

# Reference values of spatiotemporal parameters, joint angles, ground reaction forces, and plantar pressure distribution during normal gait in young women

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*Purpose:* The aim of this study was to establish the reference values of spatiotemporal parameters, joint angles, ground reaction forces and plantar pressure distribution collected simultaneously on the same measurement path during normal gait in a homogenous group of young, healthy women. *Methods:* The studied group consisted of 28 healthy women aged 21 years on average. The motion capture system BTS Smart-D, 2 AMTI force platforms and Footscan pedobarographic platform were used in this research. The 14-metre measurement path and the 6-metre distance that examined women had to walk through before entering the measurement area ensured that a natural gait pattern was recorded. Statistical analysis was performed to evaluate differences between right and left lower extremities. *Results:* The applied method enabled collecting several parameters regarding normal female gait biomechanics such as: spatiotemporal parameters, angle-time characteristics as well as range of motion of pelvis, hip, knee and ankle joints in gait cycle, force-time characteristics and peaks of ground reaction force components in stance phase, peak pressure and time of loading of defined foot regions in stance phase. *Conclusions:* The results may be used by clinicians, physiotherapists or researchers as a reference in diagnosing gait disorders or evaluating patient's walking pattern. In recent literature there are some disparities in gait parameters reference values even regarding similar research groups. These differences may arise from distinct method, slower or faster gait, other laboratory environment etc. This should be considered and more than one source of normative values should be checked when searching for reference data.

*Key words:* women, kinematics, ground reaction forces, gait biomechanics, pedobarography, reference data

## 1. Introduction

Human gait consists of repetitive cycles involving alternate movements of the basic body segments [21], [29]. During walking all parts of the motor system constitute a connected kinematic chain with the soles of the feet contacting with the ground. Spatiotemporal parameters [3], [12], [16], [19], [22], kinematics of pelvis and lower extremities (LEs) [3], [16], [20], [22], ground reaction forces (GRFs) [3], [15], [28] as well as

plantar pressure distribution (PPD) [4], [7], [23], [24] during adults' gait are widely discussed in recent literature. As they regard to different sex, age groups and conditions, reference values of gait parameters for female and male groups in specified age intervals are essential for comparison. Moreover, due to various systems and protocols implemented in different gait laboratories [18] there is a need for constant supplementations and updates on normative data.

Previous studies evaluated spatiotemporal as well as kinematic and dynamic parameters during gait in

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healthy adult persons. Öberg et al. [19], [20] studied gait of 233 subjects (117 female and 116 male) varied in age (10–79 years old). They presented reference values for basic spatiotemporal parameters [19] as well as joint angles [20] for each sex, different age groups and three gait speeds. Their gait analysis method consisted of two photocells, self-aligning electrogoniometers and PC. Normative spatiotemporal gait parameters for each sex were also collected by Hollman et al. [12] with the use of the electronic walkway GAITRite<sup>®</sup> for a group of 294 healthy elderly (186 women and 108 men) aged 70–89. Other team, Kaczmarczyk et al. [14] studied spatiotemporal parameters during normal gait in 30 females aged 21–31, using the electronic walkway Zebris. They used the results as a contrast for a group of 76 elderly women.

Bovi et al. [3] collected reference data for several gait parameters of healthy adults (11 females and 9 males aged 22–72) and younger subjects (11 females and 9 males aged 6–17), although, they did not separate results for each sex. They used 9-cameras BTS Smart-E motion capture system with total-body LAMB (Laboratory for the Analysis of Movement in Children) protocol to measure kinematic parameters and two Kistler force plates for GRFs measurement. Additionally they registered electromyography signals from selected LEs muscles. In turn, Pietraszewski et al. [22] presented normative values for healthy men (17 subjects at the age of  $22.0 \pm 1.0$  years) gait pattern, including spatiotemporal gait parameters, angle-time characteristics as well as range of motion (ROM) in gait cycle (GC) for the pelvis and LEs joints for three different gait speeds. They used 6-cameras BTS Smart-E motion capture system with modified Helen Hayes-Davis protocol. On the other hand, Kerrigan et al. [16] searched for gender effect on spatiotemporal parameters, sagittal plane kinematics and dynamics of the LEs joints during normal gait. They studied gait of 99 young adults (including 49 females) aged 20–39 using 4-cameras BTS ELITE motion capture system with SAFLo (Servizio di Analisi della Funzione Locomotoria) protocol for pelvis and LEs and two AMTI force platforms.

