



# Progressive changes in walking kinematics throughout pregnancy—A follow up study

W. Forczek<sup>a,\*</sup>, Y. Ivanenko<sup>b</sup>, M. Curyło<sup>c</sup>, B. Frączek<sup>d</sup>, A. Masłoń<sup>e</sup>, M. Salamaga<sup>f</sup>, A. Suder<sup>g</sup>

<sup>a</sup> Section of Biomechanics, Faculty of Physical Education and Sport, University of Physical Education, Krakow, Poland

<sup>b</sup> Laboratory of Neuromotor Physiology, Santa Lucia Foundation, Rome, Italy

<sup>c</sup> Section of Rehabilitation in Internal Diseases, Department of Clinical Rehabilitation, Faculty of Motor Rehabilitation, University of Physical Education, Krakow, Poland

<sup>d</sup> Section of Sports Medicine and Human Nutrition, Faculty of Physical Education and Sport, University of Physical Education, Krakow, Poland

<sup>e</sup> Section of Rehabilitation in Orthopaedics, Department of Clinical Rehabilitation and Laboratory of Pathology of the Musculoskeletal System, Faculty of Motor Rehabilitation, University of Physical Education, Krakow, Poland

<sup>f</sup> Department of Statistics, Cracow University of Economics, Krakow, Poland

<sup>g</sup> Section of Anatomy, Department of Physiotherapy, Faculty of Motor Rehabilitation, University of Physical Education, Krakow, Poland

## ARTICLE INFO

### Keywords:

Pregnancy  
Gait kinematics  
Foot placement strategy  
Energy balance  
Physical activity

## ABSTRACT

**Background:** Progressive weight gain and changes in its distribution following pregnancy may be challenging for the gravidas' ability to move in a stable way.

**Research question:** How is gait kinematics changing throughout pregnancy and to what extent is it affected by physical activity level and energy balance?

**Methods:** 30 women were enrolled. Three experimental sessions were arranged according to the same protocol in the first, second and third trimesters of pregnancy. Walking kinematics at a self-selected speed was registered. The total physical activity (TPA) was assessed from the subjects' questionnaires. Energy balance ('positive', 'balanced' or 'negative') was estimated as the difference between dietary energy intake and energy expenditure during 7 days.

**Results:** No significant differences were found in the spatiotemporal variables between experimental sessions. However, the gait analysis revealed significant increments in the single support and base of support (BoS) measures. Generally, the sagittal plane mobility of the lower limb joints did not differ, however, the pelvic tilt increased in late pregnancy. The hip and pelvis angles were significantly different over the gait cycle throughout gestation. The 'balanced' energy was dominant in the first trimester although the relative number of participants with negative balance increased over pregnancy. Overall, gait parameters were independent of the energy balance. However, significant correlation was found between gait parameters, such as BoS, velocity, stride length, and TPA in the advanced pregnancy.

**Significance:** The longitudinal assessment of walking kinematics demonstrates few changes adopted to accommodate for pregnancy. The enlargement of BoS is considered as a strategy to provide safety and stability. The increased pelvic tilt is likely to compensate for changes in the body mass distribution. The physical activity correlates with the BoS measures and stride length and thus may be important for enhancing gait stability.

## 1. Introduction

Stability is one of three major objectives recognized as driving locomotor adaptation during human walking [1]. Weight gain in combination with ligamentous laxity may increase joint discomfort and, consequently, affect the manner of walking. Bipedalism poses a unique

challenge to pregnant females because the progressive weight gain and changes in its distribution shift the trunk's center of mass anterior to the hips [2]. A 20% weight gain during pregnancy may increase the force on weight-bearing joint by 50% to 100% [3]. Gravidas are reported to be at high risk of falling (28%) [4], therefore, they enhance a more tentative walking pattern with a reduced velocity, cadence and a wider

\* Corresponding author at: Section of Biomechanics, Faculty of Physical Education and Sport, University of Physical Education, al. Jana Pawła 11 78, 31-571 Krakow, Poland.

E-mail addresses: [wanda.forczek@awf.krakow.pl](mailto:wanda.forczek@awf.krakow.pl) (W. Forczek), [y.ivanenko@hsantalucia.it](mailto:y.ivanenko@hsantalucia.it) (Y. Ivanenko), [curylom@op.pl](mailto:curylom@op.pl) (M. Curyło), [barbara.fraczek@awf.krakow.pl](mailto:barbara.fraczek@awf.krakow.pl) (B. Frączek), [agata.maslon@awf.krakow.pl](mailto:agata.maslon@awf.krakow.pl) (A. Masłoń), [salamaga@uek.krakow.pl](mailto:salamaga@uek.krakow.pl) (M. Salamaga), [agnieszka.suder@poczta.fm](mailto:agnieszka.suder@poczta.fm) (A. Suder).

