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Trunk, pelvic and hip kinematics during the Stork test in pregnant women with pelvic girdle pain, asymptomatic pregnant and non-pregnant women

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A B S T R A C T

Background: Pelvic girdle pain is prevalent during pregnancy, and women affected report weight-bearing activities to be their main disability. The Stork test is a commonly used single-leg-stance test. As clinicians report specific movement patterns in those with pelvic girdle pain, we aimed to investigate the influence of both pregnancy and pelvic girdle pain on performance of the Stork test.

Methods: In this cross-sectional study, 25 pregnant women with pelvic girdle pain, 23 asymptomatic pregnant and 24 asymptomatic non-pregnant women underwent three-dimensional kinematic analysis of the Stork test. Linear mixed models were used to investigate between-group differences in trunk, pelvic and hip kinematics during neutral stance, weight shift, leg lift and single leg stance.

Findings: Few and small significant between-group differences were found. Pregnant women with pelvic girdle pain had significantly less hip adduction during single leg stance compared to asymptomatic pregnant women (estimated marginal means (95% confidence intervals) -1.1° (−2.4°, 0.3°) and 1.0° (−0.4°, 2.4°), respectively; $P = 0.03$). Asymptomatic pregnant women had significantly less hip internal rotation compared to non-pregnant women 4.1° (1.6°, 6.7°) and 7.9° (5.4°, 10.4°), respectively ($P = 0.04$) and greater peak hip flexion angle of the lifted leg in single leg stance 80.4° (77.0°, 83.9°) and 74.1° (70.8°, 77.5°), respectively ($P = 0.01$). Variation in key kinematic variables was large across participants in all three groups.

Interpretation: Our findings indicate that trunk, pelvic and hip movements during the Stork test are not specific to pregnancy and/or pelvic girdle pain in the 2nd trimester. Instead, movement strategies appear unique to each individual.

1. Introduction

During pregnancy, women experience physiological, anatomical and functional changes (Jensen et al., 1996; Robinson et al., 2010; Vøllestad et al., 2012). In addition, a large number of pregnant women develop pelvic girdle pain (PGP) (Gutke et al., 2006; Gutke et al., 2018; Robinson et al., 2010; Vleeming et al., 2008), a musculoskeletal disorder with pain located in the posterior pelvis between the iliac crest and gluteal folds and/or the pubic symphysis (Vleeming et al., 2008). In general, the etiology of PGP is regarded multifactorial (Vleeming et al., 2008). Still, a theory of dysfunctional ability to transfer load from the spine to the legs through the pelvis has been considered a significant contributor (Pel et al., 2008; Pool-Goudzwaard et al., 1998). Positive associations have previously been found between PGP in pregnancy and altered pelvic joint mechanics and/or altered muscular function relative to pelvic movement (Aldabe et al., 2012). Importantly, pregnant women with PGP report to have reduced ability to perform weight-bearing activities such as standing and walking (Stuge et al., 2011).

We recently found that women with PGP in the 2nd trimester of pregnancy walked slower with longer double limb support and shorter step length compared to asymptomatic pregnant women, i.e. shortening the time in single leg stance (SLS) (Christensen et al., 2019a). As minimizing SLS time likely reduces the demands on load transfer, these gait characteristics might be adaptive to altered load transfer through the lumbo-pelvic-hip region (Christensen et al., 2019a). Pregnant women with PGP also walked with less pelvic frontal plane and hip

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sagittal and frontal plane movements, as well as greater lateral trunk translation (Christensen et al., 2019a). However, the kinematic differences were small and likely not observed clinically.

SLS is a necessary component of walking, and is a more difficult posture than double-leg stance as the base of support is narrower (Tropp and Odenrick, 1988). In SLS, asymmetric forces are likely to be transferred through the lumbo-pelvic-hip region in the transition between double to SLS, increasing the demands on load transfer through the pelvis (Bussey and Milosavljevic, 2015). SLS tests are commonly used to assess loading strategies in patients with lower limb disorders (Edmondston et al., 2013; Lee, 2011). Clinicians often evaluate and identify movement responses during SLS tests by visual observation (Edmondston et al., 2013). Key movement responses are lateral pelvic tilt and shift as well as lateral trunk motion relative to the stance leg (Grimaldi, 2011) during transition to (Lee, 2011) and in SLS (Grimaldi, 2011; Lee, 2011). The Stork test is a SLS test widely used when examining patients with PGP. From a double-leg stance position, the participant is instructed to stand on one leg and to lift the contralateral thigh towards the chest until 90° of hip flexion (Lee, 2011). The Stork test has been used to assess intra-pelvic motion by clinical palpation of the non-weight-bearing innominate relative to the ipsilateral sacrum (Hungerford et al., 2007; Lee, 2011). As sacro-iliac joint (SIJ) movements are found to be small (Kibsgard et al., 2012; Kibsgard et al., 2014; Sturesson et al., 2000a; Sturesson et al., 2000b) and clinical mobility tests of the SIJ in general show poor clinimetric properties (Klerx et al., 2019), the clinical value of motion palpation appears questionable. Nevertheless, as the body's center of mass moves in a more lateral direction over the standing leg during transition from double to SLS, it seems plausible that the Stork test particularly challenges medial-lateral trunk, pelvic and hip kinematics. From clinical observations in our research group, pregnant women with PGP often demonstrate a movement pattern of increased posterior pelvic tilt during the Stork test. An association between altered kinematics and PGP is largely based on clinical supposition, as only two studies have investigated pelvic kinematics during SLS tasks in individuals with PGP (Bussey and Milosavljevic, 2015; Hungerford et al., 2004). Of these, none reported kinematics in pregnant women. To inform the clinical interpretation of the Stork test in pregnant women with PGP, there is a need to explore whether the clinically reported differences in movement patterns of the trunk, pelvis and hip can be quantified, and how these patterns relate to PGP and pregnancy.

