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Kinematic and spatiotemporal gait characteristics in pregnant women with pelvic girdle pain, asymptomatic pregnant and non-pregnant women

Lene Christensen[a,*], Marit B. Veierød[b], Nina K. Vøllestad[a], Vidar E. Jakobsen[c,1], Britt Stuge[d], Jan Cabri[e], Hilde Stendal Robinson[a]

[a] Dept. of Interdisciplinary Health Sciences, Institute of Health and Society, University of Oslo, P. O. Box 1089, Blindern, 0317 Oslo, Norway
[b] Oslo Centre for Biostatistics and Epidemiology, Dept. of Biostatistics, Institute of Basic Medical Sciences, University of Oslo, P. O. Box 1122, Blindern, 0317 Oslo, Norway
[c] Norwegian School of Sport Sciences, P. O. Box 4014, Ullevål Stadion, 0806 Oslo, Norway
[d] Division of Orthopaedic Surgery, Oslo University Hospital, P. O. Box 4950, Nydalen, 0424 Oslo, Norway
[e] Dept. of Physical Performance, Norwegian School of Sport Sciences, P. O. Box 4014, Ullevål Stadion, 0806 Oslo, Norway

A B S T R A C T

Background: Walking difficulties are common among pregnant women with pelvic girdle pain. This cross-sectional study investigated the influence of pelvic girdle pain, pregnancy and speed on spatiotemporal and trunk, pelvic and hip kinematics during gait in the 2nd trimester of pregnancy.

Methods: Three-dimensional gait analysis at self-selected speed was performed in 25 pregnant women with pelvic girdle pain, 24 asymptomatic pregnant and 24 non-pregnant women. Linear mixed models were used to investigate between-group differences in gait variables. Adjustment for gait speed was included in the analysis. Correlations between speed and fear of movement, disability and pain were examined using Spearman correlation coefficient (r_s).

Findings: Pregnant women with pelvic girdle pain walked 18% slower (estimated marginal means (95% confidence intervals) 1.18 (1.22, 1.24) meter/s) compared to asymptomatic pregnant women (1.44 (1.38, 1.50) meter/s) ($P < 0.001$). Moreover, with longer double limb support (5%, $P = 0.04$), shorter contralateral step length (3%, $P = 0.03$) and more restricted pelvic and hip kinematics ($0.001 \leq P \leq 0.01$) adjusted for speed. Only stance, double limb support and thoracic rotation ($0.001 \leq P \leq 0.04$) differed between asymptomatic pregnant and non-pregnant women. Speed was negatively correlated with fear of movement ($r_s = -0.63$, $P = 0.01$) and disability ($r_s = -0.46$, $P = 0.03$) in the pelvic girdle pain group.

Interpretation: Gait is primarily influenced by pelvic girdle pain and less by pregnancy. Pregnant women with pelvic girdle pain walked slower and with a more rigid gait pattern compared to asymptomatic pregnant women, presumably related to altered load transfer. Our results may assist clinical evaluation of pelvic girdle pain, as well as direct future research.

1. Introduction

Pelvic girdle pain (PGP) is a prevalent musculoskeletal disorder in pregnant women (Gutke et al., 2006; Gutke et al., 2018; Robinson et al., 2010) affecting daily activities, work ability and quality of life (Gutke et al., 2006; Olsson and Nilsson Wilkmar, 2004; Robinson et al., 2006). Although the cause of PGP is multifactorial (Vleeming et al., 2008), dysfunctional load transfer has been related to pain and impairment in weight-bearing activities (Pel et al., 2008; Pool-Goudzwaard et al., 1998). Pregnant women with PGP frequently report walking difficulties (Robinson et al., 2006; Robinson et al., 2010; Stuge et al., 2011), and lower gait speed has been reported in this population (Gutke et al., 2008; Wu et al., 2008). Although speed is a recommended expression of overall gait performance, quantification of spatiotemporal and kinematic gait characteristics might elucidate mechanisms involved in function (Lord et al., 2013). Early treatment of PGP is recommended (Mackenzie et al., 2018). Hence, knowledge of gait kinematics in the 2nd trimester of pregnancy may improve clinical management of PGP.

To our knowledge, three studies have investigated gait biomechanics in pregnant women with PGP (Bertuit et al., 2018; Kerbourc'h et al., 2017; Wu et al., 2008). Only Wu et al. (2008) assessed kinematics and found that pregnant women with PGP walked slower and with larger transversal rotations in the pelvis, low back and thorax (although not statistical significant), reduced relative phase between rotations and earlier timing of peak thoracic rotations compared to asymptomatic pregnant women. They also found a negative correlation between gait speed and fear of movement in the PGP group (Wu et al., 2008). Kerbourc'h et al. (2017) and Bertuit et al. (2018) investigated

* Corresponding author.
E-mail addresses: lene.christensen@medisin.uio.no (L. Christensen), m.b.veierod@medisin.uio.no (M.B. Veierød), n.k.vollestad@medisin.uio.no (N.K. Vøllestad), vidar@biomekanikk.no (V.E. Jakobsen), britt.stuge@medisin.uio.no (B. Stuge), Jan.Cabri@nih.no (J. Cabri), h.s.robinson@medisin.uio.no (H.S. Robinson).
[1] Present address: Biomekanikk AS, Stårputtveien 27, 0891 Oslo.

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stance time and center of pressure (COP) displacement and velocity in pregnant women with PGP, asymptomatic pregnant and non-pregnant women, and found that PGP influenced gait minimally. They found that speed influenced most gait variables, but did not account for speed differences between groups in their gait analysis. As gait biomechanics are influenced by gait speed (Levine et al., 2012; Neumann, 2010), it seems important to include speed in the analysis of gait.