<https://doi.org/10.1016/j.gaitpost.2019.01.004>

Received 2 September 2018; Received in revised form 22 December 2018; Accepted 3 January 2019

0966-6362/ © 2019 Elsevier B.V. All rights reserved.

step [5–7]. As Maki [8] suggested, these fear-related gait changes demonstrated also by elderly increase stability and help reduce the likelihood of falling. The link between exercise and decreased falls in older people is well-established. McCrory et al. [9] found that regular exercises during pregnancy were associated with a reduced number of falls. Despite the benefits of exercise, gravidas decrease their level of activity [10]. It results from the concerns for their unborn child [11] and increased risk of maternal falls and injuries [12].

Lifestyle interventions (appropriate nutrition and regular physical activity) are critical mediators of weight gain during pregnancy. Many women gain more weight than is recommended during pregnancy. Excessive weight gain increases the risk of complications for both the mother and her infant: fetal over- and under-nutrition are both associated with impaired health in adult life [13], then it often leads to increased lower back, pelvis, and/or joint pain. Musculoskeletal pain can be attenuated with physical activity in women with mild pelvic and lumbar discomfort [14].

Although within the last years a growth of interest in the adjustment mechanisms of gait during pregnancy has been observed, there is no consistency in the study protocols [15]. Furthermore, there are only few longitudinal studies on pregnancy effect on the pattern of walking [16–18]. Thus, in the present paper a longitudinal perspective was accepted to study gravid women in the first, second and third trimesters. A kinematic analysis of pregnant walking was carried out with the focus on the dynamics of changes within the main load-bearing joints (ankle, knee, hip) and pelvis. In addition, we examined how women change their foot placement strategy in the course of pregnancy. Considering individual differences and relationships between the movement pattern and a lifestyle, we integrated the longitudinal analysis of gait kinematics, physical activity level and energy balance during pregnancy.

## 2. Material and methods

### 2.1. Subjects and protocol

The study was carried out in the Biomechanics Laboratory at University of Physical Education in Krakow. The recruitment process took 3 years (2015–2018). The participants were recruited via direct contact and fliers placed in hospitals or gynecological clinics and they volunteered to participate in the study. Inclusion criteria aimed to involve healthy 20–40 year-old women in the first trimester of gestation. The exclusion criteria included a medical history related to previous orthopedic or neurological injuries. All subjects gave signed and informed consent. The study received the Ethics Committee approval and the researches were conducted according to the ethics principles stated in the Helsinki Declaration. The sample consisted of 36 subjects who participated in the first experimental session. However, because of medical contraindications 6 women resigned from further participation. Thus, 30 women were enrolled to the second examination: 19 - primigravid, 8 - second pregnancy and 3 - third pregnancy. The average age in the group, at the time when the study started, was  $30.3 \pm 3.4$  years. All pregnancies were singletons.

Three experimental sessions (P1-P3) were arranged according to the same protocol: P1 - in the first trimester (12 gestation week), P2 - in the second trimester (25 gestation week) and P3 - in the third trimester of pregnancy (36 gestation week). First, the anthropometric measures were taken. Then, walking trials along a 12-m walkway were registered. Each woman was wearing a tight-fitting t-shirt and shorts. After the experiment, the subjects were asked to fill out a questionnaire on physical activity level. Finally, the energy balance was assessed using a measurement of energy intake: weekly food diary and measurements of energy expenditure.

### 2.2. Data collection and analysis

#### 2.2.1. Anthropometric measurements

The following anthropometric measures were taken: BH - body height, BM - body mass, BMI - body mass index, IS-IS - interspinous diameter.

#### 2.2.2. Gait analysis

Gait recordings were performed using a 5-camera video-based (120 Hz sampling rate) motion capture system (Vicon 250; Oxford Metrics Ltd.; Oxford, UK). Thirty nine infra-red reflective markers were attached to the subject's body according to the Golem set-up [5]. The participants walked barefoot at a self-selected speed. Overall, during one session, women covered the distance of ~50 m with short intervals (~1 min) between trials. Gait initiation and termination strides were excluded from the analysis. At least 10 gait cycles for each lower limb (20 steps) were analyzed. The gait cycle was defined as an interval between two successive heel strikes based on the vertical component of the ankle joint velocity and the data for both lower limbs were pooled together and averaged across strides for each subject.

The following general spatiotemporal parameters were calculated: walking velocity (V), cadence (Cad), single support duration (SS) and stride length (SL). The range of motion (RoM) at the ankle, knee, hip and pelvis joints (in the sagittal plane) was also calculated. The size of the base of support (BoS) was assessed as the mediolateral distance between 1) the ankle markers (IAD, inter-ankle distance between lateral malleolus), and 2) the 5<sup>th</sup> metatarsal markers (IMD, inter-metatarsal distance) during the double support phase. The former parameter (IAD) was also normalized to the pelvic width (NIAD).

#### 2.2.3. Energy balance assessment

The energy balance was calculated on the basis of the difference between the energy supply, assessed on the basis of the analysis of food intake in daily food rations (Weekly Food Diary) and energy expenditure derived from triaxial accelerometers (ActiTrainer by ActiGraph, USA). Energy intake was analyzed using local food tables and software. Accelerometry-based energy expenditure has been validated and previously used to assess women's physical activity during pregnancy [19]. The device was clipped to the belt of the trousers or skirt, since caloric burn estimation is more accurate when the device is worn on the waist (closer to the center-of-body-mass). Accelerometers were programmed to capture data from the first midnight after deployment to midnight 7 days after the walking session. Individual data were entered into the device's memory before they were used for the first time, such as gender, age, height and weight, included in the energy expenditure designations [19]. Because of difficulties of everyday recordings, we performed these measures only in 20 women. The participants were requested to carry on with their routine lifestyle while wearing the ActiTrainer activity monitor.

