The influence of pregnancy and pelvic girdle pain on weight-bearing activities

- A biomechanical and clinical study

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Table of Contents

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Summary

Background: During pregnancy, women experience physiological and anatomical changes that may influence their physical function. In addition, a large number of pregnant women develop pelvic girdle pain (PGP). PGP is regarded a musculoskeletal disorder and commonly affects everyday activities, work ability and quality of life. Pregnant women with PGP often report pain and limited ability to perform weight-bearing activities, particularly walking. However, few studies have assessed gait characteristics in this population. It is previously shown that self-reported disability as well as altered gait biomechanics may be present also in healthy pregnant women. Since weight-gain during pregnancy likely influences movement, it seems pertinent to investigate the influence of PGP and pregnancy on gait prior to the 3rd trimester. Still, few have studied gait biomechanics in the 2nd trimester and the results differ. Hence, there is a need to explore spatiotemporal and kinematic gait characteristics in pregnant women with and without PGP in the 2nd trimester and in asymptomatic non-pregnant women.

Despite the importance of weight-bearing activities, few functional tests have previously been available in the clinical examination of pregnant women with PGP. The Stork test is a single leg stance (SLS) test proposed to examine loading strategies also in PGP patients. Clinicians observe and describe specific movement patterns and often assume that these patterns are related to PGP. However, there is a need to explore whether movement patterns can be identified and, how these patterns relate to PGP and pregnancy.

Recently, the Timed Up and Go (TUG) test was proposed as a physical performance-based test in pregnant women with PGP. TUG is a standardized, timed functional mobility test and includes stand up, turn around, walk and sit down. Hence, it involves activities problematic for pregnant women with PGP and, may assist in determining the extent of physical disability and complement patient-reported instruments. However, further research is needed to investigate if TUG time differs between pregnant women with and without PGP and in non-pregnant women, as well as what factors potentially influence TUG time in the 2nd trimester.

Aims: The overall aim of this thesis was to explore the influence of PGP and pregnancy on weight-bearing activities in the 2nd trimester of pregnancy, by comparing pregnant women with PGP and asymptomatic non-pregnant women versus asymptomatic pregnant women. Specifically, we aimed to explore between-group differences in spatiotemporal characteristics and trunk, pelvic and hip kinematics during gait and the Stork test, measured by 3 dimensional (3D) kinematic analyses. We also aimed to compare TUG time in these three groups of women, and to identify potential factors associated with longer TUG time.

Methods: This cross-sectional study included 25 pregnant women with PGP, 24 asymptomatic pregnant (all 49 before gestation week 27) and 25 asymptomatic non-pregnant women. All underwent clinical examination including the TUG test, as well as 3D movement analysis of the Stork test and gait at self-selected speed. In paper I, one-way analysis of variance was used

to explore between-group differences in TUG, and multiple linear regression analyses to explore associations between TUG and potential explanatory variables in the total study sample and in pregnant women with PGP. In paper II and III, linear mixed models were used to investigate between-group differences in spatiotemporal gait characteristics, as well as trunk, pelvic and hip kinematics during gait and the Stork test. In addition, bivariate analyses were used in paper II to investigate the relationship between gait speed and fear of movement, self-reported disability and pain intensity in the pregnant women with PGP.

Results: During gait at self-selected speed, pregnant women with PGP demonstrated significant slower gait speed (18 %) and up to 10 % difference in spatiotemporal variables, as well as small pelvic and hip kinematic differences compared to asymptomatic pregnant women. In the PGP group, gait speed was negatively associated with fear of movement and self-reported disability, while it was not significantly associated with pain intensity. Asymptomatic pregnant women walked with longer cycle time, stance time and double limb support and less thorax rotation as compared to non-pregnant women.

In the Stork test, we generally found few and only small significant between-group differences in spatiotemporal and kinematic variables. Importantly, the variation in kinematic variables was large across participants in all three groups during this test.

TUG time varied among pregnant women with PGP, and this group used significantly longer time than asymptomatic pregnant and non-pregnant women. In the total study sample, longer TUG time was significantly associated with group, higher BMI and sick leave. In pregnant women with PGP only pain intensity remained significantly associated with longer TUG time in the multivariable analysis.

Conclusion: This thesis provides novel information on weight-bearing activities in the 2nd trimester of pregnancy. We found that PGP influenced TUG time, as well as gait characteristics in the 2nd trimester. Pregnant women with pelvic girdle pain walked slower and with a more rigid movement pattern compared to asymptomatic pregnant women. Pregnancy also influenced a few gait variables, demonstrated by significant differences between asymptomatic pregnant and non-pregnant women.

Our findings provide a basis for the clinical evaluation of gait and support TUG time as a suitable measure of activity-limitations in pregnant women with PGP in the 2nd trimester. The associations between TUG time and pain intensity, and between gait speed and both fear of movement and disability, indicate that biopsychosocial aspects relate to weight-bearing activities in women with PGP in the 2nd trimester. Neither PGP nor pregnancy appeared to influence trunk, pelvic and hip movements during the Stork test, and clinically observed movement patterns were not identified in our study. Hence, visually observing trunk, pelvic and hip movement patterns during this test may have limited clinical importance when examining pregnant women in the 2nd trimester, and clinicians using the test should pay attention to individual movement responses rather than focusing on specific patterns.

Sammendrag

Bakgrunn: Graviditet innebærer fysiologiske og anatomiske endringer som kan påvirke kvinners fysiske funksjon. I tillegg, rammes mange gravide av bekkenleddsmerter. Bekkenleddsmerter er en muskelskjelettlidelse, som kan ha stor innvirkning på dagligliv, arbeidsevne og livskvalitet. Gravide med bekkenleddsmerter rapporterer ofte smerter og nedsatt funksjon i vektbærende aktiviteter. Til tross for at det å gå er spesielt utfordrende, har få studier undersøkt gangfunksjon hos denne gruppen. Tidligere studier har imidlertid vist at friske gravide opplever funksjonsnedsettelse og har endret gangfunksjon. Siden den naturlige vektøkningen, som oppstår i løpet av svangerskapet, trolig påvirker bevegelsesfunksjon, er det hensiktsmessig å undersøke hvordan bekkenleddsmerter og graviditet påvirker gangfunksjon før 3. trimester. Dette kan gjøres ved biomekaniske undersøkelser hvor man kvantifiserer og sammenligner spatiotemporale og kinematiske gangvariabler hos gravide kvinner med og uten bekkenleddsmerter i 2. trimester og hos ikke-gravide kvinner.

Vurdering av vektbærende aktiviteter er ofte i fokus i den kliniske undersøkelsen av gravide kvinner med bekkenleddsmerter. Det finnes likevel få aktuelle funksjonstester. Stork er en ett-bens stående test, som ofte benyttes for å vurdere vektbæringsstrategier hos gravide med bekkenleddsmerter. Det er en klinisk oppfatning at de gravide med bekkenleddsmerter har spesifikke bevegelsesmønstre av overkropp, bekken og hofteledd som kan observeres og relateres til smerter. Det er derfor behov for å undersøke om man kan identifisere bevegelsesmønstre i Stork testen, samt undersøke om disse mønstrene er relatert til bekkenleddsmerter og graviditet.

Timed Up & Go (TUG) er en standardisert, funksjonell mobilitetstest utført på tid, som nylig er foreslått som en fysisk funksjonstest for gravide med bekkenleddsmerter. TUG innebærer å reise seg fra en stol, gå tre meter, snu, gå tilbake og sette seg på stolen igjen. Siden TUG utfordrer aktiviteter som ofte er smertefulle og vanskelige å utføre for de med bekkenleddsmerter, kan den være nyttig for å vurdere omfanget av fysisk funksjons-nedsettelse. Det er således behov for å undersøke om det er forskjell i TUG tide hos gravide med og uten bekkenleddsmerter og hos ikke-gravide kvinner, samt hvilke faktorer som påvirker TUG tid.

Mål: Hovedhensikten med doktorgradsarbeidet var å utforske hvordan bekkenleddsmerter og graviditet påvirker vektbærende aktiviteter i 2. trimester ved å sammenligne gravide kvinner med bekkenleddsmerter og asymptomatiske ikke-gravide kvinner med asymptomatiske gravide kvinner. Spesifikt, å kvantifisere og sammenligne gruppeforskjeller i spatiotemporale variabler og ved bevegelse av overkropp, bekken og hofter i gange og Stork testen målt ved tredimensjonal (3D) bevegelsesanalyse. Videre, å sammenligne TUG tid i disse tre gruppene, samt å identifisere potensielle faktorer assosiert med lengre TUG tid.

Metode: Tjue-fem gravide med bekkenleddsmerter, 24 asymptomatiske gravide kvinner (alle 49 inkludert før svangerskapsuke 27) og 25 asymptomatiske ikke-gravide deltok i denne

tverrsnittstudien. Alle gjennomførte en klinisk undersøkelse inkludert TUG test, samt 3D bevegelsesanalyse av gange i selvvalgt hastighet og Stork testen. I artikkel I, ble variansanalyse (one-way analysis of variance, ANOVA) benyttet for å utforske gruppeforskjeller i TUG tid, og multippel lineær regresjonsanalyse for å undersøke assosiasjoner mellom TUG tid og potensielle forklaringsvariabler i hele utvalget, samt kun i gruppen med bekkenleddsmerter. I artikkel II og III, ble «linear mixed models» benyttet for å undersøke gruppeforskjeller i spatiotemporale- og kinematikkvariabler i overkropp, bekken og hofte i gange og i Stork test. I artikkel II, ble bivariate analyser benyttet for å studere forholdet mellom ganghastighet og bevegelsesfrykt, funksjonsnedsettelse og smerteintensitet hos de med bekkenleddsmerter.

Resultater: Gravide kvinner med bekkenleddsmerter gikk signifikant saktere (18 %) og med opptil 10 % forskjell i spatiotemporale variabler ved selvvalgt ganghastighet, samt at det var små forskjeller i bevegelse av bekken og hofte sammenlignet med asymptomatiske gravide kvinner. Det var en negativ sammenheng mellom ganghastighet, bevegelsesfrykt og selvrapportert funksjonsnedsettelse hos de med bekkenleddsmerter. Asymptomatiske gravide hadde lengre gangsyklus, lengre standfase og benyttet lengre tid stående på to ben, samt gikk med mindre rotasjon i overkroppen sammenlignet med ikke-gravide kvinner.

I Stork testen fant vi få og kun små signifikante forskjeller i kinematikkvariabler mellom gruppene. Variasjonen var stor i Stork variable blant deltakerne innad i hver av gruppene.

Det var stor variasjon i TUG tid blant de gravide med bekkenleddsmerter, og disse brukte signifikant lengre tid sammenlignet med kvinner i de to andre gruppene. Gruppe, høyere BMI og sykefravær var signifikant assosiert med lengre TUG tid i hele utvalget. Smerteintensitet var den eneste faktoren med signifikant sammenheng med økt TUG tid i mulitivariable analyser blant de gravide med bekkenleddsmerter.

Konklusjon: Vi har gjennom disse studiene, utviklet ny kunnskap om vektbærende aktiviteter hos gravide kvinner i 2. trimester. Vi fant at bekkenleddsmerter påvirket TUG tid og spatiotemporale- og kinematikkvariabler i gange. Gravide med bekkenleddsmerter gikk saktere og med et mer rigid gangmønster sammenlignet med asymptomatiske gravide kvinner. Vi fant forskjeller i noen få av gangvariablene mellom asymptomatiske gravide og ikke-gravide kvinner, som tyder på at graviditet også affiserer gangfunksjon i 2. trimester.

Våre resultater gir et fundament for klinisk evaluering av gange, samt for å benytte TUG tid som et relevant mål for funksjonsnedsettelse hos gravide med bekkenleddsmerter i 2. trimester. Sammenheng mellom ganghastighet, bevegelsesfrykt og funksjonsnedsettelse, samt mellom TUG tid og smerteintensitet, kan tyde på at biopsykososiale forhold har betydning i utførelse av vektbærende aktiviteter hos de med bekkenleddsmerter. I Stork testen kunne vi ikke identifisere de klinisk, observerte bevegelsesmønstrene for overkropp, bekken og hofte, men vi fant i stedet variasjon i individuelle bevegelsesstrategier i alle tre gruppene. Dette kan tyde på at det har liten klinisk betydning å lete etter spesifikke bevegelsesmønstre, og at klinikere som benytter Stork testen heller bør se etter individuelle bevegelsesstrategier hos gravide kvinner i 2. trimester.

Articles in the thesis

Paper I

Lene Christensen, Nina K. Vøllestad, Marit B. Veierød, Britt Stuge, Jan Cabri and Hilde Stendal Robinson. *The Timed Up & Go test in pregnant women with pelvic girdle pain compared to asymptomatic pregnant and non-pregnant women.* Musculoskeletal Science and Practice. 43 (2019) 110-116

Paper II

Lene Christensen, Marit B. Veierød, Nina K. Vøllestad, Vidar E. Jakobsen, Britt Stuge, Jan Cabri and Hilde Stendal Robinson. *Kinematic and spatiotemporal gait characteristics in pregnant women with pelvic girdle pain, asymptomatic pregnant and non-pregnant women.* Clinical Biomechanics. 68 (2019) 45-52

Paper III

Lene Christensen, Nina K. Vøllestad, Marit B. Veierød, Vidar E. Jakobsen, Britt Stuge, Eva S. Bakke, Jan Cabri and Hilde Stendal Robinson. *Trunk, pelvic and hip kinematics during the Stork test in pregnant women with pelvic girdle pain, asymptomatic pregnant and non-pregnant women.* Submitted to a new Journal, 17th of January 2020: Clinical Biomechanics

Abbreviations

3D	3 Dimensional
ASIS	Anterior spina iliaca superior
AIM	Automatic identification of markers function
ASLR	Active straight leg raise test
BMI	Body mass index; kg/m2
COP	Center of pressure
EMG	Electromyography
EMM	Estimated marginal means
EQ-5D-5L	European Quality of Life 5-Dimensional Questionnaire 5 level version
FDA	Functional data analysis
GRF	Ground reaction force
ICC	Intraclass correlation coefficient
ISB	International Society of Biomechanics
LBP	Low back pain
LHS	Left heel strike
LTO	Left toe off
N	Newton
NIH	Norwegian School of Sport Sciences
NRS	Numeric Rating Scale
P4-test	Posterior pelvic pain provocation test
PGP	Pelvic girdle pain
PGQ	Pelvic Girdle Questionnaire
PSFS	Patient Specific Functional Scale
RHS	Right heel strike
ROM	Range of motion
RTO	Right toe off
SCL-10	Hopkins Symptom Check List – 10 items
SIJ	Sacroiliac joint
SLS	Single leg stance
TSD	Services for Sensitive Data
TUG-test	Timed Up and Go test
UiO	University of Oslo
V3D	Visual 3D (software)

Introduction

A large group of young, healthy women experience pelvic girdle pain during their pregnancy. Several of them perceive reduced physical function and ability to perform weight-bearing activities. Clinicians observe and describe specific movement patterns assumed to be related to PGP. Is it possible to identify, reproduce and quantify these patterns and explore how they relate to PGP and pregnancy?

Pregnancy is a unique time in a woman`s life, often filled with positive expectations for the close future. As part of a normal pregnancy, women experience several bodily changes including physiological, hormonal and anatomic adaptations [1, 2]. Although women often expect life to continue more or less normally, several experience pregnancy to have an impact on their physical function [3], defined as the ability to perform daily activities [4]. In addition, about 50 % of pregnant women experience pelvic girdle pain (PGP) [5-9]. PGP commonly affects everyday activities, work ability and quality of life [5, 9-12], and women with this condition frequently report pain and difficulties in performing weight-bearing activities [11, 13]. Particularly reduced ability to walk is a main disability, with 73 % of pregnant women with PGP reporting walking difficulties [13, 14] and with those severely affected using crutches [5]. Although the assessment of function and disability is of primary focus in the clinical evaluation of pregnant women with PGP [13], there are few studies exploring weight-bearing activities in this population. With such a large impact on life, the influence of both PGP and pregnancy on physical function should be an important field of research. In this thesis, the term physical function is used in the meaning of weight-bearing activities.

The initial research questions behind this thesis arose from the clinical experience and/or the extensive work of research of my three supervisors. Thereafter, we have worked together on further planning and conducting this project. At first, we wanted to describe and compare physical function in pregnant women with and without PGP. However, to understand more of the influence of PGP on weight-bearing activities, we decided to investigate the influence of pregnancy itself by comparing performance of weight-bearing activities also in asymptomatic pregnant and non-pregnant women.

Before I started my work as a PhD candidate, I worked several years as a physiotherapist treating patients with musculoskeletal disorders. Thereafter I worked as a teacher and supervisor for physiotherapy students at the Oslo Metropolitan University (former Oslo and Akershus University College). I have both used and taught students clinical tests purported to assess different aspects of physical function. Commonly, clinicians visually

observe and evaluate how patients move during activities and functional tests. It has been a general, clinical opinion that pregnant women with PGP move differently than asymptomatic pregnant women and that specific movement patterns could be anticipated in those with PGP. However, this is mostly unknown, as few studies have quantified movement in pregnant women with PGP.

Since my undergraduate training at the Mensendieck School at the Oslo University College 20 years ago, I have been interested in human movement. I learned to experience movement through my own body and to observe and analyze movement in patients and healthy individuals. After observing human movement for years, I remain fascinated by how different individuals move to accomplish the same task. After treating pregnant women with PGP as well as experiencing both pregnancy and mild PGP in my own body, I wondered whether pregnant women with and without PGP actually use specific movement strategies during daily activities. As a clinician and teacher, I also appreciate the complexity of human movement and the professional skills needed to identify movement patterns through visual observation. Hence, I became curious about whether functional tests could inform the clinical evaluation of daily activities such as walking. My curiosity was further stimulated and expressed through discussions in our research team and with colleagues. The work with my master degree in manipulative therapy, at the Curtin University of Technology in Perth, Australia, also provided me with an interest for research. Although latent for many years (i.e. since 2004), my masters inspired me to enroll as a PhD candidate.

Finally, I ended up wanting to learn more about biomechanical measurement instruments and research methods and to use these instruments in my PhD project. Three dimensional motion analyses provide the possibility to objectively quantify movement [15]. In this project, it required a multidisciplinary approach, combining researchers from different scientific and professional backgrounds and collaboration across institutions. Human motion analyses aim to gather quantitative information about mechanics of the musculoskeletal system during a motor task [16]. From clinical experience - physical, psychological and social factors may simultaneously influence human movement. Hence, we wanted to register a broad aspect of variables potentially affecting movement and physical function by using patient-reported information and clinical examination. This project requested my skills as an experienced clinician, my ability to learn and understand research methodology in particular biomechanics, as well as increased my competence in project administration and collaboration. For me personally, this has been a once in a lifetime learning experience. Importantly, and as intended, it has provided new knowledge about weight-bearing activities in pregnant women, relevant for both clinicians and researchers within the field of PGP.

Background

Pelvic girdle pain

Pelvic girdle pain (PGP) is regarded a musculoskeletal disorder with a unique clinical presentation [3, 17, 18]. It is defined as *"pain experienced between the posterior iliac crest and the gluteal fold, particularly in the vicinity of the sacroiliac joints (SIJ) and/or the pubic symphysis"* [18]. In contrast, low back pain (LBP) is usually defined as pain between the twelfth rib and the gluteal fold [19]. According to the current European guidelines from 2008 [18], the classification of PGP also includes *"reduced endurance in conjunction with weight-bearing activities"* and *"the exclusion of lumbar causes"*. In addition, the patient may present with symptoms such as "catching of the leg" [20] or "leg(s) giving way" [13]. However, no positive nerve root tests are found on clinical examination [21].

PGP frequently onsets during pregnancy [18] and the prevalence of PGP in pregnancy is commonly reported to be around 50 % [5-9]. Although, the prevalence varies depending on populations studied and diagnostic definitions [22-28], pregnant women worldwide commonly report PGP and/or LBP [11, 29]. Importantly, as PGP seems to have a higher impact on disability than LBP in pregnancy [3, 9], distinguishing between LBP and PGP appears important both in clinical practice and in research [21].

Although studies investigating PGP in pregnancy are increasing, the etiology of PGP is still unclear [18, 30]. From the evolving knowledge, it appears that multiple factors contribute to development of pain and disability during pregnancy such as biomechanical, anatomical, psychological, social, neurophysiologic, genetic and pregnancy-related hormonal factors [1, 17, 18, 31]. A common belief has been that the hormone relaxin contributes to PGP during pregnancy by loosening the pelvic ligaments and thereby increasing the mobility of the pelvic joints [2, 32]. However, it appears to be low level of evidence for the association between PGP during pregnancy and relaxin levels [32], as well as lack of relationships between relaxin levels and both symptoms and perceived disability in pregnant women with PGP [2]. Still, pain and impairment in weight-bearing activities have been related to a theory of dysfunctional ability to transfer load from the spine to the legs through the pelvis [33, 34]. Pelvic load transfer has commonly been described using a biomechanical model of form and force closure [34-38]. In this model, mechanical stability, the ability of a joint to bear loading without uncontrolled displacement [39], is regarded important. Form closure refers to stability from passive structures, such as bones, joints and ligaments, while force closure refers to stability from active structures i.e. compressive forces from the muscles to create stiffness of the pelvic girdle during loading [34-38]. Load transfer is also dependent on the motor control system to

regulate the appropriate muscle activation needed for a given load, task and environment [40, 41]. It is also likely influenced by pain, awareness and emotions [38, 41]. The importance of load transfer might be supported by the finding of moderate evidence in the literature for an association between PGP in pregnancy and altered motor control and kinematics or kinetics of the pelvis [42]. In addition, experts on PGP across a range of disciplines seem to highlight the importance of biomechanical factors in PGP [31]. Hence, present expert opinions appear to differ between considerations of LBP and PGP [31, 43], with an apparent greater emphasis on psychological rather than biomechanical features in LBP [43, 44]. Despite the focus on biomechanical factors and pelvic load transfer in PGP [31], few studies have investigated biomechanics during weight-bearing activities such as walking and in functional tests purported to assess pelvic load transfer in pregnant women with PGP [45-48]. In this thesis, we do not investigate and/or explain any causal theories. Moreover, we aimed to explore physical function and describe movement characteristics during weight-bearing activities and functional tests by describing associations and differences in function.

Physical function and disability in pregnant women with and without PGP

The natural history of PGP is relatively good, with the majority of women recovering soon after delivery, while about 20 % report pain persisting for years [23, 49]. Still, PGP often affects life during pregnancy for those affected, with an adverse effect on daily activities, work ability and health-related quality of life [5, 9-12, 50]. The affliction and level of disability vary among pregnant women with PGP [11, 51]. Between two and 50 % of pregnant women report sick leave related to PGP or lumbopelvic pain worldwide [5, 11, 12, 24, 50, 52], with an average length of sick leave reported in some studies to be 8-12 weeks [12, 52, 53]. Hence, PGP potentially constitutes a major public health issue during pregnancy [12, 52]. In addition, it can severely affects the individual woman [54, 55]. Qualitative studies describe that PGP greatly affects the pregnant woman´s ability to cope with pain and everyday life [54, 55]. Increased evening pain, pain with turning in bed and waking up at night due to pain also affect pregnant women with PGP [5, 51]. In particular pain and difficulties with weight-bearing activities such as walking, standing, housekeeping, pushing objects, lifting, walking stairs, running and sitting are frequently reported [5, 6, 12-14]. Accordingly, physical function and pain are essential in the clinical examination of pregnant women with PGP [3, 13].

Noteworthy, 73 % of pregnant women with PGP report walking difficulties [13, 14]. Walking is one of the domains of the International Classification of Functioning, Disability and Health (ICF) [56] and a key aspect in the activities and participation component for mobility

[15]. According to ICF, walking can also be defined in the context of body functions, with gait characteristics relating to *"gait pattern functions"*, or *"functions of movement patterns associated with walking"* [56]. Although, the words walking and gait are often used interchangeably, gait describes *"the manner of walking"*, rather than the walking process itself [15]. Gait analysis is described as the systematic study of human walking [15], and can be performed in various ways, from visual observation to methods using complicated equipment [15]. Gait is most often part of the physiotherapy examination and assessed by visual observation. Based on clinical observations of gait characteristics in our research group, we wondered whether pregnant women with PGP walked 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. However, few studies have investigated movement patterns during gait in pregnant women with PGP [46-48, 57]. Importantly, a large fraction of asymptomatic pregnant women also report disability [3] and previous studies assessing gait characteristics in asymptomatic pregnant women report gait alterations [58, 59], indicating that pregnancy itself affects function. Pregnant women with and without PGP come from a population of asymptomatic non-pregnant women in fertile age. Hence, it seems relevant to include also a group of non-pregnant women to explore concurrently the influence of pregnancy and PGP on physical function by describing differences in weight-bearing activities between pregnant women with PGP, asymptomatic pregnant and non-pregnant women.

Importantly, the prevalence and impact of PGP increase from early to late pregnancy [6] and early management of PGP during pregnancy is recommended [60]. Hence, it seems clinically relevant to explore whether differences in physical function, including gait characteristics, exist already in the 2nd trimester of pregnancy, between asymptomatic pregnant women and both pregnant women with PGP and non-pregnant women. Moreover, as the extensive individual weight-gain in late pregnancy [1] affects the individuals´ physical proportions and thus likely function, it also seems important to study the influence of pregnancy and PGP on physical function, including gait characteristics, prior to the 3rd trimester.

Walking is, apart from being an essential daily activity, a recommended physical activity for pregnant women [61]. Health benefits of physical activity during pregnancy include reduced risk of excessive gestational weight gain, gestational diabetes and preeclampsia, as well as reduced fatigue, anxiety, depression and improved well-being [62-66]. Hence, a reduced ability to walk during pregnancy likely has an adverse effect on daily life with an impact on both physical and psychological factors. Despite this, few studies have investigated

walking in pregnant women with PGP [46-48, 57]. Due to the impact of PGP on everyday functioning [5, 6, 9, 11, 13, 14, 54, 55], it is important to increase our knowledge of weight-bearing activities, in pregnant women with PGP.

Measurements of physical function

Self-reported and performance-based instruments are commonly used to assess physical function [67]. However, few clinical measures for physical function have previously been designed and validated in pregnant women with PGP [18]. The current guidelines, recommend only one functional test, the active straight leg raise (ASLR) test [18]. The ASLR is assumed to assess pelvic load transfer by self-reported impairment of leg lift from supine position [68]. Later, the Pelvic Girdle Questionnaire (PGQ) was developed including questions about activities, participation and bodily symptoms [13]. However, both the ASLR and PGQ capture the patient´s perception of their performance or condition. As self-reported function is not always indicative of the actual performance [69], performance-based instruments may capture complementary aspects of physical function [67]. Recently, Evensen and co-workers [70, 71] proposed the Timed Up and Go (TUG) test [72] undertaken at maximum speed as a reliable and valid weight-bearing physical performance-based measure for pregnant women with PGP. Based on a strong correlation between TUG time and the ASLR score, they [71] suggested that both tests might assess non-optimal stabilizing strategies for pelvic load transfer in pregnant women with PGP [71]. The TUG is a standardized, timed test originally developed as a measure of functional mobility in the elderly [72]. It requires the patient to stand up from a chair, walk 3 m, turn, walk back and sit down again [70, 71]. Hence, walking is an essential subtask of the TUG test.

Walking is the result of a cyclic series of movements, described by its most fundamental unit, the gait cycle [73]. Heel or foot contact with the ground is considered the start of the gait cycle (0 %) and the next contact by the same foot is considered the end of the gait cycle (100%) [73]. Within a gait cycle, the person experiences two periods of double-limb stance (when both feet are in contact with the ground simultaneously) and two periods of single-limb stance (when only one foot is on the ground) [15, 73]. Hence, the body`s weight is being transferred between the left and the right lower extremities during the gait cycle [73]. However, observing and evaluating gait depends on the skills and competence of the observer [15]. As reduced ability to walk is a main disability in pregnant women with PGP [13, 14], suitable clinical measures complementing the clinical evaluation of gait are particularly important in this patient population. [73]. Both the Stork test [38] and the Timed Up & Go

(TUG) test [72] are measures related to gait. The Stork test is a single leg stance (SLS) test commonly used as a functional test in the clinical examination of pregnant women with PGP. It has, as the ASLR test, been proposed to assess load transfer [38]. As the Stork test is performed in standing, while the ASLR test is performed in supine, they differ with respect to weight-bearing. However, as walking includes load transfer during transitions between double and single leg stance, it appears to be rational and more pertinent to assess the ability to transfer load in a weight-bearing position. To facilitate the clinical utility of both the Stork test and TUG time, there is a need to investigate the influence of both PGP and pregnancy on the performance of these tests.

Gait characteristics in pregnancy

The clinical gait analysis is most commonly visual and thus entirely subjective [15]. However, in clinical research, three dimensional (3D) gait analysis is widely used to quantify gait [74]. 3D gait analysis is advocated as a useful assessment tool because it provides objective information about functional outcomes not available from self-reported questionnaires or standard clinical assessments [75]. 3D kinematics describes motion in 3D space without regard to the forces that cause the motion [76]. Kinematics is defined as the geometrical description of motion, in terms of angles, positions (displacement), velocities and accelerations of body segments and joints [15]. Spatiotemporal characteristics are variables pertaining to both time and space such as speed, step length, step width and stance time [15]. 3D kinematic analysis is often used to discriminate between movement patterns in individuals with and without a specific condition [77].