Asymptomatic pregnant women also report disability (Robinson et al., 2010) and demonstrate gait alterations (Branco et al., 2016; Christensen et al., 2019a; Gilleard, 2013; McCrory et al., 2014). The progressive weight gain primarily localized in the anterior lower-trunk and pelvic region (Jensen et al., 1996) is a unique feature of pregnancy with a likely impact on biomechanics. We therefore aimed to investigate the influence of both PGP and pregnancy in the 2nd trimester on trunk, pelvic and hip kinematics during the Stork test by comparing kinematics in pregnant women with PGP and non-pregnant women with asymptomatic pregnant women. Based on our findings in gait analysis and clinical experience, we hypothesized that pregnant women with PGP would lift their leg slower and demonstrate larger posterior pelvic tilt, less hip adduction and contralateral pelvic drop, as well as greater lateral trunk translation during this test compared to asymptomatic pregnant women in the 2nd trimester. Moreover, we hypothesized that pregnancy would have little influence on Stork kinematics in the 2nd trimester, demonstrated by few significant kinematic differences between asymptomatic pregnant and non-pregnant women.

2. Methods

2.1. Participants

We included 25 pregnant women with PGP, 24 asymptomatic pregnant and 25 asymptomatic non-pregnant women in this cross sectional study. The recruitment procedure is detailed elsewhere (Christensen et al., 2019b). The pregnant women had a no-risk pregnancy and were included before gestation week 27. Inclusion criteria for PGP participants were; posterior pelvic pain between the crista iliaca and the gluteal folds (Vleeming et al., 2008), 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, 2012). The ASLR test is assumed to assess load transfer (Mens, 2012). Asymptomatic women should have no pain in the pelvic area during the last six months and negative P4 and ASLR tests on clinical examination. The Regional Committees for Medical and Health Research Ethics approved the study (2013/2312). All participants provided written informed consent.

2.2. Procedures

All participants filled out a pain drawing and standardized questionnaires, and underwent a clinical assessment of pelvic pain and function (Christensen et al., 2019b). Height and weight were measured with a stadiometer and a medical scale, respectively. Pre-pregnancy body mass index (BMI, kg/m^2) in the pregnant groups and BMI in the non-pregnant group were calculated from self-reported data. Leg dominance was assessed by the question "Which leg do you prefer to stand on?" with four response alternatives: "right", "left", "both legs" and "do not know". For three-dimensional (3D) movement analysis, reflective markers were placed on the participants (Christensen et al., 2019a). Pelvic width and trochanter major distance were determined by the distance between the two anterior spina iliaca superior (ASIS) on the pelvis and the trochanter major of each femur, respectively.

Kinematic data were recorded by 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 (Advance Mechanical Technology Inc., Watertown, MA, US) at a sampling rate of 1500 Hz. All participants started in their natural standing position with feet approximately hip width apart and one foot on each force plate (Fig. 1). Standardized instruction to lift one leg up to 90° hip flexion and maintain a steady position for two seconds was given by the main researcher (LC). One practice trial on each leg was performed, after which five right and five left trials were completed. To reflect the clinical setting, the Stork test was performed barefoot, legs were lifted alternately and in self-selected speed. Participants were asked to stand relaxed (arms by the sides) between each trial. Rest was allowed whenever needed.

2.3. Stork analyses

Kinematic and kinetic data were low-pass filtered at 6 Hz using a digital 4th order Butterworth Bidirectional Filter (Robertson and Dowling, 2003). Joint angles were computed using Visual 3D software (C-motion Inc., Crabbs Branch Way Rockville MD). The thoracic and pelvic segments were modelled as described elsewhere (Christensen et al., 2019a) and analyzed with respect to the laboratory's coordinate system, oriented so that a positive y-direction was in the direction of standing. Pelvic angles were extracted using a rotation-obliquity-tilt sequence as recommended by Baker (Baker, 2001). Lateral pelvic translation was calculated according to Allison and colleagues (Allison et al., 2016), providing a relative quantification of the position of the foot to the midline of the participant. Trunk translation denotes the C7 marker relative to the calcaneal marker on the stance foot expressed in cm. The thigh segments were oriented in relation to the pelvic coordinate system, and the hip joint centers were estimated based on the pelvic markers using the regression equation of Harrington (Harrington et al., 2007).

The first four Stork trials where the participant maintained SLS without excessive trunk sway were used in the analyses. A steady SLS was defined by the 120-ms window with the least medial-lateral