Some authors focused only on GRFs determination during gait. For example, Winiarski and Rutkowska-Kucharska [28] measured vertical component of GRF (vGRF) on Kistler force plate and by calculating it from kinematics of the center of gravity using Simi Reality Motion System with 18 markers placed on subjects' bodies, according to Clauser model. They evaluated vGRF in normal walking separately for groups of 21 females and 23 males at the age of  $21.5 \pm 2.9$  and

$22.1 \pm 3.2$  years, respectively. They implemented the results as a reference for ACL-reconstructed patients. The same parameter was collected by Keller et al. [15] in a group of 10 females and 13 males aged  $28.4 \pm 5.4$  and  $25.2 \pm 4.3$ , respectively, also independently for each sex. They used AMTI force platform to collect vGRF values in different speeds from walking through jogging to running. In turn, Kaczmarczyk et al. [13] studied vertical and anterior-posterior components of GRF using two Kistler platforms in groups of 60 healthy females ( $23.5 \pm 1.8$  years old) and 60 healthy males ( $23.1 \pm 1.8$  years old). They analyzed the symmetry index of each GRF component peak values in stance phase in normal walking for both sexes independently.

Other authors assessed PPD during gait. For instance, Putti et al. [24] used pedobarographic platform Emed<sup>®</sup> ST4 to establish normal pressure values under defined 10 regions of the foot in a group of 53 healthy persons of both sexes (17 female and 36 male, aged 19–52). Also Prochazkova et al. [23] examined PPD, but in a group of 13 sportive persons (including 8 women) at the age of  $26.1 \pm 5.3$  years and using Footscan platform. They analyzed pressure values under 10 areas of the foot during normal walking of females and males together and compare them with the results of professional dancers group. The same pedobarographic system was used by Chiu et al. [4] to examine 30 subjects (15 women and 15 men) at the age of  $23.6 \pm 2.7$  years. They recorded and analyzed several parameters that characterize center of pressure (COP) progression line in four different gait speeds independently for females and males. In turn, Fernández-Seguín et al. [7], who also used Footscan platform, measured PPD in 34 healthy subjects with a mean age of  $24.21 \pm 5.18$  years, however, they did not specified participants' sex. They used the results as a reference for persons with cavus foot.

Based on the above-described literature review most of the studies that include normative data are aimed at only one group of parameters, e.g., kinematics, GRFs or pedobarography. Moreover, some of studies cited above concern subjects of both sexes with no division on female and male group. There is lack of comprehensive set of normative data for young women' normal walking, including representative kinematic and dynamic parameters taken during one measurement session. Therefore, the aim of this study was to establish the reference values of: spatiotemporal parameters, joint angles, GRFs and PPD collected simultaneously on the same measurement path during normal gait in a homogenous group of young, healthy women.

## 2. Materials and methods

### 2.1. Research material

28 female students of different universities participated in the study. Group characteristics are presented in Table 1.

Table 1. Characteristics of studied group (mean value  $\pm$  SD)

Age [years]	21.1 $\pm$ 1.3
Body height [m]	1.67 $\pm$ 0.07
Body mass [kg]	57.1 $\pm$ 6.8
BMI [kg/m <sup>2</sup> ]	20.33 $\pm$ 1.41

\*SD – standard deviation.

All women were healthy, had no history of orthopedic or neurological diseases and were physically active at least at moderate level, according to International Physical Activity Questionnaire [9]. This project was approved by local ethics committee and all subjects gave informed consent to participate in this study.