To our knowledge, only three studies have assessed gait biomechanics in pregnant women with PGP [46-48], while a fourth study explored gait speed only [57]. Speed is reported to be lower in pregnant women with PGP compared to asymptomatic pregnant women [46, 57]. Kerbourc`h and co-workers [47] and Bertuit and co-workers [48] investigated stance time as well as center of pressure (COP) displacement and velocity during gait in pregnant women with PGP, asymptomatic pregnant and non-pregnant women. The COP is regarded an indicator of gait performance [47] and represents the point on the ground through which the resultant force would act [15]. Both studies [47, 48] found that pregnancy and speed influenced COP parameters, whereas PGP only modified a few. As speed influences gait biomechanics [15, 73], it should be included and controlled for in gait analyses. Except for speed and stance time [46-48], spatiotemporal gait characteristics have not been investigated in pregnant women with PGP. Furthermore, only Wu and co-workers [46] have assessed gait

kinematics in pregnant women with PGP compared to asymptomatic pregnant women. They found that pregnant women with PGP walked with larger transversal rotations in the pelvis, low back and thorax (although not statistical significant) compared to asymptomatic pregnant women [46]. However, they studied the relative rotation between the thorax, low back and pelvis. Hence, sagittal and frontal plane kinematics of the trunk and pelvis, as well as hip kinematics during gait have not previously been studied in pregnant women with PGP. As quantification of spatiotemporal and kinematic gait characteristics might elucidate mechanisms involved in function [78], there is a need for further research on these characteristics in pregnant women with PGP. Noteworthy, Wu and co-workers [46] also found a negative association between gait speed and fear of movement in pregnant women with PGP. As they included women in late pregnancy [46], it is relevant to explore this relationship also in pregnant women with PGP in the 2nd trimester.

In contrast, several studies have assessed gait biomechanics including kinematics in asymptomatic pregnant women [58, 59]. This is important, as knowledge of gait in asymptomatic pregnant women may complement our understanding of gait in those with PGP [59]. However, a recent systematic review and meta-analysis found that methodological approaches such as study design, participants, pregnancy periods, instrumentation and variables varied across studies [58]. Although several studies have included women pregnant in the 2nd trimester [47, 57, 79-93], only a few compared gait in pregnant women in the 2nd trimester with non-pregnant women [47, 79, 82, 89, 90, 93]. (Details are summarized in Appendix 1, Table S1). The following spatiotemporal characteristics were found in asymptomatic pregnant women in the 2nd trimester versus non-pregnant women; Slower gait speed [89, 93], decreased cadence [93], greater step width [79] and longer step time [79], double limb support [79, 82] and stance time [47, 79]. Conversely, others found no differences in speed [79, 82], or in other spatiotemporal variables [82] between pregnant women in the 2nd trimester and non-pregnant women. With regard to kinematic variables, studies have found; Greater thoracic extension and frontal plane trunk translation [90], greater both anterior and posterior pelvic tilt, decreased pelvic frontal plane and transversal plane movements [79], increased hip flexion [79] as well as decreased hip extension [79, 82] and adduction [82] in asymptomatic pregnant women in the 2nd trimester compared to non-pregnant women. In addition, three longitudinal studies included comparisons of gait characteristics in women when pregnant in the 2nd trimester and post-partum [83, 84, 91]. In asymptomatic women pregnant in the 2nd trimester compared to post-partum, Carpes and co-workers [84] found increased double limb support, step and stride length, while Branco and co-workers [83] found no differences in spatiotemporal variables. The same studies found no

significant difference in hip flexion and extension [84], in contrast to decreased hip extension and increased hip flexion and internal rotation [83], while a third study found both decreased hip flexion and adduction [91] during gait in asymptomatic pregnant women in the 2nd trimester compared to post-partum. The diverse findings and differences in methodology across studies make it difficult to conclude on the influence of pregnancy on gait characteristics in the 2nd trimester.

Based on clinical observations and disparity in results of previous studies, we aimed to explore the influence of both PGP, pregnancy and gait speed on spatiotemporal variables and trunk, pelvic and hip kinematics during gait in the 2nd trimester, by quantifying and comparing these gait variables in pregnant women with PGP and asymptomatic non-pregnant women versus asymptomatic pregnant women.

The Stork test

Single leg stance (SLS) is a necessary component of walking, as the gait cycle consists of two periods of single-limb stance (when only one foot is on the ground) [15, 73]. It is also a more difficult posture than double-leg stance as the base of support is narrower [94]. In SLS, asymmetric forces are likely to be transferred through the lumbo-pelvic-hip region and increase the demands on load transfer through the pelvis [40].

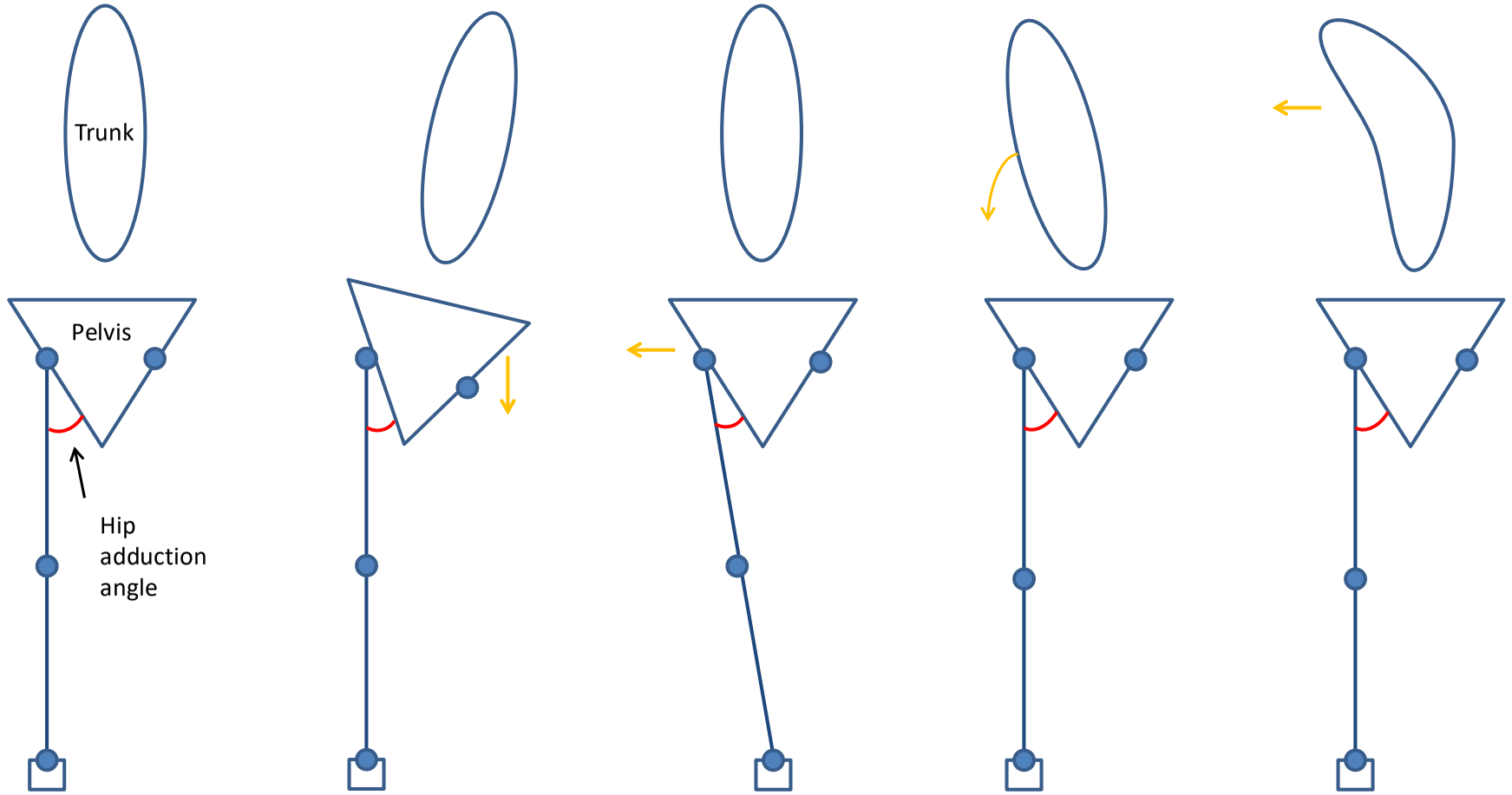
The Stork test is a SLS test proposed *"to examine the ability of the low back, pelvis and hip to transfer load unilaterally, as well as for the hip to flex, the low back to rotate and the pelvis to allow an intra-pelvic torsion"* [38]. From a double-leg stance position, the participant is instructed to stand on one leg and to lift the contralateral thigh towards the chest until 90° of hip flexion. The test is performed on both sides and repeated three to four times to evaluate consistency or inconsistency of any findings [38].

Previously, the test has been performed by the patient while the clinician palpated the movement of the non-weight-bearing innominate relative to the ipsilateral sacrum [38, 95]. However, palpation has shown only moderate inter-rater reliability among experienced manual therapists [95]. Altered intra-pelvic motion during a SLS task has been found in men with posterior pelvic pain compared to asymptomatic men using 3D kinematic analysis [96]. However, radiostereometric analysis provides increasing evidence that the SIJ movements are small with no more than 0.5-2° of rotational movements and almost no translation is reported in the loaded pelvis (e.g. in a weight-bearing position) [97-101]. Radiostereometric analysis is an invasive method where tantalum markers are inserted into the sacrum and innominate bone and two x-rays from different directions are taken at the same time at specified time

points during the studied task [98]. Special software is used to calculate translations and rotations in three dimensions [98]. The method has shown high precision and accuracy in measurement of SIJ motion [102]. Moreover, Pool-Goudzwaard and co-workers [103] found deformation of the innominate bone and mobility of the pubic symphysis in response to external force applied to the innominate. The authors suggested that pelvic deformation is a normal response during external loading and that this phenomenon could influence the clinical assessment of the pelvic joints [103]. Both the small amount of joint movement and plasticity of the innominate bone likely contribute to an uncertainty in clinical palpation and in non-invasive 3D kinematic analysis of intra-pelvic motion. Based on the above, the clinical value of SIJ movement palpation appears minimal.

Nevertheless, SLS tests, including the Stork test, are proposed to assess loading strategies in patients with lower limb disorders [38, 104]. These tests have evolved from the Trendelenburg´s test, a commonly used method of assessing hip abductor muscle function [105]. Clinicians often assess key movement responses of the pelvis and trunk in the frontal plane by visual observation [104] during transition to [38] and in SLS [38, 106]. Pelvic frontal plane movement (i.e. pelvic tilt/drop/obliquity), is usually referenced to a visualized, horizontal line in space and represents an indication of hip adduction angle (pelvis relative to femur) [105, 107] (Figure 1a and b, page 23). However, hip adduction will also increase if the pelvis translates in the frontal plane over the grounded foot [108] (Figure 1c, page 23). As the body´s center of mass moves in a more lateral direction over the stance leg during SLS, the Stork test presumptively also challenges medial-lateral trunk kinematics (Figure 1d and e, page 23). However, an increased lateral trunk movement may pertain to pregnancy itself, as asymptomatic women in late pregnancy may demonstrate a “waddling gait”, measured by an increased medial-lateral translation of the C7 vertebrae [90]. As trunk, pelvic and hip kinematics in humans occur as compound motions in multiple joints and planes and due to the paucity of previous studies exploring movement patterns during the Stork test in pregnant women, it seems important not to exclude potentially important kinematic variables in the 3D motion analysis. An exploratory approach including different operationalization of kinematic variables calculating the thoracic and pelvic segments in relation to space as depicted in Figure 1b-e, page 23), appears to be clinically relevant as trunk and pelvic motions are often visually observed in relation to space in clinical practice. In addition, calculating the femur segment relative to the pelvis expresses the “true” joint angle of the hip [109], which seems clinically relevant when evaluating movement patterns during the Stork test.

Figure 1 Key frontal plane positions and movement responses; Neutral trunk, pelvic and hip position (a), lateral pelvic tilt/drop (b), lateral pelvic shift (c) and lateral trunk translation (d)



(a) Neutral position *(b) Lateral pelvic tilt/drop* *(c) Lateral pelvic shift* *(d) Ipsilateral trunk lean* *(e) Lateral trunk translation*

Moreover, in non-pregnant individuals with PGP compared to asymptomatic controls, Bussey and co-workers [40] reported excessive flexion of the lumbar spine when standing on the symptomatic side during a SLS task. They suggested asymmetric pelvic stiffening as a compensatory strategy of failed load transfer in those with PGP [40]. Van Wingerden and co-workers [110] found reduced hip movement during forward trunk bending, as well as more posterior pelvic tilt and a slight flattened lumbar lordosis in upright standing in non-pregnant females with chronic PGP compared with both healthy individuals and LBP patients. The latter findings correspond with the clinical observations in our research group that pregnant women with PGP have increased posterior pelvic tilt during weight-bearing activities such as standing, walking and rising up from a chair, as well as during the Stork test. However, an association between altered kinematics and PGP during the Stork test is largely based on clinical supposition, as no previous study has investigated movement patterns during this test in pregnant women with PGP. Moreover, from clinical experience, some patients lift their leg in a fast speed, while others lift their leg in a slow manner. Some might also be unable to lift their leg to 90° of hip flexion. The preferred standing position also appears to differ among women, with some pregnant women with PGP standing with their feet more close together (i.e. with a small stance width). In addition, a significant effect of leg dominance during a SLS task has been found in healthy non-pregnant women [111]. Hence, factors potentially influencing movement performance during the Stork test are relevant to take into account. To inform the clinical interpretation of the Stork test, we aimed to explore the influence of PGP and pregnancy on spatiotemporal variables and trunk, pelvic and hip kinematics during the Stork test in the 2nd trimester, by quantifying and comparing these variables in pregnant women with PGP and asymptomatic non-pregnant women versus asymptomatic pregnant women.

The Timed Up and Go test

The version of the TUG test recommended for pregnant women with PGP is undertaken at maximum speed [70, 71]. It requires the person to stand up from a chair, walk 3 m, turn, walk back and sit down again [70, 71], and the time used to accomplish the test is the measure of performance. Clinical measures are recommended to reflect the person's main problem(s) [112]. Reduced ability to walk is reported to be a main disability in those with PGP [13, 14]. From clinical experience pregnant women with PGP also commonly experience pain and limitations in raising up from and sitting down on a chair and when turning around while walking. An increased TUG time reflects the ability to perform any of the subtasks. Hence, TUG time seems like a relevant measure of activity-limitations in pregnant women. Accordingly, it

is expected that pregnant women with PGP use longer time performing this test than women without PGP. However, pregnancy itself also has an impact on disability [3] and slower gait speed has been found in healthy pregnant women in the 2nd trimester compared to non-pregnant women [89, 93]. Hence, it seems plausible that asymptomatic pregnant women might also use longer time on TUG than non-pregnant women. To our knowledge, this is unknown, as no previous study has compared TUG time in pregnant women with PGP, asymptomatic pregnant and non-pregnant women.

Previously, Evensen and co-workers [71] found a strong correlation between TUG time and the ASLR score, in pregnant women with PGP. However, longer TUG time has previously been associated with multiple factors such as pain [113], increased body mass index (BMI), decreased mental health [114] and lower education levels [115] in other populations. Previously, a negative association between gait speed and fear of movement was found in pregnant women with PGP [46]. As gait is one of the TUG`s subtasks, it seems plausible that fear of movement might also be associated with a longer TUG time in pregnant women with PGP. It seems plausible that clinical variables, psychological factors and personal characteristics (e.g. BMI) might also be associated with increased TUG time in pregnant women. In the present study, we aimed to explore physical function in pregnant women with PGP in the 2nd trimester by comparing TUG time in pregnant women with PGP, asymptomatic pregnant and non-pregnant women, as well as to explore potential explanatory variables associated with increased TUG time. This knowledge may facilitate the clinical utility of TUG time as a measure of physical function in pregnant women with PGP.

Rationale for the thesis

PGP is a common musculoskeletal disorder in pregnant women [5-9], which often affects everyday activities, work ability and quality of life [5, 9-12]. The etiology of PGP is unclear, although multiple factors likely contribute to pain and disability [18]. Pregnant women with PGP often report pain and difficulties performing weight-bearing activities [11, 13], particularly walking [13, 14]. Although the assessment of function and disability is of primary focus in the clinical evaluation of pregnant women with PGP [13], few studies have investigated gait and clinical tests related to gait. This study proposed to explore physical function by quantifying and comparing spatiotemporal and kinematic characteristics during gait and the Stork test, as well as time to perform the TUG test, in pregnant women with PGP, asymptomatic pregnant and non-pregnant women. This novel knowledge should be useful to improve the clinical assessment in pregnant women with PGP.

Thesis aims

The overall aim of this thesis was to explore the influence of PGP and pregnancy on weight-bearing activities in the 2nd trimester of pregnancy, by comparing pregnant women with PGP and asymptomatic non-pregnant women with asymptomatic pregnant women.

Paper I

Primary aim; To explore physical function in pregnant women with PGP, by the use of TUG

- Hypothesis; Pregnant women with PGP demonstrate reduced function, i.e. increased TUG time, compared with asymptomatic pregnant and non-pregnant women

Secondary aim; To identify potential factors associated with increased TUG time

- Hypothesis; Increased TUG time is associated with higher ASLR scores and increased pain intensity

Paper II

Primary aim; To assess the influence of PGP, pregnancy and speed on spatiotemporal and trunk, pelvic and hip kinematics during gait in the 2nd trimester of pregnancy

- Hypothesis; Pregnant women with PGP 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

Secondary aim; To explore the relationship between gait speed and fear of movement, disability and pain intensity

- Hypothesis; Speed correlates negatively with fear of movement, disability and pain in pregnant women with PGP

Paper III

Primary aim; To investigate the influence of pregnancy and PGP in the 2nd trimester on trunk, pelvic and hip kinematics during the Stork test by comparing kinematics in pregnant women with PGP, asymptomatic pregnant and non-pregnant women

- Hypothesis; Pregnant women with PGP lift their leg slower and demonstrate less hip adduction and contralateral pelvic drop, as well as greater lateral trunk translation during this test compared to asymptomatic pregnant women

Materials and methods

Design

This thesis includes one main data collection with a cross sectional, case-control design. The thesis is mainly based on data that describe; a) movement, including spatio-temporal and kinematic data and force data, b) score on an objective performance test (TUG time), c) self-reported demographics, education and work, exercise, function, disability and pain and d) results of clinical tests assessing pelvic function and pain provocation.

The following data were also collected, but not used in this thesis: 1) Data describing muscle function, including electromyography (EMG) recordings of muscle activation patterns. 2) Data to investigate the progression and further development of PGP was collected during a small sub-study. The latter consisted of a follow-up self-reported questionnaire sent to the 49 pregnant women 12 weeks after the expected date for delivery.

Ethical considerations

The study was approved by the Regional Committees for Medical and Health Research Ethics in Norway (2013-2312). All participants signed an informed consent form prior to commencement of the study. It was emphasized that the decision for participation in the study was voluntary and of no future consequence to the participants pregnancy. All potential participants were informed that participation in the study might provoke pain in the pelvic area. Further, that no pain was expected to exceed that of normal activities of daily living. The participants could withdraw from the study at any time. We did not offer any treatment for the women with PGP. If the women asked for advice concerning their PGP, we answered any questions after completing the whole testing procedure. The study was conducted in accordance with The Code of Ethics of the World Medical Association (The Helsinki Declaration) [116].

Participants

In Norway, women are offered free health service during pregnancy and commonly seek special Maternity Care Units (MCUs) for this purpose. We collaborated with midwives at three MCUs, one University hospital and clinicians at three physiotherapy and chiropractor clinics in Oslo (capital) and the surrounding area to recruit pregnant women with PGP. Asymptomatic pregnant and non-pregnant women were recruited from the MCUs,

advertisement on websites and from other participating women. At the MCUs, all Norwegian speaking pregnant women were invited to participate by the midwives, except for women determined to have a risk pregnancy (e.g. more than one fetus, pre-pregnancy BMI over 27, gestational diabetes) and women more than 26 weeks pregnant.

Two hundred and two potential participants underwent one semi-structured telephone interview with the PhD candidate and answered questions based on the pre-defined inclusion and exclusion criteria. These criteria are detailed in Table 1.

Table 1 Inclusion and exclusion criteria for the pregnant women with pelvic girdle pain (PGP) and asymptomatic pregnant and non-pregnant women

	Pregnant with PGP	Asymptomatic pregnant	Asymptomatic non-pregnant
Inclusion			
	Posterior pelvic pain[1] with onset in current pregnancy	No posterior pelvic pain, or pubic symphysis pain during the last 6 months, that had led to disability or sick leave	
	ASLR[2] score more than 0	ASRL score = 0	
	Positive P4[3] unilateral or bilateral	Negative P4	
	Pregnant in gestation week 26 or earlier in pregnancy		Not pregnant and more than 6 months since last pregnancy
Exclusion			
	Current multiple gestation		
	Any risk pregnancy as determined by midwife		Present BMI > 27
	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		

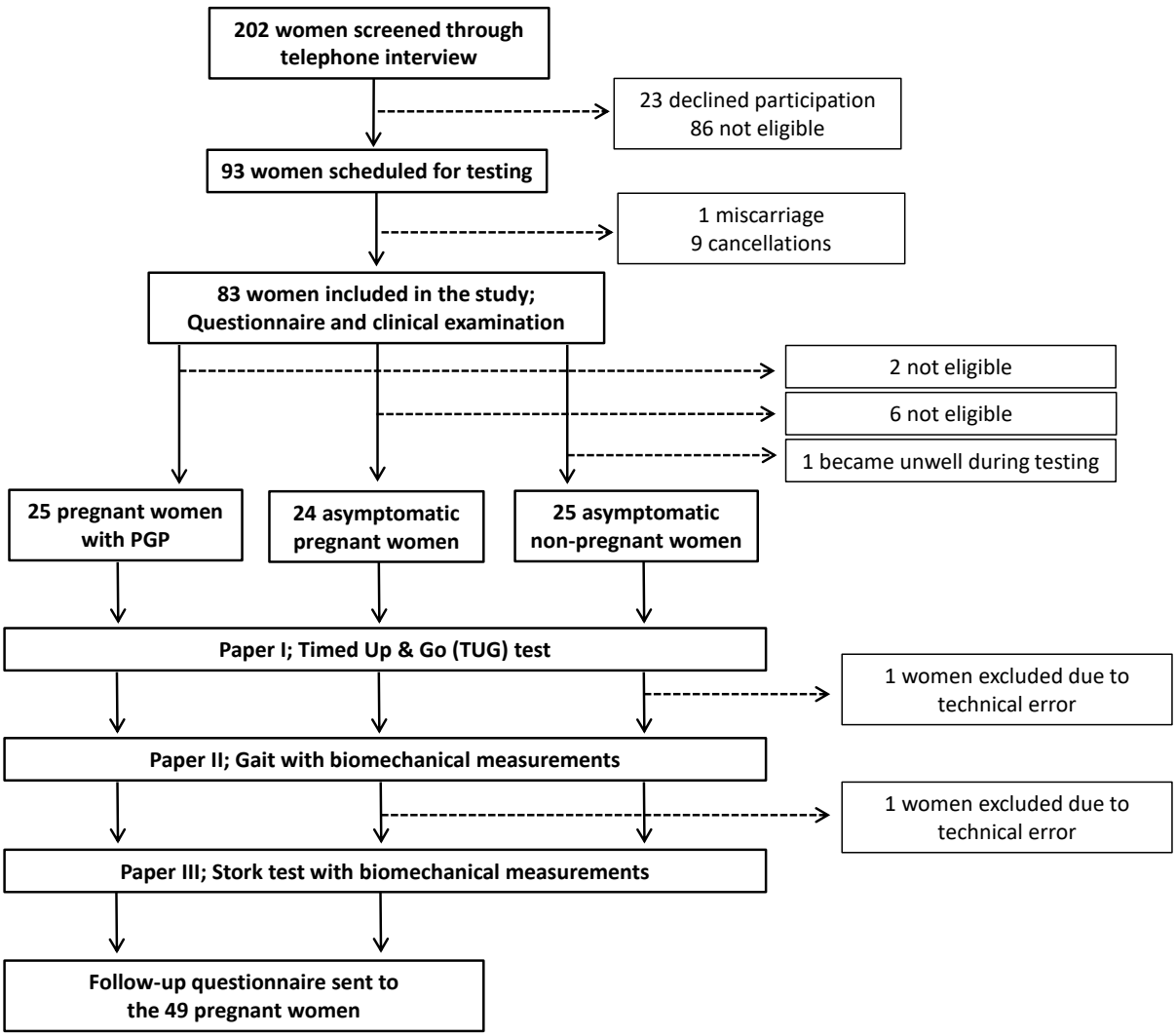
[1]Posterior pelvic pain defined as unilateral or bilateral pain in the area between the crista iliaca and the gluteal folds; [2]ASLR, active straight leg raise test; [3]P4, posterior pelvic pain provocation test. Modified from Christensen and co-workers [117] and reprinted in accordance with Elsevier´s permission guidelines [118]

The inclusion criteria were set to confirm a clinical diagnosis of PGP (for the pregnant women with PGP) and to exclude this condition in the asymptomatic women. Moreover, to include pregnant women prior to the 3rd trimester of pregnancy and non-pregnant women

with more than 6 months since last pregnancy (Table 1). A combination of screening questions for pain, (including location, onset/duration and what aggravates pain), a validated pain drawing (described on page 32) and a clinical examination (detailed on page 32) were used for this purpose. Hence, pregnant women with PGP had to have posterior pelvic pain located on a pain drawing, an ASLR score more than 0 and unilateral or bilateral reproduced familiar pain on the P4 test [119]. Conversely, asymptomatic pregnant and non-pregnant women had no posterior pelvic pain, an ASLR score = 0 and a negative P4 test. The pre-defined exclusion criteria (Table 1) were set to reduce the influence of conditions that may potentially influence performance of the activities and tests under study, and based on clinical experience and collaboration with midwives. The midwives regarded pregnant women with a pre-pregnancy BMI of more than 27 to have a risk pregnancy. Hence, we did not include pregnant women with a pre-pregnancy BMI above 27. As we wanted all the women to be comparable with regard to pre-pregnancy BMI level, the exclusion criteria of present BMI more than 27 was set also for the non-pregnant women. Pre-pregnancy BMI was assessed based on self-reported weight and height during the telephone screening. Conditions such as surgery, traumatic head injury and neurological or inflammatory systemic diseases were evaluated based on the individual`s response on specific questions. Any LBP was evaluated based on a combination of screening questions for pain, (including location, onset/duration and what aggravates pain), a validated pain drawing and a clinical examination including the Slump test to screen for symptoms of lumbar radiculopathy due to disc herniation [120, 121]. All participants went through the clinical examination to affirm inclusion.

Out of 202 interviewed women, 93 were scheduled for testing and 83 attended. Figure 2 (page 30) shows a flow diagram of the entire study. Of the 23 women who declined participation, 13 were pregnant and 10 were non-pregnant. Of these, 11 pregnant and six non-pregnant were not able to participate because the motion laboratory was not available (due to data collection in other projects) at a time that suited the person. The remaining two pregnant and four non-pregnant women gave other reasons for not participating, such as commute or aspects related to the test protocol (e.g. long duration, equipment and little clothing). Among the nine women who cancelled the scheduled testing, all except one woman were pregnant. The reasons for cancellation were sickness due to seasonal infection, sick child and unexpected work or private appointments. For these women, we were not able to reschedule the appointment due to no available times in the motion laboratory. For the eight pregnant women, the available times for rescheduling were on times when the women had passed gestation week 26 and could no longer participate due to the study`s inclusion criteria.

Figure 2 Flow diagram of the entire study



The 25 pregnant women with pelvic girdle pain (PGP) had an active straight leg raise (ASLR) score above 0, a positive posterior pelvic pain provocation (P4) test and a pain drawing with posterior pelvic pain. The 24 asymptomatic pregnant and the 25 asymptomatic non-pregnant women had both negative ALSR and P4 tests, as well as no reported posterior pelvic pain. Modified from Christensen and co-workers [117] and reprinted in accordance with Elsevier´s permission guidelines [118]

Of the included participants, women in the two asymptomatic groups were matched on age (+/-4 years) of the pregnant women with PGP. Asymptomatic pregnant women were also matched on gestational week (+/-4 weeks). A total of 74 women met the inclusion criteria. Twenty-five pregnant women with PGP, 24 asymptomatic pregnant women and 25 asymptomatic non-pregnant women completed the assessment, and data from all participants were used in paper I. Due to technical errors during testing, data from two women were excluded; one in paper II and another one in paper III.

Procedures

The data was collected between December 2015 and December 2016. Participants attended one testing session at the motion analysis laboratory at The Norwegian School of Sports Sciences (NIH) in Oslo. Firstly, participants signed an informed consent form prior to data collection. To affirm inclusion and collect self-reported data and data on results of clinical test, all participants filled in an online study questionnaire on a PC (belonging to the UiO) and a pain drawing, as well as underwent a clinical examination.

The questionnaire contained questions about age, self-reported height (cm) and weight (kg), gestation week, parity, marital status, education, work, health, exercise, pain and function. The following standardized questionnaires were also included; health related quality of life by the European Quality of Life 5-Dimensional Questionnaire 5 level version (EQ-5D-5L) [122], one question about general health from the Short form – 36 (SF-36) and Hopkins symptom checklist 10 (SCL-10) [123]. In addition, women with PGP answered questionnaires related to PGP; the Pelvic Girdle Questionnaire (PGQ) [13], Numeric Rating Scale for pain intensity (NRS) [124], one substitute question for the Tampa Scale of Kinesiophobia (fear of movement) [125] and the Patient Specific Functional Scale (PSFS) [126]. All participants located any pain on a pain drawing prior to the clinical examination. We did not use the data from EQ-5D-5L, the question from SF-36 and PSFS in this thesis. Table 2 gives an overview of questionnaire data used in the different papers.

Table 2 Contents of the study questionnaire used in paper I-III

	Paper I	Paper II	Paper III
Socio-demographical data[1]	X	X	X
Education and work[2]	X		
Exercise[3]	X		
Psychological distress by SCL-10[4]	X	X	
Current and previous pain	X		
Pain intensity by NRS[5]	X	X	X
Disability and symptoms by PGQ[6]	X	X	X
Fear of movement by 1 question from Tampa Scale of Kinesiophobia	X	X	X

[1]Includes age, self-reported height (cm), self-reported weight (kg), gestation week, parity, marital status, [2]includes education, employment, working condition, [3]exercise frequency, intensity and duration at present and prior to pregnancy, only current frequency used, [4]Hopkins symptom checklist 10 items, [5]numeric rating scale, [6]Pelvic girdle questionnaire,.