#### 2.2.4. Physical activity assessment

Since energy expenditure assessment derived from accelerometer has some limitations (influenced by the positioning of the device, duration of assessment, participant characteristics [19]), we also used the Pregnancy Physical Activity Questionnaire (PPAQ) to assess physical activity during pregnancy [20]. On its basis, the total physical activity (TPA) expressed in MET hour/week was calculated. Self-report has the advantage over accelerometry of providing detailed information on the types and duration of specific activities [21].

### 2.3. Statistical analyses

Descriptive statistics and repeated measures ANOVA for multiple measurements were used for evaluating changes through pregnancy (the effect of trimester). When significant differences were detected, post-hoc tests and multiple comparisons analyses were performed by

**Table 1**  
Anthropometric characteristics of women in the 1st (P1), 2nd (P2) and 3rd (P3) trimesters of gestation.

Variable	Trimester	Mean ± SD	CV
BH [cm]		167.1 ± 4.4	2.6
	P1	61.5 ± 6.8	11.1
BM [kg]	P2	67.4 ± 7.4	11.0
	P3	72.6 ± 8.2	11.3
	P1	25.4 ± 1.9	7.3
IS - IS [cm]	P2	26.7 ± 1.7	6.4
	P3	27.4 ± 2.0	7.3
	P1	21.9 ± 2.0	9.3
BMI [kg/ m <sup>2</sup> ]	P2	24.0 ± 2.2	9.3
	P3	25.9 ± 2.7	10.55

BH - body height, BM - body mass, BMI - body mass index, IS-IS – interspinous diameter (pelvic width), SD – standard deviation, CV – coefficient of variation.

means of the Bonferroni's test. A Pearson correlation coefficient was used to analyze the relationship between gait parameters and the individual total physical activity (TPA). Reported results are considered significant for  $p < 0.05$ .

### 3. Results

#### 3.1. Anthropometric measurements and spatiotemporal gait parameters

Table 1 shows the basic anthropometric measurements. All variables increased from the 1<sup>st</sup> trimester to the 3<sup>rd</sup> one, except for the body height.

Table 2 shows changes in the spatiotemporal gait parameters. No significant differences were found in walking speed, cadence and stride length. However, the single support duration (SS), inter-ankle distance (IAD) and inter 5<sup>th</sup> metatarsal distance (IMD) significantly differed between trimesters ( $p < 0.05$ ). Both IAD and IMD increased from P1 to P3 though the normalized inter ankle distance (NIAD) did not show significant changes. Post-hoc analyses revealed significant differences in the foot placements (IAD, IMD) between each pair of 1–3 trimesters ( $p = 0.01$ ).

**Table 2**  
Space-time Gait Parameters in 1st (P1), 2nd (P2) and 3rd (P3) trimester of gestation.

Variable	Trimester	Mean ± SD	F
V [m/s]	P1	1.33 ± 0.03	F(2,23) = 1.43, $p = 0.26$
	P2	1.36 ± 0.03	
	P3	1.31 ± 0.03	
Cad [step/min]	P1	117 ± 2	F(2,23) = 0.63, $p = 0.54$
	P2	117 ± 1	
	P3	116 ± 1	
SS [s]	P1	0.41 ± 0.00	F(2,23) = 4.79, $p = 0.02^*$
	P2	0.40 ± 0.00	
	P3	0.41 ± 0.00	
SL [m]	P1	1.36 ± 0.02	F(2,23) = 1.08, $p = 0.36$
	P2	1.38 ± 0.02	
	P3	1.35 ± 0.02	
IAD [mm]	P1	158 ± 3	F(2,23) = 35.2, $p = 0.00^*$
	P2	166 ± 3	
	P3	176 ± 3	
IMD [mm]	P1	182 ± 3	F(2,23) = 28.3, $p = 0.00^*$
	P2	194 ± 3	
	P3	207 ± 5	
NIAD	P1	0.63 ± 0.01	F(2,23) = 1.84, $p = 0.18$
	P2	0.63 ± 0.01	
	P3	0.64 ± 0.01	

V – walking velocity, Cad - cadence, SS - single support, SL -stride length, IAD - inter-ankle distance; IMD - inter 5th metatarsal distance; NIAD - normalized inter-ankle distance. Asterisks denote significant differences between sessions ( $p < 0.05$ ).

All pregnancies were singletons and the newborn's weight at birth ranged from 2.62 to 3.92 kg. No significant correlation was found between gait parameters in all trimesters and the newborn's weight. Also, we verified whether spatiotemporal gait parameters might correlate with the gestational weight gain between trimesters, however, correlations were generally low and not significant ( $r^2 < 0.1$ ).