### 2.2. Methods

To collect data on joint angles and GRFs values, optoelectronic motion capture system BTS Smart-D (BTS Bioengineering, Milan, Italy) synchronized with two AMTI force platforms type BP400600 (AMTI, Massachusetts, USA) flushed with the floor working at a sampling rate 800 Hz was used. The motion was recorded by 8 digital infrared cameras with recording frequency of 200 Hz. The total of 19 reflective markers (diameter: 20 mm) were stuck with double-sided adhesive tape on specific anatomic landmarks, according to Vaughan-Davis model [6], [26]. The spots of interest were as follows: sacrum between posterior superior iliac spines as well as right and left anterior superior iliac spines (ASISs), femoral greater trochanter, marker on the bar on the lateral side of the thigh, femoral lateral epicondyle, head of fibula, marker on the bar on the lateral side of the lower leg, lateral malleolus, calcaneus, head of the fifth metatarsal. The same investigator was responsible for markers attachment in every subject. Software used for kinematic and GRFs data collection was BTS Smart Capture, for markers tracking – BTS Smart Tracker and for data analysis – BTS Smart Analyzer.

PPD was measured with a 2-metre Footscan platform (RSscan International, Olen, Belgium) set at 126 Hz sampling frequency and Footscan 7 gait software. The obtained plantar images were divided into 10 regions: big toe (T1), toes 2–5 (T2–5), metatarsals 1–5 (M1–M5), midfoot (MF), lateral area of the heel (LH), medial area of the heel (MH). Footscan platform was 0.5 cm high, therefore, the foam chock was placed on the front edge of the platform, providing comfort and safety. To eliminate the height difference, behind the Footscan a foam mat 2.5 m long was placed.

The scheme of measurement path is presented in Fig. 1. The participants were instructed to walk barefoot at self-selected speed through 14-metre long measurement path about 10 times to get familiar with the laboratory conditions and normalize the pace before the start of the measurements. After the familiarization time, investigators determined the start line for every subject so they were able to place each foot on proper force platform without looking at them. During each measurement before walking on AMTI plates participants walked about 6-metre path to ensure a natural gait pattern when coming into measurement area. Platforms were placed so as to each subject went through AMTI plates and got on Footscan in consecutive GC.

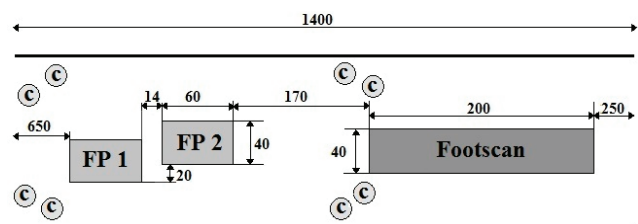


Fig. 1. The scheme of measurement path.

All distances are given in cm. FP – force platform, C – camera

For every subject, at least five trials were recorded. For further analysis, three trials with repetitive gait speed were selected. The measurement area enabled recording of the kinematics from one GC as well as GRFs and PPD from one stance phase (StP) for each LE during one trial. As a result, values of selected parameters from 168 trials, including left and right LEs, were obtained.

The gait parameters of interest included:

1. the spatiotemporal parameters: gait speed, stride length, step length and width as well as stride, stance, double stance and swing phases duration presented as raw results and normalized to body segments length [11] (spatial parameters) or GC duration (temporal parameters). Stride and step length were normalized to LE length, measured from ASIS to medial malleolus, and step width,

was normalized to pelvis width, measured as a distance between ASISs.

2. the kinematic parameters: sagittal plane angle-time characteristics and ROM of the pelvis, hip, knee and ankle joints as well as frontal and horizontal planes angle-time characteristics and ROM of the pelvis and hip joint and angle-time characteristics and ROM of the foot progression angle (FPA). Angle-time characteristics for each trial were normalized to 100% of the GC. Additionally, kinematic parameters included FPA averaged over midstance period (12–31% GC), i.e., the foot is flat on the floor [21].
3. the dynamic parameters: GRFs and PPD data. The first one included force-time characteristics of the vGRF in StP together with first vGRF local maximum within the 0–50% of StP and second vGRF local maximum within the 51–100% of StP and vGRF minimum within whole StP. Next, force-time characteristics of the horizontal anterior-posterior GRF component in StP with its peaks: first for posteriorly directed GRF component within the 0–50% of StP and second for anteriorly directed GRF component within the 51–100% of StP. The last, force-time characteristics of the horizontal lateral-medial GRF component in StP with first peak for laterally directed GRF component within first 10% of StP and second peak for medially directed GRF component within whole StP. Force-time characteristics for each trial were normalized to 100% of the GC. All GRFs values were normalized to each subject's body weight (BW). The pedobarographic parameters included time of each of 10 foot regions loading, normalized to StP duration, and peak pressure under each of 10 foot regions, normalized to BW.