The clinical examination included tests in the following sequence; Slumps test, Beighton score for hypermobility, ASLR test, joint play of the sacroiliac joints, the P4 test, palpation of the pubic symphysis, palpation of the long dorsal ligament and the TUG test. We did not use data from the joint play test, palpation of the pubic symphysis and palpation of the long dorsal ligament. Table 3 gives an overview of the data from the clinical examination used in the different papers.

Table 3 Overview of tests in the clinical examination and test results used in paper I-III

	Paper I	Paper II	Paper III
Beighton score	X		
ASLR test[1]	X	X	X
P4 test[2]	X		
TUG test[3]	X		

[1]*active straight leg raise,* [2]*posterior pelvic pain provocation test,* [3]*Timed Up and Go test*

After the clinical examination, the pain drawing was validated according to Robinson and co-workers [6]: the participants were asked to point out the pain sites on their body, and, if necessary, the examiner corrected the pain drawing to reflect the areas pointed out. Then, the following anthropometric measurements were determined with a medical scale, a stadiometer and a caliper (described on page 39). Participants answered the questionnaire in a separate room next to the motion laboratory. This room was used also for the clinical examination and preparation of the participants for motion analysis. When prepared for the motion analysis, the participants had 67 reflex markers and eight wireless EMG electrodes positioned on their body (described on page 33). Then, two static calibration trials were performed with the participants standing in the anatomical position. Finally, the participants performed the following clinical tests and activities in the motion laboratory; the ASLR test, 30 seconds static upright standing, gait at self-selected speed, the Stork test, a modified Stork test and a Sit to Stand to Sit test. Participants were allowed rest whenever they needed, and one practice trial was given on all tests so the participants could familiarize themselves with each test. As the ASLR was performed in supine position lying on a portable couch (with a height of 110 cm), while the rest of the tests were performed in upright position, the biomechanical equipment on the back of the participants could not be placed until after the performance of the ASLR test. Hence, due to practical reasons the sequence of the tests was set. Moreover, it was not possible to blind the researchers, as in most cases they discovered

whether participants were pregnant or had PGP. However, information regarding pregnancy or pain was not given orally to the researchers until after the examination.

For all participants, the PhD candidate performed the semi-structured telephone interview, administered the questionnaires, validated the pain drawing and performed the clinical examination, the anthropometric measurements and application of measurement equipment. One assistant researcher (physiotherapist with long experience from laboratory and biomechanical research as well as long clinical experience) assisted the PhD candidate. The testing procedure took approximately three hours per participant; 10-20 minutes for the questionnaire, 10-15 minutes for the clinical examination and 2.5 hours for anthropometric measurements, preparation procedures and performance of activities and clinical tests with recording of biomechanical data.

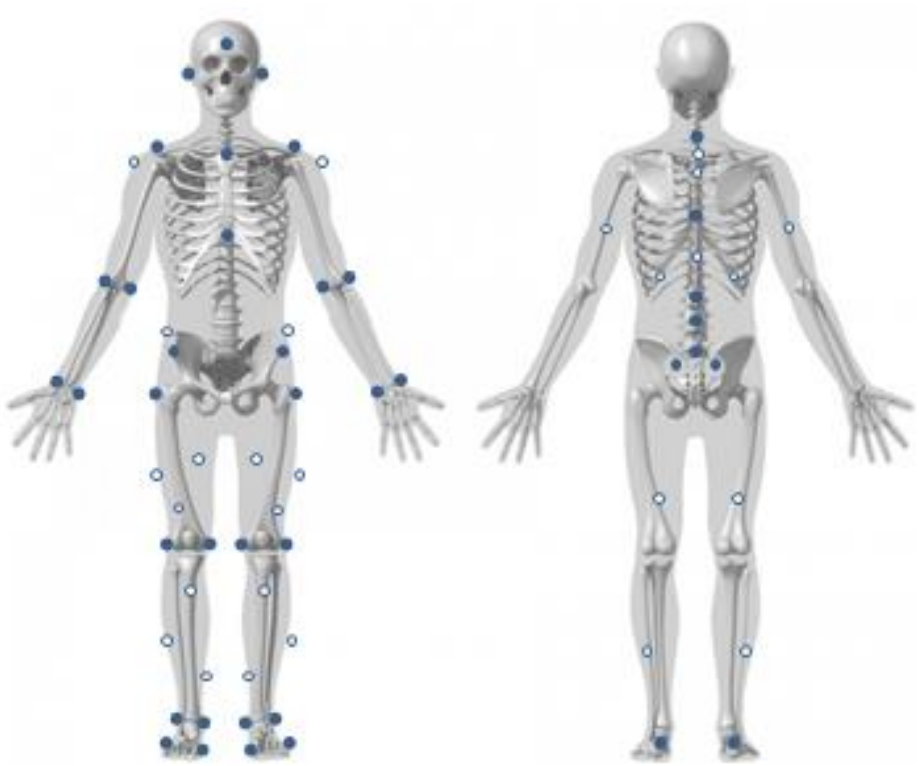
With regard to the clinical tests and activities with measurements of biomechanical data, the present thesis includes kinematic data from gait (paper II) and the Stork test (paper III) (further described on page 39). We have not analyzed data from the ASLR test, 30 seconds static upright standing, a modified Stork test and the Sit to Stand to Sit test.

Three-dimensional kinematic analyses during gait and the Stork test

Equipment and laboratory set up

To enable 3D movement analysis, 67 spherical reflective markers were positioned on specific anatomical landmarks for a full body marker set suggested by V3D [127] and consistent with the International Society of Biomechanics (ISB) recommendations [128] and the atlas for skeletal landmark definition by van Sint Jan [129] (Figure 3, page 34). Markers had a diameter of 12 mm and were fastened with double-sided adhesive tape. The PhD candidate performed the identification of anatomical landmarks and positioning of the reflective markers and EMG electrodes (described on page 40 and in Appendix 3) on all participants.

Figure 3 Marker placement in anterior and posterior view used in paper II-III



Marker placement on; The upper body (on top of the acromioclavicular joints, spinous processes of C7, T2, T4, T10, L1, L3, L5, lateral on the left and right 11th rib, xiphoid process, jugular notch). Upper limb (medial and lateral humeral epicondyles, acromioclavicular joint, lateral on the shoulder, posterior humerus, ulna styloid process and radial styloid process). Head (forehead and temporomandibular joints). Pelvis (anterior superior iliac spines, posterior superior iliac spines and on top of the lateral crista iliaca). Lower limbs (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). Illustration modified from Visual 3D Marker set guidelines [127]

A standard laboratory set-up at the motion laboratory at the NIH was used to capture kinematic, kinetic and EMG data. A written manual with standardized procedures for the set-up and recordings was adjusted to our project [130]. A motion capture system with 12 Qualisys Oqus 400 cameras at a sampling frequency of 300 Hz (Qualisys AB, Gothenburg, Sweden) was used to measure the position of the full body marker set. The cameras had different standardized vertical positions (wall and tripods) to ensure that they captured reflex markers in anterior, lateral and medial positions on the body during the ASLR test, and in all positions on the body for the other five activities/tests [130]. The set-up is detailed in Figure 4 and 5 (page 35). The kinematic data was synchronized with kinetic data captured from two AMTI

LG6 force plates (Advanced Mechanical Technology Inc, Watertown, MA, US) at a sampling rate of 1500 Hz. Muscle activity was captured from five bilateral muscles with a synchronized wireless EMG system (Noraxon USA Inc. Scottsdale, USA) (described on page 40).

Figure 4 Laboratory set-up used in paper II-III

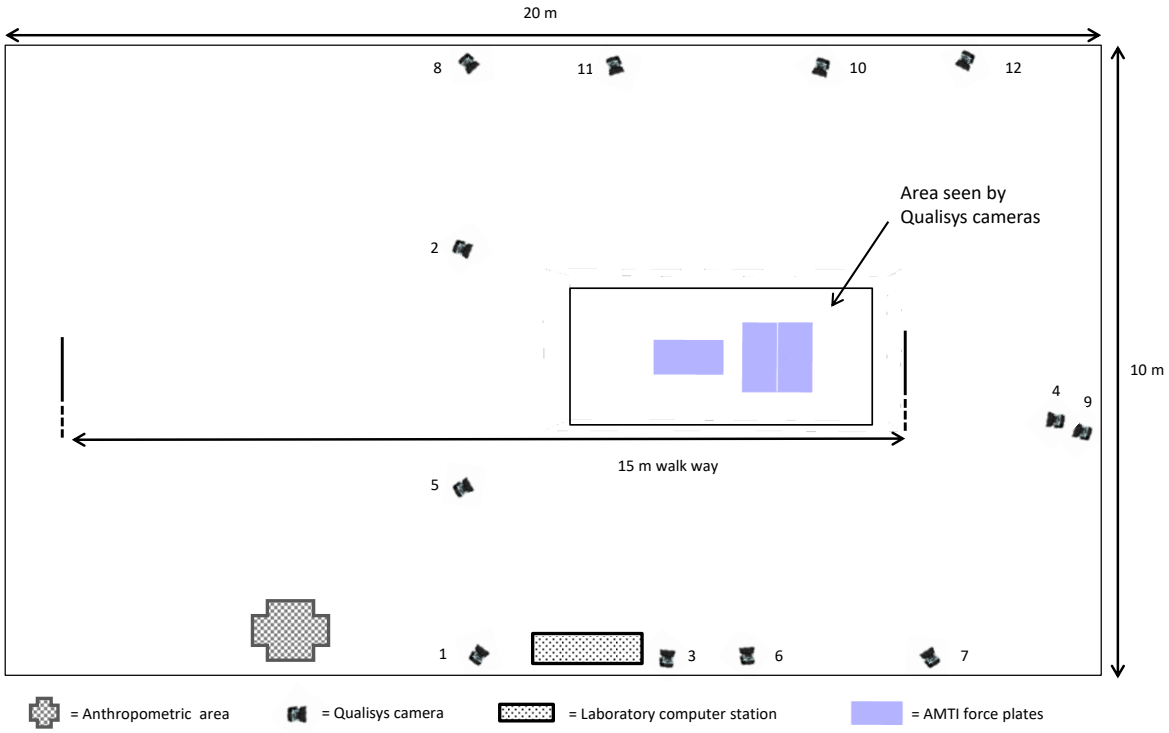
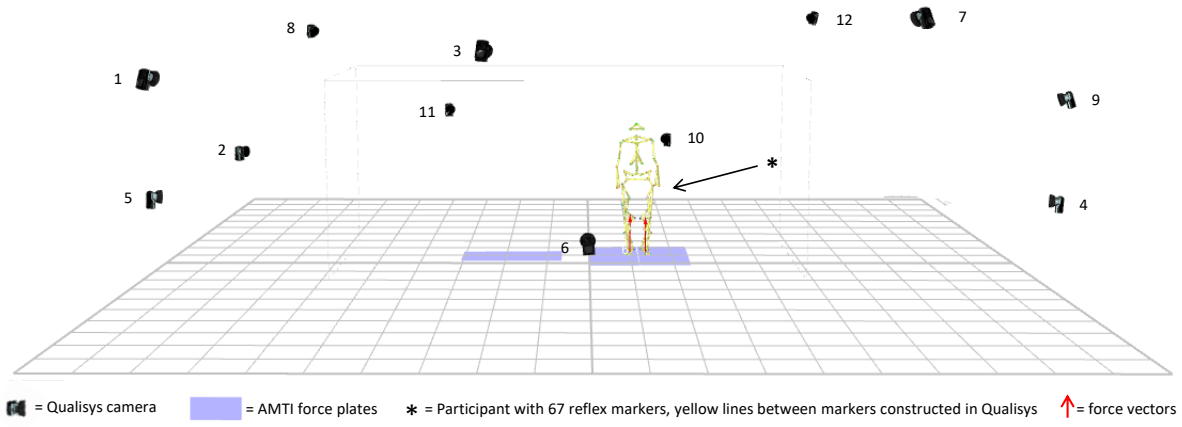


Figure 5 Laboratory set-up used in paper II-III; Participant in neutral stance in the Stork test



Calibration of the motion capture system

The motion capture system was spatially calibrated according to the manufacturer`s recommendations preceding each data acquisition. The calibration was carried out using a T-shaped carbon fiber wand (749.2 mm) with two reflective markers and an L-shaped reference frame (for the 750 wand kit) with four reflective markers. The L-frame was aligned with the force plate and defined the direction of the lab coordinate system. The calibration wand was moved systematically inside the measurement volume in all three directions (X, Y, Z). A re-calibration was performed if; 1) one of the cameras was identified as failed by the Qualisys Track Manager (QTM) software (Qualisys AB, Gothenburg, Sweden), 2) the average of the residuals of each camera`s position to the origin of the coordination system was > 3 mm [131] and 3) if the calibrated volume (by the T-shaped wand) was judged on visual inspection to have not adequately covered the recording volume. The cameras were positioned to minimize light reflections from other cameras and to cover an area of at least two subsequent gait cycles, heel-strike (HS) to toe-off (TO), with left and right foot determined by the vertical ground reaction force (GRF) data (Figure 4 on page 35).

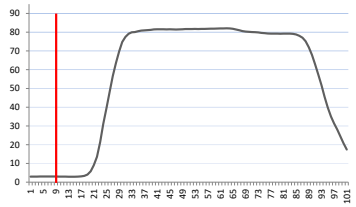
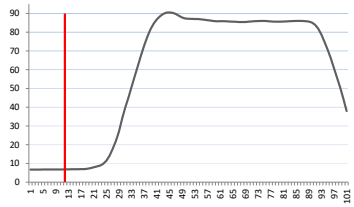
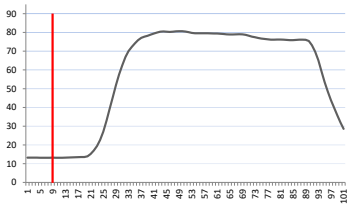
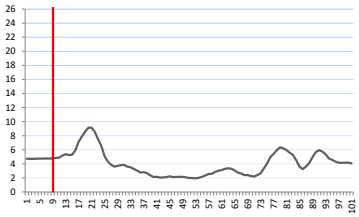
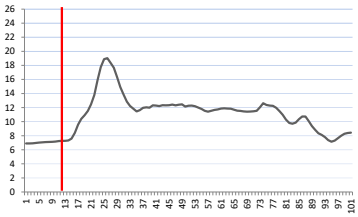
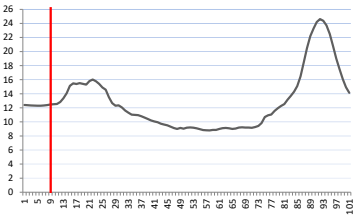
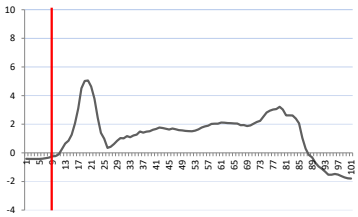
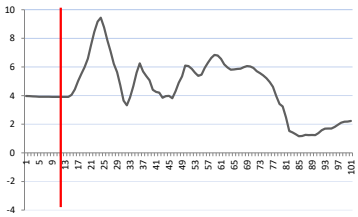
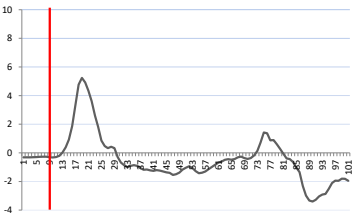
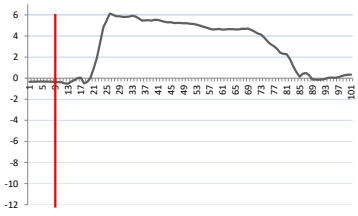
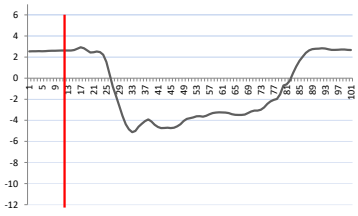
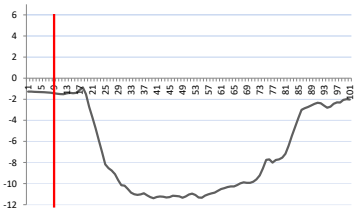
Measurement error of the motion capture system

Measurement errors and variability in 3D gait analysis can arise from at least three different sources; 1) the participant (e.g. natural variation including trial to trial variation and differences due a specific condition), 2) the measurement system (e.g. calibration, number of cameras, camera resolution and precision of computation algorithms) and 3) the assessor (e.g. marker placement and identification of anatomical landmarks) [132]. Variability is defined by the sum of variance from each of these sources [133].

With regard to the measurement error of our motion capture system, infra-red camera systems, such as the one used in this study, provide kinematic data of high accuracy [15]. The accuracy is dependent on the number of cameras used, capturing volume, calibration, technical specification and settings of system parameters [134, 135]. However, the absolute error is found to be 1.6 mm or less [15, 134, 135], which contributes marginally to the sum of variance in 3D motion analysis. This can be demonstrated for our motion capture system by inspection of motion graphs for the kinematic variables during the Stork test. Figure 6 (page 38) presents the motion graphs of four selected variables, hip sagittal plane movement of the lifted leg and hip sagittal plane, hip frontal plane and contralateral pelvic frontal plane movements of the standing leg. The motion graphs are given for one randomly selected participant from each of our study groups, and time normalized to 101 points beginning 450 ms prior to lifting the foot off the ground and ending at the time of foot contact. As illustrated

(Figure 6, page 38), the graphs on the left side of the red markers have an approximate horizontal path. In this period, the participants were standing still on both feet. Hence, the horizontal paths on the left side of the red markers was an expected observation, as little motion should occur in any of the kinematic variables when the participants were standing still. Noteworthy, the motion graphs comprise the sum of variance of the signal, including the variability of the motion capture system, the variability of participant`s performance and any other source of variability. Hence, the part of the graph prior to the vertical marker reflects a measure of the baseline variability in our kinematic variables, including the variability of the motion capture system. As illustrated on the top left graph, the baseline variability was low with the graph varying less than 1°. When the participant lifted her leg towards 90° of hip flexion, the motion graph on the right side of the vertical marker, displays a markedly increase in hip sagittal plane values on the y-axis, with the graph varying about 80°. The same pattern of low level of baseline variability was found in all the three study groups, as well as in kinematic variables with an expected smaller joint excursion, such as hip sagittal and frontal plane and pelvic frontal plane motions. This demonstrates that the variability (i.e. the measurement error) of our motion capture system was microscopic compared to the variation of an individual`s performance.

Figure 6 Continuous motion graphs of key kinematic variables in the Stork test

One pregnant woman with PGP	One asymptomatic pregnant woman	One asymptomatic non-pregnant woman
Lifted leg		
Hip sagittal plane		
		
Stance leg		
Hip sagittal plane		
		
Hip frontal plane		
		
Pelvic frontal plane		
		

Motion graphs of four kinematic variables; hip sagittal plane movement of the lifted leg and hip sagittal plane, hip frontal plane and contralateral pelvic frontal plane movements of the standing leg. Motion graphs are time normalized to 101 points beginning 450 ms prior to lifting the foot off the ground and ending at the time of foot contact. In the period prior to the red vertical marker, the participants were standing still on both their feet.

Specifications related to gait (Paper II)

Participants walked barefoot at self-selected speed along a 15 meter walk-way with force plates embedded (Figure 4 on page 35). The PhD candidate gave the standardized instruction; “Walk towards the other side of the room in your natural way. Walk in your natural speed as you would do when walking from A to B. Not as when running to the bus or walking while shopping”. The participants were unaware of the force plates, to avoid that they would adjust their normal walking to the position of the force plates. To use force plate data for the identification of gait events, we aimed to collect data until five acceptable trials with foot placement within the force plate for each limb were captured. The number of gait trials performed were comparable for the three groups, with the following median number of gait trials (min-max) for the pregnant women with PGP; 8 (5-14), asymptomatic pregnant women; 8 (5-13) and non-pregnant women; 8 (5-16).

Specifications related to the Stork test (paper III)

Participants were instructed to start in their natural standing position with feet approximately hip width apart and with one foot on each force plate. The PhD candidate gave the standardized instructions to lift one leg up to 90° hip flexion and maintain a steady position for two seconds. The participants were allowed one practice trial on each leg. Thereafter, all completed five right and five left trials. The participants were asked to stand in a relaxed position and with their arms by the side of their body between each trial. They were allowed rest whenever needed. To reflect the clinical setting, we asked the participants to perform the Stork test barefooted and to lift their legs alternately and in self-selected speed.

Anthropometrics

The participant´s body height (cm) and weight (kg) were measured with a stadiometer and a medical scale, respectively. Pelvic width (cm) was determined by the distance between the two anterior spina iliaca superior (ASISs) on the pelvis, and trochanter major distance (cm) was calculated as the distance between these two landmarks on each femur. Both pelvic width and trochanter major distance were calculated by Visual 3D software (C-motion Inc, Crabbs Branch Way Rockville MD) (V3D).

The following anthropometric measures were also taken; the diameter of the most proximal part of the thigh, foot width at the level of the head of the 5^{th} metatarsal bone and the distance between the most prominent part of the trochanter major on the femur and the

hip joint. These measures were taken to enable the possibility to use different segment modelling in the motion analyses. However, they were not used in this thesis.

Pilot studies

Prior to data collection, pilot testing including four non-pregnant and two pregnant women was conducted to increase the feasibility of the data collection procedure, as well as to investigate possible methodological errors. For the kinematic analyses, different marker sets and positioning of the optoelectronic cameras were evaluated particularly with regard to marker visibility. Our full body marker set was tested in both pregnant and non-pregnant women for the different tasks and activities in our study, and all markers were regarded to be visible. We included markers bilaterally on the iliac crest to allow for an alternative pelvic segment modelling. However, the ASIS and PSIS markers on the pelvis were visible for all the participants both during gait and the Stork test.

Electromyography

Our study protocol included recording of muscle activation from five muscles bilaterally using a wireless surface EMG system. The muscles measured are detailed in Appendix 3, Table S3. The wireless EMG system (Noraxon USA Inc. Scottsdale, USA) are extensively used in biomechanical research at the NIH. Two surface electrodes were attached to the skin overlying each muscle, and connected to a sensor (preamplifier) by two short wires. The signal was send to a desktop receiver. The used Ambu® Blue Sensor N (Ambu AS, Ballerup, Denmark) electrodes and sensors are small and specifically developed for children. The EMG equipment was carefully positioned on each participants, not to conflict with either the reflex markers or the performance of movements. As this thesis does not include EMG data, further details regarding the EMG equipment are not described.

Data processing

In order to get 3D kinematic data, the captured data from the cameras were processed using QTM software. Firstly, the trajectories of all the 67 markers were identified in each file for all gait and Stork trials in all participants. Each marker trajectory was identified in order to set the correct label of the marker. We used a combination of the Automatic Identification of Markers (AIM) function within QTM and manual identification of trajectories. The automatic identification of all the markers in each file was validated by visual inspection and corrected when necessary. In case of frame gaps, marker trajectories were manually filled using the Gap

fill trajectory with preview function within QTM, which allows inspection of a calculated probable path for the trajectory between two parts. We strictly followed a standardized written procedure for data collection including marker set and camera number, set-up and calibration procedures, as well as procedures for visual inspection of the visibility of the markers on each participant by each camera prior to testing [130]. In combination with the extensive marker-set, this contributed to high marker visibility and enabled 3D motion analysis with few errors and few missing values. The processed files were exported to the C3D format and imported into V3D.

As recommended by Robertson and Dowling [136], the kinematic data were low-pass filtered at 6 Hz using a digital 4th order Butterworth Bidirectional Filter in V3D. Local coordinate systems for the different body segments were created based upon established recommendations from the ISB [128, 137]; Markers on the manubrium sterni, xiphoid process, the spinous processes of C7, T2, T4, T10, L1, L3 and L5, as well as the bilateral markers on the posterior rib angle of the 11th rib together represented the thorax and spine. Markers placed bilaterally on the anterior superior iliac spine (ASIS) and the posterior superior iliac spine (PSIS) were used to model the pelvis. Markers bilaterally on the greater trochanter of the femur, medial and lateral femoral condyles as well as four tracking markers on the thigh were used to define the thigh. Right and left hip joint angles were calculated as the right and left thigh segments, respectively, relative to the pelvic segment. We used a predictive method to estimate the right and left hip joint center based on the pelvic markers using the regression equation of Harrington [138]. This predictive method, to locate the hip joint center, has recently been recommended among numerous predictive methods [139]. It requires information on pelvic depth and width [139], based on anatomical landmarks of the pelvis. The equation adapted in V3D is for the right hip joint center; 0.33*ASIS_Distance+0.0073, -0.24*RPV_Depth-0.0099, -0.30*ASIS_Distance-0.0109 and the left hip joint center; -0.33*ASIS_Distance-0.0073, -0.24*RPV_Depth-0.0099, -0.30*ASIS_Distance-0.0109) [140]. The thoracic and pelvic segments were analyzed with respect to the laboratory´s coordinate system and oriented so that a positive Y-direction was in the direction of forward progression in the analysis of gait (paper II) and anteriorly directed (in relation to the participants` body) for the Stork analysis (paper III). The rationale, for calculating the thoracic and pelvic segments in relation to the global (laboratory) reference frame [73], was to describe movements of the trunk and pelvis in space (i.e. in the room), as this is how these movements are commonly observed visually during gait and SLS test in clinical practice. In biomechanical texts, trunk and pelvic movements are also often analyzed in relation to the laboratory [15, 73, 141]. We used a relative (local) reference frame [73], to calculate the angle between the pelvis and the femur,

as this is regarded to express the “true” hip angle [15, 109]. Hence, our hip angle calculations express a clinically relevant angle. Joint rotations of the thorax (thoracic segment and laboratory) and hip (thigh and pelvic segments) were calculated (cardan sequence XYZ) in the sagittal (X-axis), frontal (Y-axis) and transverse (Z-axis) planes. As V3D compute joint angles based on the “Right Hand Rule” [142], rotations about the X-axis (flexion/extension) has the same sign for the left and right hip joints, but rotations about the Y-axis (adduction/abduction) and Z-axis (internal/external rotation) have opposite sign. As commonly done, we negated frontal and transversal plane rotations for the left hip, to provide the same sign convention for both hip joints (i.e. positive values represent hip adduction and hip internal rotation). As recommended, the pelvic rotations (pelvic segment and laboratory) were extracted using a rotation-obliquity-tilt (ZYX) sequence, as this rotation sequence corresponds to the clinical understanding of pelvic movements [143]. Table 4 (page 43) gives an overview of the kinematic variables in the sagittal, frontal and transversal planes and the movement directions representing the positive values.

As we aimed to compare our findings with previous studies, we added calculations of pelvic and trunk movements in accordance with calculations proposed by others. To provide a relative quantification of the foot position of the foot to the midline of the participant, we calculated lateral pelvic translation according to Allison and co-workers [144] (0 % represents 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 gait analysis (paper II), 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 [90]. In the Stork analysis (paper III), trunk translation was calculated as the lateral translation of the C7 marker relative to the calcaneal marker on the stance foot expressed in cm, to enable a quantification of the trunk in relation to the standing foot.

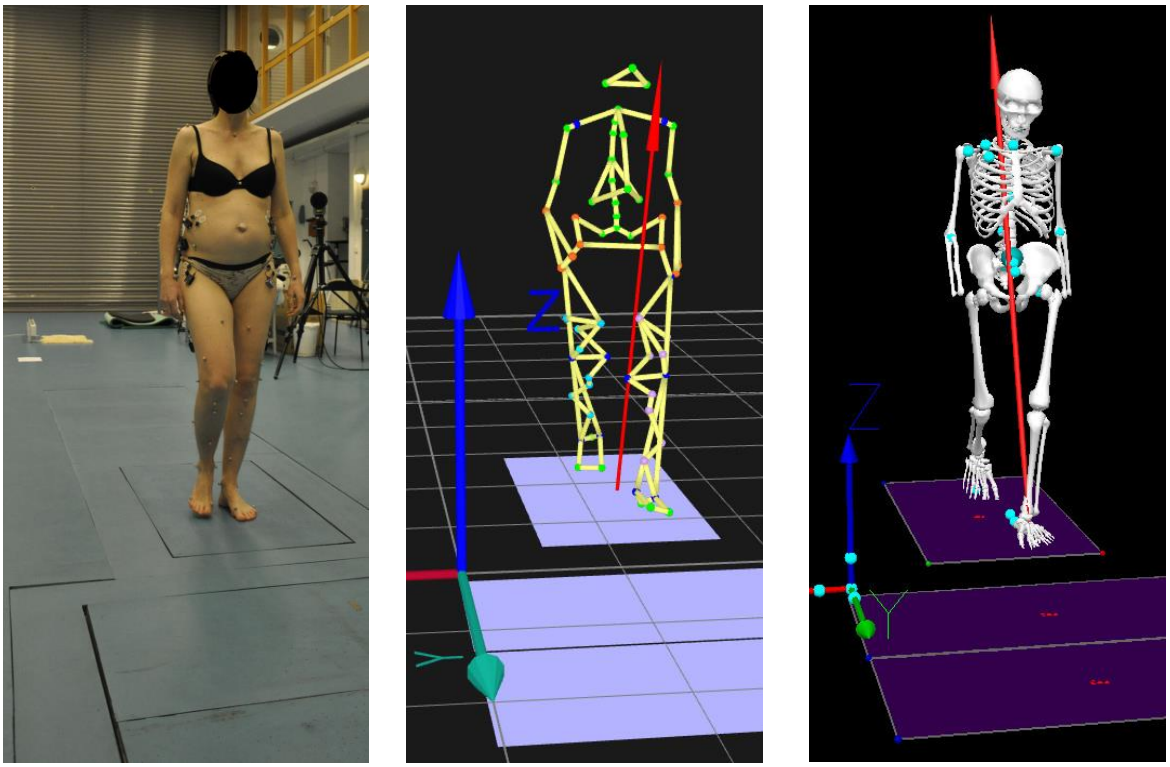
Table 4 Overview of the kinematic variables calculated at specific events and movement directions used in paper II-III

Kinematic variables	Movement direction
Thoracic sagittal plane angle	Flexion (+)
Thoracic frontal plane angle	Ipsilateral lean (+)
Thoracic transversal plane angle	Ipsilateral forward rotation (+)
C7 lateral translation (cm)[1]	C7 marker relative to the laboratory coordinate system as ROM in the frontal plane during the gait cycle
L3 lateral translation (cm) [1]	L3 marker relative to the laboratory coordinate system as ROM in the frontal plane during the gait cycle
Trunk translation (cm) [2]	C7 marker relative to the calcaneal marker on the stance foot during the Stork test
Pelvic sagittal plane angle	Anterior tilt (+)
Pelvic frontal plane angle	Contralateral obliquity (+)
Pelvic transversal plane angle	Ipsilateral forward rotation (+)
Pelvic lateral translation (% Inter-ASIS distance/2)	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
Hip sagittal plane angle	Flexion (+)
Hip frontal plane angle	Adduction (+)
Hip transversal plane angle	Internal rotation (+)

[1]calculated in the gait analysis only (paper II), [2]calculated during the Stork test analysis only (paper III)

In addition, the medial and lateral malleolus markers and four tracking markers on the leg defined the shank, while markers on the posterior aspect of each heel, the fifth and first metatarsal heads defined the foot. One marker in the middle of the forehead and two markers at the temporomandibular joints modelled the head. Finally, the upper limbs were represented by bilateral markers on the lateral shoulder, posterior humerus, on the medial and lateral humerus epicondyles and on the radius and ulna styloid processes. Joint rotations of the ankle, knee, joints in the upper extremity and the head were not calculated in this thesis. Figure 7 (page 44) illustrates a pregnant participant during a gait trial in the laboratory (a), with markers tracked in Qualisys (b) and body segments modelled in V3D (c).