#### 3.2. Kinematic data

Ensemble-averaged (across subjects) joint angular movements are plotted in Fig. 1B. Generally, the patterns were consistent across sessions, with some significant differences in the hip joint and pelvis segment angular movements. Both the differences in the joint angles during the gait cycle (Fig. 1B) and the total range of angular motion (Table 3) were analyzed.

As for the joint angles, the hip showed significantly higher values over the whole gait cycle ( $p < 0.05$ ) in the 2<sup>nd</sup> and 3<sup>rd</sup> trimesters compared to the 1<sup>st</sup> one. The hip angle also significantly increased in P3 compared to P2 ( $p < 0.05$ ) during the period of 23–100% gait cycle (corresponding to late stance and swing). The pelvis was more anteriorly tilted in P2 and P3 compared to P1 over the whole gait cycle ( $p < 0.05$  for both comparisons) (Fig. 1B). We also noted slight differences in the ankle and knee joint angles during the gait cycle (Fig. 1B, upper panels).

As for the range of angular motion, most variables were not significantly different ( $p > 0.05$ ), except for the pelvis RoM that remarkably increased between trimesters (Table 3). In particular, post hoc analyses revealed significant differences for P2 and P3 relative to P1 ( $p = 0.01$  for both comparisons).

#### 3.3. Energy balance

The average daily energy intake and expenditure were found to be  $2022 \pm 360$  kcal and  $2025 \pm 222$  kcal in the 1<sup>st</sup> trimester,  $2187 \pm 305$  kcal and  $2479 \pm 237$  kcal in the 2<sup>nd</sup> trimester and  $2283 \pm 244$  kcal and  $2655 \pm 247$  kcal in the 3<sup>rd</sup> one. In the 1<sup>st</sup> trimester, energy balance ranged from a 775 kcal deficit to a 698 kcal surplus with an average energy deficit of  $3 \pm 303$  kcal. In the 2<sup>nd</sup> trimester, energy balance ranged from a 1061 kcal deficit to a 413 kcal surplus with an average energy deficit of  $292 \pm 305$  kcal. In the 3<sup>rd</sup> trimester, energy balance ranged from a 1240 kcal deficit to a 205 kcal surplus with an average energy deficit of  $372 \pm 324$  kcal. Overall, there was a trend of increasing the relative number of women with 'negative' balance in the course of pregnancy though we did not find significant correlations between gait parameters and the energy balance.

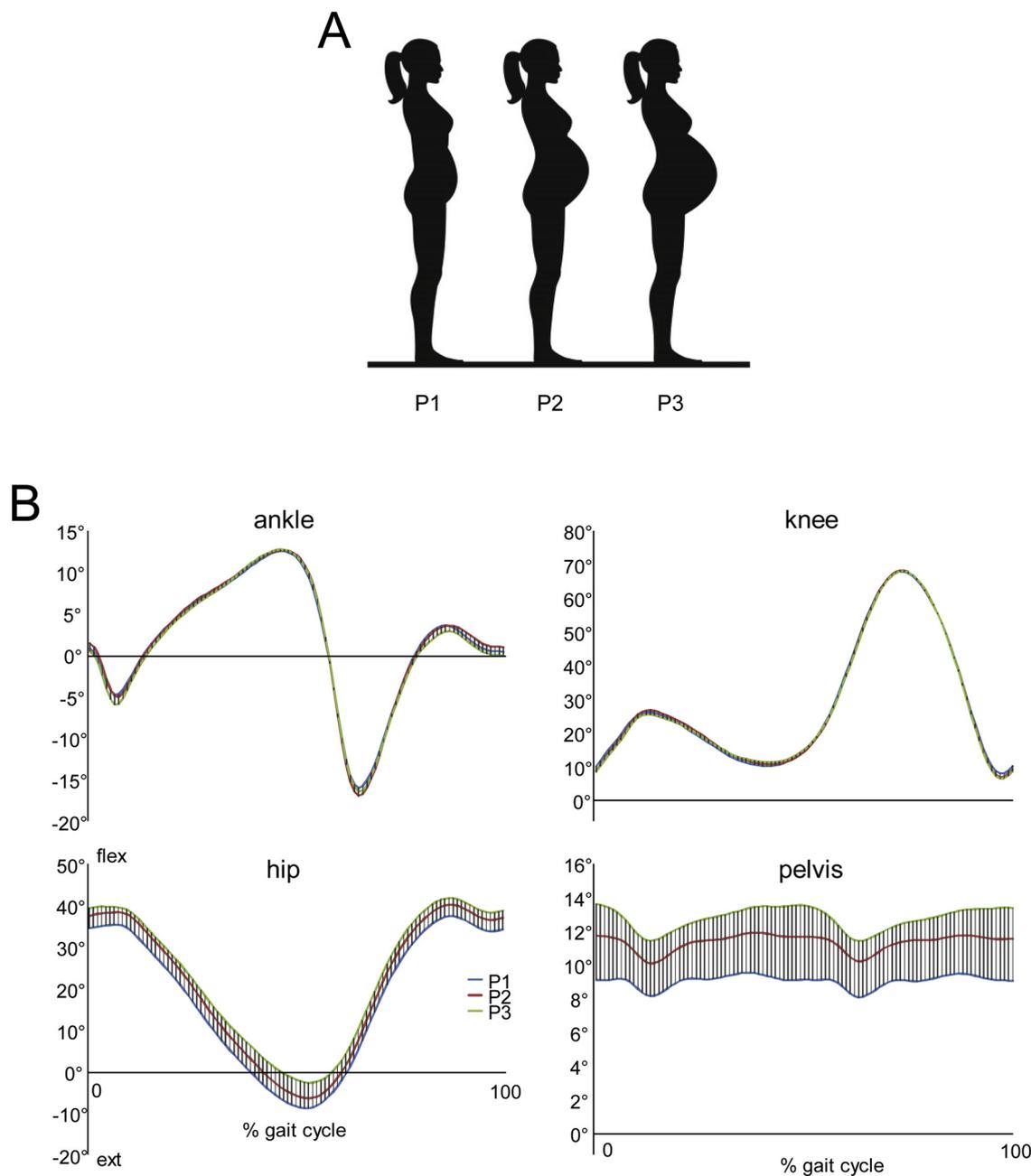
#### 3.4. Spatiotemporal gait parameters and TPA