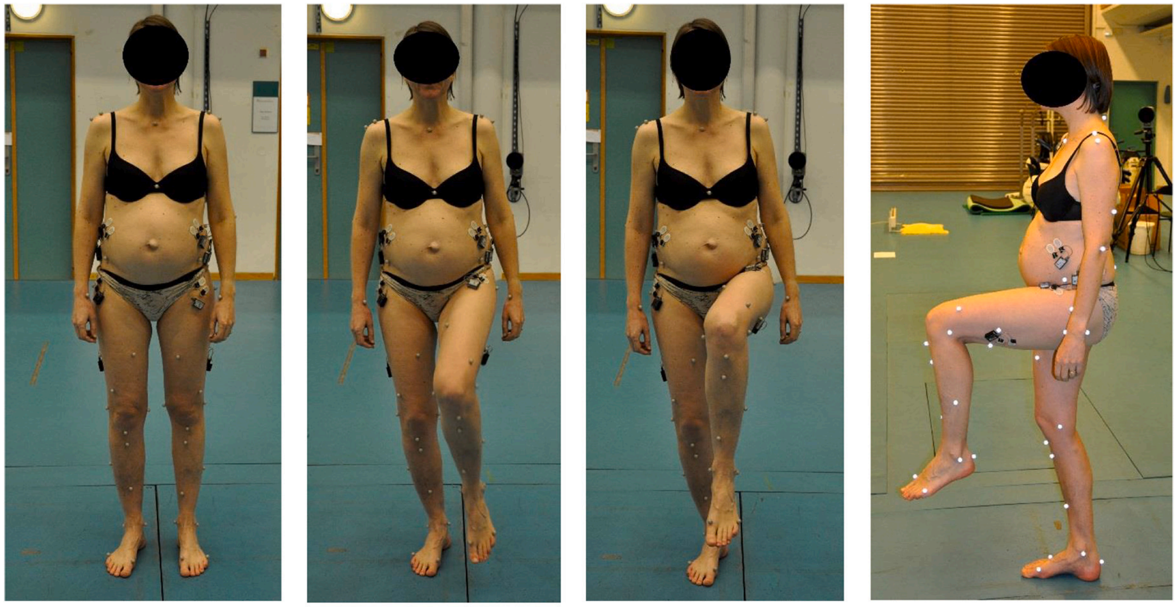

Fig. 1. Pregnant participant performing the Stork test.

movement of the ground reaction force (GRF) data from the force plate under the standing foot. This was decided by manual inspection, and trials were ignored if participants were unable to maintain SLS (Allison et al., 2016). Neutral stance represented self-selected double limb stance 450 frames prior to foot-off. Foot-off was defined using a threshold of < 20 N for the vertical GRF underneath the lifted leg (Allison et al., 2016). The weight-shift phase was defined between neutral stance and foot-off and the leg lift phase between foot-off and end of lift (EOL). EOL was determined as the first maximum of the calcaneus marker on the lifted foot in the vertical direction. Thoracic, pelvic and hip angles or range of motions (RoMs) in the sagittal, frontal and transversal planes as well as trunk and pelvic translations were calculated in neutral stance, during weight-shift and leg lift, and mean angles or translations during the 120-ms SLS period. Stance width (distance (cm) between calcaneus markers in neutral stance) and peak hip flexion angle of the lifted leg were extracted. We also calculated speed of leg lift as the first time derivative of the calcaneus marker in the +z-direction between foot-off and EOL (m/s).

Test side refers to the standing leg in the kinematic analysis. For pregnant women with PGP the painful or most painful side was determined the test side. For the four women reporting equal bilateral pain and the asymptomatic pregnant and non-pregnant women, a test side was randomly assigned using a coin toss.

2.4. Statistical analyses

Descriptive data are presented as frequencies (percentages), means (standard deviations (SDs)), or medians (interquartile range). Between-group differences were tested by chi-square test for categorical variables, and by one-way analysis of variance (ANOVA) or Kruskal-Wallis test for continuous variables. Pairwise comparisons were performed using Bonferroni corrections 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).

A linear mixed model (unstructured covariance matrix) was used to test between-group differences (asymptomatic pregnant women as reference) in kinematic variables during the four repeated Stork trials. We present estimated marginal means (EMMs) with 95% confidence intervals (CIs) to describe the level within the three groups over the four trials. We tested for interaction between group and trial, and when significant, the effect of group was studied within each trial by multiple linear regression analyses and a linear mixed model was used to study the effect of trial within each group. Except for hip frontal plane RoM during weight-shift ($P_{\text{interaction}} = 0.03$) and pelvic frontal plane angle during SLS ($P_{\text{interaction}} = 0.03$), we found no significant interaction effects in the analyses of kinematic variables ($0.15 \leq P_{\text{interaction}} \leq 0.97$). Between-group differences were very similar in all four trials for these two variables thus we present all results collapsed over trials (i.e. without interaction). The residuals were inspected for model assumptions. We repeated the analysis adjusting for pelvic width. In a recent study, leg dominance appeared to have a significant effect on anticipatory postural control strategies during SLS in healthy women (Bussey et al., 2018). To explore the potential influence of leg dominance on kinematics during the Stork test, we first repeated the analysis, adjusting for pelvic width and whether it was the dominant leg that was tested (yes/no). Secondly, we repeated the analysis in 1) the subgroup reporting their dominant leg as "both legs" or "do not know", as well as 2) the subgroup of asymptomatic pregnant and non-pregnant women. In the latter, we also adjusted for pelvic width and if dominant leg was tested. Finally, we performed sensitivity analyses in the whole study sample with additional adjustment for peak hip flexion angle of the lifted leg and then for speed of leg lift for the kinematic variables during leg lift and in SLS.

We used scatter plots to visually evaluate between and within individual variation for the significantly different variables. Furthermore, the variables stance width in neutral stance and speed of leg lift were selected for inspection as they may influence Stork performance, and frontal plane trunk and pelvic kinematics during SLS as they are commonly evaluated clinically.

Sample size calculation is described elsewhere (Christensen et al., 2019a). Data was analyzed using the IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp with a 5% significance level.

