Podometric Assessment of Gait Parameters

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Abstract: This pilot study is aimed to compare the gait parameters of two healthy subjects when wearing barefoot shoes and classic shoes, using a pedogait device. The study was conducted in a laboratory setting, and each participant performed three walking trials (barefoot, barefoot shoes, and classic shoes). The pedogait device recorded various gait parameters, including gait line, foot pressure, step length, and gait speed. Results showed that when wearing classic shoes, participant that is not barefoot user had a significantly shortened support phase of the step, and the maximum forces at the initial contact of the heel and the rebound from the toe increased compared to barefoot. These preliminary findings suggest that barefoot shoes may alter walking parameters compared to normal shoes and it is necessary to emphasize the correct walking technique since there is no compensatory cushioning in the shoe itself. However, the small sample size of this pilot study limits the generalizability of the results, and further research with larger sample sizes and more diverse populations is needed to confirm these findings.

Keywords: Barefoot shoes; Gait analysis; Gate line

1 Introduction

The first interface between the body and the ground during the human gait are shoes. Their primary purpose is mainly ensuring to protect the feet against thermal, chemical, or mechanical influences and possible injuries [1]. During one step, the human foot is transformed from a flexible shock absorber, which occurs when the heel strikes, to a rigid lever, which occurs when stepping forward. The foot is defined as a structure formed by transverse and longitudinal arches. During the stance phase of the gait cycle, the human foot is an elastic and arched structure that actively works to maintain body stability through small mediolateral and anteroposterior movements [2]. Footwear significantly affects the distribution of pressure on the foot, which is often associated with changes in upright posture. Shoes also significantly affect postural and dynamic stability, it degrades somatosensory feedback to the foot through the tactile proprioceptive system, because of the design elements of the footwear itself [3]. The aim of the presented work is to compare and evaluate the gait lines recorded during the measurements on the sensory treadmill. The DIERS 4D Lab Motion - Pedogait device was used for the individual measurements. Two subjects took part in the podometric assessment, one of them is a user of barefoot shoes and the other wears classic shoes. The parameters such as: gait line, average pressure, and basic walking parameters such as: step length, step width, speed, cadence, and foot rotation were evaluated.

2 Materials and methods

During the pilot study aimed at assessing the biomechanical parameters of gait, the following methodology was determined, and the described equipment was used. Two female participants were measured. The subjects were familiarized with the entire measurement procedure, they filled in and confirmed the informed consent and a brief questionnaire before the measurement. The measurement was non-contact, painless and safe and took a few

minutes. The participants were measured barefoot, in classic and barefoot shoes, between individual measurements there were breaks to avoid the fatigue effect. During the adaptation to walking on the surface of the sensory treadmill, the gait velocity gradually increased to the standard 4.5 km/h. Each measurement lasted 5 minutes, while a time of 20 seconds was recorded, representing a path of 25 meters.

The first measured participant was a 22-year-old woman with a weight of 59 kg and a height of 162 cm. The number of shoes used during the measurement was 36. Classic footwear was sport shoes with a sole thickness of 3 cm (Fig. 1a), and barefoot footwear was characterized by a wider and rounded shape of the front part of the shoe with a sole thickness of 0.6 cm (Fig. 1b). Subject 1 is not a user of barefoot shoes; in this study, it is her first contact with this type of shoes.

The second measured participant was a 42-year-old woman with a height of 169 cm and a weight of 61 kg. The number of shoes used when measuring the subject was 40. Classic footwear was sport shoes with a sole thickness of 3 cm, and a higher slope of the toe (Fig. 1c), and barefoot footwear was characterized by an elongated shape of the front part of the shoe, which provides enough space for the toes, but is not of a particularly wide type with a sole thickness of 0.65 cm (Fig. 1d). Subject 2 common uses barefoot shoes during her daily life.

Fig. 1 Classic (a) and barefoot (b) shoes of the first subject. Classic (c) and barefoot (d) shoes of the second subject.