Several authors assessed gait biomechanics in asymptomatic pregnant women (Forczek et al., 2018; Wong and McGregor, 2018), however few studied gait in the 2nd trimester. Moreover, there is a disparity in results with slower speed (McCrory et al., 2011), greater step width, longer double limb support and stance time (Aguiar et al., 2015; Kerbourc'h et al., 2017), greater thoracic (McCrory et al., 2014) and pelvic kinematics (Branco et al., 2016) reported. Conversely, others reported no or other alterations (Branco et al., 2016; Gilleard, 2013; McCrory et al., 2014). Further knowledge of gait in the 2nd trimester is important, as appreciating gait characteristics in healthy pregnant women may complement our understanding of gait in PGP (Wong and McGregor, 2018).

Our primary aim was to assess the influence of PGP, pregnancy and speed on spatiotemporal and trunk, pelvic and hip kinematics during gait in the 2nd trimester. Secondary, we aimed to explore the relationship between speed and fear of movement, disability and pain. Based on clinical observations, we hypothesized that pregnant women with PGP would walk slower and with shorter step length, longer stance and double limb support as well as altered trunk, pelvic and hip kinematics compared to asymptomatic pregnant women. Furthermore, that speed would correlate negatively with fear of movement, disability and pain in pregnant women with PGP.

2. Methods

2.1. Participants

In this cross-sectional study, we included pregnant women with PGP, asymptomatic pregnant and non-pregnant women from and around Oslo. Inclusion criteria for all pregnant women were no-risk pregnancy before gestation week 27. Women with PGP should have posterior pelvic pain between the crista iliaca and the gluteal folds (Vleeming et al., 2008) with onset in current pregnancy, a positive posterior pelvic pain provocation (P4) test (Ostgaard et al., 1994) and an active straight leg raise (ASLR) test score > 0 on clinical examination (Mens et al., 2012a). Exclusion criteria are given in Table 1. All participants provided written informed consent.

2.2. Procedures

Prior to the biomechanical testing, all participants filled out a comprehensive questionnaire including demographics, pain drawing and selected standardized questionnaires on function (Christensen et al., 2019). In addition, women with PGP answered questionnaires related to PGP and function: the Pelvic Girdle Questionnaire (PGQ) (Verwoerd et al., 2012), Numeric Rating Scale for present pain intensity (NRS) (Grotle et al., 2004) and one substitute question for the Tampa Scale of Kinesiophobia (fear of movement) (Verwoerd et al., 2012). All participants underwent a clinical examination with assessment to confirm our inclusion criteria and to collect results of clinical tests. Height and weight were measured with a stadiometer and a medical scale, respectively, and body mass index (BMI, kg/m^2) was calculated. Pre-pregnancy BMI in the pregnant women and BMI in the non-pregnant group were calculated from self-reported height and weight. Spherical reflective markers (12 mm diameter) were positioned, using double-sided adhesive tape, on specific anatomical landmarks in accordance with the International Society of Biomechanics (ISB) recommendations (Wu et al., 2002) and van Sint Jan (2007) (Fig. 1). Pelvic width was determined by the distance between the anterior spina iliaca superior (ASISs) on the pelvis. One researcher (LC) with post-graduate education in manual therapy performed the identification of anatomical landmarks to reduce inter-tester variability.

Table 1
Exclusion criteria for the pregnant women with pelvic girdle pain (PGP), asymptomatic pregnant women and asymptomatic non-pregnant women.

Pregnant with PGP (n = 25)	Asymptomatic pregnant (n = 24)	Asymptomatic non-pregnant (n = 24)
Pregnant ≥ 26 gestation week		Pregnant
Current multiple gestation		< 6 months since last pregnancy
Any risk pregnancy as determined by midwife		
No posterior pelvic pain[a], or pubic symphysis pain during the last 6 months, that had led to disability or sick leave		
ASRL[b] score > 0		
Positive P4[c]		
Low back pain during the last 6 months, that had led to disability or sick leave		
Surgery in the pelvis, back or abdomen during the last 6 months		
Any former surgery in the lower extremities		
Any former traumatic head injury		
Any neurological or inflammatory systemic diseases (e.g., multiple sclerosis, rheumatoid arthritis, ankylosing spondylitis)		
Positive Slumps test indicating symptoms referred from the lumbar spine		

[a] Posterior pelvic pain defined as unilateral or bilateral pain in the area between the crista iliaca and the gluteal folds.
[b] active straight leg raise test.
[c] posterior pelvic pain provocation test.