3. Results

3.1. Participant characteristics

Two women were excluded due to technical test errors, thus 25 pregnant women with PGP, 23 asymptomatic pregnant and 24 non-

Table 1
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 = 23)	Asymptomatic non-pregnant (n = 24)	P-value
Age (years), mean (SD)[1]	30.9 (2.2)	31.1 (3.3)	31.4 (4.0)	0.90 [2]
Height (m), mean (SD)	1.67 (0.07)	1.67 (0.07)	1.66 (0.06)	0.85[2]
Weight (kg), mean (SD)	68.7 (8.0)	67.7 (7.7)	63.4 (6.7)	0.04[2]
Pre-pregnancy BMI[3] in pregnant and BMI in non-pregnant (kg/m^2), mean (SD)	22.6 (2.2)	22.1 (2.1)	23.0 (1.7)	0.29[2]
Pelvic width[4] (cm), median (IQR)[5]	26 (25–28)	26 (25–27)	23 (22–25)	< 0.001[6]
Trochanter major distance[7] (cm), median (IQR)	39 (37–41)	39 (37–40)	38 (36–39)	0.15[6]
Test side[8] (right), n (%)	11 (44)	15 (65)	12 (50)	0.32[9]
Dominant leg tested[10] (yes), n (%)	13 (52)	16 (70)	17 (71)	0.27[9]
Pain duration (weeks), mean (SD)	7 (5)			
PGQ[11], mean (SD)[12]	42.7 (16.0)			
NRS for pain intensity[13], mean (SD)[12]	2.5 (1.9)			
One substitute question for TSK[14], median (IQR)[12]	6.5 (2–8)			
ASLR[15] score, median (IQR)	3 (2–5)			

[1]Standard deviation, [2]one way analysis of variance, [3]body mass index, self-reported, [4]determined by the distance between the anatomical landmarks anterior spina iliaca superior on the pelvis, [5]interquartile range, [6]Kruskal-Wallis test, [7]distance between trochanter major on the right and left femur, [8]side of symptomatic posterior pelvic pain, designated in asymptomatic participants by a coin toss, [9]chi-square test, [10]defined as match between the self-reported dominant leg ("right", "left" and "both legs") and the leg tested (when dominant leg and the test leg is the same, it is defined as match (yes)), [11]Pelvic Girdle Questionnaire, [12]n = 24, [13]numeric rating scale, [14]fear of movement measured by one substitute question for the Tampa Scale of Kinesiophobia, [15]active straight leg raise test.

pregnant women were included in the final analyses.

Weight and pelvic width were significantly different between groups ($P \leq 0.04$) (Table 1). Post hoc analyses revealed that weight was higher in pregnant women with PGP compared to non-pregnant women ($P = 0.049$), while no significant differences were found between asymptomatic pregnant women and neither pregnant women with PGP nor non-pregnant women ($0.16 \leq P \leq 1.00$). Pelvic width was significantly increased in both pregnant groups compared to the non-pregnant group ($P \leq 0.003$), but not significantly different between the two pregnant groups ($P = 0.43$).

3.2. Kinematic variables

In total, 47 kinematic variables were investigated. We found no significant effect of group in either crude or analyses adjusted for pelvic width ($0.051 \leq P_{group} \leq 0.99$) for 44 of these variables and these results are presented in Supplementary material, Table S1. Additional adjustment for dominant leg tested did not change the results ($0.08 \leq P_{group} \leq 0.99$) (Supplementary material, Table S1). For three variables, we found significant between-group differences in the crude or adjusted analyses (Table 2). When comparing pregnant women with PGP and asymptomatic pregnant women, EMMs showed 2.1° less ($P = 0.03$) hip adduction (frontal plane angle) during SLS in the crude analysis, remaining significantly different after adjustment for pelvic width ($P = 0.01$) (Table 2). Asymptomatic pregnant women had 3.8° ($P = 0.04$) less hip internal rotation (transversal plane angle) during SLS and 6.3° ($P = 0.01$) greater peak hip flexion angle of the lifted leg in the crude analysis compared to the asymptomatic non-pregnant women. Only peak hip flexion angle remained significantly different between these two groups after adjustment for pelvic width ($P = 0.02$) (Table 2). Additional adjustment, for whether dominant leg was tested, did not change the results (Table 2). We further explored the potential influence of leg dominance in the asymptomatic women ($n = 47$) and in the "both legs" and "do not know" (together, $n = 24$) subgroup. The results for most kinematic variables remained unchanged, except for one and eight variables, respectively, showing statistical significant between-group differences (Supplementary material, Table S4). In the "both legs" and "do not know" subgroup, two variables were no longer statistically different (Supplementary material, Table S4). Importantly, all between-group differences were small and EMMs in these subgroups differed little from the EMMs in the crude and adjusted analyses in the whole study sample.

In sensitivity analyses in the whole study sample, neither additional adjustment for peak hip flexion angle of the lifted leg nor speed of leg lift changed the results for any of the kinematic variables during leg lift and SLS (Supplementary material, Table S2). Scatter plots showed large variation across participants in all three groups, while the intra-individual variation over the four trials was generally small (Fig. 2-3).

4. Discussion

Few and small significant differences in trunk, pelvic and hip kinematics during the Stork test were found when comparing pregnant women with PGP and non-pregnant women with asymptomatic pregnant women. Moreover, visual inspection of kinematics using scatter plots indicates large variation in kinematics across participants in all three groups, with small intra-individual variation.