Overall, the level of physical activity tended to decrease throughout pregnancy ( $246 \pm 74$  MET hour/week in P1,  $227 \pm 76$  MET hour/week in P2 and  $206 \pm 84$  MET hour/week in P3) though the changes were not significant. Nevertheless, there were considerable variations in the individual TPAs (ranged from ~50 to 500 MET hour/week) and therefore potential correlations between gait parameters and TPA were examined (Fig. 2).

No significant correlations were found in the 1<sup>st</sup> trimester. However, in the 2<sup>nd</sup> trimester, a significant and negative correlation was found between IMD and TPA ( $p = 0.001$ ) (Fig. 2, lower middle panel). In the 3<sup>rd</sup> trimester, significant positive correlations were found between gait velocity ( $p = 0.029$ ), stride length ( $p = 0.023$ ) and TPA and negative correlation between IMD and TPA ( $p = 0.004$ ) (Fig. 2, right column).

### 4. Discussion

This study aimed at examining the effects of pregnancy on



**Fig. 1.** Schematic drawings (A) and ensemble-averaged ankle, knee, hip and pelvis joint angular motion (B) in the 1st (P1), 2nd (P2) and 3rd (P3) trimesters of gestation. Angular waveforms are plotted as function of gait cycle. flex – flexion, ext – extension.

**Table 3**  
Range of motion (RoM) of the lower limb joints and pelvis (in the sagittal plane) in the 1st (P1), 2nd (P2) and 3rd (P3) trimesters of pregnancy.

RoM	Trimester	Mean ± SD	F
Ankle [deg]	P1	29.9 ± 0.7	F(2,23) = 1.95, p = 0.16
	P2	30.2 ± 0.7	
	P3	30.4 ± 0.8	
Knee [deg]	P1	61.5 ± 0.5	F(2,23) = 2.43, p = 0.11
	P2	62.1 ± 0.6	
	P3	62.4 ± 0.7	
Hip [deg]	P1	46.8 ± 0.7	F(2,23) = 3.01, p = 0.07
	P2	47.2 ± 0.7	
	P3	45.0 ± 0.8	
Pelvis [deg]	P1	2.44 ± 0.13	F(2,23) = 5.20, p = 0.01
	P2	2.71 ± 0.21	
	P3	2.83 ± 0.13	

locomotor kinematics. Its novelty is that it has integrated the longitudinal analyses of gait kinematics, physical activity level and energy balance over the whole pregnancy period.

In general, the results showed no significant differences between trimesters in the speed, cadency or other spatiotemporal parameters. These results are supported by the findings of Branco et al. [17] though other researchers [5,6] noted between-terms differences in the self-selected speed and stride length. While walking, stability is related to foot placement characteristics [1]. A significant increase in the IAD and IMD measurements was observed. The first measure is more related to the stride width whereas the second one more accurately reflects functional BoS, considering the positioning of the whole feet on the ground. Gil-leard [16] reported, as pregnancy progressed, a decrease in the stride length and an increase in the step width with no significant trend for velocity. The enlargement of the area of support may be attributed to improving lateral gait stability and to changing anthropometry in