Figure 7 Pregnant participant during a gait trial (a), with the markers tracked in the Qualisys software (b) and the body segments modelled in the Visual 3D software (c)



(a) Pregnant participant with markers

(b) Markers tracked in Qualisys

(c) Body segments modeled in Visual 3D

Test side refers to the standing leg in the kinematic analysis. 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.

Gait analysis (Paper II)

We used the first four gait cycles with foot placement within the force plates in the analyses for each participant. 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 (GRF) [144]. The ranges of motion (ROMs) of the thorax, pelvis and hip as well as translation of the C7, L3 markers and the pelvis during the gait cycle between HS and the subsequent HS of the same foot were determined. We also calculated the thoracic, pelvic and hip angles (degrees) at four pre-defined events during stance phase of gait. The four events were HS, mid-stance (identified as the midpoint temporal observation of the stance phase when normalized from 0-100 %), peak hip adduction angle and TO.

In addition, the following spatiotemporal variables were derived from 3D kinematic data using the "Metric compute temporal distance command" within V3D; speed (meter/second), cycle time (second), stance time (seconds), stride width (meter), stride length (meter) and ipsilateral and contralateral step length (meter) (denoting step length on the same and the opposite side of the "test side" respectively). Stance phase (% of gait cycle) and double limb support (% of gait cycle) were also extracted. (Definitions given in Table 5).

Table 5 Definition of the spatiotemporal variables used in paper II

Spatiotemporal variable	**Definition**
Speed (meter/second)	Computed using the actual stride length / actual stride time
Cycle time (seconds)	RHS-RHS[1] and LHS-LHS[2]
Stance time (seconds)	Right stance time = RHS-RTO[3] and left stance time= LHS-LTO[4]
Stride width (meter)	Medio-lateral distance between proximal end position of the foot at ipsilateral heel strike to the proximal end position of the foot at the next contralateral heel strike. Calculated by taking a stride vector, and the step in between, and computing the cross product (distance between the stride vector and the opposing step (heel) position
Stride length (meter)	Distance between proximal end position of the foot at ipsilateral heel strike to the proximal end position of the foot at the next ipsilateral heel strike
Ipsilateral step length (meter)	Distance between proximal end position of the contralateral foot at the previous contralateral heel strike to the proximal end position of the ipsilateral foot at the ipsilateral heel strike. On the side of the painful/most painful side, or test side
Contralateral step length (meter)	Calculated the same way as ipsilateral step length, but on the contralateral side of the painful/most painful side, or test side
Stance phase (% gait cycle)	Computed as stance phase / gait cycle
Double limb support (% gait cycle)	Computed as double limb support / gait cycle. (Double limb support defined as LHS to RTO[5] and RHS to LTO[6], or RHS-LTO[7] and LHS-RTO[8])

[1]right heel strike to right heel strike of the same foot, [2]left heel strike to left heel strike of the same foot, [3]right heel strike to right toe-off of the same foot, [4]left heel strike to left toe-off of the same foot, [5]left heel strike to right toe-off, [6]right heel strike to left toe-off, [7]right heel strike to left toe-off, [8]left heel strike to right toe-off

The Stork test (paper III)

We manually inspected data from each Stork trial to be able to select four trials where the participants maintained SLS without excessive trunk sway. A 120-ms window with the least medial-lateral movement of the GRF data from the force plate under the standing foot defined a steady SLS in each trial. If participants were unable to maintain SLS, the trial was ignored and not used [108]. Neutral stance was defined as 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 [108]. During the development of analysis script in V3D, we evaluated two more methods to determine foot off event. One was using the vertical movement of the calcaneal marker, while the other was using the anterior-posterior component of the GRF instead of the vertical GRF. We explored the three different methods in 15 participants and decided on the most consistent and feasible method, which was the method previously used by Allison and colleagues [108]. Then, we defined the weight-shift phase between neutral stance and foot-off and the leg lift phase between foot-off and end of lift (EOL) of the thigh. EOL was determined as the first maximum of the calcaneus marker on the lifted foot in the vertical direction. Thoracic, pelvic and hip angles (degrees) in the sagittal, frontal and transversal planes were calculated as angles in neutral stance, as ROMs during weight-shift and leg lift and mean angles during the 120-ms SLS period. In addition, trunk translation (cm) and pelvic translation (% Inter-ASIS distance/2) were calculated in neutral stance, as ROMs during weight-shift and leg lift, and as mean values during the 120-ms SLS period. The following variables were calculated, as they were regarded to potentially influence performance of the Stork test; Stance width was calculated as the distance (cm) between the calcaneus markers on each foot in neutral stance, peak hip flexion angle of the lifted limb as the maximum angle of hip flexion during the test and speed of leg lift as the first time derivative of the calcaneus marker in the +Z-direction between foot-off and EOL (meter/second).

Study questionnaire and clinical examination

Prior to the data collection, we composed the study questionnaire and decided on the tests in the clinical examination. The contents build on; 1) the European guidelines for the diagnosis and treatment of pelvic girdle pain [18], 2) standardized instruments and clinical tests used in previous studies on PGP [6, 9, 13, 145], 3) single-items questions/questionnaires used in Norwegian population surveys and registers [146-149] and 4) previous research at the Department of Interdisciplinary Health Sciences [51, 150]. To provide a comprehensive

description of our study participants and to enable comparisons with previous studies in pregnant women with PGP, we aimed to collect self-reported data covering a biopsychosocial perspective. However, to reduce the burden on the participants, we chose several single-item questions and short-versions of standardized instruments.

To control for the feasibility of the study questionnaire, we let two pregnant and two non-pregnant women fill out the questionnaire prior to study start. Based on their feedback, we let only the women with PGP answer the questions regarding pain in the pelvic area and disability related to PGP. The questionnaire was constructed as an online form using the Nettskjema service [151]. Nettskjema is a tool for secure data collection and management provided by the University Center for Information Technology at the UiO. The participants answered the questionnaire on a PC (belonging to the UiO) and their response was sent directly to the Services for Sensitive Data (TSD) at the UiO [152], where our research data is securely stored. Pilot testing of the online form was performed using four test submissions containing dummy data.

The relevant psychometric properties of the measures, from which data has been used as independent/explanatory variables in this thesis, are described in Appendix 2, Table S2.

Study questionnaire

Socio-demographical data

Socio-demographical data included age (years), pregnant (yes, no), gestation week, parity, ethnicity, marital status (married/partner, divorced, widow, single), use of contraceptive pills last year before pregnancy (yes, no) and smoking status (yes, no). We did not include the latter two questions in this thesis. Based on the participant´s response, we dichotomized ethnicity into Norwegian and others, and marital status into married/partner and single.

All participants gave self-reported height (cm) and weight (kg). The pregnant participants reported these data retrospective, i.e. pre-pregnancy, while the non-pregnant participants reported present height and weight. In paper II and III, pre-pregnancy body mass index (BMI, kg/m^2) in the pregnant women and BMI in the non-pregnant group were calculated from self-reported height (m) and weight (kg). We also compared present BMI between the two pregnant groups (paper II) and between the three groups (paper I) (variables named BMI). For the latter two variables, we used measured height (cm) and weight (kg) on the day of testing. Finally, we calculated weight gain (kg) as the difference between measured weight and self-reported pre-pregnancy weight in the two pregnant groups (paper I).

Leg dominance was assessed by the question “Which leg do you prefer to stand on?” with four response alternatives; “right”, “left”, “both right and left”, “do not know”. There are different ways to determined leg dominance [153-155]. We chose self-reported “which leg do you prefer to stand on” as we regarded this activity to be familiar to our participants and relevant particularly for the Stork test. In SLS, the standing leg has been suggested to be the dominant leg [153]. In a recent study, leg dominance appeared to have a significant effect on anticipatory postural control strategies during SLS in healthy women [111]. Hence, to investigate the influence of leg dominance on Stork performance, we defined a variable describing whether it was the dominant leg that was tested (i.e. analyzed) during the Stork test, “Dominant leg tested”. This variable was defined as match between the self-reported dominant leg (“right”, “left” and “both legs”) and the leg tested, hence when dominant leg and the test leg was the same, it was defined as match (yes). (Further analysis is described on page 54).

Education and work

The following variables regarding education and work were assessed in the questionnaire:

Education (with response alternatives; 9-10 years of school attendance, 12-13 years of school attendance, four or less years at university, or more than four years at university). Based on the response in our study sample, we dichotomized this variable into four or less, or more than four years at university (paper I).

For employment status, the response alternatives were; full time work, part time work, student, sick leave, receiving disability benefit, work assessment allowance, unemployed, housewife or other and was a multi select question. Based on the response we recoded this variable to include; full time work, part time work, student and sick leave (paper I).

We assessed the women´s working situation using the question; “How would you describe your work situation?” The question had four response alternatives; 1) Most of the time seated, 2) A lot of walking, 3) A lot of walking and lifting, 4) Heavy work [146]. No one answered category four and we used this variable with three categories (paper I). In the thesis, we have dichotomized this variable; 1) Most of the time seated and 2) A lot of walking/a lot of walking and lifting, and presented the numbers for the second category for each group in all three papers (Table 7 on page 57).

The participants reported current work ability on a numeric rating scale with scores ranging from 0 (unable to work) to 10 (work at best) [156].

Exercise

Exercise was defined as go for a walk, cross-country skiing, swimming or work out/ be active in athletics/sports. Participants reported exercise frequency, intensity and duration during the last seven days and prior to pregnancy (for the pregnant groups) [157].

Exercise frequency had five response alternatives: never, less than one day/week, one day/week, two to three days/week, nearly every day [146]. Based on the response, we categorized exercise frequency into one day or less/week, two to three days/week and almost every day. Only present exercise frequency was used in this thesis (paper I). We have dichotomized this variable < one day/week and ≥ one day/week, and presented the numbers for the second category for each group in all three papers (Table 7 on page 57).

Exercise intensity (slow intensity without being breathless and sweat, intensity so that I become out of breath and sweat, hard exercise) and exercise duration (less than 15 minutes, 15 to 29 minutes, 30 minutes to one hour, more than one hour) were also reported, but not used in this thesis.

Psychological distress

The Hopkins Symptom Checklist-10 (SCL-10) (117) was used to assess psychological distress (symptoms of anxiety, depression and somatization). The SCL-10 consists of 10 items on a four-point scale ranging from one (not at all) to four (extremely). An average item score was calculated and a score of 1.85 or more indicates non-specific distress [123] (paper I-II).

Disability and symptoms

We used the Pelvic Girdle Questionnaire (PGQ) to assess activity limitations (20-item subscale) and symptoms (five-item subscale). Response alternatives on a four-point scale ranging from 0 (not at all) to three (to a large extent) give a total score between 0 and 75. The sum scores are converted to percentages between 0 and 100 % where higher percentages indicate reduced function. In paper I, we presented the activity and symptom subscales separately [13], while in paper II we used the PGQ total score to investigate the relationship with mean gait speed.

Current and previous pain

All participants answered questions regarding pain history, e.g. whether they had experienced PGP in past pregnancy (yes, no), previous pain or trauma in the back, pelvis or lower limbs (yes, no) and current use of medication (none, sleeping tablets, asthmatic, inflammatory or pain medication, other). Participants with PGP also answered questions

regarding onset of PGP in current pregnancy (week), symptom location (no pelvic pain, anteriorly over the pubic symphysis, right sided posterior pelvis, left sided posterior pelvis, over the sacrum) and current use of walking aids (no never, yes but not every day, yes every day). Based on the response, we dichotomized symptom location into posterior pain (uni- and bilateral) and combined posterior and pubic symphysis pain as well as use of walking aids into yes or no.

Pain intensity

Women with PGP reported pain intensity on a numeric rating scale (NRS) with scores ranging from 0 (no pain) to 10 (worst pain imaginable) [124]. The women scored present pain intensity prior to testing on the day of data collection, as well as the average pain intensity during the last 48 hours and the last 14 days. Finally, they also scored present pain intensity during the testing procedure to monitor whether the testing provoked pain. We used present pain intensity prior to testing as pain may influence physical function as assessed by the TUG test and movement patterns during gait and the Stork.

Fear of movement

Women with PGP answered one substitute question of the Tampa Scale for Kinesiophobia [125]: "How much fear do you have that your PGP would be increased by physical activity?" This question measures fear of movement and scores range from 0 (no fear) to 10 (very much fear) on a NRS [125].

Tests in the clinical examination

Timed up and go

The TUG was performed in a large room with a linoleum floor. A three-meter walkway was marked using two white parallel lines on the floor. A chair with a seat height of 46 cm, back-support and armrest was used. All participants assumed a start position with their back resting against the back-support of the chair and with their arms on the armrests and their toes against the white line. Participants wore sneakers and could use walking aids if needed. However, none of our participants used any walking aids. A demonstration was given and one practice trial was allowed. The time to perform the TUG was recorded by a SPORTX PRO 30 Lap Stopwatch (Wenaas Nordic AS, Norway). The standardized instruction translated into English was; "After "ready, set, go", stand up, walk as fast as you can until you cross the white line. Cross the line with both your feet. Turn around, walk back to the chair and sit down." This reliable and valid TUG variant [70, 71] instructed participants to walk as fast as they could, and

timing commenced on the word “go” and ended when the participant`s buttocks made contact with the chair again after the walk [158].

Active straight leg raise

The ASLR was performed with the women in supine position with their feet approximately 20 cm apart [68]. The standardized instruction was; “Lift your right/left leg 20 cm up from the bench keeping your leg straight”. Participants rated the degree of difficulty from 0 (no difficulties) to five (impossible to lift). The score for each leg was added to a sum score (0-10). Higher score indicates more reduced function [68]. To distinguish between strong and less affliction (paper I), the ASLR was dichotomized based on a cut off value of four [159]. In paper II and III, the ASLR score was used as a continuous variable to describe the study sample.

P4 test

The P4 test [119] was performed with the participants in supine position with the actual hip joint flexed to 90°. While stabilizing on the contralateral side, the PhD candidate applied a graded force into the pelvis through the longitudinal axis of the femur (5). Both left and right side were tested. Reproduction of familiar pain in the posterior pelvis on the test side was recorded (yes, no) for each side separately [51].

Beighton score

The Beighton score was used as a measure of general joint hypermobility [160, 161]. It consists of nine tests of joint laxity; Knee hyperextension (yes, no), elbow hyperextension (more than 10°) (yes, no), passive opposition of the thumb to the forearm with straight elbows (yes, no), passive hyperextension of the 5^{th} metacarpophalangeal joint with the forearm on the table (90° or more) (yes, no), forward trunk flexion with straight knees and palms of the hands resting easily on the floor (yes, no) [160]. All angles were measured with a goniometer. A sum score (0-9) of five or more was considered as hypermobility [161].

Sample size and power estimates

Initially, this project was planned with two groups, pregnant women with and without PGP. Prior to the start of the data collection (December 2015), we examined relevant kinematic cross-sectional studies on SLS tasks with regard to sample size. The two previous studies on a SLS task in PGP populations included 12 [40] and 14 [96] participants in each group. Other studies describing SLS kinematics in healthy individuals reported study samples of 9-30 participants [104, 162-164], while kinematic and EMG studies in patient populations such as low back and knee pain reported 17-21 participants in each group [165-168]. We originally planned for a sample size of 23 in each group, sufficient to detect a between-group 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. The sample size calculation was performed based on a previous study investigating a SLS test in individuals with and without patellofemoral pain syndrome including 20 participants in each group using a cross-sectional study design with four groups [165]. Pelvic frontal plane angle was regarded the relevant variable for the sample size calculation, as it is one of the key movements visually inspected by clinicians in the assessment of movement patterns during SLS tests [38, 104, 106, 108]. 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.

Statistical analyses

Different statistical analyses were used depending on the research questions, the variables used and the post hoc sensitivity analyses. (Overview given in Table 6, page 55). A 5 % significance level was used in all papers. Statistical analyses were conducted using the IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.

For all papers, descriptive data are presented as frequencies (percentages), means (with standard deviations (SDs) or 95 % confidence intervals (CIs), or median values (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 correcting for multiple comparisons. We used Bonferroni correction for the ANOVA tests with p-value correction implemented in the posthoc procedure for pairwise comparisons. In the Kruskal-Wallis tests, we used pairwise Mann-Whitney tests with p-value correction (P = 0.05/3 = 0.017). Differences between the

two pregnant groups, such as weight gain, gestation week and BMI, were tested by Mann-Whitney tests.

Paper I

Differences in TUG time between pregnant women with PGP, asymptomatic pregnant and non-pregnant women were tested by one-way ANOVA. Pairwise comparisons were performed using Bonferroni correction.

To investigate factors potentially associated with an increased TUG time, we initially considered potential explanatory variables based on previous studies reporting factors associated with TUG time in different study populations, as well as studies assessing factors related to PGP in pregnant women. Hence, the following explanatory variables found in previous studies were considered; Increased BMI, decreased mental health education level, pain and ALSR score [71, 113-115], as well as previous given birth, former low back pain, former PGP, working conditions, gestation week, exercise level, sick leave, fear of movement and generalized joint laxity [6, 8, 12, 46, 52, 169-171]. In the total sample, the variable group included both pregnancy and PGP (i.e. pain location, positive ASLR and P4 test). We used simple linear regression analyses (with a 10 % level of significance) and clinical considerations to select explanatory variables in the multiple linear regression models. Pearson or Spearman correlation coefficients (as appropriate) were used to study associations between explanatory variables in the multiple linear regression models. We recoded the categorical variables using dummy variables and performed linear regression analyses both in the total study sample and in the group of women with PGP. Furthermore, plausible interaction effects were tested and the residuals inspected for model assumptions.

Paper II-III

A linear mixed model (unstructured covariance matrix) was used to test between-group differences in spatiotemporal and kinematic variables during four repeated trials of gait (paper II) and the Stork test (paper III), respectively. To investigate both the influence of pregnancy and PGP on gait and Stork performance, asymptomatic pregnant women were the reference group. We calculated estimated marginal means (EMMs) with 95 % confidence intervals (CIs) to describe the level in the three groups over the four repeated gait and Stork trials. In paper II, we also present percentage differences between the groups based on the EMMs for the spatiotemporal gait variables.

In our linear mixed model procedure, we tested for interaction between group and repeated trials (i.e. gait trials in paper II and Stork trials in paper III, respectively). When significant, the effect of group was studied within each gait or Stork trial, respectively, using multiple linear regression analyses. The effect of trials was studied by linear mixed models within each group. The residuals were inspected for model assumptions.

In paper II, we also explored the influence of speed by repeating the mixed model analyses with adjustment for speed, given the potential influence of speed on gait biomechanics [172]. As stride length is reported to affect thoracic kinematics [173], sensitivity analyses with additional adjustment for contralateral step length were performed for the kinematic variables. As stride length consists of both ipsilateral and contralateral step length, we chose to adjust for contralateral step length as this variable was significantly different between asymptomatic pregnant women and pregnant women with PGP in the crude analysis, as well as when adjusted for speed. Correlations between mean gait speed and fear avoidance, self-reported disability and pain intensity were investigated in the PGP group using Spearman correlation coefficient.

In paper III, we also explored the influence of pelvic width by repeating the linear mixed models with adjustment for pelvic width. Based on both clinical observations and previous studies on SLS tests [111], we explored variables potentially influencing movement performance during the Stork test. To explore the potential influence of leg dominance on Stork kinematics, 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 analysis, we also adjusted for pelvic width and if dominant leg was tested. Finally, we did sensitivity analysis in the whole study sample with additional adjustment for peak hip flexion angle of the lifted limb 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 variability for some selected variables; 1) Stance width in neutral stance and speed of leg lift, as these variables presumptively may influence Stork performance. 2) Frontal plane trunk and pelvic kinematics during SLS, as these movements are commonly evaluated clinically. 3) The three variables with significant between-group differences. These variables are referred to as key variables during the Stork test.

Reliability and measurement variation of the kinematic data

As all measurements, including kinematic data, have some amount of measurement error [15], knowledge of reliability and typical measurement variation are important in the interpretation of 3D kinematic data [74, 174]. To study reliability over the four gait and Stork trials, we calculated the intraclass correlation coefficient (ICC; 1,1) with 95 % CI [175]. Based on the 95 % CI of the ICC estimate, values less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 indicated poor, moderate, good, and excellent reliability, respectively [176]. We also calculated the intra-individual standard deviation (SD) over the four gait and Stork trials in each group as an absolute measure of measurement variation as recommended by McGinley and co-workers [74].

Table 6 Statistical methods used in paper I-III

Statistical method	Paper I	Paper II	Paper III
Descriptive analyses	X	X	X
Chi-square test	X	X	X
Fisher exact test	X	X	
ANOVA	X	X	X
Kruskal-Wallis		X	X
Mann-Whitney	X	X	X
Intraclass correlation coefficient		X	X
Pearson and/or Spearmann correlation coefficient	X	X	
Simple/univariate linear regression	X		
Multiple linear regression analyses	X	X	X
Linear mixed models		X	X

Data handling and storage

All research data collected in this project has been handled and stored in accordance with the guidelines of UiO and according to the approval from the Regional Committees for Medical and Health Research Ethics in Norway. The project has its own area in the Services for Sensitive Data (TSD) at the UiO where all the collected data are stored and analyzed. The TSD is a platform for collecting, storing, analyzing and sharing sensitive data in compliance with the Norwegian privacy regulations [152].

Main results

An overview of the study sample and the main results related to the five aims will be presented here. First the results of the biomechanical studies (paper II and III) and the results on reliability and measurement variation of the gait and Stork data will be presented. Then the results from the TUG test (paper I) are presented. More detailed results are reported in paper I-III.

Study sample

The three papers of this thesis are based on data from the same study sample. In paper I, we used data from all 74 participating women. Due to technical errors, data from 73 and 72 women were used in paper II and paper III, respectively.

In paper I, weight, BMI, marital status, sick leave and working conditions were significantly different between groups (P-values ≤ 0.04). Post hoc analyses revealed that pregnant women with PGP had significantly higher weight (P = 0.04) and BMI (P = 0.03) than non-pregnant women. No significant differences were found between the asymptomatic pregnant women and either pregnant women with PGP (P = 1.0) or non-pregnant women ($0.12 \leq P \leq 0.82$). In paper I, we found no significant difference in weight gain between the two pregnant groups (P = 0.58). In paper II and III, we also presented self-reported pre-pregnancy BMI in the pregnant women and self-reported BMI in the non-pregnant women, and found no significant between-group differences. With regard to working condition, 16 women with PGP reported a lot of walking or a lot of walking and lifting, compared to four asymptomatic pregnant and six non-pregnant women. Despite the loss of data from one and two participants in paper II and III respectively, the same participant characteristics as in paper I remained significantly different in paper II and III (Table 7, page 57).

The number of participants in the PGP group was constant (n = 25) in all three papers. The clinical variables showed large variation in the pregnant women with PGP: PGQ total score ranged between 10-73 %, pain intensity score ranged from 0 to 7, fear of movement from 1 to 10 and ASLR scores from 1 to 8. Eight out of 25 women had an ASLR sum score of 5 or more.

Table 7 Characteristics of the pregnant women with pelvic girdle pain (PGP), asymptomatic pregnant and asymptomatic non-pregnant women in paper I-III

Paper	I-III	I-II	I	III	II-III
Number of participants in each group	25 pregnant women with PGP	24 asymptomatic pregnant	25 asymptomatic non-pregnant	23 asymptomatic pregnant	24 asymptomatic non-pregnant
Age (years), mean (SD)	30.9 (2.2)	31.5 (3.7)	31.7 (4.1)	31.3 (3.3)	31.4 (4.0)
Weight (kg), mean (SD)	68.7 (8.0)*	67.3 (7.8)	63.4 (6.5)*	67.7 (7.7)	63.4 (6.7)*
Weight gain[1] (kg), median (min-max)	5.0 (0.04-11.2)	5.2 (1.7-15.9)	-	5.2 (1.7-15.9)	-
Pre-pregnancy BMI[2] (kg/m^2), mean (SD)	22.6 (2.1)	22.0 (2.1)	23.0 (1.7)	22.1 (2.1)	23.0 (1.7)
Gestation week, median (min-max)	23 (13-26)	23 (14-26)	-	23 (14-26)	-
Education, n (%) , ≤ 4 years higher education	15 (60.0)	9 (37.5)	8 (32.0)	9 (39.1)	8 (33.3)
> 4 years higher education	10 (40.0)	15 (62.5)	17 (68.0)	14 (60.9)	16 (66.7)
Working condition (a lot of walking/walking and lifting)[3], n (%)	16 (64.0)*	4 (16.6)*	6 (24.0)*	4 (17.4)*	6 (25.0)*
Sick leave[4], n (%)	7 (28.0)*	1 (4.2)*	1 (4.0)*	1 (4.4)*	1 (4.2)*
Exercise frequency (≤ 1 day/week), n (%)	14 (56.0)	9 (37.5)	7 (28.0)	9 (39.1)	7 (29.2)
SCL-10[5], n (%)	4 (16.0)	0 (0.0)	1 (4.0)	0 (0.0)	1 (4.2)
Onset of PGP (week), mean (SD)	14.9 (5.9)				
PGQ[6] total score, mean (SD)	42.7 (16.0)				
PGQ[6] symptom subscale score, mean (SD)	43.1 (18.2)				
Pain intensity[7], mean (SD)	2.5 (1.9)				
Fear of movement[8], median (min-max)	6.5 (1-10)				
ASLR[9] score (≥4), n (%)	8 (32.0)				

**significant between-group differences; P <0.05, [1]difference in kg between self-reported weight and measured weight on the day of testing, [2]self-reported body mass index (kg/m^2) prior to pregnancy for the pregnant women and current for the non-pregnant women, [3]the variable working conditions dichotomized on "mostly seated" and "a lot of walking/walking and lifting"; numbers for the latter category is presented, [4]Numbers (%) within each group with the response "sick leave", [5]Hopkins symptom checklist 10 items, [6]Pelvic Girdle Questionnaire, [7]pain intensity measured by numeric rating scale, [8]fear of movement measured by one substitute question for the Tampa Scale for Kinesiophobia, [9]Active Straight Leg Raise*

Spatiotemporal and kinematic gait characteristics (paper II)

In paper II, we explored the influence of pregnancy and PGP on gait characteristics in the 2nd trimester, by quantifying spatiotemporal characteristics and trunk, pelvic and hip kinematics in asymptomatic non-pregnant women and pregnant women with PGP compared with asymptomatic pregnant women. We also explored the influence on gait characteristics of variables potentially influencing movement performance, such as speed and contralateral step length.

Spatiotemporal variables

We found significant between-group differences for all spatiotemporal variables (P_{group} < 0.001), except stride width (P_{group} = 0.32) in the crude analyses (Table 8, page 60-61). Pregnant women with PGP had 18 % slower gait speed compared to asymptomatic pregnant women (P < 0.001). All other spatiotemporal variables differed significantly with about 10 % between the two pregnant groups ($P \leq 0.001$), except for stance phase (2 %, P = 0.001). Compared to non-pregnant women, 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) (Table 8, page 60-61).

After adjustment for speed, only contralateral step length (3 %, P = 0.03) and double limb support (5 %, P = 0.04) remained significantly different between the pregnant women with PGP and the asymptomatic pregnant women. Stance time, stance phase and double limb support remained significantly different ($0.006 \leq P \leq 0.01$) between the asymptomatic pregnant and the non-pregnant women (Table 8, page 60-61).

In the pregnant women with PGP, we also investigated the associations between gait speed and fear of movement, self-reported disability and pain intensity, respectively. In this group, mean gait speed was negatively correlated with both fear of movement (r_s = -0.63, P = 0.01) and disability as measured with PGQ (r_s = -0.46, P = 0.03). However, gait speed was not significantly correlated with pain intensity (r_s = -0.21, P = 0.32).

Kinematic variables

We investigated 52 kinematic variables in total and found no significant effect of group either in crude or in the adjusted analyses ($0.07 \leq P_{group} \leq 0.99$) for 43 of these variables. For the last nine kinematic variables we found significant between-group differences in the crude analysis ($P_{group} \leq 0.04$) (Table 9, page 62-63). During the gait cycle in women with PGP the EMM for lateral translation of C7 was 1.1 cm greater ($P = 0.01$), and pelvic frontal and transversal plane ROMs were 2.6° ($P < 0.001$) and 2.8° ($P = 0.03$) less, respectively, compared to asymptomatic pregnant women. 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 9, page 62-63).

Among trunk kinematic variables at specific gait events, we found a significant group effect for thoracic transversal plane angle at TO ($P_{group} = 0.01$, crude and adjusted analyses) (Table 9, page 62-63). Furthermore, asymptomatic pregnant women had less forward rotation of the ipsilateral thorax compared to non-pregnant women (EMMs -0.2° versus 2.8°, $P = 0.003$, adjusted for speed) (Table 9, page 62-63).