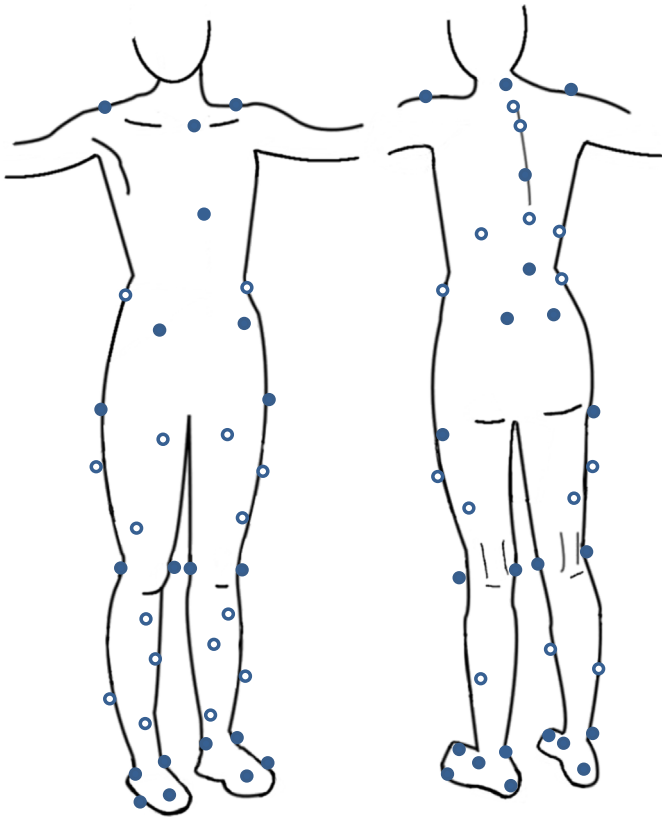

Fig. 1. Marker placement in anterior and posterior view; Upper body (on top of the acromioclavicular joints, spinous processes of C7, T2, T4, T10, L3, lateral on the left and right 11th rib, xiphoid process, jugular notch), pelvis (anterior superior iliac spines, posterior superior iliac spines, on top of the lateral crista iliaca), lower limbs (trochanter major, medial and lateral femoral epicondyles, 4 markers on the thigh, medial and lateral malleoli and 4 markers on the shank) and feet (calcaneus, 2nd and 5th metatarsal heads). Calibration markers (filled circles) and tracking markers only (unfilled circles).

Kinematic data were collected using a Qualisys pro-reflex motion analysis system (Qualisys AB, Gothenburg, Sweden) with twelve cameras at a sampling frequency of 300 Hz, synchronized with kinetic data from two AMTI LG6 force plates (Advanced Mechanical Technology Inc., Watertown, MA, US) at a sampling rate of 1500 Hz. The participants were instructed to walk barefoot at self-selected speed along a 15 m walk-way with force plates embedded.

2.3. Gait analysis

The first four gait cycles with foot placement within the force plates for each participant were used in the analyses. The kinematic data were low-pass filtered at 6 Hz using a digital 4th order Butterworth Bidirectional Filter (Robertson and Dowling, 2003). Joint angles and segment positions were computed using Visual 3D software (C-motion Inc., Crabbs Branch Way Rockville MD). The thoracic and pelvic segments were modelled in accordance with ISB recommendations (Wu et al., 2002; Wu et al., 2005), and were analyzed with respect to the laboratory's coordinate system, oriented so that a positive y-direction was in the direction of forward progression. The thigh segments were oriented in relation to the pelvic coordinate system, and hip joint centers estimated based on the pelvic markers using the regression equation of Harrington et al. (2007). Pelvic angles were extracted using a rotation-obliquity-tilt sequence as recommended by Baker (2001).

Heel strike (HS) and toe off (TO) were determined from the force plates using a threshold of 20 N for the vertical ground reaction force (Allison et al., 2016a). Thoracic, pelvic and hip angles were calculated as range of motions (RoMs) during the gait cycle between HS and the subsequent HS of the same foot and as angles at four pre-defined events during stance phase of gait; HS, mid-stance (identified as the midpoint temporal observation of the stance phase when normalized from 0 to 100%), peak hip adduction (PHA) and TO. In the sagittal plane, positive values represent thoracic flexion, anterior pelvic tilt and hip flexion. In the frontal plane, positive values denote thoracic ipsilateral lean towards the stance limb, drop of contralateral pelvis relative to the stance limb and hip adduction. In the transversal plane, positive values represent ipsilateral forward rotation of the thorax and pelvis and internal rotation of the hip. To provide a relative quantification of the position of the foot to the midline of the participant, we calculated lateral pelvic translation according to Allison et al. (2016a) (0% representing foot placement under the midpoint between the two ASISs on the pelvis, while 100% represents foot placement under the ASIS on the same side). In addition, lateral trunk translation was expressed in cm by the frontal plane RoMs of the C7 and L3 vertebrae markers with respect to the laboratory coordinate system according to McCrory et al. (2014).

The following spatiotemporal variables were derived from 3-dimensional kinematic data; speed (m/s), cycle time (s), stance time (seconds), stance phase (% of gait cycle), double limb support (% of gait cycle), stride width (m), stride length (m) and ipsilateral and contralateral step length (m) (denoting step length on the same and the opposite side of the “test side” respectively). For pregnant women with PGP the painful or the most painful side was determined to be the “test side”. For the four women reporting equal bilateral pain and for the asymptomatic pregnant and non-pregnant women, a “test side” was randomly designated using a coin toss.

2.4. Statistical analyses

Descriptive data are presented as frequencies (percentages), means (standard deviations (SDs)), or medians (min-max). Between-group differences were tested by chi-square or Fisher exact tests for categorical variables, and by one-way analysis of variance (ANOVA) or Kruskal-Wallis test for continuous variables. Pairwise comparisons were performed using Bonferroni correction to adjust for multiple comparisons (ANOVA: *p*-value correction implemented in the posthoc procedure for pairwise comparisons; Kruskal-Wallis test: pairwise Mann-Whitney tests with p-value correction). Differences in gestation week and BMI between the two pregnant groups were tested by Mann-Whitney test.

A linear mixed model (unstructured covariance matrix) was used to test between-group differences (with asymptomatic pregnant women as the reference group) in spatiotemporal and kinematic variables during the four repeated gait trials. We present estimated marginal means (EMMs) with 95% confidence intervals (CIs) to describe the level in the three groups over the four repeated gait trials, and percentage differences between the groups based on the EMMs. We tested for interaction between group and repeated gait trials, and when significant, the effect of group was studied within each gait trial by multiple linear regression analyses and a linear mixed model was used to study the effect of gait trial within each group. Except for ipsilateral step length ($P_{interaction} = 0.02$), pelvic transversal plane RoM ($P_{interaction} = 0.04$), hip sagittal plane RoM ($P_{interaction} = 0.006$) and pelvic transversal plane angle at HS ($P_{interaction} = 0.03$), we found no significant interaction effects in the analyses of spatiotemporal and kinematic variables ($0.05 \leq P_{interaction} \leq 1.00$). Between-group differences were very similar in all four trials for these four variables thus we present all results collapsed over trials (i.e. without interaction). The residuals were inspected for model assumptions. Given the potential influence of speed on gait biomechanics (Wu et al., 2004), the mixed model analyses were also performed with adjustment for speed. Sensitivity analyses with additional adjustment for contralateral step length were performed for the kinematic variables. Correlations between mean gait speed and fear avoidance, PGQ score and pain intensity were investigated in the PGP group using Spearman correlation coefficient. To study reliability over the four trials, we calculated the intraclass correlation coefficient (ICC; 1,1) (Shrout and Fleiss, 1979) with 95% CI. We also calculated the intra-individual SD over the four gait trials in each group as an absolute measure of measurement variation (McGinley et al., 2009).