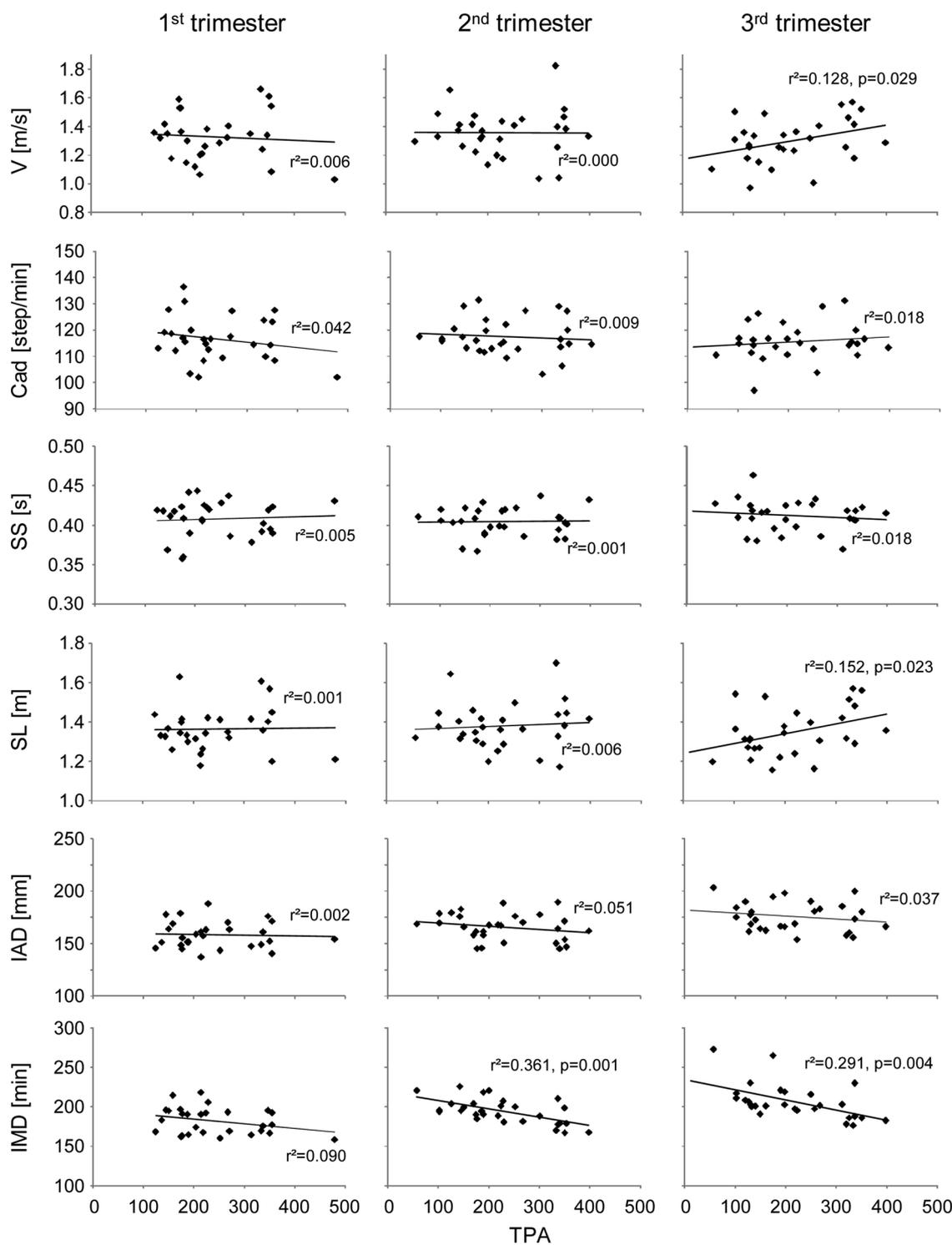


Fig. 2. Correlations between gait parameters and total physical activity (TPA). Each point represents the stride-averaged value for the individual participant. Linear regression lines with corresponding  $r^2$  values are reported (only significant correlations, with p-values < 0.05, are indicated). V – walking velocity, Cad - cadence, SS - single support, SL - stride length, IAD - inter-ankle distance; IMD - inter 5th metatarsal distance.

advanced pregnancy [22]. Indeed, normalization of the ankle separation width to the pelvic width revealed no significant increments (NIAD, Table 2) being consistent with the findings of Foti et al. [22]. However, a remarkable increase of the IMD was found, which exceeded the corresponding changes in IAD. There is also pronation and an increase in contact area of the foot as pregnancy advances [23]. Pronation of foot along with increased foot width as a result of fluid retention and increased body weight may be the possible reasons for this change.

Assuming that step width variability is the most sensitive descriptor of locomotion control [24], increased step width is predictive of falling in elderly [8]. It is generally accepted that a wider stride increases stability in different populations, e.g., in toddlers at the onset of independent walking, in different gait pathologies [25] or in elderly [8]. In view of evidence that elderly fallers have difficulty in controlling lateral stability [8], it may be that they are forced to adopt a wider stride in order to "recapture" the center of mass as it falls sideways

during single-leg support.

The most visible pregnancy-related anthropometric adjustment is weight gain and wider pelvis. In our study we noted a 11 kg increase in late pregnancy. Also, the pelvic width significantly increased in response to a growing fetus (by ~2 cm). Progressive weight gain and changes in its distribution place an increased demand on the lumbar spine and the abdominal muscles, causing an anterior pelvic tilt [26]. The gravidas demonstrated the increased anterior pelvic tilt (from ~10° in early gestation to 14° in late pregnancy, Fig. 1B) which may create an increased lumbar lordosis. In other longitudinal studies [16–18], the authors consistently reported an increase in the anterior pelvic tilt and lumbar curvature of the spine [7]. These postural changes aimed at absorbing extra forces and ensuring better postural balance [27]. A limited hip extension mobility was found to be a possible cause of both the increased anterior pelvic tilt and subsequent exaggerated lumbar lordosis during walking (Fig. 1B).