The measurement was carried out in cooperation with MUDr. Ján Sekáč in the Orthopedic Clinic and Movement Laboratory with the DIERS pedogait system (DIERS International GmbH, Germany) allows the functional representation of the foot pressure reaction forces while walking. The integrated measuring platform is 1.0 m long with 5.376 sensors for an exact capture of the pressure values. The admission frequency amounts to 100 Hz The standing treadmill can be used for static measurements of the foot pressure measurement as well as for the stabilometry.

2.1 Measured and analyzed biomechanical parameters of the gait

One of the main parameters evaluated during the dynamic test is the level and distribution of plantar pressure. Average and maximum pressure are mostly evaluated. In the graphical display, the pressure values are displayed as a line of points of the maximum load that was recorded during the dynamic analysis. The curve of this graph should rise for normal values in the middle part and slightly decrease at the end of the graph. The curve of the graph of the average value of the pressure shows the line of the average pressure recorded.

Another important parameter is impulse force over time. It can be expressed as the area under the pressure versus time curve. The greater the pressure and the longer it acts, the greater the impulse, so it is the total load.

An important aspect of plantar pressure measurement is the centre of pressure line. The physiological gait line should start in the rear third of the foot, continue towards the 5th metatarsal, then proceed centrally to the 4th metatarsal, then the 3rd to 2nd metatarsal, and end at the big toe, as it is the last in contact with a ground. This movement represents a shift in about 83% of the length and 18% of the width of the contact surface of the foot in middle-aged adults. Pressure line velocity is also an important indicator, which should be approximately 22-27 cm/s and 38 cm/s for middle-aged adults and young adults [4].

3 Results

The evaluated parameters are the distribution of plantar pressures, the course and length of the gait lines, the maximum pressures during contact of the heel with the mat and the toe off, mediolateral deviations of the centre of gravity, the percentage of the individual phases of the gait cycle, the step parameter (length, width, foot rotation, cadence) and also the total force of segment [N] in time on individual foot areas. Tables 1 and 2 represent evaluated biomechanical parameters of gait for different types of shoes and bare feet of subject 1 (Table 1) and subject 2 (Table 2).

Table 1. Biomechanical parameters of gait for subject 1.

Step parameters	Classic shoes		Barefoot shoes		Bare feet		Standard
	R	L	R	L	R	L	
Step length [cm]	64+/-1	63+/-2	64+/-1	63+/-2	63+/-21	62+/-2	
Step time [ms]	514+/-2	499+/-2	511+/-2	495+/-2	503+/-24	486+/-2	
Stride length [cm]	127+/-6		126+/-6		124+/-6		141
Stride time [ms]	1013		1005		990		1200
Track width [cm]	12+/-1		12+/-1		9+/-2		10
Foot rotation [°]	7	2	4	2	4	10	10-15
Cadence [step/min]	114		114		117		113

Table 2. Biomechanical parameters of gait for subject 2.

Step parameters	Classic shoes		Barefoot shoes		Bare feet		Standard
	R	L	R	L	R	L	
Step length [cm]	66+/-2	64+/-2	64+/-1	63+/-2	62+/-2	62+/-1	
Step time [ms]	512+/-2	518+/-2	504+/-1	512+/-2	498+/-3	496+/-2	
Stride length [cm]	129+/-6		127+/-6		124+/-6		141
Stride time [ms]	1029		1016		994		1200
Track width [cm]	8+/-1		8+/-1		9+/-1		10
Foot rotation [°]	3	5	3	7	4	8	10-15
Cadence [step/min]	114		114		117		113

The pressure distribution of subject 1 (Fig. 2) on individual feet is uneven in classic and barefoot shoes, in the case of barefoot, the pressure is adequately distributed, and subject 1

loads the foot equally on the heel and in the forefoot. In none of the measurements was pressure exerted over the 5th metatarsal, which also captures the shape of the rolling curve, which is flat (i.e. straight). In classic shoes, can be observed that the gait line did not go through 5., 4., 3. nor the 2nd metatarsal. It's beginning was not in a third of the heel, and the line of pressure went directly to the toe, which was the most loaded. The pressure was exerted through the centre of the foot and not through the individual metatarsals.