This study is part of a project initially planned with two groups, pregnant women with and without PGP. We originally planned for a sample size of 23 in each group, sufficient to detect a difference of 2.9° in pelvic frontal plane angle, assuming a standard deviation of 3.4, a power of 80% and a significance level of 5% during a single leg stance task (Allison et al., 2016b). Prior to commencement of the data collection, we added a third group consisting of asymptomatic non-pregnant women to study the influence of pregnancy itself. To ensure that all three groups reached at least 23 participants, we included between 24 and 25 women in each group. Data from one woman was excluded due to technical errors during the gait measurements. A 5% significance level was used. Data was analyzed using SPSS (version 24, SPSS Inc., Chicago, IL).

3. Results

3.1. Participant characteristics

Twenty-five pregnant women with PGP, 24 asymptomatic pregnant and 24 non-pregnant women were included in the analyses.

Weight and pelvic width were significantly different between groups ($P_{group} = 0.047$ and < 0.001, respectively) (Table 2). Pregnant women with PGP had higher weight ($P = 0.049$) than non-pregnant women, while no significant weight differences were found when comparing asymptomatic pregnant to neither pregnant women with PGP ($P = 1.0$) nor non-pregnant women ($P = 0.23$). Pelvic width differed significantly between non-pregnant women and both pregnant groups ($P \leq 0.001$), but not between the two pregnant groups ($P = 0.40$). The clinical variables showed large variation in pregnant women with PGP: PGQ score 10–73%, pain intensity 0–7, fear of movement 1–10 and ASLR sum score 1–8. In the PGP group, 32% had an ASLR score > 4.

In the PGP group, mean gait speed was negatively correlated with both fear of movement ($r_s = -0.63$, $P = 0.01$) and disability measured

Table 2
Selected participant characteristics for the pregnant women with pelvic girdle pain (PGP), asymptomatic pregnant women and asymptomatic non-pregnant women.

	Pregnant with PGP (n = 25)	Asymptomatic pregnant (n = 24)	Asymptomatic non-pregnant (n = 24)	P_{group}
Age (years), mean (SD)	30.9 (2.2)	31.5 (3.7)	31.4 (4.0)	0.79[a]
Height (m), mean (SD)	1.67 (0.07)	1.67 (0.07)	1.66 (0.06)	0.88[a]
Weight (kg), mean (SD)	68.7 (8.0)	67.3 (7.8)	63.4 (6.7)	0.047[a]
BMI[c] (kg/m^2), median (min-max)	24.4 (19.5–30.3)	23.0 (21.2–29.4)	–	0.52[d]
Pre-pregnancy BMI in pregnant and BMI in non-pregnant[e] (kg/m^2), mean (SD)	22.6 (2.1)	22.0 (2.1)	23.0 (1.7)	0.21[a]
Pelvic width[f] (cm), median (min-max)	26 (22 − 31)	26 (21–29)	23 (21–26)	< 0.001[b]
Gestation week, median (min-max)[d]	23 (13–26)	23 (14–26)	–	0.90[d]
Test side[g], n (%) Right	11 (44.0)	15 (62.5)	12 (50.0)	0.41[h]
Left	14 (56.0)	9 (37.5)	12 (50.0)	
SCL-10[i], n (%) < 1.85	21 (84.0)	24 (100.0)	23 (95.8)	0.12[j]
≥ 1.85	4 (16.0)	0	1 (4.2)	
PGQ[k], mean (SD)	42.7 (16.0)			
Pain intensity[l], mean (SD)	2.5 (1.9)			
Fear of movement[m] median (min-max)	6.5 (1 − 10)			
ASLR[n], median (min-max)	3 (1–8)			

[a] One way analysis of variance.
[b] Kruskal-Wallis test.
[c] Body mass index, calculated from height and weight measured on the day of testing.
[d] Mann-Whitney test.
[e] Self-reported.
[f] Determined by the distance between the anatomical landmarks, anterior spina iliaca superior on the pelvis.
[g] Side of symptomatic posterior pelvic pain, designated in asymptomatic participants by a coin toss.
[h] Chi-square test
[i] Hopkins Symptom Checklist – 10 items.
[j] Fisher exact test.
[k] Pelvic Girdle Questionnaire.
[l] Measured by numeric rating scale on the day of testing.
[m] Measured by one substitute question for the Tampa Scale of Kinesiophobia.
[n] Active straight leg raise test.

with PGQ ($r_s = -0.46$, $P = 0.03$), but not significantly correlated with pain intensity ($r_s = -0.21$, $P = 0.32$).

3.2. Spatiotemporal variables

In the crude analysis, we found significant between-group differences for all spatiotemporal variables ($P_{group} < 0.001$), except stride width ($P_{group} = 0.32$) (Table 3). Gait speed was 18% slower in pregnant women with PGP compared to asymptomatic pregnant women ($P < 0.001$). Except for stance phase (2%, $P = 0.001$), the other spatiotemporal variables differed significantly with about 10% between the pregnant groups ($P \leq 0.001$). Asymptomatic pregnant women walked with longer cycle time (4%, $P = 0.04$), stance time (7%, $P = 0.002$), stance phase (2%, $P = 0.002$) and double limb support (10%, $P = 0.004$) than non-pregnant women (Table 3).