Statistical analysis was performed using the STATISTICA 12.0 software (StatSoft, Inc., Tulsa, USA). For each parameter, mean and standard deviation (SD) were calculated. The shape of distribution of the sample data collected was checked using the Shapiro–Wilk test. The Student's *t*-test (for normally distributed variables) and Wilcoxon test (for variables that were not assumed to be normally distributed) were applied to determine whether the differences between left and right LEs were significant ( $p < 0.01$  and  $p < 0.001$ ).

### 3. Results

For most variables there was no difference between left and right side at a significance level set at  $p < 0.01$ . For time of loading of M1, M2 and M5, peak

pressure under M5 and MF, raw and relative stride length, relative stance duration and sagittal plane pelvis ROM there was no difference between left and right side at a significance level set at  $p < 0.001$ . Therefore, the results for both sides were pooled together. There was one exception: for peak for medially directed GRF component significant difference between right and left side was found (Student's *t*-test,  $p < 0.001$ ). For this variable results are presented separately for both sides.

Spatiotemporal gait parameters are presented in Table 2.

Table 2. Spatiotemporal gait parameters (mean value  $\pm$  SD)

Gait speed [m/s]	1.37 $\pm$ 0.11
Stride length [m]	1.41 $\pm$ 0.09
Step length [m]	0.64 $\pm$ 0.04
Step width [m]	0.14 $\pm$ 0.02
Relative stride length [-]	1.61 $\pm$ 0.16
Relative step length [-]	0.74 $\pm$ 0.04
Relative step width [-]	0.60 $\pm$ 0.08
Stride duration [s]	1.02 $\pm$ 0.05
Stance duration [s]	0.60 $\pm$ 0.03
Swing duration [s]	0.42 $\pm$ 0.02
Double stance duration [s]	0.09 $\pm$ 0.01
Relative stance duration [%GC]	59 $\pm$ 1
Relative swing duration [%GC]	41 $\pm$ 1
Relative double stance duration [%GC]	9 $\pm$ 1

Angle-time characteristics for LEs joints are depicted in Fig. 2. ROM for hip joint in the sagittal plane was  $50.6 \pm 4.6^\circ$ , in the transverse plane it amounted to  $22.5 \pm 5.3^\circ$  and in the frontal plane – to  $17.3 \pm 3.2^\circ$ . Knee joint ROM in the sagittal plane amounted to  $59.9 \pm 5.8^\circ$ . The ankle ROM in the sagittal plane was  $35.1 \pm 5.9^\circ$ . FPA ROM amounted to  $14.2 \pm 4.1^\circ$  and FPA in midstance equaled  $6.1 \pm 5.0^\circ$  of external rotation.

Graphs presenting pelvis angular course are shown in Fig. 3. The lowest ROM occurred in the sagittal plane ( $3.6 \pm 1.1^\circ$ ), then the frontal plane ( $11.5 \pm 2.6^\circ$ ) and the highest ROM was present in the transverse plane ( $18.0 \pm 5.6^\circ$ ).

Force-time characteristics of the three GRF components are presented in Figs. 4 and 5. Two local maxima of vGRF amounted to  $113.6 \pm 6.7\%$  BW and  $119.5 \pm 7.4\%$  BW. The minimum equaled  $71.5 \pm 4.9\%$  BW. The peaks for posteriorly and anteriorly directed GRF component equaled  $19.5 \pm 3.4\%$  BW and  $22.3 \pm 3.0\%$  BW, respectively. The peak for laterally directed GRF component amounted to  $3.4 \pm 1.6\%$  BW while for medially directed it was  $4.8 \pm 1.5\%$  BW and  $5.6 \pm 1.8\%$  BW for the right and left LEs, respectively.