With regard to pelvic and hip kinematics at specific gait events, we found significant group differences for pelvic frontal and hip sagittal plane angles at peak hip adduction ($0.004 \leq P_{group} \leq 0.04$, crude and adjusted analyses) (Table 9, page 62-63). 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 peak hip adduction compared to asymptomatic pregnant women when adjusting for speed (Table 9, page 62-63).

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 (paper II, Supplementary material, Table S2).

Table 8 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). Taken from Christensen and co-workers [177] and reprinted in accordance with Elsevier´s permission guidelines [118]

		Crude[1]		Adjusted[2]	
Spatiotemporal variables	**Group**	**EMM (95 % CI)**	***P*[3]**	**EMM (95 % CI)**	***P*[3]**
Speed (meter/second)			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 (meter)			P_{group}=0.32		P_{group}=0.62
	Asymptomatic pregnant	0.10 (0.09, 0.11)	Ref.	0.10 (0.095, 0.11)	Ref.
	Asymptomatic non-pregnant	0.10 (0.10, 0.11)	0.56	0.11 (0.10, 0.12)	0.35
	Pregnant with PGP	0.11 (0.10, 0.12)	0.14	0.10 (0.095, 0.11)	0.95
Stride length (meter)			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] (meter)			P_{group}=<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] (meter)			P_{group}=<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 (second)			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 (second)			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) included. 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 pregnant 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)

Table 9 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). Taken from Christensen and co-workers [177] and reprinted in accordance with Elsevier´s permission guidelines [118]

		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 pregnant 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

Trunk, pelvic and hip kinematics during the Stork test (paper III)

In paper III, we explored the influence of pregnancy and PGP in the 2nd trimester on performance of the Stork test, by quantifying spatiotemporal characteristics and trunk, pelvic and hip kinematics in asymptomatic non-pregnant women and pregnant women with PGP compared with asymptomatic pregnant women. We also explored the influence on Stork kinematics of variables potentially influencing movement performance, such as pelvic width, leg dominance, peak hip flexion angle of the lifted leg and speed of leg lift.

We investigated 47 kinematic variables during the Stork test. For 44 of these variables, no significant effect of group was found either in crude or analyses adjusted for pelvic width and also for whether it was the dominant leg that was tested (yes/no) ($0.051 \leq P_{group} \leq 0.99$) (results presented in paper III, Supplementary material, Table S1). Three variables showed significant between-group differences in the crude and/or adjusted analyses (paper III, Table 2); EMMs for pregnant women with PGP 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 ($P = 0.01$) and dominant leg tested ($P = 0.03$) compared with asymptomatic pregnant women. 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 the two groups after adjustment for pelvic width ($P = 0.02$) and dominant leg tested ($P = 0.02$) (paper III, Table 2). The potential influence of leg dominance in the asymptomatic women (n=47) and the "both legs" and "do not know" (together, n=24) subgroups were further explored. Most kinematic variables remained unchanged, except for one and eight variables, respectively, showing statistical significant between-group differences (paper III, Supplementary material, Table S4). Two variables in the "both legs" and "do not know" subgroups were no longer statistically different (paper III, 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. Finally, we performed sensitivity analyses in the whole study sample with additional adjustment for peak hip flexion angle of the lifted leg and for speed of leg lift. However, this did not change the results for any of the kinematic variables during leg lift and SLS (paper III, Supplementary material, Table S2).

We used scatter plots to visually evaluate between and within individual variability for some selected key variables; 1) Stance width in neutral stance and speed of leg lift, as these variables presumptively may influence Stork performance, 2) Frontal plane trunk and pelvic kinematics during SLS, as these movements are commonly evaluated clinically and 3) The

three variables with significant between-group differences. Scatter plots of these key kinematic variables showed large variation across participants in all three groups, while the intra-individual variation over the four Stork trials was generally small in all three groups (paper III, Figure 2-3).

Reliability and measurement variation (paper II and III)

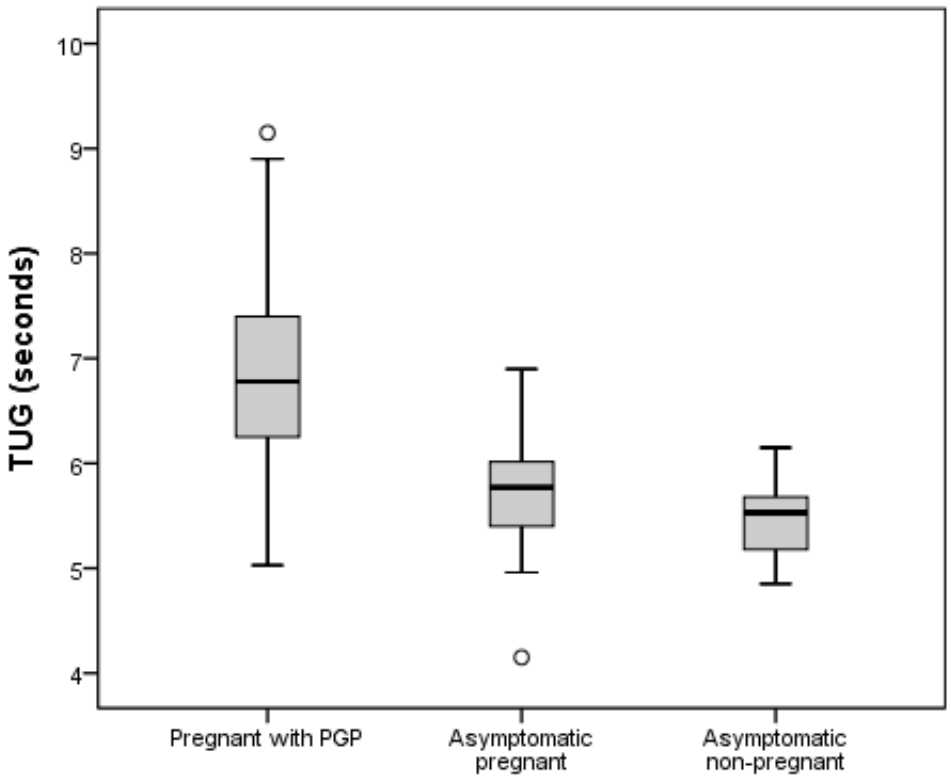
In paper II, we found good to excellent reliability for the majority of spatiotemporal variables in the three groups ($0.75 \leq ICC \leq 0.95$), while reliability was moderate for stance phase in asymptomatic non-pregnant women (ICC = 0.57) and in pregnant women with PGP (ICC = 0.68) and for double limb support in non-pregnant women (ICC = 0.74) (paper II, Supplementary material , Table S3). Reliability was also good to excellent for all kinematic variables in all three groups ($0.80 \leq ICC \leq 0.97$) (paper II, 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 (paper II, Supplementary material, Table S3-4).

In paper III, we found good to excellent reliability for the significant kinematic variables in the three groups ($0.87 \leq ICC \leq 0.95$) (Appendix 4, Table S4). Moreover, the intra-individual SDs were smaller than the between-group differences of the EMMs of each group (Appendix 4, Table S4).

Physical function as assessed by the Timed Up and Go test (paper I)

In paper I, we investigated physical function as assessed by the time to perform the TUG test in pregnant women with PGP, asymptomatic pregnant and non-pregnant women. TUG time differed significantly between the three groups ($P < 0.001$). Pregnant women with PGP used significantly longer time on TUG (mean (95% CI); 6.9 (6.5, 7.3) seconds) than asymptomatic pregnant (5.8 (5.5, 6.0) seconds) and non-pregnant women (5.5 (5.4, 5.6) seconds). However, there was no significant difference between asymptomatic pregnant and non-pregnant women ($P = 0.62$). Pregnant women with PGP also demonstrated a much larger variation in TUG time than the other groups. The boxplots in Figure 8 (page 66) show that about 75 % of the pregnant women with PGP use longer time on TUG than did the slowest among non-pregnant women (75 % percentile on the boxplot).

Figure 8 Box plot of the Time Up and Go (TUG) test for the three different groups: Pregnant women with pelvic girdle pain (PGP) (n = 25), asymptomatic pregnant women (n = 24), asymptomatic non-pregnant (n = 25). Median, quartiles and range are shown. Circles represents outliers (>1.5 inter quartile range above the 75th percentile or under the 25th percentile). Taken from Christensen and co-workers [117] and reprinted in accordance with Elsevier´s permission guidelines [118]



To assist the clinical interpretation of TUG time, we investigated potential explanatory variables associated with an increased TUG time in the total study sample and in the PGP group. In the simple linear regression analyses in the total sample, height, previous given birth, former low back pain, former PGP, education, working conditions and Beighton score (i.e. general joint hypermobility) were not significantly associated with TUG time ($0.15 \leq P \leq 0.86$). Gestation week was significantly correlated with TUG time ($P = 0.001$), but highly correlated with group ($P = 0.01$). Thus, these variables were not included in the multiple linear regression model. Group, sick leave, BMI and exercise frequency were significantly associated with TUG in the simple linear regression analysis (Table 10, page 67). However, in the multivariable regression analysis, only group, sick leave and BMI remained significant ($P \leq 0.02$; $R^2 = 0.58$) (Table 10, page 67). The multiple regression analysis showed that pregnant women with PGP used significantly longer TUG time than the non-pregnant women did (adjusted mean

difference (95 % CI) between the two groups 1.05 (0.66, 1.45) seconds), while not significantly different between asymptomatic pregnant and non-pregnant women (0.15 (-0.22, 0.52) seconds).

Table 10 Simple and multiple linear regression analyses of the association between Timed Up and Go (TUG) (seconds) and potential explanatory variables (n = 74). Taken from Christensen and co-workers [117] and reprinted in accordance with Elsevier´s permission guidelines [118]

	Simple linear regression		**Multiple linear regression**	
	ß[1] (95 % CI[2])	*P*-value	ß[1] (95 % CI[2])	*P*-value
Group				
Asymptomatic non-pregnant	Reference	0.001	Reference	0.001
Asymptomatic pregnant	0.26 (-0.14,0.66)		0.15 (-0.22, 0.52)	
Pregnant with PGP	1.43 (1.04, 1.83)		1.05 (0.66, 1.45)	
BMI (kg/m^2)	0.11 (0.03, 0.20)	0.01	0.08 (0.01, 0.15)	0.02
Sick leave				
No	Reference	0.001	Reference	0.001
Yes	1.47 (0.90, 2.04)		1.03 (0.55, 1.51)	
Exercise frequency				
≤1day/ week	Reference	0.006		
2-3 days/week	-0.68 (-1.16, -0.20)			
Almost every day	-0.71 (-1.23, -0.20)			

[1]Estimated regression coefficient, [2]CI, confidence interval. PGP, pelvic girdle pain; BMI, present body mass index.

There was significant interaction between sick leave and BMI ($P_{interaction}$ = 0.005), with a stronger effect of BMI on TUG time in women on sick leave than in women not on sick leave. Due to the low number of women on sick leave (Table 7, page 57), we present the model without interaction (Table 10). Moreover, univariate analyses showed weak associations between group and both BMI and sick leave (r-values = -0.30), and no significant association between BMI and sick leave (*P* = 0.45). In paper I, the terms univariate analyses and simple linear regression models have been used interchangeably.

Among the women with PGP, simple linear regression analysis identified significantly longer TUG time in women with strong affliction of ASLR (sum score four or more) compared to less afflicted women (sum score less than four) (crude mean difference (95 % CI) 1.62 (1.02, 2.20) seconds, (*P* > 0.001)). More fear of movement and higher pain intensity were also significantly associated with longer TUG time (0.15 (0.05, 0.25) seconds, (*P*-value = 0.007)) and 0.29 (0.12, 0.46) seconds, (*P*-value = 0.002) respectively). However, when including ASLR score, fear of movement and pain intensity in a multiple linear regression model, ASLR and

fear of movement were not significantly associated with TUG time (*P*-values ≥ 0.09), while pain intensity remained significant (0.29 (0.12, 0.46) seconds (*P* = 0.02, R^2 = 0.37)).

Discussion

The discussion will emphasize two topics, the main findings of this thesis and the key methodological aspects. In the first part, the influence of PGP and pregnancy on spatiotemporal and kinematic characteristics during gait and the Stork test, as well as associations on TUG time will be discussed. Implications for clinical practice and future research will be highlighted throughout the discussion. In the second part, methodological considerations such as study design, participants, blinding procedures, questionnaires and clinical examination, three-dimensional analysis, reliability and measurement variation, statistical analysis and sample size will be discussed.

Main findings

The main findings of this thesis were that PGP influenced the time to perform the TUG test, as well as gait characteristics in the 2nd trimester. Pregnancy apparently did not influence TUG time, but influenced a few gait variables, as demonstrated by significant differences between asymptomatic pregnant and non-pregnant women. During gait at self-selected speed, pregnant women with PGP walked slower and with a more restricted movement pattern compared to asymptomatic pregnant women. TUG time varied among pregnant women with PGP, and this group used significantly longer time than asymptomatic pregnant and non-pregnant women. In addition, a longer TUG time was associated with pain intensity, while gait speed was negatively associated with fear of movement and disability in pregnant women with PGP. These findings might indicate that biopsychosocial aspects are related to performance of weight-bearing activities in those with PGP in the 2nd trimester. Surprisingly, neither PGP nor pregnancy appeared to influence performance of the Stork test in the 2nd trimester. Since, only few and small between-group differences in trunk, pelvic and hip movements were found. Large variation across participants in all three groups and generally small intra-individual variation in key kinematic variables during the Stork test, suggest that individual, self-selected movement strategies were used to accomplish SLS.

The influence of pregnancy and pelvic girdle pain on spatiotemporal and kinematic gait characteristics (paper II)

In paper II, our findings indicate that pregnancy has some influence, whereas PGP has a larger and additive influence on spatiotemporal and kinematic gait characteristics in the 2nd trimester. Hence, our findings complement the results of a large Norwegian pregnant cohort

study reporting an influence of pregnancy and an additive influence of PGP on self-reported disability both in week 15 and week 30 of pregnancy [51].

In our study, pregnant women with PGP versus asymptomatic pregnant women walked on average 18 % slower and with shorter stride (10 %), shorter ipsilateral and contralateral step length (9 % and 11 % respectively) as well as longer cycle time (9 %), longer stance time (12 %) and longer double limb support (10 %). The lower speed in pregnant women with PGP is in accordance with the findings from Gutke and co-workers [57] and Wu and co-workers [47] in week 15 and week 29 of pregnancy, respectively. Our finding of longer stance time is in contrast to the finding of Kerbourc`h and co-workers in the 2nd trimester of pregnancy [47]. However, when we adjusted for speed in our model, only double limb support and contralateral step length remained significantly different between pregnant women with PGP and asymptomatic pregnant women. This finding is interesting as it indicates an independent influence of PGP on these variables. As asymmetric forces transferred through the pelvis likely increase during the SLS phase of gait, standing on both legs for a longer proportion of the gait cycle presumptively reduces the demands on load transfer. Hence, our finding of longer double limb support in pregnant women with PGP compared to asymptomatic pregnant women might be a strategy to minimize stance time on one foot. Accordingly, bringing the other foot sooner to the ground shortens the stance time on one foot and thus shortens the contralateral step [15]. Hence, it seems plausible that the shorter contralateral step length in the PGP group could be related to impaired weight-bearing abilities on the painful or most painful side. Double limb support and contralateral step length remained significantly different between groups also when adjusted for speed. Noteworthy, as increased double limb support inherently accompanies slower speed [73], it seems plausible that a slower gait speed in itself may be adaptive to altered load transfer.

In addition, pregnant women with PGP walked with less movement in the pelvis and hip compared to the asymptomatic pregnant women and with similar EMMs both in the crude and adjusted analyses: Less hip sagittal plane ROM (5.2°, crude analysis) and less hip flexion at HS (5.7°, sensitivity analysis) and at PHA (6.9°, crude analysis). These findings may indicate an increased activity or altered timing of the biceps femoris muscle restricting hip flexion in those with PGP, as have previously been suggested during SLS tasks [40, 178]. Correspondingly, an increased hip abductor muscle activity may explain our findings of 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 in pregnant women with PGP versus asymptomatic pregnant women. Answering these hypotheses is beyond the scope of this thesis. However previous studies have found increased muscle activity in the abdominal and hip flexor muscles during

ASLR [45]. For example, Hu and co-workers [179] suggested that in healthy non-pregnant individuals, hip extensor activity counteracted the forward rotation torque exerted on the pelvis by the hip flexor muscles during ASLR and in treadmill walking, given that the pelvis moved as one unit. Interestingly, it has been suggested that individuals with PGP use muscular bracing strategies (i.e. combined agonist and antagonist muscle activation) in response to impaired load transfer and pain during ASLR [180] and SLS [40]. Moreover, that these bracing strategies may lead to more rigid movement patterns, potentially overloading spinal and/or pelvic structures and thereby contribute to an ongoing nociceptive pain mechanism [40, 180, 181]. Noteworthy, this could potentially play a role in the transition from an acute pain state into a chronic pain condition as suggested in LBP patients [182]. Considering these aspects, future studies are needed to investigate whether and how muscle activity influence pelvic and hip movements during gait in pregnant women with PGP. Moreover, it seems plausible that small kinematic differences may precede and/or influence the development of PGP later in pregnancy and/or in post-partum. These hypotheses are beyond the scope of this thesis, and both EMG and longitudinal studies are needed to elucidate these questions.

In our study, pregnancy itself apparently did not influence gait speed, as self-selected speed was not significantly different between asymptomatic pregnant and non-pregnant women. Compared to results from studies previously reporting gait speed, our participants walked slightly faster [81, 83, 87, 90, 183]. For the asymptomatic pregnant women, this might be related to our inclusion of women earlier in pregnancy. However, studies differ with regard to speed changes in late pregnancy [81-83, 87, 89, 172, 184]. Still, our EMMs showed 7 % longer stance time and 10 % longer double limb support in the asymptomatic pregnant women compared to the non-pregnant. These variables remained significantly different between groups (3 % and 10 % respectively) when adjusted for speed. This result indicates that pregnancy influenced gait performance regardless of speed. Our findings complement previous studies in reporting longer stance time and double limb support in healthy pregnant women [47, 79, 81, 82], supporting that these gait alterations might be related to a need for pregnant women to increase stability and safety during gait [58] already in the 2nd trimester. Regarding kinematic variables, we found that only thoracic transversal plane angle at TO was significantly different in asymptomatic pregnant versus non-pregnant women. Pregnant women had 3° less forward rotation of the ipsilateral thorax relative to the stance limb (adjusted for speed). This finding can be seen in concordance with those of Gilleard during the course of pregnancy [87], and could indicate that trunk motion was restricted by requirements for higher muscle activity [87] or increased anterior mass in the lower trunk [1].

We found that spatiotemporal and kinematic gait characteristics in the 2nd trimester was primarily influenced by PGP and less influenced by pregnancy. This finding is interesting, and could be due to the impact of pregnancy being more of a weight problem and thus appears later in pregnancy. We wanted to explore if there was an influence of pregnancy independently of weight. However, due to practical issues described in the following methodological discussion (under Study participants, page 82-83), we included pregnant women between gestation week 13 and 26. Although the median weight gain was 5 and 5.2 kg in our pregnant groups, it varied from 0.04 to 15.9 kg across the pregnant women. The lower trunk segment mass increases more than any other segment in the 2nd and 3rd trimester [1]. Although the overall influence of pregnancy in our study was small, we cannot exclude an influence of weight gain on spatiotemporal and kinematic variables in some of our pregnant participants.

Gait speed in pregnant women with PGP

In the pregnant women with PGP, we also explored gait further and used gait speed as an expression of overall gait performance [78]. Interestingly, we found that mean gait speed was negatively associated with perceived fear of movement and disability as measured by the PGQ total score, but not associated with pain intensity in the PGP group. Although the latter was surprising, this could be because we measured present pain intensity on the day of testing. The rationale for doing this was that we suspected present pain to influence movement patterns during both gait, the Stork test, as well as TUG time. However, the pregnant women with PGP had a mean present pain intensity of 2.5 out of 10 on a NRS (scores ranging from 0 to 7). It might seem surprising that some of the women with PGP scored 0 for present pain intensity. However, pregnant women with PGP often report large pain variations during the day and that pain is worsened by weight-bearing activities [6, 11, 13, 185]. Although, we aimed to test participants at the same time of the day, the natural fluctuation of pain likely contributed to the low level of pain intensity prior to testing in our study. Importantly, the inherent fluctuation in pain is regarded a general challenge of pain measures, as it influences psychometric properties such as test-retest reliability and responsiveness [186]. Still, pain intensity measured on NRS (with variations in phrasing and recall periods), has commonly been used in PGP populations [11, 187, 188] and other pain populations [186, 189, 190], both in research and clinical settings. Moreover, pain is regarded a subjective, complex and multi-dimensional experience [191, 192], which is influenced variably by biological, psychological and social factors [193]. Hence, pain appears in general to be a challenging construct to measure.

Another consideration is that we measured gait characteristics in a laboratory setting, and that this could have influenced the usual walking performance of the participants. However, this is a general concern in biomechanical studies. Moreover, it is a general concern in clinical research that being included in a study could influence the participants` performance. Hence, they could improve, or worsen, compared to their daily performance just due to the observation of the researchers [194].

Our results complement those of Wu and co-workers [46] who found associations between speed and fear of movement, but not with pain intensity in pregnant women with PGP, although later in pregnancy. As pregnant women with PGP commonly report reduced ability to walk [13], our results may be seen in contrast to a large Norwegian pregnant cohort study reporting associations between disability and pain intensity, but neither with fear avoidance beliefs nor ASLR score [6]. However, we measured disability using the PGQ total score. As the PGQ total score incorporates questions about activity limitations and bodily symptoms [13], it includes aspects of pain particularly relevant for pregnant women with PGP. Unfortunately, we could not include fear of movement and disability as factors in the gait analyses, as we only collected these data in the PGP group. Still, our results provide a basis to include gait assessment within a biopsychosocial framework in the clinical evaluation of function in pregnant women with PGP in the 2nd trimester.

Clinical implications

Speed is a recommended expression of overall gait performance [78] and an average of 18 % slower gait speed in pregnant women with PGP compared to asymptomatic pregnant women appears also to be a clinical significant finding. Moreover, gait speed can easily be measured by timing an individual while walking a known distance [15]. Determining whether an individual`s gait speed is reduced requires reference values for comparison [183]. Normative data indicates that healthy non-pregnant women between 20-49 years of age walk 1.34-1.39 m/s [183]. Moreover, previous studies in healthy pregnant women prior to the 3rd trimester, report self-selected gait speed ranging from 0.97-1.36 m/s [57, 79, 81-83, 86, 87, 89, 93]. The asymptomatic pregnant and non-pregnant women in our study walked 1.44-1.51 m/s, which is slightly faster than the reference values for non-pregnant women and the fastest among pregnant women. However, in studies reporting slow self-selected gait speed in healthy pregnant women, the non-pregnant controls walked 1.24-1.26 m/s [79, 81-83, 93], which is slower than the reference values [183]. In studies reporting fast self-selected gait speed in pregnant women, also the non-pregnant walked faster with values between 1.3-1.47 m/s [87, 89].

As walking is an essential daily activity and a recommended physical activity for pregnant women [61], gait speed is important. Health benefits of physical activity during pregnancy include reduced risk of excessive gestational weight gain, gestational diabetes and preeclampsia, as well as reduced fatigue, anxiety, depression and improved well-being [62-66]. Hence, a reduced ability to walk during pregnancy likely has an adverse effect on general health with an impact on both physical and psychological factors. In other populations, self-selected gait speed has been related to factors such as muscle strength [195], cardiovascular disease, physical inactivity [196], mental health [197, 198], cognitive function [199], perception [200] and mortality [201]. As our study does not explore how gait speed is related to other clinical factors, future studies are needed to further explore this question in pregnant women.

With regard to the kinematic differences identified in our study, it should be noted that these were generally small. Although small kinematic differences are likely not identified clinically, they may still have clinical relevance. Measurement systems identify more gait abnormalities than visual observation, and the latter is highly dependent on the observer`s skills and competence (15). Despite that both visual observation and 3D kinematic analysis only describe movements and not what causes them [15], quantification of spatiotemporal and kinematic gait characteristics might potentially elucidate mechanisms involved in function [78]. Hence, it appears to be a clinical challenge that small kinematic differences are likely not observed visually. Nevertheless, it should be remembered that the observed or measured movement during an activity is not the result of a pathological condition, but the net result of a condition and the individual´s attempts to compensate for it [15].

In summary, our findings provide a basis for the clinical evaluation of gait in pregnant women with PGP in the 2nd trimester. Gait speed appears to be an important variable to consider, since it is a proposed expression of overall gait performance [78], and the effect size in gait speed between pregnant women with and without PGP was large in our study. Furthermore, gait speed is easy to measure and independent of the clinician`s skills to visually observe movement. Importantly, clinicians should also take into account that speed might influence other gait characteristics commonly observed visually in clinical gait analysis.

The influence of pregnancy and pelvic girdle pain on spatiotemporal and kinematic characteristics during the Stork test (paper III)

In paper III, we explored the influence of pregnancy and PGP in the 2nd trimester on movements during the Stork test, by quantifying spatiotemporal and trunk, pelvic and hip kinematics in non-pregnant women and pregnant women with PGP compared with

asymptomatic pregnant women. Surprisingly, we found few and only small significant between-group differences in trunk, pelvic and hip kinematics during the Stork test, as well as large variation across participants in all three groups and generally small intra-individual variation in key kinematic variables.

In pregnant women with PGP versus asymptomatic pregnant women, only one variable was significantly different, with EMMs showing 2.1° less hip adduction angle in SLS. This variable remained significantly different when adjusting for pelvic width. 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, only peak hip flexion of the lifted leg remained significantly different between the asymptomatic pregnant and non-pregnant women, indicating an influence of pelvic width. In comparison, Edmondston and co-workers [104] reported small trunk movements during SLS tasks in asymptomatic young women. Bussey and co-workers [40] found slower leg lift and altered hip-spine kinematics in non-pregnant women and men with PGP compared to asymptomatic controls during a SLS task. However, methodological differences limit comparison as their participants lifted the leg as fast as possible and the participants with PGP had a long lasting (i.e. chronic) condition [40].

Since we wanted to mimic clinical practice, we instructed participants to lift their leg at self-selected speed. Moreover, our PGP participants were pregnant with a recent onset of posterior PGP. From our clinical experience, we have observed that some patients are unable to lift their leg to 90° of hip flexion. Moreover, that some lift their leg in a fast speed during a SLS task, while others lift their leg in a slow manner. Differences in speed probably reflect different movement strategies, however it is unknown if one is easier than the other. Comparable to the influence of speed on biomechanics during gait [15, 46, 73, 172, 202], it seems reasonable that different strategies regarding speed of leg lift may affect trunk, pelvic and hip kinematics during the Stork test. Therefore, we provided additional sensitivity analysis with adjustment for peak hip flexion of the lifted leg, and then for speed of the leg lift. However, the results did not change significantly, indicating that these aspects of performance did not influence Stork kinematics in our study.

Clinical important differences (although not statistical significant) have previously been found between the dominant and the non-dominant leg in different functional tasks [155]. Moreover, leg dominance was recently found to have a significant effect on anticipatory postural control strategies during SLS in healthy women [111]. The literature reports different methods to determine leg dominance [153, 154]. Although self-reported *"preferred leg to kick a ball"* is a commonly used method [155], leg dominance may vary between tasks [154], such

as bilateral mobilizing tasks (e.g. kicking a ball) and unilateral stabilizing tasks (e.g. SLS) [154, 155]. In SLS, the standing leg has been suggested to be the dominant leg [153], and thus relevant in our study. To explore whether leg dominance influenced Stork kinematics in our study, we repeated the analyses with additional adjustment for dominant leg tested (i.e. analyzed), as well as performed subgroup analyses. The additional adjustment for dominant leg tested did not change the results in the whole study sample (paper III, Table 2 and Supplementary material, Table S1). In the subgroup analyses, a few more variables reached statistical significance (paper III, Supplementary material, Table S3-4). 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 during the Stork test in our study.

Noteworthy, we instructed our participants to lift their leg to 90° of hip flexion. Interestingly, it has been advocated that lifting the leg to 90° in contrast to 30° of hip flexion facilitates an excessive elevation of the contralateral pelvis [106]. Although, we did not explore this hypothesis, we found large inter-individual variation in the frontal plane pelvic angle across all three groups. During SLS, some participants demonstrated contralateral pelvic elevation (<0°), while others had contralateral pelvic drop (>0°) (paper III, Figure 3). Interestingly, large variation across participants in all three groups was also found in selected kinematic variables during the Stork test as assessed by visual evaluation of scatter plots (paper III, Figure 2-3). The selected variables were regarded as key variables based on the following; 1) Stance width in neutral stance and speed of leg lift, as these variables presumptively may influence Stork performance. 2) Frontal plane trunk and pelvic kinematics during SLS, as these movements are commonly evaluated clinically. 3) The three variables with significant between-group differences. For all selected variables, the intra-individual variation over the four trials was generally small. This indicates that each individual regardless of condition performed the Stork test quite consistently. Large inter-individual variation has previously been reported in biomechanical studies on gait in pregnant women [46, 87, 90, 203], presumptively reflecting that adaptation to pregnancy is unique to each individual [87, 90]. Our finding of large inter-individual variation in all three groups implies that participants regardless of condition use individual movement strategies to accomplish SLS. This may further reflect the complexity of achieving balance on one foot and the inherent possibility for subtle adjustments in multiple joints during this task. Hence, the large movement variation across participants in paper III supports that SLS tests reflect an individual´s self-selected movement strategy [106].

Clinical implications

In summary, hardly any between-group differences in kinematics were found during the Stork test in the present study. Hence, objective measurements using 3D kinematic analysis did not identify specific movement patterns of trunk, pelvic and hip previously observed clinically in pregnant women with PGP during this test. On the contrary, large inter-individual variation and generally small intra-individual variation in key kinematic variables across participants in all three groups indicate that trunk, pelvic and hip movements during the Stork test appear not specific to pregnancy and/or PGP in the 2nd trimester. These findings are of clinical importance, as the clinician cannot 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.