We hypothesized that pregnant women with PGP would lift their leg slower and demonstrate larger posterior pelvic tilt, less hip adduction and contralateral pelvic drop, as well as greater lateral trunk translation during the Stork test compared to asymptomatic pregnant women. However, in pregnant women with PGP compared to asymptomatic pregnant women, only one variable was significantly different, with EMMs showing 2.1° less hip adduction angle in SLS (Table 2). When adjusted for pelvic width, EMMs for the groups differed little from the EMMs in the crude analysis (Table 2). In contrast, Bussey and colleagues (Bussey and Milosavljevic, 2015) found slower leg lift and altered hip-spine kinematics in individuals with PGP compared to asymptomatic controls during a SLS. Importantly, their participants lifted the leg as fast as possible and the PGP participants were non-pregnant and had a long lasting condition (Bussey and Milosavljevic, 2015). Thus, comparisons are limited. In the present study, we wanted to mimic clinical practice and instructed participants to lift their leg at self-selected speed. From our clinical experience, some patients lift their leg in a fast speed during a SLS task, while others lift their leg in a slow manner. This probably reflects different movement strategies, although it is unknown if one is easier than the other. Since speed has an influence on biomechanics during gait (Levine et al., 2012; Neumann, 2010; Roislien et al., 2009; Wu et al., 2004; Wu et al., 2008), it seems reasonable that the speed of leg lift may affect trunk, pelvic and hip kinematics during the Stork test. In response, we performed sensitivity analyses with additional adjustment for speed of leg lift. However, this did not change the results. In contrast to the study by Bussey and colleagues (Bussey and Milosavljevic, 2015), our PGP participants were pregnant with onset of posterior pelvic pain in current pregnancy (i.e. recently). PGP affliction varied illustrated by the wide range of scores

Table 2
Estimated marginal means (EMMs) and 95% confidence intervals (CIs) for kinematic variables comparing asymptomatic pregnant women (n = 23), asymptomatic non-pregnant women (n = 24) and pregnant women with PGP (n = 25).

Kinematic variables	Group	Crude[1] EMM (95% CI)	P^4	Adjusted[2] EMM (95% CI)	P^4	Adjusted[3] EMM (95% CI)	P^4
Stance leg							
Single leg stance							
Hip frontal plane angle[5] (°)[6]			P_{group} = 0.10		P_{group} = 0.03		P_{group} = 0.07
	Asymptomatic pregnant	1.0 (−0.4, 2.4)	Ref	0.8 (−0.6, 2.1)	Ref	0.5 (−0.9, 1.8)	Ref
	Asymptomatic non-pregnant	−0.1 (−1.5, 1.3)	0.25	0.7 (−0.7, 2.2)	0.98	0.5 (−1.0, 2.0)	0.97
	Pregnant with PGP	−1.1 (−2.4, 0.3)	0.03	−1.6 (−3.0, −0.3)	0.01	−1.6 (−3.0, −0.3)	0.03
Hip transversal plane angle[7] (°)			P_{group} = 0.045		P_{group} = 0.75		P_{group} = 0.64
	Asymptomatic pregnant	4.1 (1.6, 6.7)	Ref	4.6 (2.2, 7.0)	Ref	4.1 (1.6, 6.5)	Ref
	Asymptomatic non-pregnant	7.9 (5.4, 10.4)	0.04	5.9 (3.4, 8.5)	0.46	5.5 (3.0, 8.1)	0.42
	Pregnant with PGP	4.0 (1.6, 6.4)	0.94	5.4 (3.0, 7.8)	0.65	5.4 (3.0, 7.7)	0.46
Lifted leg							
Peak hip flexion angle in SLS[8] (°)			P_{group} = 0.04		P_{group} = 0.07		P_{group} = 0.07
	Asymptomatic pregnant	80.4 (77.0, 83.9)	Ref	80.4 (77.0, 84.0)	Ref	80.8 (77.2, 84.4)	Ref
	Asymptomatic non-pregnant	74.1 (70.8, 77.5)	0.01	74.2 (70.5, 78.0)	0.02	74.7 (70.8, 78.5)	0.02
	Pregnant with PGP	77.6 (74.5, 81.0)	0.27	77.7 (74.2, 81.2)	0.27	77.6 (74.1, 81.1)	0.20

[1]Linear mixed model with group and Stork trial (1 to 4) in the model. The estimated marginal means describe the level within the three groups over the four repeated Stork trials, [2]adjusted for pelvic width, [3]adjusted for pelvic width and dominant leg tested (defined by match of the dominant leg (defined by "right", "left" and "both legs") and the leg tested, when dominant leg and the test leg is the same, it is defined as match (yes)), [4]*P*-value for group and for comparison with asymptomatic pregnant women, Ref. = reference, [5]postive values denote hip adduction, [6]degrees, [7]positive values denote hip internal rotation, [8]positive values denote hip flexion.

on PGQ (10–73%), NRS for pain intensity (0–7) and ASLR (1–8) (Christensen et al., 2019a). Importantly, the affliction of our participants is comparable with a large Norwegian pregnant cohort (Robinson et al., 2010). Still, we cannot exclude greater kinematic differences in more afflicted women or later in pregnancy.

The asymptomatic pregnant women had on average 3.8° less hip internal rotation on the stance leg and 6.3° greater peak hip flexion of the lifted leg compared to non-pregnant women. When adjusting for pelvic width, hip internal rotation was no longer significantly different between the two asymptomatic groups, indicating an influence of pelvic width. Although weight differed significantly between groups, weight gain is an inherent feature of pregnancy. Thus, we did not adjust for weight in our analysis, otherwise excluding the effect of pregnancy.