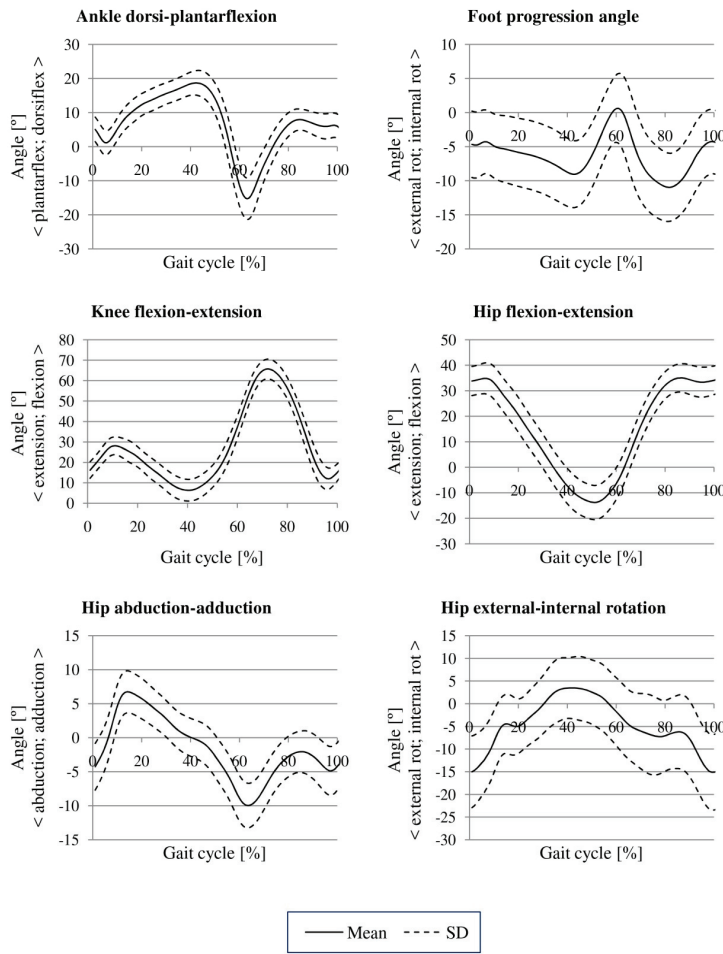


Fig. 2. Angle-time characteristics of LEs joints in gait cycle

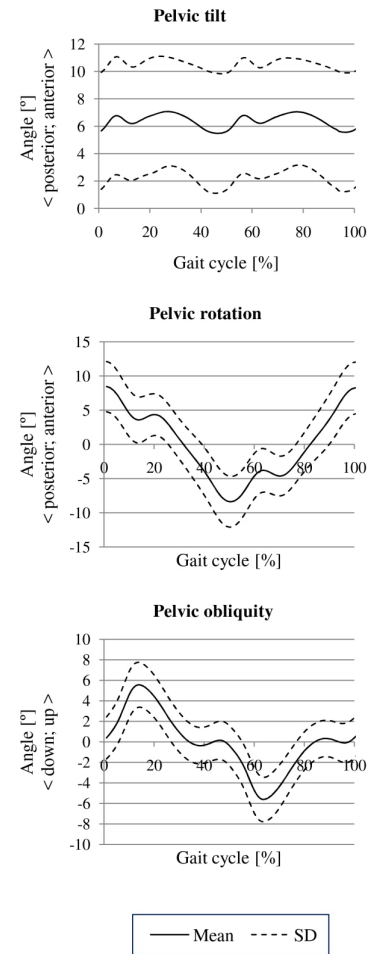


Fig. 3. Angle-time characteristics of the pelvis in gait cycle

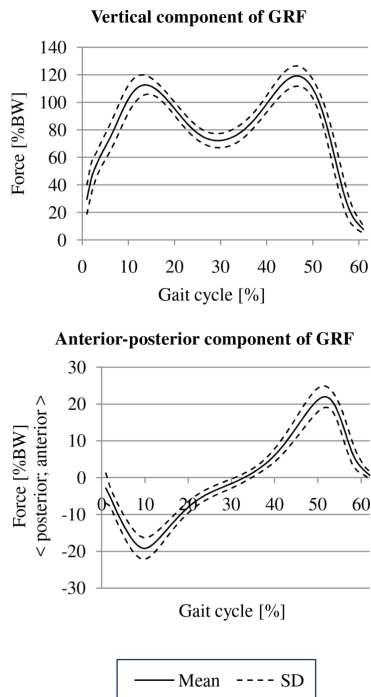


Fig. 4. Force-time characteristics of vertical and anterior-posterior GRF components in gait cycle