After adjustment for speed, only contralateral step length (3%, $P = 0.03$) and double limb support (5%, $P = 0.04$) remained significant in pregnant women with PGP versus asymptomatic pregnant women, while stance time, stance phase and double limb support remained significantly different ($0.006 \leq P \leq 0.01$) between asymptomatic pregnant and non-pregnant women (Table 3).

3.3. Kinematic variables

In total 52 kinematic variables were investigated. We did not find any significant effect of group in neither crude nor adjusted analyses ($0.07 \leq P_{group} \leq 0.99$) for 43 of these variables and these results are presented in detail in Supplementary material, Table S1. Crude and adjusted results for the other 9 kinematic variables are presented in Table 4, and here we found significant between-group differences in the crude analysis ($P_{group} \leq 0.04$). When comparing pregnant women with PGP versus asymptomatic pregnant women during the gait cycle, EMM for lateral translation of C7 was 1.1 cm greater ($P = 0.01$), while pelvic frontal and transversal plane RoMs were 2.6° ($P < 0.001$) and 2.8° ($P = 0.03$) less, respectively. Further, hip sagittal and frontal plane RoMs were 5.2° ($P < 0.001$) and 2.5° ($P = 0.01$) less, respectively. Pelvic frontal plane RoM and hip sagittal and frontal plane RoMs remained significantly different between groups and with similar effect estimates after adjustment for speed with similar EMMs as in the crude analysis ($0.002 \leq P_{group} \leq 0.02$) (Table 4).

Among trunk kinematic variables at specific events, a significant group effect was found for thoracic transversal plane angle at TO ($P_{group} = 0.01$, crude and adjusted analyses) (Table 4). Asymptomatic pregnant women had less forward rotation of the ipsilateral thorax compared to non-pregnant women (EMMs −0.2° vs 2.8°, $P = 0.003$, adjusted analysis) (Table 4).

Among pelvic and hip kinematics at specific gait events, significant group differences were found for pelvic frontal and hip sagittal plane angles at PHA ($0.004 \leq P_{group} \leq 0.04$, crude and adjusted analyses) (Table 4). Pregnant women with PGP had 1.8° ($P = 0.005$) less pelvic frontal plane angle and 6.5° ($P = 0.01$) less hip sagittal plane angle at PHA compared to asymptomatic pregnant women when adjusting for speed (Table 4).

After sensitivity analysis with additional adjustment for contralateral step length, hip sagittal plane angle at HS almost reached a significant effect of group ($P_{group} = 0.052$), with pregnant women with PGP demonstrating 5.7° ($P = 0.02$) less hip sagittal plane angle at HS than asymptomatic pregnant women. For all other kinematic variables, results remained unchanged (Supplementary material, Table S2).

3.4. Reliability

We found good to excellent reliability for the majority of spatiotemporal variables in the three groups ($0.75 \leq ICC \leq 0.95$), while reliability was moderate for stance phase in asymptomatic non-pregnant women (ICC = 0.57) and in pregnant with PGP women (ICC = 0.68)

Table 3
Spatiotemporal variables presented as estimated marginal means (EMMs) and 95% confidence intervals (CIs) comparing asymptomatic pregnant women (n = 24), asymptomatic non-pregnant women (n = 24) and pregnant women with PGP (n = 25).

		Crude[1]		Adjusted[2]	
Spatiotemporal variables	Group	EMM (95% CI)	P^3	EMM (95% CI)	P^3
Speed (m/s)			$P_{group} < 0.001$		
	Asymptomatic pregnant	1.44 (1.38, 1.50)	Ref.		
	Asymptomatic non-pregnant	1.51 (1.45, 1.57)	0.10		
	Pregnant with PGP	1.18 (1.12, 1.24)	< 0.001		
Stride width (m)			$P_{group} = 0.32$		$P_{group} = 0.62$
	Asymptomatic pregnant	0.10 (0.09, 0.11)	Ref.	0.1 (0.095, 0.11)	Ref.
	Asymptomatic non-pregnant	0.10 (0.10, 0.11)	0.56	0.11 (0.1, 0.12)	0.35
	Pregnant with PGP	0.11 (0.10, 0.12)	0.14	0.1 (0.095, 0.11)	0.95
Stride length (m)			$P_{group} < 0.001$		$P_{group} = 0.25$
	Asymptomatic pregnant	1.42 (1.39, 1.46)	Ref.	1.39 (1.36, 1.41)	Ref.
	Asymptomatic non-pregnant	1.43 (1.39, 1.46)	0.95	1.36 (1.34, 1.38)	0.37
	Pregnant with PGP	1.28 (1.24, 1.31)	< 0.001	1.37 (1.35, 1.39)	0.10
Ipsilateral step length[4] (m)			$P_{group} \leq 0.001$		$P_{group} = 0.89$
	Asymptomatic pregnant	0.70 (0.68, 0.72)	Ref.	0.69 (0.67, 0.70)	Ref.
	Asymptomatic non-pregnant	0.71 (0.69, 0.73)	0.45	0.68 (0.67, 0.70)	0.65
	Pregnant with PGP	0.64 (0.62, 0.66)	< 0.001	0.69 (0.67, 0.70)	0.96
Contralateral step length[5] (m)			$P_{group} \leq 0.001$		$P_{group} = 0.03$
	Asymptomatic pregnant	0.72 (0.70, 0.73)	Ref.	0.70 (0.69, 0.71)	Ref.
	Asymptomatic non-pregnant	0.71 (0.69, 0.73)	0.64	0.68 (0.67, 0.69)	0.02
	Pregnant with PGP	0.64 (0.62, 0.66)	< 0.001	0.68 (0.67, 0.69)	0.03
Cycle time (s)			$P_{group} < 0.001$		$P_{group} = 0.19$
	Asymptomatic pregnant	1.00 (0.97, 1.03)	Ref.	1.03 (1.01, 1.04)	Ref.
	Asymptomatic non-pregnant	0.96 (0.93, 0.99)	0.04	1.01 (0.99, 1.02)	0.08
	Pregnant with PGP	1.09 (1.06, 1.12)	< 0.001	1.02 (1.00, 1.04)	0.60
Stance time (s)			$P_{group} < 0.001$		$P_{group} = 0.045$
	Asymptomatic pregnant	0.60 (0.58, 0.63)	Ref.	0.62 (0.61, 0.63)	Ref.
	Asymptomatic non-pregnant	0.56 (0.53, 0.58)	0.002	0.60 (0.58, 0.61)	0.01
	Pregnant with PGP	0.67 (0.65, 0.69)	< 0.001	0.61 (0.60, 0.63)	0.33
Stance phase (% gait cycle)			$P_{group} < 0.001$		$P_{group} = 0.001$
	Asymptomatic pregnant	60 (59, 60)	Ref.	60 (59, 60)	Ref.
	Asymptomatic non-pregnant	59 (58, 59)	0.002	59 (58, 59)	0.003
	Pregnant with PGP	61 (61, 62)	0.001	61 (60, 61)	0.14
Double limb support (% gait cycle)			$P_{group} < 0.001$		$P_{group} = 0.001$
	Asymptomatic pregnant	20 (19, 21)	Ref.	20 (19, 21)	Ref.
	Asymptomatic non-pregnant	18 (17, 19)	0.004	18 (17, 19)	0.006
	Pregnant with PGP	22 (21, 23)	0.001	21 (20, 22)	0.04

