	–0.09	–3.20; 5.34	–0.16	–5.10; 2.50	–0.27	–0.32; –0.24

(hallux angle, foot progression angle, and arch index), as in the older group the effect of gender was observed only in the arch index.

4. Discussion

To compare the dynamic gait characteristic in younger (60–69 years of age) and older (70–79 years of age) elderly, and to investigate the possible gender differences in these two age groups, 61 healthy elderly (21 men, 40 women) participated in this study.

Effect of age

In general, the effect of age was observed by decreased mean plantar pressures in this study. However, in males, higher mean pressure was observed in the older age group (70–79), compared to 60–69 age group in region MH4, MH5 and mid-foot, suggesting a greater weight-bearing by the lateral side of the

foot and decreased longitudinal arch of the foot, both also reported in previous studies [6], [18]. In females, higher mean pressure was found in the 70–79 age group, compared to 60–69 age group in region MH1. A similar finding was observed in a study by Menz and Morris [10], where higher loading of MH1 was associated with a reduced range of motion of 1st metatarsal-phalangeal joint (MPJ). In all other regions, the mean pressures were reduced in the older age group despite the similar body mass in both female age groups. A similar finding, i.e., reduced force and pressures under the heel, lateral forefoot and hallux was observed in healthy older people (approximately 68 years old) by Scott et al. [18] and explained mainly by the reduced step length and different foot characteristics in their older age group of elderly.

Foot progression angle increased significantly with age in the female group. In previous study by Rosenbaum [17], out-toeing was observed to increase the load on the medial aspect of the mid-foot and forefoot,

observed in this group by increased plantar pressures in MH1 region. In contrast to findings of this study, no significant difference in foot progression angle between young and old adults was observed in a previous study where both males and females were observed [8]. The increased foot progression angle may result from external rotation of the hip, femoral or tibial torsion [7].

Hallux valgus may contribute to the instability and risk of falling [9], [1]. Its prevalence increases with age, as observed by increased hallux angle in the male 70–79 group in this study. No significant difference in hallux angle in younger and older female age groups was observed.

The arch index provides information about the foot longitudinal arch development. Effect size analysis of this index shows significant foot flattening with age in males. On the other hand, in females, the higher arch index was observed in the younger group.

Effect of gender

In our study, greater gender differences were observed in the younger group of elderly (hallux angle, foot progression angle, and arch index). In the older group, the effect of gender was observed only in the arch index. As mentioned above, gender differences in the hallux angle were observed only in the younger age groups, as with age the angle increased in males, which is in accordance with the previous studies reporting the magnitude of hallux angle to be associated with the female gender and age [3], [5], [14]. Females are at special risk, as wearing high heel shoes increase the risk of hallux valgus development and other deleterious effect, e.g., chronic paraspinal muscles fatigue associated with the posture alterations and pain [25], [27]. Gender differences in foot progression angle were also observed in the younger age groups, as it increased significantly with age in females. Similar observation of gender difference in foot progression angle was reported previously in a study by Røislien et al. [16], who found the angle more internally rotated in females and more externally rotated in males. Gender differences in the foot arch index were observed in both age groups. However, no clear trend for this variable was observed.

Limitations of this study consist mainly of a relatively small number of participants making the generalization of our findings difficult. In future studies, a large number of elderly participants divided into more precise age groups and the analysis of differences between left and right foot will bring more detailed insight into the effect of aging and gender on gait.

5. Conclusion

The dynamic gait characteristic in younger (60–69 years of age) and older (70–79 years of age) male and female elderly were compared. In males 70–79 of age, greater mean pressure in the region MH4, MH5 and mid-foot observed suggests a greater weight-bearing by the lateral side of the foot and decreased longitudinal arch of the foot. In females, the higher mean pressure was found in a 70–79 age group in region MH1, probably associated with reduced first MPJ range of motion and with greater foot progression angle. These findings suggest that the effect of aging on plantar pressure distribution during the gait is affected by gender and should be considered by health care professionals when caring after the elderly.

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