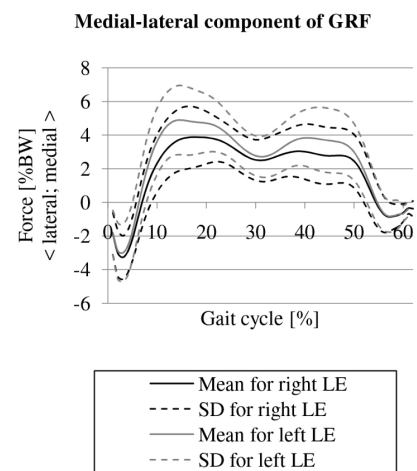


Fig. 5. Force-time characteristics of medial-lateral GRF component in gait cycle

Figures 6 and 7 show, respectively, peak pressure values and time of loading of 10 regions of feet.

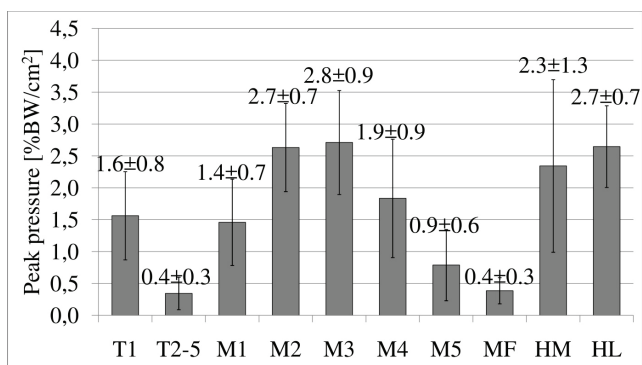


Fig. 6. Peak pressure (mean value  $\pm$  SD) under defined regions of feet during stance phase

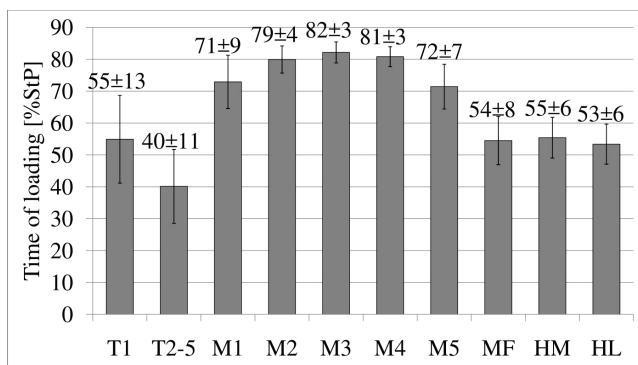


Fig. 7. Time of loading (mean value  $\pm$  SD) of defined regions of feet during stance phase

## 4. Discussion

It is known that gait analysis systems are time-consuming and expensive [25], and have some technical limitations, such as discomfort due to markers placement on the body, skin movement artifacts under the markers or unnatural laboratory environment [18]. However, these systems may support, i.a., diagnostics of musculoskeletal disorders [5], [7], [8], [10], [14], gait retraining process [2], [8], surgery outcome evaluation [5], [8], [10] as well as physiotherapeutic intervention [27], [28], different walking aids [8], [17] or orthotics [1], [8] effectiveness assessment. Still, reference values of variables of interest are needed. In literature there are some normative data for different gait parameters for adults [3], [4], [12], [15], [16], [19]–[22], [24], [28], [29], although, there is lack of comprehensive reference for biomechanics of young women' gait. For this reason, data focused on spatiotemporal parameters, joint angles, GRFs as well as

PPD in female normal walking are presented in this work. In following paragraphs different groups of studied gait parameters are discussed.