[1]Linear mixed model with group and gait trial (1 to 4) in the model. The estimated marginal means describe the level within the three groups over the four repeated gait trials [2]adjusted for speed [3]P-value for group and for the comparison of asymptomatic women to asymptomatic non-pregnant women and pregnant women with PGP, Ref. = reference, [4]denoting step length on the side of symptomatic posterior pelvic pain (designated in asymptomatic participants by a coin toss), [5]denoting step length on the non-affected or less affected (non-test side for the asymptomatic women).

and for double limb support in non-pregnant women (ICC = 0.74) (Supplementary material, Table S3). Reliability was also good to excellent for all kinematic variables in all three groups (0.80 ≤ ICC ≤ 0.97) (Supplementary material, Table S4). For all variables, the intra-individual SDs were smaller than the between-group differences of the EMMs and the CI-differences for the EMMs of each group (Table S3–4).

4. Discussion

We found that spatiotemporal and kinematic gait characteristics in the 2nd trimester were primarily influenced by PGP and less by pregnancy. Pregnant women with PGP walked with a slower and more restricted gait pattern, as well as a greater side-to-side motion of the trunk compared to asymptomatic pregnant women. Although some gait variables were no longer significantly different between groups when adjusting for gait speed, PGP still influenced gait as indicated by longer double limb support, shorter step length and less pelvic and hip movement.

Pregnant women with PGP walked on average 18% slower and with shorter stride (10%), ipsilateral and contralateral step length (9% and 11% respectively) as well as longer cycle time (9%), stance time (12%) and double limb support (10%) compared to asymptomatic pregnant women. The effect estimates suggest a clinical significant influence of PGP. The lower speed in pregnant women with PGP is in concordance with Gutke et al. (2008) and Wu et al. (2008), while our finding of longer stance time in pregnant women with PGP versus asymptomatic pregnant women is in contrast to Kerbourc'h et al. (2017). However, we included analyses with adjustment for speed to reveal whether our findings persisted when accounting for between-group differences in speed. Then, only double limb support and contralateral step length remained significantly different between the two pregnant groups. This finding might have clinical implications. As asymmetric forces are likely to be transferred through the pelvis during the single leg stance phase of gait, a longer double limb support presumably reduces the demands on load transfer by minimizing stance time on one foot. Reducing stance time on one foot implies bringing the other foot to the ground sooner, shortening the step (Levine et al., 2012). Hence, the shorter contralateral step length in the PGP group might indicate impaired weight-bearing abilities on the painful or most painful side. As increased double limb support inherently accompanies slower gait speed (Neumann, 2010), slower speed in itself may be adaptive to altered load transfer. Accordingly, eight participants had an ASLR sum score > 4, indicating severe load transfer dysfunctions (Mens et al., 2002, 2012) in almost 1/3 of our PGP group.

Furthermore, we found that mean speed was negatively correlated with fear of movement and disability, but not with pain intensity in the PGP group. This is in line with Wu et al. (2008), implying that multiple

Table 4
Kinematic variables presented as estimated marginal means (EMMs) and 95% confidence intervals (CIs) comparing asymptomatic pregnant women (n = 24), asymptomatic non-pregnant women (n = 24) and pregnant women with PGP (n = 25).