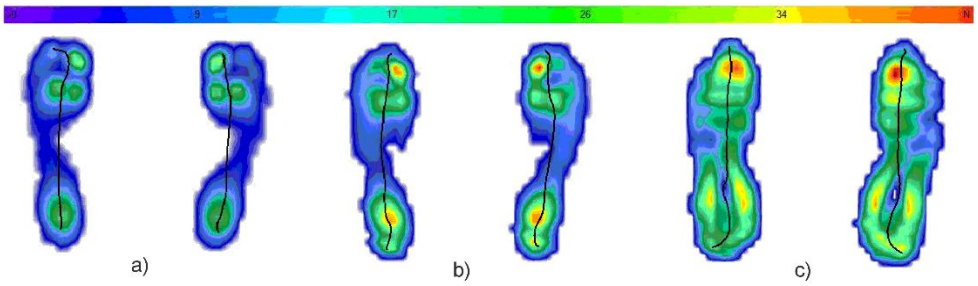

Fig. 2 Graphical representation of the average pressure distribution and gait line in subject 1: a) bare foot vs. mat, b) barefoot shoes vs mat, c) classic shoes vs mat.

On all prints of subject 2 (Fig. 3), the pressure lines are also unevenly distributed. In barefoot shoes, the medial part of the forefoot was the most loaded. The gait line was flat, i.e. straight throughout its entire course in barefoot shoes on the left foot. Barefoot was also the most loaded forefoot in the medial part. The most deformed gait line can be seen in classic footwear. Its beginning is not in a third of the heel and does not gradually pass through the metatarsals. In this case, the forefoot and the area of the toes, i.e. the thumb in particular, are more stressed. The pressure is not exerted through the metatarsals but through the middle of the foot and the roll curve ends at the 2nd metatarsal.

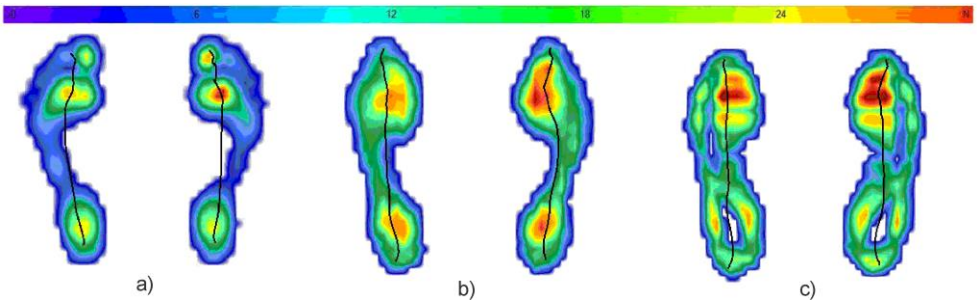

Fig. 3 Graphical representation of the average pressure distribution and gait line in subject 2: a) bare foot vs. mat, b) barefoot shoes vs mat, c) classic shoes vs mat.

The maximum forces at the heel strike of subject 1 were lower in each of the measurements than at the toe-off phase and their values ranged from 437-528 N (Fig. 4). The maximum forces at the toe-off phase were higher than at the heel strike in each of the measurements. Their values ranged from 530-592 N (Fig. 5). The biggest difference between impact and reflection was captured barefoot on the right foot. The smallest values were measured barefoot shoes and barefoot. The measured values of the maximum forces of subject 1 are shown in the Table 3.

Table 3. Maximum forces during heel strike and toe-off gait phase for subject 1.