### *Spatiotemporal parameters*

The participants were instructed to walk at self-selected speed to gain their most natural walking pattern. It is known that gait speed influences walking kinematics and dynamics [3], [19], [20], [22]. The average value of gait speed, defined as “self-selected”, obtained in our studied group amounted to  $1.37 \pm 0.11$  m/s which is similar to gait speed termed as “comfortable” in study concerning similar group of young healthy women ( $1.34 \pm 0.17$  m/s) [16] and slightly faster than “normal” gait speed in Öberg et al. [19] 20–29 years old female group ( $1.24 \pm 0.17$  m/s). In Pietraszewski et al. [22] study of male normal walking average gait speed, named as “preferred”, amounted to  $1.36 \pm 0.17$  m/s, what is similar to that obtained in our research. However, average stride length –  $1.47 \pm 0.13$  m – and width –  $0.17 \pm 0.03$  m – obtained in Pietraszewski et al. [22] male group was greater than in our female participants. This may arise from mean body height discrepancy, although Kerrigan et al. [16] found statistically significant difference between female and male stride length but not step width. In their young healthy female group average stride length and step width amounted to  $1.33 \pm 0.10$  m and  $0.12 \pm 0.03$  m, respectively, and were lesser than in our research despite similar material, research method and gait speed. Öberg et al. [19] studied step frequency and step length. In their research, a group of 15 women aged 20–29 walked with smaller step length, which amounted on average to  $0.59 \pm 0.06$  m, than female in our research. Heel strike determination by manual switch and slower “normal” gait pace in Öberg et al.'s work [19] may be the reason for this discrepancy.

Kaczmarczyk et al. [14] presented step time, stride time, total double support time and cadence for free gait in healthy women aged 21–31. Although overall they measured 26 spatiotemporal parameters, their results were focused on comparison between young and elder women. Stride time – the only parameter that can be referred to our results – in Kaczmarczyk et al. [14] study, on average amounted to  $1.03 \pm 0.06$  s, what is close to our outcomes, however, there was no information on walking velocity, except for the description that it was “normal”.

Bovi et al. [3] presented a set of reference data for, i.a., “normal” walking including spatiotemporal parameters, however they specified only two age groups, without division into sexes. On the other hand, Hollman et al. [12] found it relevant to establish reference val-



ues of spatiotemporal gait parameters that would be useful for researchers and clinicians for gait evaluation in female and male elders. They identified five domains of gait: rhythm, phase, variability, pace and base of support, each including several specific parameters.

### *Joint angles*

In our research, angle-time characteristics as well as ROM for the pelvis and hip joint in all three planes, knee and ankle joints in the sagittal plane as well as FPA in GC were collected. The same kinematic parameters were obtained by Pietraszewski et al. [22], however, in male group. Bovi et al. [3], besides characteristics mentioned above, presented peak values of these parameters in specific GC events, however, for both sexes together. On the other hand, Kerrigan et al. [16] showed angles at the hip, knee and ankle as a function of time as well as peak values of these parameters in specific phases of GC for each sex separately, but solely in the sagittal plane. Next, Öberg et al. [20] presented only three kinematic gait characteristics: angle at the knee joint in midstance and maximal knee flexion in swing as well as hip joint ROM in GC. They specified several groups of subjects according to their age and sex. For females aged 20–29 the hip joint ROM was lesser than in our research and amounted on average to  $46.4^\circ$  and  $47.4^\circ$  for the right and left hip. This disparity may arise from different methodology. Nevertheless in Pietraszewski et al. work [22] where the same motion capture system as in our method was used, the hip joint ROM for normal walking in males was lesser than in our female group as well and amounted on average to  $45.5^\circ$ .

### *Ground reaction forces*

In this paper, force-time characteristics and peak values of all three GRF components are showed. Bovi et al. [3] presented all three GRF components values changes in GC as well as values of both vGRF local maxima, midstance force minimum, peak anterior and posterior force. In turn, Keller et al. [15] gave values of loading rate as well as maximum of vGRF which they identified generally as first peak. For female group and gait speed 1.5 m/s they recorded peak vGRF of  $1.15 \pm 0.10$  BW on average which is similar to our results. Contrary to their observation, in our research the second peak was greater.