		Crude estimates[1]		Adjusted estimates[2]	
Kinematic variables	Group	EMM (95% CI)	P^3	EMM (95% CI)	P^3
RoM[4] during gait cycle					
C7 lateral translation RoM (cm)[5]			$P_{group} = 0.004$		$P_{group} = 0.75$
	Asymptomatic pregnant	4.7 (4.4, 5.4)	Ref.	5.1 (4.7, 5.6)	Ref.
	Asymptomatic non-pregnant	4.6 (4.1, 5.1)	0.52	5.2 (4.8, 5.7)	0.76
	Pregnant with PGP	5.8 (5.3, 6.3)	0.01	4.9 (4.0, 5.4)	0.57
L3 lateral translation RoM (cm)[6]			$P_{group} = 0.01$		$P_{group} = 0.24$
	Asymptomatic pregnant	4.8 (4.4, 5.3)	Ref.	5.0 (4.6, 5.2)	Ref.
	Asymptomatic non-pregnant	4.2 (3.8, 4.7)	0.08	4.7 (4.3, 5.2)	0.11
	Pregnant with PGP	5.2 (4.8, 5.7)	0.25	4.5 (4.0, 5.0)	0.29
Pelvic frontal plane RoM (°)[7]			$P_{group} < 0.001$		$P_{group} = 0.003$
	Asymptomatic pregnant	10.9 (10.0, 11.9)	Ref.	10.9 (9.9, 11.8)	Ref.
	Asymptomatic non-pregnant	10.7 (9.8, 11.7)	0.80	10.6 (9.7, 11.6)	0.77
	Pregnant with PGP	8.3 (7.4, 9.3)	< 0.001	8.5 (7.5, 9.5)	0.002
Pelvic transversal plane RoM (°)			$P_{group} = 0.04$		$P_{group} = 0.35$
	Asymptomatic pregnant	13.9 (12.1, 15.8)	Ref.	13.8 (12.0, 15.6)	Ref.
	Asymptomatic non-pregnant	13.8 (11.9, 15.6)	0.92	13.2 (11.4, 15.1)	0.65
	Pregnant with PGP	11.1 (9.3, 12.8)	0.03	11.8 (9.9, 13.7)	0.15
Hip sagittal plane RoM (°)			$P_{group} = 0.001$		$P_{group} = 0.002$
	Asymptomatic pregnant	48.6 (46.9, 50.2)	Ref.	48.4 (46.7, 49.9)	Ref.
	Asymptomatic non-pregnant	48.1 (46.4, 49.8)	0.71	47.7 (46.0, 49.3)	0.56
	Pregnant with PGP	43.4 (41.7, 45.0)	< 0.001	44.0 (42.4, 45.7)	< 0.001
Hip frontal plane RoM (°)			$P_{group} = 0.01$		$P_{group} = 0.02$
	Asymptomatic pregnant	17.2 (15.9, 18.5)	Ref.	17.2 (15.9, 18.6)	Ref.
	Asymptomatic non-pregnant	17.1 (15.8, 18.5)	0.89	17.1 (15.8, 18.5)	0.77
	Pregnant with PGP	14.7 (13.4, 16.0)	0.008	14.6 (13.2, 16.0)	0.002
Trunk kinematics at specific events					
Thoracic transversal plane angle[8] at toe off (°)			$P_{group} = 0.01$		$P_{group} = 0.01$
	Asymptomatic pregnant	−0.2 (−1.5, 1.2)	Ref.	−0.2 (−1.5, 1.2)	Ref.
	Asymptomatic non-pregnant	2.7 (1.4, 4.1)	0.003	2.8 (1.3, 4.2)	0.003
	Pregnant with PGP	1.3 (−0.06, 2.6)	0.13	1.2 (−0.3, 2.7)	0.19
Pelvic kinematics at specific events					
Pelvic frontal plane angle[9] at peak hip adduction (°)			$P_{group} = 0.004$		$P_{group} = 0.005$
	Asymptomatic pregnant	5.3 (4.4, 6.1)	Ref.	5.3 (4.5, 6.2)	Ref.
	Asymptomatic non-pregnant	5.5 (4.6, 6.3)	0.79	5.5 (4.6, 6.4)	0.75
	Pregnant with PGP	3.6 (2.8, 4.4)	0.006	3.5 (2.6, 4.4)	0.005
Hip kinematics at specific events					
Hip sagittal plane angle[10] at peak hip adduction (°)			$P_{group} = 0.007$		$P_{group} = 0.04$
	Asymptomatic pregnant	28.2 (25.0, 31.3)	Ref.	28.1 (24.8, 31.3)	Ref.
	Asymptomatic non-pregnant	27.0 (23.4, 29.8)	0.49	26.4 (23.1, 29.7)	0.42
	Pregnant with PGP	21.3 (18.2, 24.4)	0.003	21.6 (18.2, 25.0)	0.01

[1]Linear mixed model with group and gait trial (1 to 4) in the model. The estimated marginal means describe the level within the three groups over the four repeated gait trials [2]adjusted for speed, [3]*P*-value for group and for the comparison of asymptomatic women to asymptomatic non-pregnant women and pregnant women with PGP, Ref. = reference, [4]range of motion during gait cycle, [5]translation of C7 spinal vertebra in relation to the laboratory coordinate system given in cm, [6]translation of L3 spinal vertebra in relation to the laboratory coordinate system given in cm, [7]degrees, [8]positive values indicate that the ipsilateral thorax is rotated forward on the side of the stance limb, [9]positive values indicate that the contralateral pelvis is dropped relative to the stance limb, [10]positive values denote hip flexion.

factors influence gait. As pregnant women with PGP report walking to be a main disability (Stuge et al., 2011), our results may be seen in contrast to a large cohort study of pregnant women reporting associations between disability and pain intensity, while no associations between disability and neither fear of movement nor ASLR score (Robinson et al., 2010). As we only had data on fear of movement and disability for the PGP group, we could not include these variables as factors in the gait analyses. Still, the observed correlations between speed and both fear of movement and disability in the PGP group suggest that further assessment of biopsychosocial factors in relation to gait kinematics is needed.

Interestingly, we found no significant difference in speed between asymptomatic pregnant and non-pregnant women. Our participants walked faster or slightly faster compared to what previous studies have reported (Bertuit et al., 2015; Bohannon and Williams Andrews, 2011; Branco et al., 2016; Gilleard, 2013; McCrory et al., 2014), possibly related to our inclusion of women earlier in pregnancy. Still, our EMMs showed 7% longer stance time and 10% longer double limb support in asymptomatic pregnant than non-pregnant women. After adjustment for speed, both variables remained significantly different between groups (3% and 10% respectively). Previous studies have also found longer stance time and double limb support (Aguiar et al., 2015; Bertuit et al., 2015; Branco et al., 2013; Kerbourc'h et al., 2017), presumably to increase stability and safety during gait in healthy pregnant women (Forczek et al., 2018).