The kinematic parameters were only slightly affected by the progression of pregnancy (Table 3). However, a longitudinal effect of pregnancy was observed in the sagittal plane hip and pelvis kinematics in the study by Branco et al. [17]. In addition to the significant increase in the anterior tilt, they reported that the increase occurs between the first and second trimesters and remained similar between the second and third trimesters [17]. In our study, the dynamics of pelvic tilt changes was higher in the 3rd trimester compared to the 2nd one than between the 2nd and 1st trimesters.

We did not find significant correlations between gait parameters and the energy balance. However, energy expenditure derived from accelerometers only approximates energy values [28]. Nevertheless, using these estimates we found that the ‘balanced’ energy was dominant in the first trimester and the relative number of participants with negative balance increased over pregnancy.

Foti et al. [22] emphasized the need of the physical training during pregnancy as a helpful tool to avoid overuse injury to specific muscles. While the level of physical activity decreased throughout pregnancy, however, foot placement (IMD) occurred to be significantly and negatively associated with the level of physical activity, which means that the growth of TPA leads to a decrease of IMD. Furthermore, in the 3rd trimester, significant and positive correlations were found for TPA and speed and stride length (Fig. 2), suggesting that TPA enhances the velocity and stride length. McCrory et al. [9] examined the effect of exercise on fall risk in gravidas and found that participation in regular exercises during pregnancy was associated with a reduced number of falls. This finding supports the hypothesis that increased muscle strength may reduce fall risks and enhance subject's stability.

#### 4.1. Limitations

The current study has some limitations. Majority of recreational activity during pregnancy relied on questionnaires. Although PPAQ is a reliable and credible tool for estimating physical activity among pregnant women [20], we are aware that it is subject to self-report errors. That is why we additionally used ActiTrainer activity monitor as an objective method. However, there was a lack of significant effect of energy balance on gait parameters throughout pregnancy that could also be related to the accelerometer limitations for assessing whole body movements. In addition, 7-days monitoring might be too demanding for some subjects. Thus, we performed these measures on only 20 women. In gravidas, activity diaries were shown to overestimate physical activity, whereas accelerometry underestimated activity compared with heart rate telemetry [29], nevertheless, both self-report activity and accelerometry are valuable methods for examining within-subject changes in physical activity. Furthermore, two important methodological issues arose from the study of Rousham et al. [19]. First, compliance with the accelerometers diminished over pregnancy, and second, the correlation between physical activity values produced by the accelerometer and the self-report interview decreased over time.

It is also worth noting that moderate-intensity activities are less well described by PRAQ than vigorous and structured exercise [30]. Therefore, the fact that we found correlations between gait parameters and self-reported (not accelerometry-based) TPA might suggest that structured exercise could be more efficient in affecting gait stability/performance. Future studies may provide more holistic pregnancy information on types and duration of specific activities to get further insights into the role of physical activity in pregnancy.

#### Conflict of interest statement

The authors declare that there is no conflict of interests regarding the publication of this paper.

#### Acknowledgements

Sources of financing: Research project No 99/BS/INB/2016 realised within statutory activities.