Maximum forces	Classic shoes		Barefoot shoes		Bare feet	
	L	R	L	R	L	R
Heel strike [N]	528	470	486	485	480	437
Toe off [N]	530	531	570	530	592	540

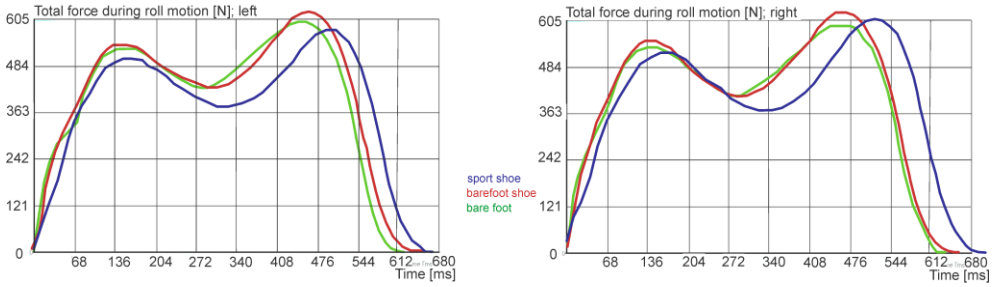

Fig. 4 Force-time diagram subject 1: a) left foot, b) right foot; the blue curve represents classic shoes, the red curve represents barefoot shoes and the green curve represents bare feet.

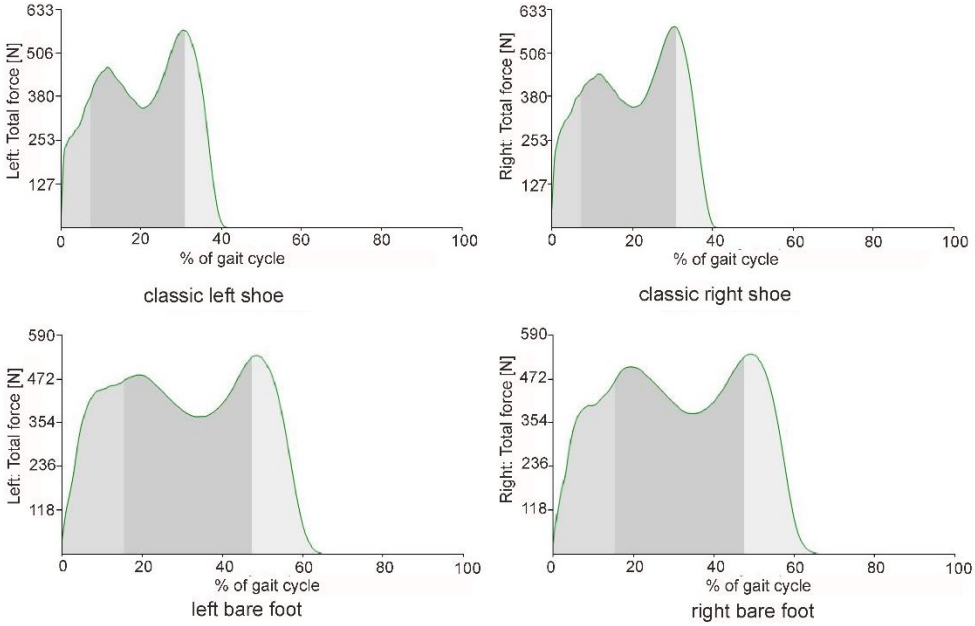

Fig. 5 Total force diagram - subject 1.

The maximum forces of subject 2 at heel strike were lower in each of the measurements and their values ranged from 506-565 N (Fig. 6). The maximum forces at the toe-off phase were higher than at impact in each of the measurements. Their values ranged from 588-630 N (Fig.7). The biggest difference between impact and reflection was in barefoot on the left foot. The smallest values were measured barefoot. We did not notice significant differences between the shoes. The measured values of the maximum forces of subject 2 are shown in the Table 4.

Table 4. Maximum forces during heel strike and toe-off gait phase for subject 2.