The ability to transfer load from the spine to the legs through the pelvis in a weight-bearing, upright position is particularly important in walking. Although the Stork test is thought to challenge pelvic load transfer, it did not retrieve subtle sagittal and frontal plane kinematic differences previously identified during gait in our study sample [177]. Accordingly, the carryover between the Stork test and gait at self-selected speed appears limited. Hence, it seems pertinent to question whether and/or how visual observation of kinematics during an isolated SLS task could assist in gait evaluation. Interestingly, de Groot and coworkers [45], found higher trunk and hip muscle activity in pregnant women with PGP compared to asymptomatic pregnant women during the ASLR test. They suggested that changes in muscle activity could occur during daily activities [45]. We cannot exclude the presence of similar mechanisms during the Stork test. Furthermore, we do not know, whether different tests/activities challenge different aspects of load transfer. As the Stork test potentially may capture other aspects of load transfer than gait, further research is needed to understand more of what phenomena the Stork test assesses, and whether there is a link between gait and SLS tests. Meanwhile and based on our findings, we question the clinical value of observing trunk, pelvic and hip movements during the Stork test in pregnant women with and without PGP in the 2nd trimester. Although we cannot recommend the Stork test as part of a clinical examination, clinicians still advocating its use, should pay attention to individual movement responses rather than specific movement patterns in pregnant women with and without PGP in the 2nd trimester.

Performance of the TUG test (paper I)

In paper I, we found that TUG time is influenced by PGP and apparently not by pregnancy in the 2nd trimester. Pregnant women with PGP had larger variation and used longer time on TUG, amounting 1.1 and 1.4 seconds compared to asymptomatic pregnant and non-pregnant women, respectively. The large variation in TUG time is in line with the findings in a previous study on TUG in pregnant women with PGP [71]. Interestingly, we found no significant difference in TUG time between asymptomatic pregnant and non-pregnant women, and the variation in TUG time was smaller in these groups. This can be seen as contradictory with previous studies reporting reduced walking speed in the 2nd trimester [89, 93] as well as increased and large variation in self-reported disability in asymptomatic pregnant women both in week 15 and week 30 of pregnancy [51]. This discrepancy could be related to differences in methodology, for example; different tasks being studied, self-reported versus objectively measured data and differences in pregnancy periods. As we included pregnant women in the 2nd trimester, our finding of no significant between-group difference in TUG time in asymptomatic pregnant and non-pregnant women might be due to the possibility that the influence of pregnancy itself had not yet developed. On the other hand, it might reflect that performance-based measures capture complementary aspects of physical function [67], as self-reported functioning has been proposed to not always be indicative of the actual performance [69].

Importantly, the TUG includes multiple tasks such as raising up from and sitting down on a chair, walking and turning. A longer TUG time does not provide specific information on the most limited task. Our finding of slower gait speed in the women with PGP (paper II), might indicate that slower walking could be one factor reducing TUG time. Although this is unknown, all TUG`s subtasks appear highly relevant for physical functioning in pregnant women with PGP. Particularly the large variation found in TUG time in the PGP group and the smaller variation in the asymptomatic groups, support that TUG time captures differences in the ability to perform relevant weight-bearing activities in pregnant women with PGP in the 2nd trimester. Hence, our findings strengthens the TUG tests potential to measure activity-limitations in this population.

Factors associated with TUG time in the total study sample

In multivariable analyses of the total study sample, group, sick leave and BMI were significantly associated with increased TUG time. As this is the first study to explore TUG time in pregnant women using multivariable analyses, comparisons are limited. Previously, Gutke and co-workers [24] found that disability and pain intensity were associated with sick leave due to lumbopelvic pain. Further suggesting that the most afflicted women were the ones on sick leave. Surprisingly, none of the participants in our study answered that they were sick-listed due to PGP. Unfortunately, we did not ask about other causes for being sick-listed. Still, sick leave and increased BMI could be caused by both pregnancy and PGP or also be related to gestation week. However, neither BMI nor weight gain were significantly different between the two pregnant groups. This finding indicates that the increase in BMI was related to pregnancy and not to PGP. In the total study sample, we found a weak association between gestation week and BMI but no significant association with sick leave. Moreover, there was a weak association between group and BMI. Among the pregnant women with PGP, there were no significant associations between gestation week and BMI, pain intensity and ASRL score. Together, these findings support that group, sick leave and BMI independently influenced TUG time in our study.

It should be noted that the variable "group" was predefined due to our inclusion criteria and included both pain location, response on clinical tests and pregnancy. Hence, group could be regarded as multifactorial, and as such might have reduced the influence of other variables in our analyses. For example, the effect of BMI on TUG time was likely reduced when adjusting for group, since weight gain is expected during pregnancy and group included pregnancy as a factor. Nevertheless, in this study, both being on sick leave and having an increased BMI, in addition to being pregnant and having PGP, were factors associated with increased TUG time.

Factors associated with TUG time in pregnant women with pelvic girdle pain

Using multivariable analysis in the PGP group, we found that pain intensity was the only variable significantly associated with TUG time. Surprisingly, ASLR and fear of movement had no significant additional effect on TUG time. The lack of association between fear of movement and TUG time was a surprising finding, as we found an association between gait speed and fear of movement in the same study sample [177]. However, this might be related to that TUG consists of several subtasks. Only a few studies have previously assessed fear of movement (i.e. kinesiophobia) in pregnant women with PGP and the results are not

consistent. Robinson and co-workers [51] found that fear avoidance beliefs in early pregnancy were no risk factor for disability and pain intensity in pregnant women later in pregnancy and post-partum. Olsson and co-workers [25] found higher levels of catastrophizing and fear-avoidance beliefs in women with lumbopelvic pain than in asymptomatic women in early pregnancy. However, this could be related to the combined PGP and LBP (lumbopelvic pain) in their study sample, as psychological factors are commonly present and associated with disability in LBP conditions [204, 205]. Moreover, Wu and co-workers [46] found that walking velocity was negatively associated with fear of movement in pregnant women with PGP in late pregnancy. Recently, Fakari and co-workers [206] found that increased pain intensity was associated with higher fear-avoidance beliefs in pregnant women with PGP in late pregnancy. However, based on their methodology (i.e. diagnosing PGP based on one clinical test; pain provocation on palpation of the long dorsal ligament) [206], it might be questioned whether their results only pertain to women with PGP. Future studies should investigate fear of movement in pregnant women with PGP to understand more of its influence on physical function in this population.

Noteworthy, in our univariate analysis, we found a positive association between TUG and ASLR in our PGP group. This is in line with the findings of Evensen and co-workers [71]. Surprisingly, when we controlled for pain intensity, there was no association between TUG time and ASLR score. As both the ASLR and TUG presumptively include elements of load transfer, our findings may reflect that the two tests challenge different aspects of load transfer. However, it seems reasonable that a test in weight-bearing position is not associated with a test in non-weight-bearing position. Furthermore, it could also be that different compensatory muscle strategies were used [45, 180]. Since we did not measure muscle activity during the TUG test, the question about muscle activity cannot be answered. Nevertheless, as the TUG test includes walking, load is clearly transferred through the pelvis during the cyclic transitions between double and single leg stance. Based on our results, we cannot support that the ASLR and TUG measure the same construct. Instead, the affliction of PGP manifested in increased TUG time appears to be associated with pain intensity.

Clinical implications

The between-group differences in TUG time were around 1 second, which constitutes about 20 % difference in performance between pregnant women with PGP and both asymptomatic pregnant and non-pregnant women. Accordingly, this is both a statistical and clinical meaningful difference in this test. However, the large variation in TUG time in our PGP group compared to the smaller variation in both asymptomatic groups (Figure 8, page 66),

appears to be an even more relevant result for clinical practice. Although not all, a large proportion of the women with PGP used longer time performing the TUG than the slowest among the asymptomatic women. The large variation in TUG time likely reflects differences in the ability to perform the TUG`s subtasks. Hence, TUG time seems to capture activity-limitations and severity of PGP in pregnant women in the 2nd trimester. This has clinical relevance, as it is important for clinicians to have methods to evaluate affliction. Noteworthy, there are no other performance-based measures in the activity domain for pregnant women with PGP.

Looking at the boxplots of the TUG time for the two pregnant groups (Figure 8, page 66), we might hypothesize that a TUG time of more than 7 seconds could be above what could be considered normal for pregnant women in the 2nd trimester. However, future studies are needed to be able to answer this question. Recently, TUG time was found to have adequate responsiveness in chronic LBP populations undergoing surgery [207-209]. Hence, to further increase the clinical utility of TUG time in pregnant women with PGP, future studies should investigate TUG´s ability to determine change over time also in this population.

The TUG times in our study are comparable with previous TUG times undertaken at maximum speed in pregnant women with PGP [70] and non-pregnant women aged 20-39 years [210]. To our knowledge, our study is the first reporting values of TUG time in asymptomatic pregnant women. As reference data may be useful when evaluating measures in a clinical population [210], our results in asymptomatic pregnant women might be useful when interpreting TUG time in those with PGP in the 2nd trimester.

The use of multivariable analyses in the total study sample and in pregnant women with PGP provide knowledge of factors associated with longer TUG time. These novel findings may assist the clinical interpretation of TUG time. Particularly present pain intensity should be considered when using this test in pregnant women with PGP in the 2nd trimester.

In summary, our findings support that TUG time targets relevant activities, limited in pregnant women with PGP. We recommend TUG time as a relevant measure of activity-limitations in the clinical examination of pregnant women with PGP in the 2nd trimester.

Methodological considerations

Study design

This thesis is based on an observational study design and no treatment/intervention was provided. We collected data at one time point for each participant and compared pregnant women with PGP, asymptomatic pregnant and non-pregnant women. Hence, we used a combination of a cross-sectional and case-control design. In a classic case control study, individuals who have developed a condition are identified and compared with a control group of asymptomatic individuals using already-established data to draw conclusions [211]. However, as most of our variables were concurrent measures (i.e. spatiotemporal and kinematic data, TUG time and results of clinical examination) acquired on the day of testing, we applied a variation to the classic design. The use of concurrent measures reduces bias from different recall of prior exposure between cases and controls [212]. The combination of a cross-sectional and a case-control design is particularly appropriate to explore the influence of both PGP and pregnancy on activities and functional tests, by assessing between-group differences and describing associations.

Study participants

We included 25 pregnant women with PGP, 24 asymptomatic pregnant women and 25 asymptomatic non-pregnant women. In case-control studies, a potential source of bias is the selection of study samples and whether participants are representative of the source population [212]. We intended to include pregnant women early in pregnancy to study the influence of pregnancy and to avoid the influence of the excessive weight gain in late pregnancy. However, based on the information from one of the MCUs that most pregnant women register around gestation week 18, we changed our study protocol, prior to the start of the data collection, to include women in the 2nd trimester of pregnancy (i.e. before gestation week 27). As our data collection was comprehensive and we needed time to schedule time in the motion analysis laboratory for each test session, this change was crucial for the recruitment process. Prior to data collection, we also changed the exclusion criteria regarding pre-pregnancy BMI for the pregnant women and present BMI for the non-pregnant women from “30 or more”, to “more than 27”. The reason for this change was that the midwives regarded women with BMI “more than 27” to have a potential risk pregnancy. The following exclusion criteria for all participants were also changed; “any former low back pain” was changed to “low back pain during the last 6 months that had led to disability or sick leave” and “any surgery in the pelvis, back or abdomen” was changed to “surgery in the pelvis, back

or abdomen during the last 6 months". We also added "any neurological or inflammatory systemic diseases (e.g. multiple sclerosis, rheumatoid arthritis and ankylosing spondylitis)" to the exclusion criteria for all women. For the asymptomatic pregnant and non-pregnant women, "no posterior pelvic pain or pubic symphysis pain in previous pregnancies" was changed to "no posterior pelvic pain or pubic symphysis pain during the last 6 months that had led to disability or sick leave". These adjustments were made to reduce potential uncertainties and thus the need for individual interpretation. However, the adjustments allowed the inclusion of women with a previous history of PGP and/or LBP, which could have introduced more variation in our study sample.

The data collection took one year (December 2015-2016). As we experienced difficulties in recruiting participants, some additional changes in our recruitment procedures were needed. After approval from the Regional Committees for Medical and Health Research Ethics in Norway, we collaborated with three more MCU´s as well as physiotherapy and chiropractor clinics. Moreover, we advertised on Facebook and the intranet at the UiO, NIH and Ullevål University Hospital. Hence, we cannot exclude bias concerning that women willing to participate may be different to women in the general population. We could speculate that the women participating in our study, which included three hours of performing activities, dressed in their underwear only, and with biomechanical equipment attached to their skin, might e.g. be more positive to physical activity, less skeptical to measurement equipment, less afflicted with PGP or less afraid of pain provocation than women who did not volunteer. Nevertheless, for the 25 out of 32 women who volunteered, but not participated in our study, it was impossible to adapt test-time and available times in the motion laboratory. This occurred randomly, and we do not suspect that these 32 women would be markedly different from the women who participated.

Importantly, we had strict, pre-defined inclusion and exclusion criteria (Table 1, page 28) to reduce the influence of conditions that may potentially influence performance of the activities and tests under study. Hence, our inclusion and exclusion criteria were important to be able to answer the aims and hypotheses in our study. Accordingly, it is a major strength that all women included were clinically examined to verify and/or exclude PGP. However, due to the inclusion and exclusion criteria and the recruitment procedure, our study sample is a highly selected, convenience sample. Although biomechanical studies often include convenience samples, this might limit the generalizability of the results. However, the representativeness of our sample can be illustrated by comparing descriptive data and some key findings in our study with normative data and results from previous studies.

Accordingly, the PGP affliction in our study varied as illustrated by the wide range of scores on the PGQ total score (10-73 %), NRS for pain intensity (0-7) and ASLR (1-8) [177]. Variation in PGP affliction has also been found in previous studies on PGP in Norway [3, 12] and in a large multinational study on PGP and LPB [11]. With regard to the level of PGP affliction, the mean PGQ total score of 42.7 in our PGP group was comparable to previous studies reporting values of 44.1 [11] and 43.0 [213] in larger samples of pregnant women with PGP and/or LBP. In contrast, the women in these studies had higher pain intensity (mean score, 4.5 [213] and median score, 5 [11]) than in our sample (mean score, 2.5). This difference was likely related with the wording of the question used. We asked for present pain intensity, while the others asked for evening pain [11, 213]. Interestingly, the PGQ symptom subscale score in the same studies were 44.5 [11] and 43.4 [213] and comparable with the score of 43.1 in our sample. As the PGQ subscale measures pain and symptoms, the women in our PGP group appear comparable with study samples in previous studies, and moderately affected by PGP. With regard to the ASLR test, our PGP group had a median score of three. Interestingly, we dichotomized the ASLR score in paper I to distinguish between strong and less affliction of PGP [159]. As the eight participants with a score of four or more actually scored five or more, almost 1/3 of the women in our PGP group was severely affected by PGP [150]. Based on the above comparisons, we regard our study sample of pregnant women with PGP to be comparable with participants in previous studies of pregnant women with PGP.

The mean age in our study sample was 31.2 years and comparable to the mean age of 29.7-32.0 years, reported in other studies in pregnant women with and without PGP [6, 11, 50, 213, 214]. According to Statistics Norway, the average age for women giving birth in Norway was 30.9 years for the period 2015 – 2018, while the average age was 32.5 years for women in Oslo [215]. All of our participants had up to four years or more than four years of higher education, compared to 56.6 % of Norwegian women aged 25-49 years in 2018 [216]. However, previous studies in pregnant women with and without PGP also reported high levels of higher education with numbers between 83-90 % [6, 11, 50]. Furthermore, TUG time and gait speed are two measures reflecting aspects of physical function, explored in this thesis. The mean TUG times for the asymptomatic pregnant and non-pregnant women in our study were 5.8 and 5.5 seconds, respectively. As normative values on the time to perform the TUG undertaken at maximum speed are 5-6 seconds in non-pregnant women aged 20-39 years [210], our asymptomatic participants performed within the expected time for this population. With regard to gait speed, the asymptomatic women in our study walked slightly faster (1.44-1.52 m/s) compared with values reported in some previous studies (1.30-1.47 m/s) [87, 89] and normative data in non-pregnant women only (1.34-1.39 m/s) [183]. This difference was

likely related to the instruction of gait in our study and likely negligible. Based on the above comparisons, we do not suspect that the results on performance of weight-bearing activities in our study sample would differ markedly from the performance in a pregnant and non-pregnant population of women between 20-40 years of age. However, we do not know whether performance would differ in specific subpopulations, such as women with comorbidities, obesity or a risk pregnancy.

Blinding procedures

Another important procedure in research is blinding of the researchers to avoid bias from awareness [211]. In this thesis, the PhD candidate was not blinded due to practical issues. The PhD candidate performed both the semi-structured telephone interviews evaluating eligibility to the study, scheduled the participants for data collection and performed both the clinical examination and the data collection in the motion analysis laboratory. Moreover, as the pregnant participants were between gestation week 13-26, most of them had developed a smaller, or larger pregnant abdomen. The tests were performed and the responses recorded following a standardized research protocol. Importantly, the clinical examination was not performed with individual adjustments based on a clinical reasoning process and conclusions were not drawn during the examination. The importance of following the standardized procedures and merely recording responses on each test was highlighted during the pilot studies. Our examination procedure increased the quality of the data for research purposes in the sense that a standardized approach may to some extent reduce or control potential sources of variability [211].

Questionnaire and clinical examination

In the questionnaire, we mostly used continuous or categorical variables intended to provide more graded information than dichotomous variables. This has previously been recommended in pregnant women with PGP since the affliction of PGP may vary [51]. To provide a comprehensive description of our study participants and to enable comparisons with previous studies in pregnant women with PGP, we aimed to collect self-reported data covering biopsychosocial perspectives. However, to reduce the burden on the participants, we chose several single-item questions and short-versions of standardized instruments. However, for pain intensity and fear of movement, used as outcome variables in our analyses, some caution must be taken when interpreting our results. With regard to NRS for pain

intensity, its psychometric properties and psychosocial and context sensitivity have previously been discussed on page 72. With regard to the measurement of fear of movement, we used a single-item question with scores on a NRS (0-10) [125]. Although this measure has been proposed as a substitute for the original 17-item Tampa Scale for Kinesiophobia in a non-pregnant population with sciatica [125], psychometric properties have not been investigated in pregnant women with PGP. This is a limitation of our findings. However, the score varied between 1-10 in our PGP group and spread across almost the whole measurement scale. This might indicate that the question captured differences in fear of movement in our sample of pregnant women with PGP in the 2nd trimester, possibly reflecting its potential as a relevant measure of fear of movement in this population. As studies are needed to investigate the psychometric properties of this measure in pregnant women with PGP in the 2nd trimester, our results on fear of movement must be interpreted with caution.

With regard to the ASLR test, we calculated a sum score between 0 and 10, and we used the ASLR score as a continuous variable in paper II and III and a dichotomous variable in paper I. The ASLR was dichotomized based on a cut off value of 4 to distinguish between strong and less strong affliction of PGP [159]. In comparison, Evensen and co-workers [71] used the ASLR as a continuous variable and reported a strong, statistical significant correlation between the ASLR and TUG tests. To investigate whether dichotomizing this variable could have influenced our results, we repeated the multivariable analysis with the ASLR as a continuous score in the thesis. However, when using the ASLR as a continuous variable, ASLR and fear of movement were still not significantly associated with TUG time (p-values ≥ 0.20) while pain intensity remained significant (β = 0.21 (0.12, 0.46), p = 0.04).

The clinical examination to verify and/or exclude PGP is an important strength of our study. The standardized protocol combined with the clinical experience of the PhD candidate likely improved the quality of the data collected. For example, although the standardized protocol of the TUG test provides a guide to the examiner, there is presumptively some uncertainty introduced to the data by the manual timing of the test. This variation was likely reduced in our study.

Three-dimensional kinematic analyses

Different marker sets are available for 3D kinematic analyses [15]. We applied 67 spherical reflective markers for a full body marker set suggested by V3D [127], consistent with the International Society of Biomechanics (ISB) recommendations [128] and the atlas for skeletal landmark definition by van Sint Jan [129] (Figure 3, page 34). When a marker can be

seen by only one camera, its 3D position cannot be calculated [15]. The extensive protocol consisting of 12 cameras and 67 markers likely increased the probability of a camera to capture a moving marker. This is a major strength of our study. On the other hand, it was a time consuming procedure, to apply 67 markers on the participant´s body, for both the participants and our research team. A main concern of our research protocol was not to provoke unnecessary pain for the participants with PGP. Hence, we chose to use a predictive approach rather than a functional approach to identify the hip joint center. In a functional approach, the participant typically stands on one leg performing repeating multi-plane movements of the other hip [139]. The ISB recommends a functional approach for estimating the position of the hip joint center in participants with adequate hip ROM [128]. However, as we suspected SLS to be pain provocative or difficult for the pregnant women with PGP, we decided to use the regression equation of Harrington as recommended among the predictive approaches [139].

According to our protocol, we instructed the participants to lift their left and right leg interchangeably during the Stork test as is common in clinical practice. During both the Stork test and in gait, we mostly analyzed joint angles and marker positions on the painful or most painful side for the women with PGP and a randomly chosen test side for the asymptomatic women. We did not explore between limb differences, since our intention was to investigate whether spatiotemporal and kinematic patterns were influenced by pregnancy and/or PGP and not whether these patterns were asymmetric within women with different conditions. We used force plates and a threshold of 20 N for the vertical ground reaction force (GRF) to determine the events that defined different phases during gait and the Stork test. This method has previously been used in studies investigating kinematics during gait and SLS [108, 144]. As we investigated joint ROM during weight shift and weight lift as well as mean joint angles during maintained SLS, we regard the level of accuracy obtained from a threshold of 20 N for the vertical GRF to be acceptable.

Reliability and measurement variation in spatiotemporal and kinematic data

Reliability is an essential requirement of all measurements in clinical practice and research [217]. It is defined as *"the degree to which the measurement is free from measurement error"* [218]. However, the measured value consists of two components, the true value plus the measurement error, and the error occurs during each measurement [219]. According to McGinely and co-workers [74], the term "error" in 3D gait analysis refers to the variation found across repeated measurements. Repetitions of walking or other activities

normally vary from trial to trial. However, variability in 3D kinematic analysis can arise from several sources and can be divided into extrinsic and intrinsic variability [220]. Extrinsic variability arises from experimental errors such as the measurement instrument, marker misplacement and soft tissue artifacts (i.e. movement between a skin marker and the underlying bone) [15, 132, 220, 221]. With regard to the measurement error of our motion capture system, infra-red camera systems, such as the one used in this study, provide kinematic data of high accuracy [15]. Recent improvements especially in calibration of kinematic systems have reduced typical errors to less than 1 mm [15]. As described in the methods (page 36-37) and illustrated by the motion graphs in Figure 6 (page 38), the measurement error (i.e. variability) of our motion capture system was microscopic compared to the variability of the participants` performance. As the accuracy is dependent on the number of cameras used, capturing volume, calibration, technical specification and settings of system parameters [15, 134, 135], our extensive protocol and standardized procedure on these matters likely contributed to the low measurement error and high quality of our data.

Intrinsic variability is the natural variability within the participants or between trials [220] and may reflect the inherent variation between individuals with a specific condition and those without [74]. As measures of reliability are considered population specific [174, 217], reliability of 3D kinematic data should be addressed to enhance interpretation of findings [174]. This can be done without organizing separate test sessions since the kinematic data collected for experimental purpose often include repeated measures of the same task [174]. As recommended by McGinley and co-workers [74], we reported both the ICC and the intra-individual SD over the four gait and Stork trials in each group. The intra-individual SDs describe the variability in the same measurement unit as the spatiotemporal and kinematic data and are given in addition to ICCs to increase the clinical interpretation [74].

In our gait analysis, the reliability was good to excellent in all three groups for the majority of spatiotemporal variables ($0.75 \leq ICC \leq 0.95$) and kinematic variables ($0.80 \leq ICC \leq 0.97$). Reliability was moderate for stance phase in asymptomatic non-pregnant women (ICC = 0.57) and in pregnant women with PGP (ICC = 0.68) and for double limb support in non-pregnant women (ICC = 0.74). For all variables, the intra-individual SDs were smaller than the between-group differences of the EMMs of each group. A 2° of “error” or less, has been regarded an acceptable measurement “error” in gait analyses [74]. Although all the between-group kinematic differences were small, all differences exceeded 2° (i.e. were acceptable), except for pelvic drop contralateral to the stance limb at PHA (1.8°). For the Stork data, we also found good to excellent reliability for the significant kinematic variables in the three

groups (0.87 ≤ ICC ≤ 0.95) as well as smaller intra-individual SDs than the between-group differences of the EMMs of each group.

Although our spatiotemporal and kinematic data were generally considered to be within the acceptable level of measurement "error", two main sources of extrinsic variability in kinematic data need to be discussed, namely marker placement and soft tissue artifacts [15, 221]. Inconsistent marker placement often occur in data obtained from different testing sessions of the same participant [74]. As we used a cross-sectional design, this extrinsic day-to-day variation does not pertain to our data. The large anatomical intra- and inter-individual differences in the pelvis [222, 223], the pregnant abdomen and increased adipose tissue likely around the trochanter major area in some participants could have made it difficult to identify the ASIS and trochanter major for marker placement. As we used the regression equation of Harrington based on the ASIS markers on the pelvis [138], misplacement of the ASIS marker could influence the identification of hip joint centers. However, the ASIS and trochanter major landmarks were identifiable in all participants. As we included pregnant women in the 2nd trimester with a pre-pregnancy BMI of 27 or less and non-pregnant women with a present BMI of 27 or less, features of late pregnancy such as a large pregnant abdomen and excessive weight-gain were not present in our study. In addition, the PhD candidate, with long clinical experience and a post-graduate education in manual therapy, identified all the anatomical landmarks. This likely reduced the variability introduced by an inter-tester procedure and/or a less experienced assessor. The use of a standardized research protocol specifying the position of each marker likely also decreased extrinsic variability introduced by marker misplacement [132, 220].

Soft tissue artifacts also introduce inaccuracy to 3D kinematic calculations [224]. As skin markers are not fixated to the underlying bone, movement between a skin marker and the underlying bone is an inherent feature of non-invasive 3D kinematic analyses [15, 76]. These movements introduce an error called soft tissue artifacts [225]. Soft tissue artifacts commonly arise from skin or subcutaneous tissue movements, muscular contractions and inertial effects such as changes in speed or direction of motion [226]. The extent of soft tissue artifacts is dependent upon physical characteristics of individuals, the movement performed, the body segment measured and marker location [225]. Soft tissue artifacts from the pelvis markers have shown to be smaller in walking than activities with large hip flexion-extension and adduction-abduction excursions, as well as larger in individuals who were overweight than normal weight [227]. However, the latter was found in males [227] and cannot be generalized to our pregnant participants. Although the Stork test includes larger hip flexion excursion than walking, this movement did not conflict with the pelvic markers. The test is also performed in

a slow manner and without impact from perturbations like heel strike or uncontrolled movements. Hence, we find no reason to suspect greater soft tissue artifacts during the Stork test than during walking. Still, the exact magnitude of soft tissue artifacts is difficult to determine [225]. Although different methods to assess and control for soft tissue artifacts have been proposed [224, 225], they appear not to be implemented in practice [225]. To our knowledge, few clinical studies using 3D kinematic analysis describe and present estimations of soft tissue artifacts. The lack of such estimates likely introduces some degree of unknown inaccuracy in our data, and thus constitutes a limitation of our study. However, to reduce the amount of potential soft tissue artifacts, we chose a standardized marker placement avoiding areas with high muscle activity and large amounts of soft tissues, which are likely more susceptible to these artifacts [228]. Nevertheless, as marker movement is shown particularly to impact transverse plane measurements [15] especially at the thigh [225], the transversal plane hip kinematics in both paper II and III should be interpreted with this in mind.

Finally, more repetitions may be associated with less error in 3D kinematic analyses [229, 230]. However, performing numerous repetitions of a task may not be feasible for individuals with pain or reduced functional capacity [75]. In our study, the pregnant women with PGP constituted a vulnerable group, and we expected the tasks under study likely to be difficult and/or provoke pain in these women. Moreover, we wanted our participants to perform the tasks as similar as possible to the clinical setting. Although the latter was important for the external validity of our results, it could have increased the measurement variation in our study. To reduce this variation, we could have instructed the participants to walk or perform the Stork test in a more consistent manner such as walking and lifting their leg during the Stork test in a pre-determined speed. Although this strategy potentially could have maximized between-group differences, we would likely have introduced a more rigid control of performance [211]. In this sense, our study protocol affirms the generalizability to activities and tests as performed in the clinical setting.

Taken the above considerations on 3D methodology into account, we regard our measurements in paper II and III to be based on the current knowledge of methodology. Hence, despite an uncertainty related to potential soft tissue artifacts, the spatiotemporal and kinematic data in this thesis appear to be trustworthy.

Statistical analyses

In paper II and III, we used linear mixed models taking variation within and between groups into account. This is unlike most previous biomechanical studies were the average of

several trials (i.e. repetitions of the task studied) represent an individual´s performance in the group score [75]. Several trials performed by the same individual may be regarded as repeated measurements, implying that the independence assumption behind traditional regression models will not be fulfilled [212]. Hence, repeated measurements of walking and other activities in biomechanical studies on the same individual might imply dependencies in the data [231]. The consequence of overlooking dependencies may lead to significant effects that are not real, and/or to miss true substantial effects [212]. Mixed models have some major capabilities as they handle correlated data (e.g. repeated measures in the same individual), unequal variances and allow an unequal number of repetitions [232]. We had missing data for two participants in the gait and Stork analyses. However, using linear mixed model analyses allowed the use of all trials available for all participants. Hence, the linear mixed model is an important strength of our study, allowing for repeated measurements and individual responses, while not being very sensitive to missing data.