#### References

- [1] S. Park, J.M. Finley, Characterizing dynamic balance during adaptive locomotor learning, July 2017, Conference Proceedings: Annual International Conference of the IEEE Engineering in Medicine and Biology Society (2017).
- [2] K. Whitcome, L.I. Shapiro, D.E. Lieberman, Fetal load and the evolution of lumbar lordosis in bipedal hominins, *Nature* 450 (2007) 1075.
- [3] J.R. Ritchie, Orthopaedic considerations during pregnancy, *Clin. Obstet. Gynecol.* 46 (2003) 456–466.
- [4] J.L. McCrory, A.J. Chambers, A. Daftary, M.S. Redfern, Ground reaction forces during gait in pregnant fallers and non-fallers, *Gait Posture* 34 (4) (2011) 524–528.
- [5] W. Forczek, R. Staszkievicz, Changes of kinematic gait parameters due to pregnancy, *Acta Bioeng. Biomech.* 14 (2012) 113–119.
- [6] J.A. Błaszczyk, A. Opala-Berdzik, M. Plewa, Adaptive changes in spatiotemporal gait characteristics in women during pregnancy, *Gait Posture* 43 (2016) 160–164.
- [7] H. Yoo, D. Shin, Ch. Song, Changes in the spinal curvature, degree of pain, balance ability, and gait ability according to pregnancy period in pregnant and non pregnant women, *J. Phys. Ther. Sci.* 27 (2015) 279–284.
- [8] B.E. Maki, Gait changes in older adults: predictors of falls or indicators of fear, *J. Am. Geriatr. Soc.* 45 (1997) 313–320.
- [9] J.L. McCrory, A.J. Chambers, A. Daftary, M.S. Redfern, Dynamic postural stability in pregnant fallers and non-fallers, *BJOG An. Int. J. Obstet. Gynaecol.* 117 (8) (2010) 954–962.
- [10] D.B. Fell, K.S. Joseph, B.A. Armon, L. Dodds, The impact of pregnancy on physical activity level, *Matern. Child Health J.* 13 (5) (2009) 597–603, <https://doi.org/10.1007/s10995-008-0404-7> Epub 2008 Aug 22.
- [11] N.M. Ezmerli, Exercise in pregnancy: primary care update, *Obstet. Gynecol.* 7 (2000) 260–265.
- [12] P.E. Clarke, H. Gross, Women's behaviour, beliefs and information sources about physical exercise in pregnancy, *Midwifery* 20 (2) (2004) 133–141.
- [13] J. Baird, D. Fisher, P. Lucas, J. Kleijnen, H. Roberts, C. Law, Being big or growing fast: systematic review of size and growth in infancy and later obesity, *BMJ* 331 (2005) 929.
- [14] K. Melzer, Y. Schutz, M. Boulvain, et al., Physical activity and pregnancy: cardiovascular adaptations, recommendations and pregnancy outcomes, *Sports Med.* 40 (2010) 493–507.
- [15] W. Forczek, Y.P. Ivanenko, J. Bielatowicz, K. Waclawik, Gait assessment of the expectant mothers – systematic review, *Gait Posture* 62 (2018) 7–19.
- [16] W.L. Gilleard, Trunk motion and gait characteristics of pregnant women when walking: report of a longitudinal study with a control group, *BMC Pregnancy Childbirth* 13 (2013) 71, <https://doi.org/10.1186/1471-2393-13-71>.
- [17] M. Branco, R. Santos-Rocha, F. Vieira, L. Aguiar, A.P. Veloso, Three-dimensional kinematic adaptations of gait throughout pregnancy and post-partum, *Acta Bioeng. Biomech.* 18 (2) (2016), <https://doi.org/10.5277/ABB-00418-2015-05>.
- [18] A.M. ElDeeb, A. Hamada, A.A. Abdel-Aziem, A.M. Youssef, The relationship between trunk and pelvis kinematics during pregnancy trimesters, *Acta Bioeng. Biomech.* 18 (4) (2016), <https://doi.org/10.5277/ABB-00544-2016-03>.
- [19] E.K. Rousham, P.E. Clarke, H. Gross, Significant changes in physical activity among pregnant women in the UK as assessed by accelerometry and self-reported activity, *Eu. J. Clin. Nutr.* 60 (2006) 393–400.
- [20] L. Chasan-Taber, M.D. Schmidt, D.E. Roberts, D. Hosmer, G. Markenson, P.S. Freedson, Development and Validation of a Pregnancy Physical Activity Questionnaire, *Med. Sci. Sports Exerc.* 36 (10) (2004) 1750–1760.
- [21] P.E. Clarke, Maternal Daily Activity in Low Risk Pregnancy: a Longitudinal Study, Doctoral Dissertation Loughborough University, Loughborough, UK, 2001.
- [22] T. Foti, J.R. Davids, A. Bagley, A biomechanical analysis of gait during pregnancy, *J. Bone Jt. Surg. Am.* 82 (2000) 625–632.
- [23] P. Ramachandra, P. Kumar, A. Kamath, A.G. Maiya, Do Structural Changes of the Foot Influence Plantar Pressure Patterns During Various Stages of Pregnancy and Postpartum? *Foot Ankle Spec.* 10 (6) (2017) 513–519, <https://doi.org/10.1177/1938640016685150>.
- [24] T.M. Owings, M.D. Grabiner, Variability of step kinematics in young and older adults, *Gait Posture* 20 (1) (2004) 26–29, [https://doi.org/10.1016/S0966-6362\(03](https://doi.org/10.1016/S0966-6362(03)

- 00088-2.
- [25] N. Peyrot, D. Thivel, L. Isacco, J.B. Morin, P. Duche, A. Belli, Do mechanical gait parameters explain the higher metabolic cost of walking in obese adolescents? *J. Appl. Physiol.* 106 (2009) 1763–1770, <https://doi.org/10.1152/jappphysiol.91240.2008>.
- [26] P. Ponnampala, J.S. Boberg, Lower extremity changes experienced during pregnancy, *J. Foot Ankle Surg.* 49 (2010) 452–458.
- [27] M.E. Franklin, T. Conner-Kerr, An analysis of posture and back pain in the first and third trimesters of pregnancy, *J. Orthop. Sports Phys. Ther.* 28 (3) (1998) 133–138.
- [28] K.D. Hall, S.B. Heymsfield, J.W. Kemnitz, Klein, D.A. Schoeller, J.R. Speakman, Energy balance and its components: implications for body weight regulation, *Am. J. Clin. Nutr.* 95 (4(1)) (2012) 989–994.
- [29] A.D. Stein, J.M. Rivera, J.M. Pivarnik, Measuring energy expenditure in habitually active and sedentary pregnant women, *Med. Sci. Sports Exerc.* 35 (8) (2003) 1441–1446, <https://doi.org/10.1249/01.MSS.0000079107.04349.9A>.
- [30] D.R. Bassett, B.E. Anisworth, A.M. Swartz, S.J. Strath, W.L. O'Brien, G.A. King, Validity of four motion sensors in measuring moderate intensity physical activity, *Med. Sci. Sports Exerc.* 32 (2000) S471–S480.