Clinical important differences, although not statistical significant, have been found in the performance of the dominant leg compared to the non-dominant leg in different functional tests (McGrath et al., 2016). Although self-reported "preferred leg to kick a ball" is often used to decide leg dominance (McGrath et al., 2016), the literature reports different methods to determine leg dominance (Peters, 1988; van Melick et al., 2017). Leg dominance may also vary between tasks (McGrath et al., 2016), such as bilateral mobilizing tasks (e.g. kicking a ball) and unilateral stabilizing tasks (e.g. SLS) (McGrath et al., 2016; van Melick et al., 2017). In SLS the standing leg has been suggested to be the dominant leg (Peters, 1988), thus relevant in our study. To explore the potential effect of dominant leg on trunk, pelvic and hip kinematics, we repeated our analyses with additional adjustment for dominant leg tested as well as performed subgroup analyses. The adjustment for dominant leg tested did not change the results (Table 2 and

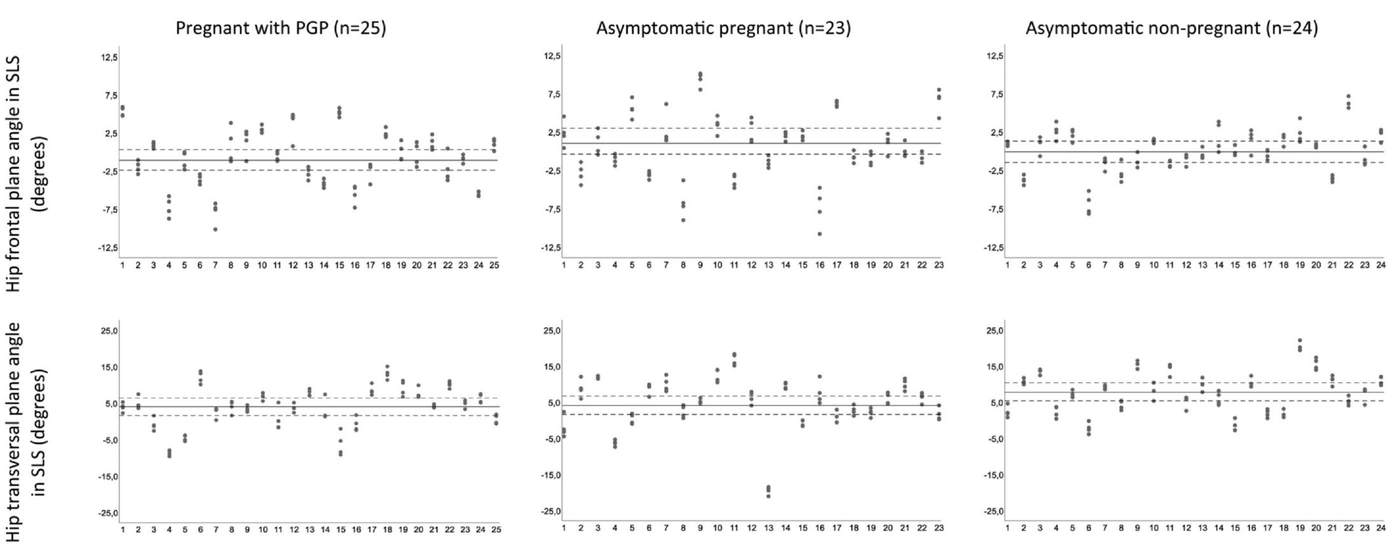

Fig. 2. Scatter plots of each woman's results in the four Stork trials illustrating between and within participant variation for hip frontal plane angle in SLS (positive values denote hip adduction in degrees), hip transversal plane angle in SLS (positive values denote hip internal rotation in degrees) and peak hip flexion angle of the lifted leg (positive values denote hip flexion in degrees). Results are presented for pregnant women with PGP, asymptomatic pregnant women and asymptomatic non-pregnant women. Estimated marginal means (solid line) with 95% confidence intervals (dotted lines) from the crude analysis are shown, describing the level within the three groups over the four trials.

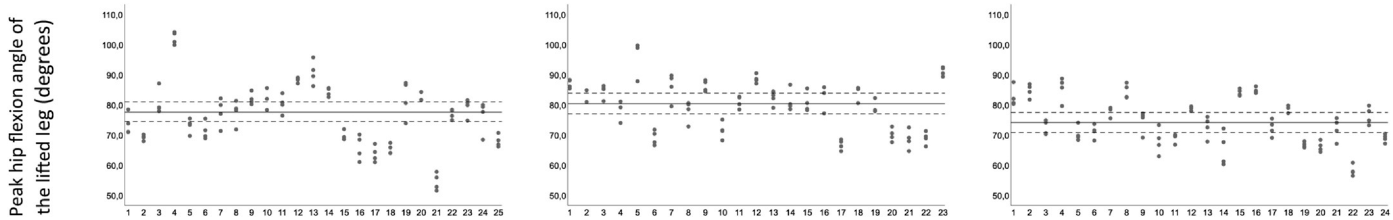

Fig. 2. (*continued*)

Supplementary material, Table S1-S4). In the subgroup analyses, a few more variables reached statistical significance. However, the between-group differences were small and EMMs for the groups differed little from the EMMs in the crude and adjusted analyses in the whole study sample. Based on these results, leg dominance did not seem to influence trunk, pelvic and hip kinematics in our study. We instructed the participants to lift their leg to 90° of hip flexion. On the other hand, lifting the leg to 30° of hip flexion might be considered more functional, as it better resembles hip flexion excursion during for example walking. It has also been advocated that lifting the leg to 90° in contrast to 30° of hip flexion facilitates an excessive elevation of the contralateral pelvis (Grimaldi, 2011). We found that frontal plane pelvic angles ranged from contralateral pelvic elevation ($< 0°$) to contralateral pelvic drop ($> 0°$) during SLS (Fig. 3). Even though the Stork test likely challenges load transfer and particularly frontal plane kinematics, hardly any between-group differences were evident in our study. Hence, the Stork test apparently did not reveal between-group kinematic differences in contrast to our findings during gait in the same study sample (Christensen et al., 2019a). This is clinically relevant and questions the carry-over between kinematics during an isolated SLS task and cyclic gait movements.