Regarding kinematic variables, only thoracic transversal plane angle at TO was significantly different in asymptomatic pregnant versus non-pregnant women. When adjusting for speed, pregnant women had 3° less forward rotation of the ipsilateral thorax relative to the stance limb. This between-group difference remained significant after adjustment for contralateral step length, supporting that pregnancy itself influenced thoracic rotation. Our finding is consistent with those of Gilleard (2013), and might imply that the requirements for higher muscle activity (Gilleard, 2013) or increased anterior mass in the lower

trunk (Jensen et al., 1996) restrict trunk motion.

In pregnant women with PGP versus asymptomatic pregnant women, less hip sagittal plane RoM (5.2°) and less hip flexion at HS (5.7° in sensitivity analysis) and at PHA (6.9°) may indicate an excessive activity or altered timing of biceps femoris restricting hip flexion. Correspondingly, 2.6° less pelvic frontal plane RoM, 1.8° less pelvic drop contralateral to the stance limb at PHA and 2.5° less frontal plane hip RoM on the stance limb suggest increased hip abductor muscle activity. These hypotheses are supported by evidence of excessive muscle activity and bracing strategies (i.e. agonist and antagonist muscle activation) in individuals with PGP (Beales et al., 2009; Bussey and Milosavljevic, 2015; de Groot et al., 2008). However, muscular bracing may lead to more rigid movement patterns, overloading pelvic structures and thereby contribute to ongoing pain responses (Beales et al., 2009; Bussey and Milosavljevic, 2015).

Moreover, pregnant women with PGP walked with 1.1 cm greater lateral translation of the C7 vertebra than did asymptomatic pregnant women. We did not find a concurrent increased step width, as commonly reported in late pregnancy (Bertuit et al., 2015; Forczek and Staszkiewicz, 2012; Foti et al., 2000; McCrory et al., 2014). Hence, the greater side-to-side trunk motion was probably not related to a more lateral foot position. Instead, this may be a strategy to avoid pain provocation of pelvic structures, as moving the body's center of mass more laterally presumably shortens the hip abductor moment arm, reducing the demand on hip abductor muscles to control frontal pelvic position (Neumann, 2010). However, after adjustment for speed only frontal plane pelvic as well as sagittal and frontal plane hip kinematics remained significantly different between the pregnant groups. This might be seen in concordance with Foti et al. (2000), who suggested that changes in hip moment and power in pregnant women indicated an overuse of hip extensor and abductor muscles during gait possibly contributing to low-back, pelvic and hip pain.

Notably, the kinematic differences were small and likely not observed clinically. Except for pelvic drop contralateral to the stance limb at PHA (1.8°), all differences exceeded 2° and are larger than the proposed limit for acceptable measurement error in gait analyses ($\leq 2°$) (McGinley et al., 2009). Small differences may have clinical implications as they possibly reflect altered muscle function. Furthermore, they may precede and/or influence the development of PGP in late pregnancy or/and post-partum. However, electromyography (EMG) and longitudinal studies are needed to explore these hypotheses.

A major strength of our study is the inclusion of pregnant women with PGP, asymptomatic pregnant and non-pregnant women enabling assessment of the influence of both PGP and pregnancy on gait. Furthermore, all women were clinically examined to verify and/or exclude PGP. The use of linear mixed model analysis, taking variation within and between women into account is also an important strength of our study. This is unlike previous studies were the average of several gait trials represent an individual's performance in the group score (McClelland et al., 2009) even though repeated measurements on the same individual might imply dependencies in the data (Krueger, 2004). Still, we performed numerous tests and the concern with multiple comparisons must be kept in mind. The cross-sectional design is a main limitation, as no cause and effect relationships between PGP, pregnancy and the gait variables can be made. Finally, soft tissue artefacts and validity of skin markers to track underlying skeletal segments are common sources of error in kinematic analyses (McGinley et al., 2009).

5. Conclusion

We found that spatiotemporal and kinematic gait characteristic in the 2nd trimester were primarily influenced by PGP and less by pregnancy. Pregnant women with PGP walked on average 18% slower and with a more rigid gait pattern compared to asymptomatic pregnant women. Although speed influenced some gait variables and the kinematic differences were small, longer double limb support and restricted contralateral step length, pelvic and hip kinematics indicate altered load transfer in pregnant women with PGP. However, the negative correlation between gait speed and both fear of movement and disability in the PGP group suggest that biopsychosocial factors influence gait kinematics. Our results may assist the clinical assessment of pregnant women. However, EMG and longitudinal studies are needed to illuminate the underlying mechanisms and clinical implications of gait alterations in pregnant women with and without PGP.

Ethical approval

The Regional Committee for Medical and Health Research Ethics in Norway approved the study (2013/2312).

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CRediT authorship contribution statement

Lene Christensen: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization, Project administration. **Marit B. Veierød**: Methodology, Writing - review & editing, Visualization, Supervision. **Nina K. Vøllestad**: Conceptualization, Methodology, Writing - review & editing, Visualization, Supervision, Funding acquisition. **Vidar E. Jakobsen**: Software, Methodology, Resources, Writing - review & editing, Supervision. **Britt Stuge**: Conceptualization, Methodology, Writing - review & editing, Supervision, Funding acquisition. **Jan Cabri**: Conceptualization, Methodology, Resources, Writing - review & editing, Supervision. **Hilde Stendal Robinson**: Conceptualization, Methodology, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition.

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Declaration of Competing Interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clinbiomech.2019.05.030.

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