Maximum forces	Classic shoes		Barefoot shoes		Bare feet	
	L	R	L	R	L	R
Heel strike [N]	530	513	565	515	510	506
Toe off [N]	620	612	615	630	600	588

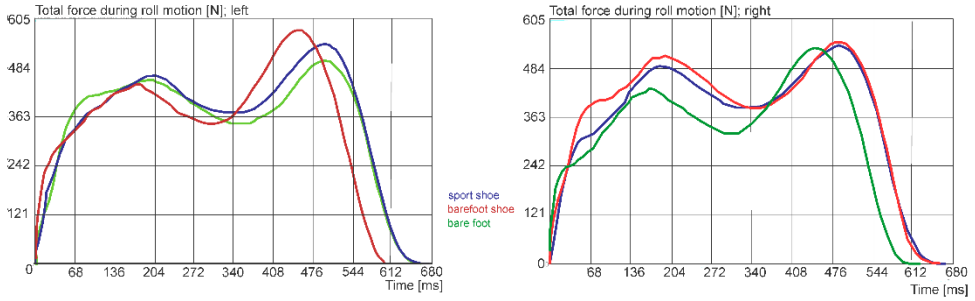

Fig. 6 Force-time diagram subject 2: a) left foot, b) right foot; the blue curve represents classic shoes, the red curve represents barefoot shoes and the green curve represents bare feet.

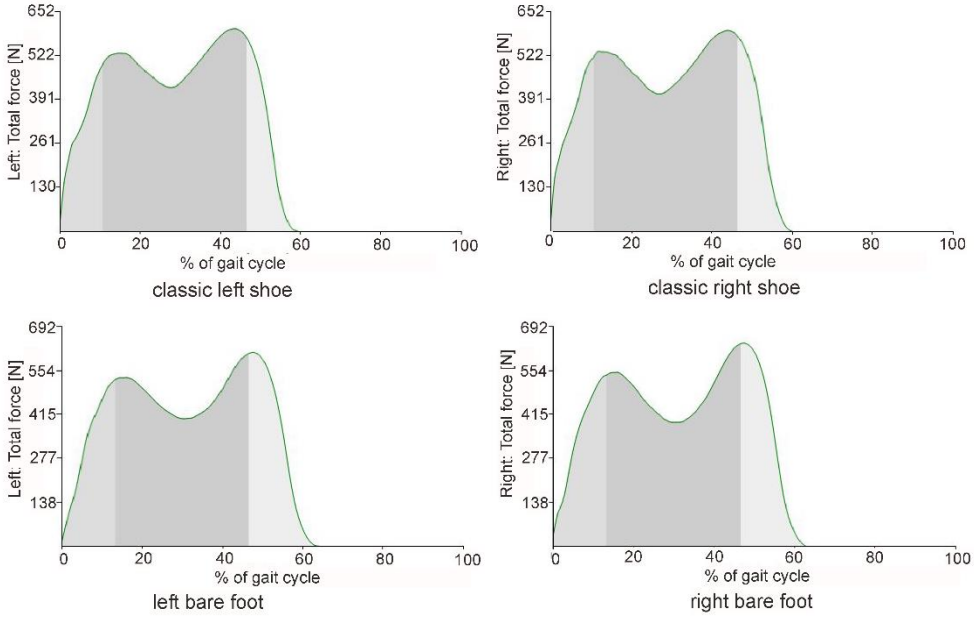

Fig. 7 Total force diagram - subject 2.

The length of the gait line of subject 1 (Fig. 8a) varied between 14.8-17.3 cm during the measurements. Significant differences were not captured between individual measurements. In the total length of the gait line, we noticed a significant difference between classic shoes and bare feet, and that's on the left foot.

Table 5. Gait line length and mediolateral deviations of COG for subject 1.

Shoe type	Classic shoes		Barefoot shoes		Bare feet	
	L	R	L	R	L	R
Length of gait line in midstance phase	16+/-4,2	15.6+/-1,2	17.3+/-1,1	14.8+/-4	16.3+/-1	15.8+/-3.9
Total length of gait line	26.4+/-6.6	27.5+/-0.2	25.4+/-0.2	23.5+/-5.9	21.6+/-0.3	20.6+/-5
Mediolateral deviations of COG	6.9+/-1.3	7.3+/-0.9	7.3+/-1.2	6.0+/-1.2	7.1+/-1.7	6.4+/-1.3

The length of the gait line of subject 2 (Fig. 8b) varied between 17.3-19.3 cm during the measurements. Significant differences between individual measurements were not captured. In the total length of the gait line, we detected slight differences between the classic and barefoot, and the significant difference was in the right foot. During the measurement, individual fluctuations of the centre of gravity were recorded, which are related to the course of the gait line.