Similar to an ANOVA procedure, the use of linear mixed models can only provide information regarding a discrete time point (e.g. hip flexion at heel strike) or summary of movement (e.g. hip flexion ROM during gait cycle) [233]. Hence, we only gain information from a part of the movement of interest. For example in 3D gait analysis, gait is sampled at a given frequency, e.g. 300 Hz, which provides a sequence of measured values over a specific time period, e.g. the gait cycle [234]. These values may be presented as gait curves from 0-100 % of a gait cycle. Functional data analysis (FDA) are statistical approaches that use the whole movement curve (i.e. time function), and are capable of detecting differences at any point in time throughout the entire movement [233]. However, different FDA methods exist [234] and the analyses can be very complex, likely requiring experience if incorporated in kinematic studies [233]. We extensively studied previous research and literature on biomechanical analyses of gait and SLS in order to define relevant time points, movement phases and variables for our spatiotemporal and kinematic analyses. Commonly, statistical approaches analyzing time points and summary measures have been used in kinematic studies (Appendix 1, Table S1). We regard that our analyses cover significant parts of both gait and Stork movements, include relevant operationalization of kinematic variables and that the linear mixed models are particular adequate to answer our research questions in a sound methodological manner. However, we cannot exclude that FDA could have been a beneficial alternative in our study. Future studies should consider incorporating FDA for an even more informative investigation of movement than linear mixed models.

Sample size

The sample size in this thesis is based on our sample size calculation, and as performed in a comparable biomechanical study [165]. Sample size calculation is important, as a low number of participants will reduce the statistical power and subsequently the possibility of detecting a true between-group difference. Due to the paucity of previous biomechanical studies in pregnant women with PGP, we examined comparable kinematic cross-sectional studies on SLS tasks prior to our sample size calculation. The two previous studies on a SLS task in non-pregnant individuals with PGP included 12 [40] and 14 [96] participants in each group. Other studies describing SLS kinematics in healthy individuals reported study samples of 9-30 participants [104, 162-164], while kinematic and electromyography studies in patients with low back and knee pain reported 17-21 participants in each group [165-168]. Hence, in paper II and III, our sample size of 23-25 participants in each group is either comparable to or exceeds the sample size in other biomechanical studies. However, as we aimed to explore clinically observed movement patterns during gait and the Stork test, we included a comprehensive kinematic analysis with a large number of variables. Hence, we performed numerous tests, increasing the probability of rejecting a true null hypothesis (i.e. committing a type 1 error). Accordingly, the concern with multiple comparisons must be kept in mind.

In paper I, we included four independent variables in the multiple regression model in the whole study sample (n=74) and three independent variables in the multiple regression model in the pregnant women with PGP (n = 24). A sample size of 91 and 107 participants have been reported to be the required sample size with five and eight independent variables respectively [235]. Hence, for the analysis in the whole study sample, the power should presumptively be sufficient to investigate the four independent variables. However, we found significant interaction between sick leave and BMI, with a stronger effect of BMI on TUG in women on sick leave than in women not on sick leave. Due to the low number on sick leave, we were not able to investigate this further and present the model without interaction. For the multivariable regression analysis in the PGP group, the sample size was small. Hence, the results from this specific analysis should be interpreted with caution.

Conclusions, implications and future perspectives

This thesis provides novel information regarding the influence of PGP and pregnancy on weight-bearing activities in the 2nd trimester. This was explored by quantifying and comparing spatiotemporal and kinematic characteristics during gait and the Stork test, as well as TUG time in pregnant women with PGP, asymptomatic pregnant and non-pregnant women.

Overall, we found that PGP influenced the time to perform the TUG test, as well as gait characteristics in the 2nd trimester. Moreover, both pregnancy and gait speed also influenced a few gait characteristics. Pregnant women with PGP walked slower and with a more restricted gait pattern compared to asymptomatic pregnant women. In the PGP group, gait speed was negatively associated with fear of movement and disability, while a longer TUG time was associated with pain intensity. This might indicate that biopsychosocial aspects relate to performance of weight-bearing activities in women with PGP in the 2nd trimester. Our findings support TUG time as a suitable measure of activity-limitations in pregnant women with PGP in the 2nd trimester, and provide a basis for the clinical evaluation of gait in this population. Gait speed appears to be a particularly relevant variable with high clinical utility. However, clinicians should take into account that speed might influence other gait characteristics commonly observed visually in clinical gait analysis. In contrast, neither PGP nor pregnancy appeared to influence trunk, pelvic and hip movements during the Stork test, and clinically observed movement patterns were not identified in our study. Instead, large inter-individual variation across all participants and generally small intra-individual variation in Stork kinematics were found, suggesting that individual, self-selected movement strategies were used to accomplish SLS. Hence, visually observing trunk, pelvic and hip movement patterns during this test may have limited clinical importance when examining pregnant women in the 2nd trimester, and clinicians using the test should pay attention to individual movement responses rather than focusing on specific patterns.

Through this work, new hypotheses have been generated and methodological considerations discussed. All of which should be useful for researchers planning future studies in the field of PGP. To improve the clinical utility of TUG time, responsiveness should be investigated in pregnant women with PGP. To elucidate whether the observed gait patterns in pregnant women with PGP are related to altered muscle function, as well as whether kinematic alterations precede and/or influence the development of PGP in late pregnancy and/or post-partum, both EMG and longitudinal studies are needed. Based on the findings in this thesis, we suggest that future research, including biomechanical studies, in pregnant women with PGP should involve biological, psychological and social aspects.

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Paper I

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Original article

The Timed Up & Go test in pregnant women with pelvic girdle pain compared to asymptomatic pregnant and non-pregnant women

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ABSTRACT

Background: The Timed Up and Go (TUG) test, a standardized functional mobility test, has been proposed as a physical performance-based measure in pregnant women with pelvic girdle pain (PGP).
Objectives: This cross-sectional study aimed to investigate physical function by the use of TUG in pregnant women with PGP compared to asymptomatic pregnant and non-pregnant women, and to identify factors associated with increased TUG.
Methods: In total, 25 pregnant women with PGP, 24 asymptomatic pregnant and 25 asymptomatic non-pregnant women participated. One-way analysis of variance was used to explore difference in TUG between the groups and multiple linear regression analyses to explore associations between TUG and potential explanatory variables.
Results: The time on TUG varied among pregnant women with PGP, and was significantly higher (mean (95% CI) 6.9 (6.5, 7.3) seconds) than for asymptomatic pregnant (5.8 (5.5, 6.0), $p < 0.001$) and non-pregnant (5.5 (5.4, 5.6), $p < 0.001$) women. In the total study sample, group, increased BMI and sick leave were significantly associated with increased TUG (p-values ≤ 0.02). In pregnant women with PGP, pain intensity was the only significant clinical factor associated with increased TUG ($p = 0.002$).
Conclusion: Pregnant women with PGP used longer time and showed larger variation in TUG than asymptomatic pregnant and non-pregnant women, this underpins that TUG targets activities relevant to PGP. Our results provide new knowledge about factors influencing TUG time. Importantly, multivariable analyses suggest that pain intensity should be considered when interpreting TUG time in pregnant women with PGP.

1. Introduction

Pelvic girdle pain (PGP) is common during pregnancy (Robinson et al., 2010b; Gutke et al., 2017), and limits daily activities, work capacity and quality of life (Olsson and Nilsson Wilkmar, 2004; Robinson et al., 2006). As pregnant women with PGP report weight-bearing activities, particularly walking, to be their main disability (Stuge et al., 2011), physical function i.e. the ability to perform daily activities (Terwee et al., 2006a) is a core issue in the clinical evaluation of these women. Commonly, self-reported and performance-based instruments capture complementary aspects of physical function (Guildford et al., 2017). Only the active straight leg raise (ASLR) test, assumed to assess pelvic load transfer by self-reported impairment of leg lift (Mens et al., 2001), has previously been recommended to evaluate function in PGP patients (Vleeming et al., 2008). Later, the self-reported Pelvic Girdle Questionnaire (PGQ) including activities, participation and bodily symptoms was developed (Stuge et al., 2011). However, both the ASLR and PGQ capture the patient's perception of their performance or condition. As self-reported functioning is not always indicative of the actual performance (Terwee et al., 2006b), performance-based measures assist in determining the extent of disability.

Recently, Evensen and colleagues (2015, 2016) proposed the Timed Up and Go (TUG) test (Podsiadlo and Richardson, 1991) undertaken at maximum speed as a reliable and valid weight-bearing physical performance-based measure for pregnant women with PGP. The TUG is a standardized, timed, functional mobility test (Podsiadlo and

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Table 1
Description of the inclusion and exclusion criteria for the pregnant women with pelvic girdle pain (PGP) and asymptomatic pregnant and non-pregnant women.

	Pregnant with PGP (n = 25)	Asymptomatic pregnant (n = 24)	Asymptomatic non-pregnant (n = 25)
Inclusion			
	Posterior pelvic pain[a] with onset in current pregnancy	No posterior pelvic pain, or pubic symphysis pain during the last 6 months, that had led to disability or sick leave	
	ASLR[b] score > 0		ASRL score = 0
	Positive P4[c] unilateral or bilateral		Negative P4
	Pregnant ≤ 26 gestation week		Not pregnant > 6 months since last pregnancy
Exclusion			
	Current multiple gestation		
	Any risk pregnancy as determined by midwife		
	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] ASLR, active straight leg raise test.
[c] P4, posterior pelvic pain provocation test.

Richardson, 1991), requiring the patient to stand up from a chair, walk 3 m, turn, walk back and sit down again. As the TUG targets core activities commonly limited in pregnant women with PGP, TUG time is presumably increased in these women. However, a large fraction of asymptomatic pregnant women report disability (Robinson et al., 2010a) and walk slower than non-pregnant women (McCrory et al., 2011; Bertuit et al., 2015), implying that pregnancy in itself limits physical function. Hence, it is relevant to investigate whether TUG differs in pregnant women with PGP, asymptomatic pregnant and non-pregnant women.

Measurement of physical function is complex as it contains multi-dimensional constructs (Terwee et al., 2006a) and no gold standard for its assessment exists (Dobson et al., 2012). Evensen et al. (2016) found a strong correlation between TUG and ASLR in pregnant women with PGP. In other populations, increased TUG time has been associated with multiple factors such as pain (Kwan et al., 2011), increased body mass index (BMI), decreased mental health (Kear et al., 2017) and lower education levels (Gomes Gde et al., 2015). Hence, it seems important to investigate the TUG further and identify whether other factors influence TUG in pregnant women. This may facilitate TUG's clinical utility as a measure of physical function in this population. Clinical variables, psychological factors and personal characteristics (e.g. BMI) could be of relevance.

The primary aim of this study was to explore physical function in pregnant women with PGP, by the use of TUG. Further, to identify potential factors associated with increased TUG time. We hypothesized that pregnant women with PGP would demonstrate reduced function, i.e. increased TUG time, compared with asymptomatic pregnant and non-pregnant women, and that increased TUG time would be associated with higher ASLR scores and increased pain intensity.

2. Methods

2.1. Participants and procedures

Commonly, women in Norway seek maternity care units (MCU) for health services during pregnancy. In this cross-sectional study, pregnant women with PGP were recruited by midwifes at MCUs, one hospital and from women treated by physiotherapists and chiropractors. Asymptomatic pregnant and non-pregnant women were recruited through MCUs, participants, colleagues and advertisement on websites. All were recruited from around Oslo, aged 18–50 years and with Norwegian language proficiency. We matched participants on age (± 4 years) and pregnant women on gestational week (± 4 weeks). Pregnant women with no-risk pregnancy were included before gestation week 27. Pregnant 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, and have a positive posterior pelvic pain provocation (P4) test (Ostgaard et al., 1994) and an ASLR score > 0 (Mens et al., 2012) on clinical examination. Asymptomatic pregnant and non-pregnant women should have no pelvic pain during the last 6 months and have negative results on the clinical tests. Exclusion criteria are presented in Table 1. One researcher (LC) performed all clinical examinations.

Data was collected during 2016. Eligibility to participation was determined through a semi-structured telephone interview. Out of 202 interviewed women, 93 were scheduled for testing and 83 attended (Fig. 1). In total 74 women who met the inclusion criteria completed one assessment.

The 25 pregnant women with pelvic girdle pain (PGP) had a positive active straight leg raise (ASLR) score above 0, a positive posterior pelvic pain provocation (P4) test and a pain drawing with posterior pelvic pain. The 24 asymptomatic pregnant and the 25 asymptomatic non-pregnant women had both negative ALSR and P4 tests, as well as no reported posterior pelvic pain.

As this study was part of a larger biomechanical study, the researchers were not blinded due to practical issues. The Regional Committee for Medical and Health Research Ethics in Norway approved the study (2013/2312). All women gave written informed consent prior to inclusion.

2.2. TUG

The TUG was performed in a large room with a linoleum floor. Participants wore sneakers and could use walking aids if needed. A demonstration was given and one practice trial was allowed. Time was recorded by a SPORTX PRO 30 Lap Stopwatch (Wenaas Nordic AS, Norway). All participants performed the TUG from a chair (height: 46 cm) with back-support and armrests. A 3-m walkway was marked using two white parallel lines on the floor. This reliable and valid TUG variant (Evensen et al., 2015, 2016) included a standardized instruction, asking participants to walk as fast as they could, and a timing protocol.

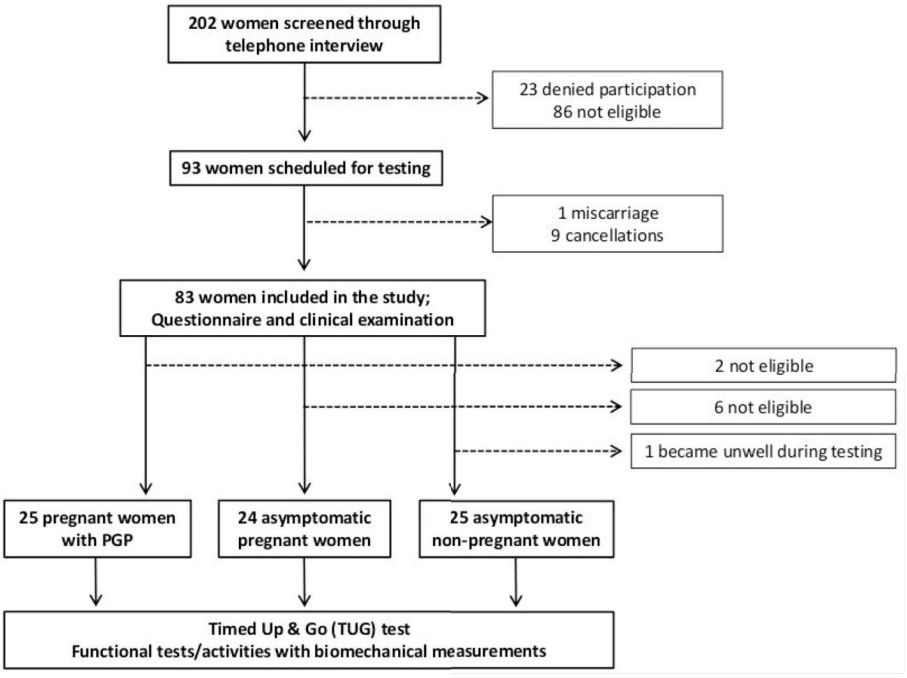

Fig. 1. Flow diagram of the study.

2.3. Questionnaires

Prior to performing the TUG, all participants filled out an online questionnaire recording variables such as age, marital status (married/partner, single), education (≤ 4 and $>$ 4 years at university), gestation week, exercise frequency during the last seven days (≤ 1 day/week, 2–3 days/week, almost every day) and working conditions (most of the time seated, a lot of walking, a lot of walking and lifting). For employment (full time, part time, student and sick leave) participants could answer yes or no to more than one category.

All participants completed the Hopkins Symptom Checklist-10 (SCL-10), assessing distress (symptoms of anxiety, depression and somatization). The SCL-10 consists of 10 items on a four-point scale ranging from 1 (not at all) to 4 (extremely). An average item score was calculated. A score of 1.85 or more indicates non-specific distress (Strand et al., 2003).

Women with PGP reported current pain intensity on a numeric rating scale with scores ranging from 0 (no pain) to 10 (worst pain imaginable) (Grotle et al., 2004). Fear of movement was measured by the response to one substitute question of the Tampa Scale for Kinesiophobia (Verwoerd et al., 2012): "How much "fear" do you have that your PGP would be increased by physical activity?" Scores ranged from 0 (no fear) to 10 (very much fear) (Verwoerd et al., 2012). Furthermore, we used the PGQ to assess activity limitations (20-item subscale) and symptoms (5-item subscale). Response alternatives on a four-point scale gave a total score between 0 and 75. The sum scores were converted to percentages between 0 and 100% where higher percentages indicated reduced function. Activity and symptom subscales were calculated separately (Stuge et al., 2011).

2.4. Clinical examination

All participants performed the ASLR in supine with feet approximately 20 cm apart (Mens et al., 2001). The standardized instruction was; "Lift your right/left leg 20 cm up from the bench keeping your leg straight". Participants rated the degree of difficulty from 0 (no difficulties) to 5 (impossible to lift). The score from each leg was added to a sum score (0–10). Higher score indicates more reduced function (Mens et al., 2001). To distinguish between strong and less affliction the ASLR was dichotomized based on a cut off value of 4 (Vøllestad and Stuge, 2009).

The P4 test (Ostgaard et al., 1994) was performed as previously described (Robinson et al., 2010b). Both left and right side were tested. Reproduction of familiar pain in the posterior pelvis on the provoked side was recorded (yes, no) for each side separately.

The Beighton score, consisting of 9 tests of joint laxity in peripheral joints, was used to determine general joint hypermobility (sum score 0–9) (Verhoeven et al., 1999). A sum score ≥ 5 was considered as hypermobility (van Dongen et al., 1999).

Height and weight were measured with a stadiometer and a scale, respectively and present BMI (Kg/m^2) calculated (variable named BMI). Weight gain was calculated as the difference between present weight and self-reported pre-pregnancy weight in the two pregnancy groups.

2.5. Statistical analyses

Descriptive data are presented as frequencies (percentages), means (standard deviations (SDs) or 95% confidence intervals (CIs)), or medians (min-max). Between-group differences were tested by chi-squared test or Fisher exact test for categorical variables, and by one-way analysis of variance (ANOVA) for continuous variables. Pairwise comparisons were performed using Bonferroni correction. Differences in weight gain and gestation week between the pregnancy groups were tested by Mann-Whitney test.

Simple linear regression analysis (with a 10% level of significance) and clinical considerations formed basis for the selection of explanatory variables in the multiple linear regression analyses. Associations between explanatory variables were studied using Pearson or Spearman correlation coefficients (as appropriate). Categorical variables were coded by dummy variables in the regression analysis. We performed linear regression analyses in the total study sample and in women with PGP.

Plausible interaction effects were tested. The residuals were inspected for model assumptions. Data was analyzed using SPSS (version 24, SPSS Inc., Chicago, IL), and a 5% level of significance was used.

Table 2
Characteristics and results of clinical assessment for the total sample and in pregnant women with pelvic girdle pain (PGP) and asymptomatic pregnant and non-pregnant women.

Variable	All (n = 74)	Pregnant with PGP (n = 25)	Asymptomatic pregnant (n = 24)	Asymptomatic non-pregnant (n = 25)	P-value
Age (years), mean (SD)	31.2 (3.7)	30.9 (2.2)	31.5 (3.7)	31.7 (4.1)	0.82[a]
Height (cm), mean (SD)	167.0 (6.7)	167.3 (7.0)	167.0 (7.3)	166.6 (6.2)	0.93[a]
Weight (kg), mean (SD)	66.5 (7.7)	68.7 (8.0)	67.3 (7.8)	63.4 (6.5)	0.04[a]
BMI[b] (kg/m^2), mean (SD)	23.8 (2.4)	24.5 (2.6)	24.1 (2.4)	22.8 (1.8)	0.03[a]
Weight gain[c] (kg), median (min-max)[d]	5.1 (0.04–15.9)	5.0 (0.04–11.2)	5.2 (1.7–15.9)	–	0.58[e]
Gestation week, median (min-max)[d]	23 (13–26)	23 (13–26)	23 (14–26)	–	0.90[e]
Parity (≥1 child), n (%)	23 (31.1)	11 (44.0)	4 (16.7)	8 (32.0)	0.12[f]
Ethnicity, n (%)					
Norwegian	67 (90.5)	24 (96.0)	21 (87.5)	22 (88.0)	0.62[g]
Other	7 (9.5)	1 (4.0)	3 (12.5)	3 (12.0)	
Marital status, n (%)		25 (100)	24 (100)		0.001[g]
Married/Partner	66 (89.2)			17 (68.0)	
Single	8 (10.2)			8 (32.0)	
Education, n (%)					0.12[f]
≤ 4 years higher education	32 (43.3)	15 (60.0)	9 (37.5)	8 (32.0)	
> 4 years higher education	42 (56.8)	10 (40.0)	15 (62.5)	17 (68.0)	
Employment[h] (Yes), n (%)					
Full time	65 (87.8)	20 (80.0)	23 (95.8)	22 (88.0)	0.28[g]
Part time	5 (6.8)	1 (4.0)	1 (4.2)	2 (12.0)	0.61[g]
Student	4 (5.4)	1 (4.0)	1 (4.2)	1 (4.0)	1.00[g]
Sick leave	9 (12.2)	7 (28.0)	1 (4.2)	1 (4.0)	0.02[g]
Working conditions, n (%)					
Mostly seated	48 (64.9)	9 (36.0)	20 (83.3)	19 (76.0)	0.007[g]
A lot of walking	11 (14.9)	6 (24.0)	2 (8.3)	3 (12.0)	
A lot of walking and lifting	15 (20.3)	10 (40.0)	2 (8.3)	3 (12.0)	
Exercise frequency (days), n (%)					
≤1day/week	30 (40.5)	14 (56.0)	9 (37.5)	7 (28.0)	0.12[f]
2–3 days/week	25 (33.8)	9 (36.0)	7 (29.2)	9 (36.0)	
Almost every day	19 (25.7)	2 (8.0)	8 (33.3)	9 (36.0)	
PGP in past pregnancy, n (%)					
Yes	13 (21.6)	7 (28.0)	2 (8.3)	4 (16.0)	0.25[g]
No	16 (17.6)	4 (16.0)	4 (16.7)	8 (32.0)	
No previous pregnancies	45 (60.8)	14 (56.0)	18 (75.0)	13 (52.0)	
SCL-10[i], n (%)					
< 1.85	69 (93.2)	21 (84.0)	24 (100.0)	24 (96.0)	0.12[g]
≥ 1.85	5 (6.8)	4 (16.0)		1 (4.0)	
Beighton score[j], n (%)					
< 5	66 (89.2)	24 (96.0)	19 (79.2)	23 (92.0)	0.16[g]
≥ 5	8 (10.8)	1 (4.0)	5 (20.8)	2 (8.0)	
Onset of PGP (week), mean (SD)[k]		14.9 (5.9)			
Symptom location, n (%)[k]					
Posterior pain (uni- and bilateral)		12 (48.0)			
Combined posterior and pubic symphysis pain		13 (52.0)			
Use of walking aids (Yes), n (%)[k]		3 (12.5)			
PGQ[l], mean (SD)[k]					
Activity subscale		42.6 (16.2)			
Symptom subscale		43.1 (18.2)			
Pain intensity[m] mean (SD)[j]		2.5 (1.9)			
Fear of movement[n]median, (min-max)[j]		6.5 (1–10)			
ASLR[o] score (cut off ≥ 4), n (%)[p]					
< 4		17 (68.0)			
≥ 4		8 (32.0)			
P4[q] test, n (%) [p]					
Positive unilateral		7 (28.0)			
Positive bilateral		18 (72.0)			

[a] One way analysis of variance.
[b] Present BMI, body mass index calculated from measures of weight and height on the day of testing.
[c] Weight gain calculated from measured weight and self-reported pre-pregnancy weight.
[d] n = 49.
[e] Mann Whitney test.
[f] Chi-squared test.
[g] Fisher exact test.
[h] Multiple answers were allowed.
[i] SCL-10, Hopkins Symptom Checklist – 10 items.
[j] Beighton score for general joint hypermobility.
[k] n = 24.
[l] PGQ, Pelvic Girdle Questionnaire.
[m] Pain intensity measured by numeric rating scale.
[n] Fear of movement measured by one substitute question for the Tampa Scale for Kinesiophobia.
[o] ASLR, active straight leg raise test.
[p] n = 25.
[q] P4, posterior pelvic pain provocation test.

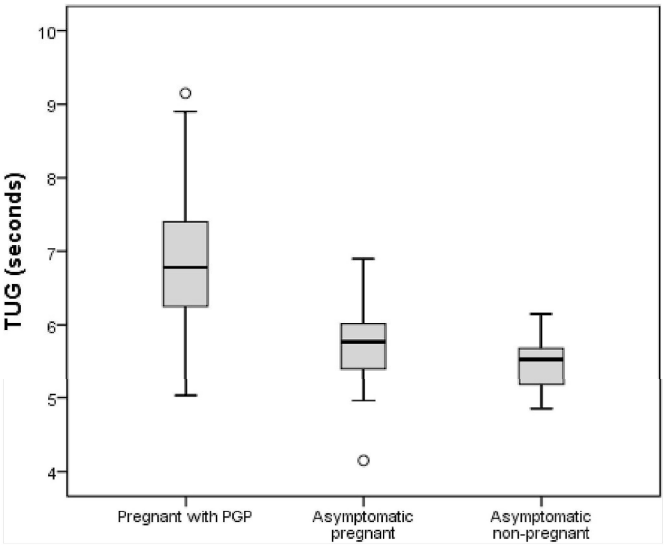

Fig. 2. Box plot of the Timed Up and Go (TUG) test for the three different groups: Pregnant women with pelvic girdle pain (PGP) (n = 25), asymptomatic pregnant women (n = 24), asymptomatic non-pregnant women (n = 25). Median, quartiles and range are shown.

3. Results

3.1. Participant characteristics

In total, 25 pregnant women with PGP, 24 asymptomatic pregnant and 25 non-pregnant women, participated in the study (Fig. 1). Weight, BMI, marital status, sick leave and working conditions were significantly different between groups (p-values ≤ 0.04) (Table 2). Post hoc analyses revealed that pregnant women with PGP had significantly higher weight (p = 0.04) and BMI (p = 0.03) than non-pregnant women, while no significant differences were found between the two pregnancy groups (p-values = 1.0). Moreover, pregnant women with PGP had higher prevalence of sick leave and working conditions with a lot of walking or walking and lifting than both asymptomatic pregnant and non-pregnant women ($0.004 \leq p \leq 0.05$). Only 9 women were on sick leave and only five participants scored ≥1.85 on the SCL-10.

The clinical variables showed large variation in pregnant women with PGP: ASLR scores ranged 1–8, pain intensity 0–7, fear of movement 1–10 and PGQ 10–73%.

3.2. TUG

TUG differed significantly between groups ($p < 0.001$). Pregnant women with PGP used significantly longer time (mean (95% CI) on TUG 6.9 (6.5, 7.3) seconds) than asymptomatic pregnant (5.8 (5.5, 6.0), $p < 0.001$) and non-pregnant (5.5 (5.4, 5.6), $p < 0.001$) women. No significant difference was found between asymptomatic pregnant and non-pregnant women (p = 0.62). As shown in Fig. 2 there was much larger variation in TUG among the pregnant women with PGP than for the other groups, with about 75% having higher TUG times than the slowest among non-pregnant women.

3.3. Factors associated with TUG in the total study sample

Group, sick leave, BMI and exercise frequency were significantly associated with TUG in the simple linear regression analyses of the total sample (Table 3). Group, sick leave and BMI remained significant in the multiple linear regression model ($p \leq 0.02$; $R^2 = 0.58$) (Table 3). Univariate analyses showed weak associations between group and both BMI and sick leave (r-values = −0.30), and no significant association between BMI and sick leave (p = 0.45). Age, height, previous given birth, former low back pain, former PGP, education, working conditions and Beighton score were not significantly associated with TUG in univariate analyses ($0.15 \leq p \leq 0.86$). Gestation week was significantly associated with TUG (p = 0.001), but highly correlated with group (p = 0.01). Thus, these variables were not included in the multiple linear regression model. Gestation week showed weak associations with BMI (r = 0.31), while no significant association with sick leave (p = 0.15). Furthermore, we found no significant correlations between gestation week and BMI, pain intensity or ASLR in pregnant women with PGP ($-0.11 \leq r_s \leq 0.39$, $0.06 \leq p \leq 0.84$).

In the multiple regression analysis, pregnant women with PGP had significantly increased TUG than non-pregnant women (adjusted mean difference (95% CI) between the two groups 1.05 (0.66, 1.45) seconds), while no significant difference was found between asymptomatic pregnant and non-pregnant women (0.15 (−0.22, 0.52) seconds). We found significant interaction between sick leave and BMI ($p_{interaction} = 0.005$), with a stronger effect of BMI on TUG in women on sick leave than in women not on sick leave. Due to the low number of women on sick leave (Table 2), the model is presented without interaction (Table 3).

3.4. Factors associated with TUG in pregnant women with PGP

Based on simple linear regression analysis among pregnant women with PGP, ASLR, pain intensity and fear of movement were included in a multiple linear regression model (Table 4). Then, ASLR and fear of movement were not significantly associated with TUG (p-values ≥ 0.09) while pain intensity remained significant (p = 0.02, $R^2 = 0.37$).

Table 3
Simple and multiple linear regression analyses of the association between Timed Up and Go (TUG) (seconds) and potential explanatory variables (n = 74).

	Simple linear regression ß[a] (95%CI[b])	p-value	Multiple linear regression ß[a] (95%CI[b])	p-value
Group				
Asymptomatic non-pregnant	Reference	0.001	Reference	0.001
Asymptomatic pregnant	0.26 (−0.14,0.66)		0.15 (−0.22, 0.52)	
Pregnant with PGP	1.43 (1.04, 1.83)		1.05 (0.66, 1.45)	
BMI (kg/m^2)	0.11 (0.03, 0.20)	0.01	0.08 (0.01, 0.15)	0.02
Sick leave				
No	Reference	0.001	Reference	0.001
Yes	1.47 (0.90, 2.04)		1.03 (0.55, 1.51)	
Exercise frequency				
≤1day/week	Reference	0.006		
2–3 days/week	−0.68 (−1.16, −0.20)			
Almost every day	−0.71 (−1.23, −0.20)			

[a] Estimated regression coefficient.
[b] CI, confidence interval. PGP, pelvic girdle pain; BMI, present body mass index.