Noteworthy, the present kinematic differences were in range of a few degrees and unlikely detectable clinically. In comparison, Edmondston and colleagues (Edmondston et al., 2013) found that trunk movements during SLS tasks were small in asymptomatic, young women. As noted in Figs. 2 and 3, we found large variation in the key kinematic variables across participants in all three groups. Conversely, intra-individual variation over the four trials was generally small indicating that participants performed the Stork test quite consistently.

Large inter-individual variation has been reported in biomechanical studies on pregnant gait (Foti et al., 2000; Gilleard, 2013; McCrory et al., 2014; Wu et al., 2008), and proposed to reflect that adaptation to pregnancy is unique to each individual (Gilleard, 2013; McCrory et al., 2014). Interestingly, we found large inter-individual variation in all three groups (Figs. 2 and 3). This may reflect the complexity of achieving balance on one foot and that participants used individual movement strategies to accomplish SLS. Presumptively an inherent feature of SLS is the possibility for subtle adjustments in multiple joints. The large movement variation across participants support that SLS tests reflect an individual's self-selected movement strategy (Grimaldi, 2011). This has clinical relevance, suggesting that trunk, pelvic and hip movements during the Stork test are not specific to pregnancy and/or PGP in the 2nd trimester. Accordingly, the clinician may not anticipate specific movement patterns on visual observation of trunk, pelvic and hip kinematics during this test in pregnant women with and without PGP in the 2nd trimester. Interestingly, de Groot and colleagues (de Groot et al., 2008) found higher trunk and hip muscle activity in pregnant women with PGP compared to asymptomatic pregnant women during the ASLR test. We cannot exclude the presence of similar mechanisms during the Stork test.

As far as we know, this is the first study of the influence of pregnancy and PGP on three-dimensional kinematics of a SLS task. The strict inclusion criteria and clinical examination of all women to verify and/or exclude PGP are important strengths. Moreover, linear mixed model analysis was used, taking variation within and between women into account. However, the concern with multiple comparisons must be kept in mind as numerous tests were performed. The relatively small sample size is a limitation, but we have found several significant between-

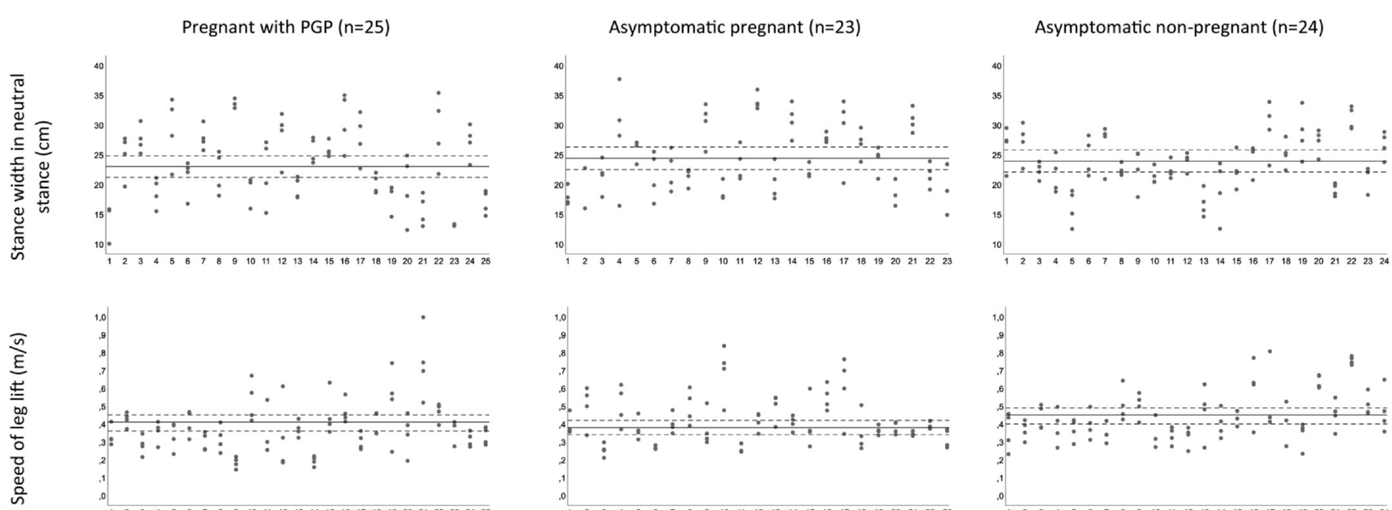

Fig. 3. Scatter plots of each woman's results in the four Stork trials illustrating between and within participant variation for stance width in neutral stance (cm), speed of leg lift (m/s), thoracic frontal plane angle in SLS (positive values denote ipsilateral thoracic lean in degrees), trunk translation in SLS (represents the marker on the 7th cervical vertebra relative to the stance leg in cm), pelvic frontal plane angle in SLS (positive values denote that the contralateral pelvis is dropped relative to the stance leg in degrees) and pelvic translation in SLS (% inter-ASIS distance/2, where 0% represents a position of the calcaneus directly under the midline between the two anterior superior iliac spines (ASIS), 100% represents the calcaneus directly under the ASIS, negative values indicate that the foot has crossed the midline). Results are presented for pregnant women with PGP, asymptomatic pregnant women and asymptomatic non-pregnant women. Estimated marginal means (solid line) with 95% confidence intervals (dotted lines) from the crude analysis are shown, describing the level within the three groups over the four trials.