Table 6. Gait line length and mediolateral deviations of COG for subject 2.

Shoe type	Classic shoes		Barefoot shoes		Bare feet	
	L	R	L	R	L	R
Length of gait line in midstance phase	19.3+/-0.8	17+/-4.4	17.4+/-4.4	18.2+/-0.5	17.3+/-4.2	18+/-0.4
Total length of gait line	28.9+/-0.4	27.5+/-6.9	25.5+/-6.4	27+/-0.3	22.1+/-5.4	23.1+/-0.4
Mediolateral deviations of COG	3.1+/-1.8	5.5+/-1.5	4.3+/-1.0	3.8+/-1.4	5.1+/-1.1	3.4+/-1.3

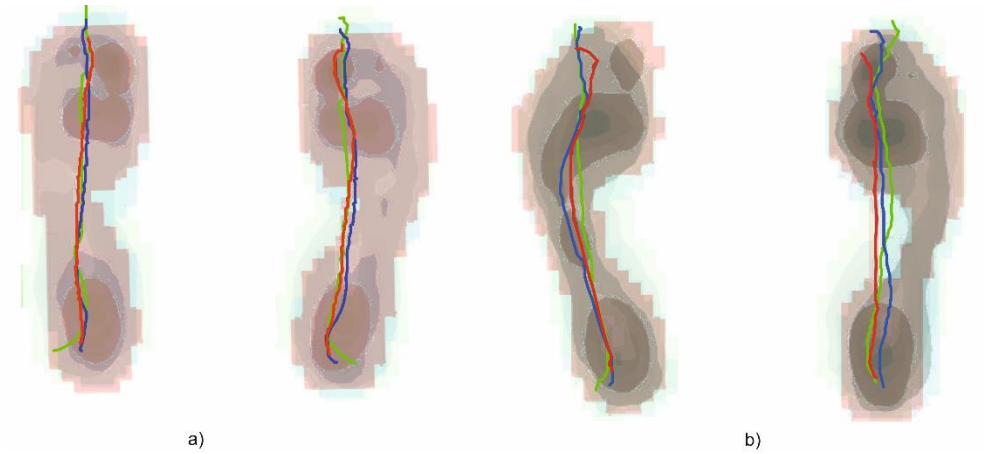

Fig. 8 Gait line during gait cycle: a) subject 1, b) subject 2, the blue curve represents classic shoes, the red curve represents barefoot shoes, and the green curve represents bare feet.

Conclusion

Significant differences in the movement pattern were observed in subject 1, who is not a regular user of barefoot footwear. The difference between barefoot shoes and bare feet walking was minimal, but significantly different from classic footwear. In classic shoes, the support phase of the step has been significantly shortened and the maximum forces at the

initial contact of the heel and the rebound from the toe have increased. This may be due to the subject relying on the cushioning ability of the sole. When walking barefoot and walking in barefoot shoes, the subject focused more on the initial contact of the heel, which increased its duration and also reduced the forces acting in this phase. Since subject 2 is a regular barefoot shoes user, the walking pattern differed minimally.

The presented work is a pilot study from which the following hypotheses result, which need to be subsequently verified. In further studies, it would therefore be appropriate to verify different movement patterns in individual types of footwear, especially in subjects who are not regular users of barefoot footwear. Step time decreases significantly during barefoot walking in both measurement cases. In classic shoes, the impact on the heel is lower than in barefoot or bare feet. When walking bare feet, the length of the gait line is shortened. As it results from the biomechanics of gait, the area of the heel during contact with the mat and the toes during the toes off phase were the most heavily loaded. These values were mitigated by the influence of a thicker sole in classic shoes. Classic shoes also ensured a more optimal distribution of pressure in the area of the metatarsals. From the results, it can be concluded that when walking barefoot or in barefoot shoes, it is necessary to emphasize the correct walking technique, since there is no compensatory cushioning in the shoe itself.

Acknowledgements

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