Next, Winiarski and Rutkowska-Kucharska [28] presented several parameters concerning vGRF. Beside two maxima and midstance minimum, they evaluated the

magnitude of vGRF at the end of the initial double stance and at the beginning of the terminal double stance as well as force loading rate measured from the beginning of the StP to first local maximum and force unloading rate measured from the second local maximum to the end of the StP. They presented results for healthy female group from indirect method based on center of gravity kinematics. First and second local maxima of vGRF amounted on average to  $1.16 \pm 0.02$  BW and  $1.12 \pm 0.02$  BW respectively and mean minimum value equaled  $0.80 \pm 0.05$  BW. There is small disparity between our and Winiarski and Rutkowska-Kucharska's [28] results, however, different method and no information on gait speed made it hard to compare these outcomes, even though studied groups are similar.

Kaczmarczyk et al. [13] presented both local maxima of vGRF as well as peaks for posteriorly and anteriorly directed GRF in stance phase for each LE. For the young female group for the right LE they obtained on average  $1.15 \pm 0.10$  BW and  $1.16 \pm 0.10$  BW for vGRF first and second local maximum, respectively, whereas  $0.21 \pm 0.06$  BW and  $0.26 \pm 0.06$  BW for the posteriorly and anteriorly directed GRF. Although the methodology and studied group were similar to ours, no information on gait speed, except it was "self-selected", made it difficult to compare the results.

### *Plantar pressure*

In our study pressure peak values and time of loading under 10 regions of the feet sole were measured. The variability of pedobarographic parameters presented below and differences in defining foot areas as well as non-homogenous examined groups made it impossible to compare the results between studies, therefore, we aimed only to list analyzed parameters.

Putti et al. [24] collected data involving peak pressure, contact area, contact time, pressure-time integral, force-time integral, instant of peak pressure for heel, mid-foot, 1-5 metatarsal heads, hallux, second toe and third to fifth toes. Nevertheless, they did not present results separately for women and men. Prochazkova et al. [23] also examined females and males together taking into account: pressure peak of each foot area normalized to the pressure peak of the sum of pressure of all foot areas, time of loading of each foot area normalized to StP duration and pressure impulse of each foot area normalized to the pressure impulse of the whole foot. Areas of the foot were automatically determined with Footscan gait software: big toe, toes 2–5, metatarsals 1–5, midfoot, lateral and medial areas of the heel. In turn Fernández-Seguín et al. [7]

did not specified sex of examined persons, however, it had been confirmed with Foot Posture Index test that all subjects had “neutral foot”. The analyzed parameters involved plantar pressure mean values under each foot area: big toe, toes 2–5, metatarsals 1–5, whole forefoot, all metatarsals, midfoot and hindfoot as well as contact area of the whole foot and percentage load distribution under toes, all metatarsals and each of them, midfoot and hindfoot. Chiu et al. [4], on the other hand, specified female and male groups however they measured other parameters than we did, although we used the same pedobarographic platform. They analyzed COP progression angle as well as COP velocity and COP  $x$ - and  $y$ -coordinates at defined events of StP and time of COP progression in these events.

## 5. Conclusions

In this paper the normative data on spatiotemporal parameters, joint angles, GRFs and PPD in normal walking in young healthy women are presented. The results may be used by clinicians, physiotherapists or researchers as a reference in diagnosing gait disorders or evaluating patient’s walking pattern. The length of the measurement path and the distance that examined women had to walk through before entering the measurement area ensured that a natural gait pattern was recorded. According to our knowledge, this is the first research that presents gait parameters collected simultaneously by these three measurement systems: optoelectronic motion capture, force platforms and pedobarographic platform, and the first that includes pelvis and hip joint angle-time characteristics in GC in all three dimensions, force-time characteristics in StP and peaks of all three GRF components for homogeneous young, healthy female group. When comparing our results concerning parameters of gait that were analyzed also by other authors who examined young female walking, disparities in their results are noticeable. These differences may arise from distinct method, slower or faster gait, other laboratory environment etc. This should be considered and more than one source of normative values should be checked when searching for reference data.

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