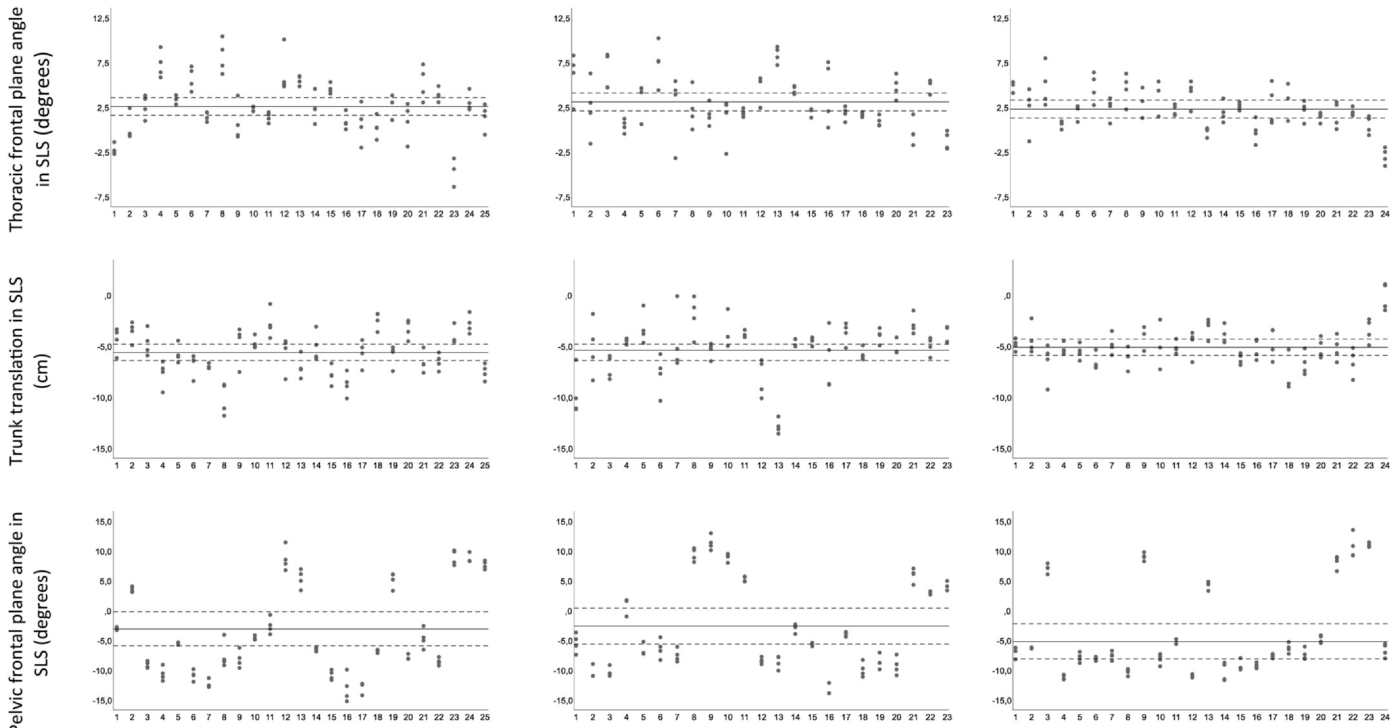

Fig. 3. (*continued*)

group differences in gait kinematics in this sample (Christensen et al., 2019a). Soft tissue artefacts should be taken into account as this is a common source of error in 3D kinematic analyses (McGinley et al., 2009). Finally, the single kinematic variables examined in this study might not sufficiently reflect the composite picture of a single leg stance movement. Thus, there is a need for further studies of the relation between clinical observation and kinematic assessments.

5. Conclusion

We found few and small significant differences in trunk, pelvic and hip kinematics during the Stork test in pregnant women with PGP and asymptomatic non-pregnant women compared with asymptomatic pregnant women. The large variation found in kinematic variables across all participants and small intra-individual variation indicate that individual movement strategies were used to accomplish SLS. Our findings have clinical relevance, indicating that trunk, pelvic and hip movements during the Stork test are not specific to pregnancy and/or PGP in the 2nd trimester. Although further studies are needed of the relation between clinical observation and kinematic assessments, clinicians using the Stork test should be aware of that movement responses during this test appear to be unique to each individual in the 2nd trimester.

Credit author statement

Acknowledgement section of the submitted paper as shown below:

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Ethical approval

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

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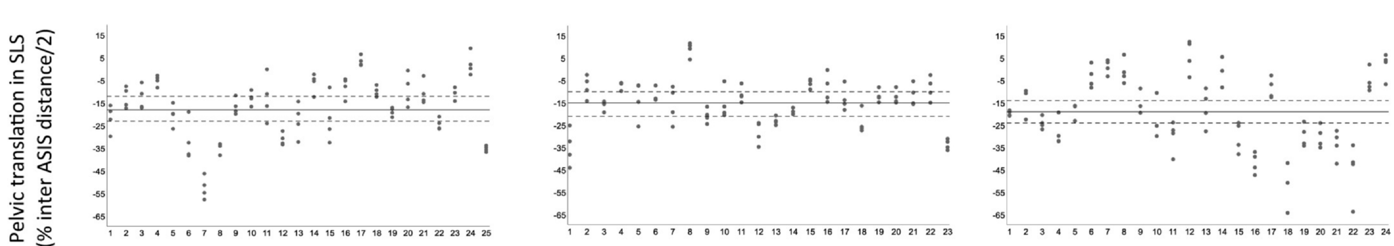

Fig. 3. (*continued*)

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clinbiomech.2020.105168.

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