Table 4
Simple and multiple linear regression analyses of the association between Timed Up and Go (TUG) (seconds) and potential explanatory variables. Only pregnant women with PGP (n = 24).

	Simple linear regression		Multiple linear regression	
	ß[a] (95%CI[b])	p-value	ß[a] (95%CI[b])	p-value
Pain intensity (0–10)	0.29 (0.12, 0.46)	0.002	0.29 (0.12, 0.46)	0.002
Fear of movement (0–10)	0.15 (0.05, 0.25)	0.007		
ASLR		0.001		
< 4	Reference			
≥ 4	1.62 (1.02, 2.20)			

[a] Estimated regression coefficient.
[b] CI, confidence interval. Pain intensity measured on a numeric rating scale for present pelvic girdle pain, Fear of movement measured by one substitute question for the Tampa Scale for Kinesiophobia; ASLR, active straight leg raise test.

4. Discussion

4.1. TUG

Pregnant women with PGP had larger variation and used significantly longer time on TUG, amounting 1.1 and 1.4 s compared to asymptomatic pregnant and non-pregnant women, respectively. As the expected time on TUG undertaken at maximum speed is 5–6 s in non-pregnant women aged 20–39 years (Isles et al., 2004), the present between-group differences of above 1 s constitute around 20% difference in TUG. This is presumably a clinical meaningful difference in physical function and underpins that TUG targets relevant activities in pregnant women with PGP. The TUG times in this study were comparable with previous results on TUG in pregnant women with PGP (Evensen et al., 2016). However, the paucity of studies on TUG in younger women as well as the use of different TUG variants preclude comparison with other populations. This highlights the necessity of standardized TUG protocols in future research.

Although not designed to establish normative data, this is the first study reporting values of TUG in asymptomatic pregnant women. We found no significant difference in TUG between asymptomatic pregnant and non-pregnant women. This can be seen as contradictory with previous studies reporting disability and reduced walking velocity in asymptomatic pregnant women (Robinson et al., 2010a, 2010b; McCrory et al., 2011; Bertuit et al., 2015). However, this might also reflect that TUG as a performance-based measure captures the actual performance of multiple activities (Terwee et al., 2006b).

The large variation in TUG in pregnant women with PGP was in concordance with the study of Evensen et al. (2016). The smaller variation in TUG in asymptomatic pregnant women can be considered to be in contrast to a previous study reporting large variation in disability also in asymptomatic pregnant women (Robinson et al., 2010a). This might be due to our inclusion of women in early pregnancy, suggesting that the effect of pregnancy itself had not yet developed. However, it may also reflect inherent differences between self-reported and performance-based instruments, supporting that TUG captures complementing information about physical function.

4.2. Factors associated with TUG in the total study sample

In the multivariable analyses of the total study sample, group, sick leave and BMI were significantly associated with increased TUG. As no previous studies have explored TUG in pregnant women using multivariable analyses, comparisons are limited. From a clinical perspective, it seems plausible that each of the identified variables might influence physical function. Conversely, sick leave and increased BMI might be caused by PGP or be related to gestation week. Due to the cross-sectional design, we are unable to draw causal associations. Still, neither BMI nor weight gain were significantly different between the two pregnancy groups indicating that the increase in BMI was related to pregnancy. However, there was a weak association between group and BMI, and gestation week showed weak association with BMI and no significant association with sick leave in the total study sample. There were no significant associations between gestation week and BMI, pain intensity and ASRL in the PGP group. Together, these findings support that group, sick leave and BMI independently influenced TUG in our study.

It should be noted that the variable group was predefined and included both pain location and response on clinical tests, and can as such be considered as multifactorial. Thus, group might have reduced the influence of other variables in our analyses. Since weight gain is expected during pregnancy and group included pregnancy as a factor, the effect of increased BMI on TUG was likely reduced when adjusting for group. Similarly, this observation applies to the association between sick leave and increased TUG, as PGP has been identified as the most common cause of sick leave in pregnant women (Robinson et al., 2006; Gutke et al., 2014). Nevertheless, in this study, both being on sick leave and having an increased BMI, in addition to being pregnant and having PGP, were factors associated with increased TUG.

Finally, exercise frequency was not associated with TUG in the final model, implying that it did not influence physical function. This is surprising, as exercise is reported to improve functional ability and maternal health during pregnancy (Nascimento et al., 2012). However, the lack of association could be influenced by the other variables in the model and by the short time frame used in the formulation of the question (last seven days).

4.3. Factors associated with TUG in pregnant women with PGP

In pregnant women with PGP, only pain intensity was significantly associated with TUG in the multivariable analysis. TUG increased with 0.29 s with 1 point increase in pain intensity, which amounts to 3 s increase in TUG with an increase in pain intensity from 0 (no pain) to 10 (worst imaginable pain). ASLR and fear of movement had no significant additional effect. These findings can be seen in concordance with a larger cohort study of pregnant women reporting associations between pain intensity and disability, while no associations were found between disability and ASLR or fear-avoidance (Robinson et al., 2010b). Previously, fear of movement has been associated with reduced walking velocity in pregnant women with PGP (Wu et al., 2008). Due to the low number of women with PGP (and thereby low statistical power), we cannot exclude an influence of fear of movement on TUG.

Interestingly, we found a positive association between TUG and ASLR in pregnant women with PGP in our univariate analyses, which is in line with Evensen et al. (2016). However, we also performed multivariable analysis revealing no association between TUG and ASLR when controlling for pain intensity. This is surprising, as it seems plausible that the TUG subtasks challenge load transfer. One explanation could be the difference in test position (supine vs. sitting, standing and walking). Biomechanical studies have identified altered motor control in PGP populations, suggesting increased muscle activity as a compensatory strategy, which paradoxically might be a mechanism for ongoing pain (de Groot et al., 2008; Beales et al., 2009; Bussey, 2015). Hence, we might speculate whether compensations could explain the lack of association between ASLR and TUG. To shed light on these potential mechanisms, biomechanical studies are needed to quantify movement and motor control strategies. From our results, we cannot support that increased TUG is related to dysfunctional load transfer as measured with the ASLR. Instead, the affliction of PGP manifested in increased TUG seems to be influenced by pain intensity.

4.4. Strengths and limitations

Strengths of this study are the inclusion of pregnant women with PGP, asymptomatic pregnant and non-pregnant women based on predefined criteria and clinical examination, the use of a standardized TUG version and multivariable statistical analysis. The small sample size and few women on sick leave are limitations. Hence, some of the results should be interpreted with caution. Further, we cannot draw causal associations due to the cross-sectional design, or explore potential compensatory mechanisms.

5. Clinical implications

The TUG targets core activities commonly impaired in pregnant women with PGP, and is quick to perform, easy to administer and can be applied in most environmental settings. Our finding that pregnant women with PGP use longer time on TUG, with about 75% having higher TUG times than the slowest among non-pregnant women, support that TUG may assist in determining the extent of functional disability. Multivariable analyses suggest that BMI, sick leave, pregnancy and PGP, in particular pain intensity are important to consider when interpreting TUG. We recommend TUG as a measure of physical function in pregnant women with PGP used together with self-reported instruments and clinical tests.

6. Conclusion

Our findings support that the TUG undertaken at maximum speed is a suitable physical performance measure in pregnant women with PGP. We found larger variation and significant longer time on TUG in this group compared to asymptomatic pregnant and non-pregnant women. In addition, our results provide new knowledge about factors influencing TUG and indicate that the affliction of PGP manifested in an increased TUG seems to be influenced by pain intensity.

Conflicts of interest

None declared.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.msksp.2019.03.006.

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Paper II

Lene Christensen, Marit B. Veierød, Nina K. Vøllestad, Vidar E. Jakobsen, Britt Stuge, Jan Cabri and Hilde Stendal Robinson. *Kinematic and spatiotemporal gait characteristics in pregnant women with pelvic girdle pain, asymptomatic pregnant and non-pregnant women.* Clinical Biomechanics. 68 (2019) 45-52

II

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Kinematic and spatiotemporal gait characteristics 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: 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

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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 < 6 months since last pregnancy
Current multiple gestation		
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.

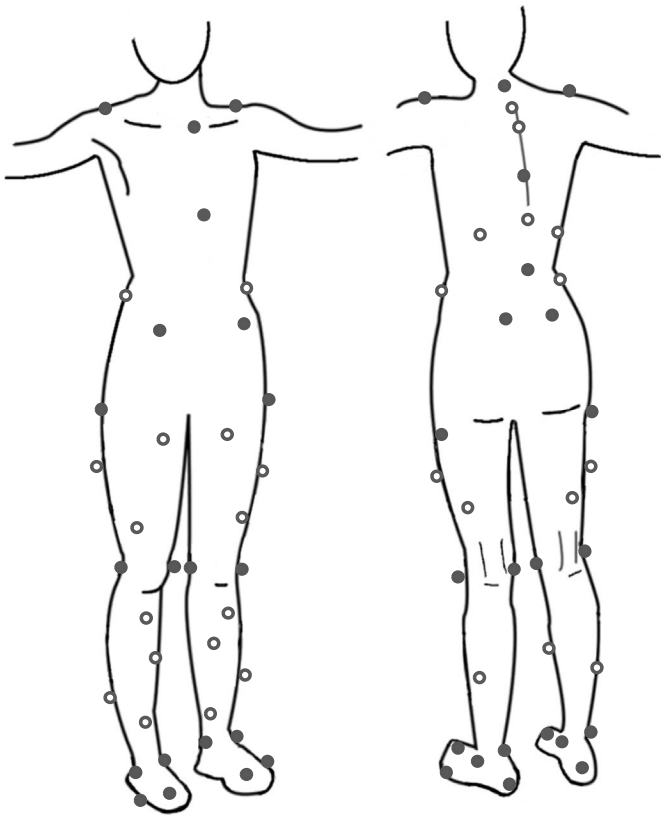

Fig. 1. Marker placement in anterior and posterior view; Upper body (on top of the acromioclavicular joints, spinous processes of C7, T2, T4, T10, L3, lateral on the left and right 11th rib, xiphoid process, jugular notch), pelvis (anterior superior iliac spines, posterior superior iliac spines, on top 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 (≤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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Supplementary material paper II

Table S1 Kinematic variables, estimated marginal means (EMMs) with 95% confidence intervals (CIs) comparing asymptomatic pregnant women (n = 24), asymptomatic non-pregnant women (n = 24) and pregnant women with PGP (n = 25)

VARIABLES	Group	Crude EMM[1] (95% CI)	P_{group}	Adjusted EMM[2] (95% CI)	P_{group}
RoM during gait cycle					
Thoracic sagittal plane RoM (°)[3]			0.55		0.94
	Asymptomatic pregnant	3.5 (3.2, 3.9)		3.5 (3.1, 3.9)	
	Asymptomatic non-pregnant	3.5 (3.1, 3.8)		3.6 (3.2, 4.0)	
	Pregnant with PGP	3.7 (3.4, 4.1)		3.6 (3.2, 3.9)	
Thoracic frontal plane RoM (°)			0.83		0.71
	Asymptomatic pregnant	3.5 (3.0, 4.0)		3.5 (3.0, 4.1)	
	Asymptomatic non-pregnant	3.5 (2.9, 4.0)		3.5 (2.9, 4.0)	
	Pregnant with PGP	3.3 (2.8, 3.8)		3.2 (2.6, 3.8)	
Thoracic transversal plane RoM (°)			0.76		0.59
	Asymptomatic pregnant	8.2 (7.3, 9.0)		8.2 (7.2, 9.1)	
	Asymptomatic non-pregnant	7.8 (7.0, 8.6)		7.5 (6.6, 8.4)	
	Pregnant with PGP	7.8 (6.9, 8.6)		8.0 (7.2, 8.9)	
Pelvic sagittal plane RoM (°)			0.90		0.94
	Asymptomatic pregnant	3.4 (3.0, 3.7)		3.3 (3.0, 3.7)	
	Asymptomatic non-pregnant	3.4 (3.1, 3.8)		3.3 (3.0, 3.8)	
	Pregnant with PGP	3.3 (3.0, 3.7)		3.4 (3.0, 3.8)	
Pelvic lateral translation (%Inter ASIS distance/2)[4] RoM			0.09		0.58
	Asymptomatic pregnant	45.2 (41.1, 49.4)		44.7 (40.4, 49.0)	
	Asymptomatic non-pregnant	44.8 (40.7, 49.0)		43.8 (39.2, 48.4)	
	Pregnant with PGP	39.6 (35.6, 43.6)		44.7 (40.4, 49.0)	
Hip transversal plane RoM (°)			0.28		0.55
	Asymptomatic pregnant	15.6 (14.2, 16.9)		15.5 (14.1, 16.9)	
	Asymptomatic non-pregnant	16.1 (14.8, 17.5)		16.0 (14.6, 17.5)	
	Pregnant with PGP	14.6 (13.3, 16.0)		14.8 (13.3, 16.3)	

Thoracic kinematics at specific events				
Thoracic sagittal plane angle[5] at heel strike (°)			0.39	0.45
	Asymptomatic pregnant	-2.2 (-3.7, -0.8)		-2.2 (-3.6, -0.7)
	Asymptomatic non-pregnant	-1-1 (-2.6, 0.3)		-1.0 (-2.5, 0.5)
	Pregnant with PGP	-0.9 (-2.3, 0.5)		-1.1 (-2.6, 0.4)
Thoracic frontal plane angle[6] at heel strike (°)			0.45	0.46
	Asymptomatic pregnant	-0.4 (-1.2, 0.4)		-0.4 (-1.2. 0.4)
	Asymptomatic non-pregnant	-1.0 (-1.8, -0.2)		-1.0 (-1.8, -0.2)
	Pregnant with PGP	-1.1 (-1.8, -0.3)		-1.1 (-1.9, -0.2)
Thoracic transversal plane angle[7] at heel strike(°)			0.99	0.92
	Asymptomatic pregnant	-1.2 (-2.6, 0.3)		-1.2 (-2.7, 0.3)
	Asymptomatic non-pregnant	-1.2 (-2.6, 0.3)		-1.3 (-2.8, 0.2)
	Pregnant with PGP	-1.03 (-2.5, 0.4)		-0.9 (-2.4, 0.7)
Thoracic sagittal plane angle at mid-stance (°)			0.48	0.49
	Asymptomatic pregnant	-2.6 (-4.1, -1.1)		-2.6 (-4.1, -1.1)
	Asymptomatic non-pregnant	-1.4 (-2.9, 0.1)		-1.4 (-2.9, 0.2)
	Pregnant with PGP	-1.6 (-3.0, -0.1)		-1.6 (-4.1, -1.1)
Thoracic frontal plane angle at mid-stance (°)			0.34	0.33
	Asymptomatic pregnant	0.9 (0.1, 1.7)		0.9 (0.1, 1.7)
	Asymptomatic non-pregnant	0.1 (-0.7, 0.9)		0.06 (-0.8, 0.9)
	Pregnant with PGP	0.5 (-0.3, 1.3)		0.6 (-0.3, 1.4)
Thoracic transversal plane angle at mid-stance (°)			0.31	0.32
	Asymptomatic pregnant	2.8 (1.5, 4.0)		2.7 (1.4, 4.0)
	Asymptomatic non-pregnant	4.1 (2.9, 5.4)		4.0 (2.6, 5.3)
	Pregnant with PGP	3.5 (2.3, 4.7)		3.7 (2.4, 5.1)
Thoracic sagittal plane angle at peak hip adduction (°)			0.32	0.31
	Asymptomatic pregnant	-2.6 (-4.1, -1.1)		-3.6 (-5.2, -2.1)
	Asymptomatic non-pregnant	-2.1 (-3.7, -0.6)		-2.0 (-3.6, -0.3)
	Pregnant with PGP	-2.6 (-4.1, -1.1)		-2.8 (-4.4, -1.1)
Thoracic frontal plane angle at peak hip adduction (°)			0.52	0.57
	Asymptomatic pregnant	1.2 (0.5, 1.9)		1.2 (0.5, 1.9)
	Asymptomatic non-pregnant	0.8 (0.07, 1.5)		0.7 (-0.07, 1.4)
	Pregnant with PGP	0.7 (0.04, 1.4)		0.9 (0.1, 1.6)

Thoracic transversal plane angle at peak hip adduction (°)			0.56		0.57
	Asymptomatic pregnant	-0.9 (-2.3, 0.5)		-0.9 (-2.3, 0.5)	
	Asymptomatic non-pregnant	0.02 (-1.4, 1.4)		0.1 (-1.4, 1.6)	
	Pregnant with PGP	-0.02 (-1.4, 1.3)		-0.1 (-1.6, 1.4)	
Thoracic sagittal plane angle at toe off (°)			0.53		0.52
	Asymptomatic pregnant	-4.2 (-5.7, -2.7)		-4.2 (-5.8, -2.7)	
	Asymptomatic non-pregnant	-3.1 (-4.6, -1.5)		-3.1 (-4.7, -1.5)	
	Pregnant with PGP	-3.2 (-4.7, -1.7)		-3.1 (-4.8, -1.5)	
Thoracic frontal plane angle at toe off (°)			0.53		0.52
	Asymptomatic pregnant	-0.4 (-1.2, 0.5)		-0.4 (-1.2, 0.5)	
	Asymptomatic non-pregnant	-1.05 (-1.9, -0.2)		-1.0 (-1.9, -0.1)	
	Pregnant with PGP	-0.8 (-1.7, 0.01)		-0.9 (-1.8, 0.2)	
Pelvic kinematics at specific events					
Pelvic sagittal angle[8] at heel strike (°)[5]			0.54		0.55
	Asymptomatic pregnant	11.2 (9.0, 13.5)		11.2 (8.9, 13.5)	
	Asymptomatic non-pregnant	9.5 (7.3, 11.8)		9.5 (7.1, 11.8)	
	Pregnant with PGP	9.9 (7.7, 12.2)		10.0 (7.8, 12.3)	
Pelvic frontal plane angle[9] at heel strike (°)[6]			0.40		0.22
	Asymptomatic pregnant	-0.8 (-1.5, -0.04)		-0.7 (-1.4, 0.01)	
	Asymptomatic non-pregnant	-0.2 (-1.0, 0.5)		-0.1 (-0.8, 0.6)	
	Pregnant with PGP	-0.9 (-1.6, -0.2)		-1.1 (-1.8, -0.3)	

Pelvic transversal plane angle[10] at heel strike (°)			0.09		0.38
	Asymptomatic pregnant	5.9 (4.6, 7.2)		5.7 (4.5, 7.0)	
	Asymptomatic non-pregnant	5.3 (4.0, 6.6)		4.6 (3.3, 5.9)	
	Pregnant with PGP	4.0 (2.7, 5.2)		4.8 (3.5, 6.2)	
Pelvic lateral translation at heel strike (%Inter ASIS distance/2)			0.12		0.11
	Asymptomatic pregnant	42.4 (37.8, 47.0)		42.7 (38.0, 47.4)	
	Asymptomatic non-pregnant	49.1 (44.5, 53.7)		49.7 (44.7, 54.8)	
	Pregnant with PGP	46.4 (41.9, 50.8)		45.5 (40.1, 50.9)	
Pelvic sagittal angle at mid-stance (°)[5]			0.48		0.59
	Asymptomatic pregnant	11.6 (9.4, 13.9)		11.4 (9.2, 13.7)	
	Asymptomatic non-pregnant	10.2 (7.9, 12.4)		9.8 (7.5, 12.1)	
	Pregnant with PGP	9.8 (7.6, 12.0)		10.3 (8.1, 12.6)	
Pelvic frontal plane angle at mid-stance (°)[6]			0.43		0.16
	Asymptomatic pregnant	1.2 (0.5, 1.9)		1.3 (0.6, 2.0)	
	Asymptomatic non-pregnant	1.3 (0.5, 2.0)		1.4 (0.7, 2.1)	
	Pregnant with PGP	0.7 (-0.02, 1.4)		0.4 (-0.3, 1.2)	
Pelvic transversal plane angle at mid-stance (°)			0.77		0.55
	Asymptomatic pregnant	2.2 (1.3, 3.1)		2.1 (1.2, 3.1)	
	Asymptomatic non-pregnant	1.8 (0.9, 2.7)		1.6 (0.6, 2.6)	
	Pregnant with PGP	2.2 (1.3, 3.0)		2.4 (1.4, 3.5)	

Pelvic lateral translation at mid-stance (%Inter ASIS distance/2)			0.34	0.35
	Asymptomatic pregnant	22.8 (18.0, 27.7)	22.9 (17.9, 27.8)	
	Asymptomatic non-pregnant	27.5 (22.7, 32.3)	27.6 (22.4, 32.8)	
	Pregnant with PGP	26.7 (22.0, 31.4)	26.6 (21.1, 32.1)	
Pelvic sagittal angle at peak hip adduction (°)[5]			0.53	0.63
	Asymptomatic pregnant	10.8 (8.4, 13.1)	10.7 (8.3, 13.0)	
	Asymptomatic non-pregnant	9.5 (7.2, 11.9)	9.3 (6.9, 11.7)	
	Pregnant with PGP	8.9 (6.7, 11.2)	9.3 (6.9, 11.6)	
Pelvic transversal angle at peak hip adduction (°)			0.83	0.81
	Asymptomatic pregnant	3.3 (2.1, 4.4)	3.1 (1.8, 4.3)	
	Asymptomatic non-pregnant	3.0 (1.8, 4.1)	2.7 (1.5, 4.0)	
	Pregnant with PGP	2.8 (1.7, 3.9)	3.1 (2.1, 4.4)	
Pelvic lateral translation at peak-hip adduction (%Inter ASIS distance/2)			0.48	0.22
	Asymptomatic pregnant	29.0 (24.7, 33.3)	28.9 (24.6, 33.3)	
	Asymptomatic non-pregnant	34.5 (30.2, 38.8)	34.4 (29.6, 39.9)	
	Pregnant with PGP	31.7 (27.5, 35.9)	31.9 (26.9, 36.9)	
Pelvic sagittal plane angle at toe off (°)[6]			0.43	0.76
	Asymptomatic pregnant	10.9 (8.6, 13.2)	10.6 (8.3, 12.9)	
	Asymptomatic non-pregnant	10.0 (7.8, 12.3)	9.7 (7.4, 12.0)	
	Pregnant with PGP	8.9 (6.7, 11.1)	9.5 (7.2, 11.7)	

Pelvic frontal plane angle at toe off (°)[6]			0.34		0.36
	Asymptomatic pregnant	-3.9 (-4.6, -3.2)		-3.9 (-4.6, -3.2)	
	Asymptomatic non-pregnant	-3.2 (-3.0, -2.5)		-3.2 (-3.9, -2.5)	
	Pregnant with PGP	-3.7 (-4.4, -3.1)		-3.7 (-4.5, -3.0)	
Pelvic transversal plane angle at toe off (°)			0.31		0.78
	Asymptomatic pregnant	-4.4 (-5.7, -3.2)		-4.3 (-5.6, -3.0)	
	Asymptomatic non-pregnant	-4.6 (-5.9, -3.4)		-4.4 (-5.7, -3.1)	
	Pregnant with PGP	-3.4 (-4.6, -2.2)		-3.7 (-5.1, -2.3)	
Pelvic lateral translation at toe off (%Inter ASIS distance/2)			0.10		0.34
	Asymptomatic pregnant	40.1 (34.4, 45.8)		41.0 (35.4, 46.7)	
	Asymptomatic non-pregnant	44.2 (38.5, 49.8)		46.3 (40.3, 52.3)	
	Pregnant with PGP	48.6 (43.0, 54.2)		45.7 (39.3, 52.0)	
Hip kinematics at specific events					
Hip sagittal plane angle[11] at heel strike (°)			0.08		0.07
	Asymptomatic pregnant	38.6 (35.7, 41.4)		38.6 (35.8, 41.5)	
	Asymptomatic non-pregnant	36.0 (33.2, 38.8)		36.1 (33.2, 39.0)	
	Pregnant with PGP	34.1 (31.3, 36.8)		33.9 (31.0, 36.7)	
Hip frontal plane angle[12] at heel strike (°) [7]			0.25		0.53
	Asymptomatic pregnant	-0.5 (-1.7, 0.7)		-0.3 (-1.4, 0.8)	
	Asymptomatic non-pregnant	0.1 (-1.1, 1.3)		0.6 (-0.6, 1.8)	
	Pregnant with PGP	0.9 (-0.3, 2.0)		0.2 (-1.0, 1.4)	

Hip transversal plane angle[13] at heel strike (°)			0.43		0.43
	Asymptomatic pregnant	4.9 (2.5, 7.4)		5.1 (2.6, 7.5)	
	Asymptomatic non-pregnant	7.0 (4.6, 9.4)		7.3 (4.8, 9.8)	
	Pregnant with PGP	6.6 (4.3, 9.0)		6.2 (3.7, 8.8)	
Hip sagittal plane angle at mid-stance (°)			0.69		0.71
	Asymptomatic pregnant	9.0 (6.0, 12.0)		8.9 (5.9, 11.9)	
	Asymptomatic non-pregnant	7.3 (4.3, 10.3)		7.2 (4.1, 10.2)	
	Pregnant with PGP	7.5 (4.5, 10.4)		7.7 (4.7, 10.7)	
Hip frontal plane angle at mid-stance (°)			0.38		0.43
	Asymptomatic pregnant	6.8 (5.8, 7.9)		6.9 (5.9, 8.0)	
	Asymptomatic non-pregnant	5.8 (4.8, 6.9)		6.0 (4.9, 7.1)	
	Pregnant with PGP	6.5 (5.4, 7.5)		6.2 (5.1, 7.3)	
Hip transversal plane angle at mid-stance (°)			0.13		0.10
	Asymptomatic pregnant	9.7 (7.4, 12.1)		9.9 (7.5, 12.2)	
	Asymptomatic non-pregnant	12.6 (10.2, 14.9)		12.8 (10.4, 15.3)	
	Pregnant with PGP	9.6 (7.3, 11.9)		9.3 (6.9, 11.7)	
Hip frontal plane angle at peak hip adduction (°)			0.11		0.08
	Asymptomatic pregnant	10.8 (9.6, 11.9)		10.8 (9.7, 12.0)	
	Asymptomatic non-pregnant	10.4 (9.3, 11.5)		10.5 (9.3, 11.7)	
	Pregnant with PGP	9.1 (8.0, 10.3)		9.0 (7.8, 10.1)	

Hip transversal plane angle at peak hip adduction (°)			0.90		0.60
	Asymptomatic pregnant	8.4 (5.7, 11.0)		8.1 (5.5, 10.8)	
	Asymptomatic non-pregnant	8.8 (6.2, 11.4)		8.3 (5.6, 11.0)	
	Pregnant with PGP	9.2 (6.6, 11.8)		10.0 (7.2, 12.7)	
Hip sagittal plane angle at toe-off (°)			0.14		0.11
	Asymptomatic pregnant	-1.6 (-4.5, 1.2)		-1.8 (-4.7, 1.2)	
	Asymptomatic non-pregnant	-4.9 (-7.8, -2.0)		-5.1 (-8.1, -2.2)	
	Pregnant with PGP	-1.2 (-4.1, 1.6)		-0.9 (-3.8, 2.0)	
Hip frontal plane angle at toe-off (°)			0.76		0.73
	Asymptomatic pregnant	-4.3 (-5.4, -3.1)		-4.3 (-5.4, -3.1)	
	Asymptomatic non-pregnant	-3.8 (-4.9, -2.6)		-3.8 (-5.0, -2.6)	
	Pregnant with PGP	-3.7 (-4.9, -2.6)		-3.7 (-4.9, -2.5)	
Hip transversal plane angle at toe-off (°)			0.23		0.25
	Asymptomatic pregnant	1.7 (-0.9, 4.3)		1.7 (-0.9, 4.2)	
	Asymptomatic non-pregnant	4.6 (2.1, 7.2)		4.6 (2.0, 7.2)	
	Pregnant with PGP	2.2 (-0.4, 4.7)		2.2 (-0.3, 4.8)	

Kinematic values denote joint range of motion (RoM) during gait cycle and angles at the time of heel strike, mid-stance, peak hip adduction and toe-off during stance phase of gait, [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]degrees, [4]pelvic lateral translation represents the position of foot placement (calcaneus marker) relative to the midline of the participant (0% represent a position of the calcaneus directly under the midline and 100% directly under the anterior superior iliac spines), [5]thoracic flexion is positive, [6]thoracic ipsilateral lean is positive, [7]thoracic ipsilateral forward rotation is positive [8]pelvic anterior tilt is positive [9]pelvic obliquity indicates the contralateral pelvis is dropped relative to the stance limb, [10]pelvic ipsilateral forward rotation is positive, [11]hip flexion is positive, [12]hip adduction is positive, [13]hip internal rotation is positive

Table S2 Sensitivity analysis of kinematic variables, estimated marginal means (EMMs) with 95% confidence intervals (CIs) comparing asymptomatic pregnant women (n = 24), asymptomatic non-pregnant women (n = 24) and pregnant women with PGP (n = 25)

VARIABLES	Group	Adjusted for speed and step length EMM[1] (95% CI)	P_{group}
RoM[2] during gait cycle			
C7 lateral translation RoM (cm)[3]			0.57
	Asymptomatic pregnant	5.0 (4.5, 5.4)	
	Asymptomatic non-pregnant	5.4 (4.8, 5.7)	
	Pregnant with PGP	5.0 (4.5, 5.5)	
L3 lateral translation RoM (cm)[4]			0.25
	Asymptomatic pregnant	5.1 (4.6, 5.5)	
	Asymptomatic non-pregnant	4.7 (4.3, 5.2)	
	Pregnant with PGP	4.5 (4.0, 5.0)	
Thoracic sagittal plane RoM (°)[5]			0.93
	Asymptomatic pregnant	3.6 (3.2, 3.9)	
	Asymptomatic non-pregnant	3.6 (3.2, 4.0)	
	Pregnant with PGP	3.5 (3.1, 3.9)	
Thoracic frontal plane RoM (°)			0.76
	Asymptomatic pregnant	3.5 (3.0, 4.0)	
	Asymptomatic non-pregnant	3.5 (2.9, 4.1)	
	Pregnant with PGP	3.2 (2.7, 3.8)	
Thoracic transversal plane RoM (°)			0.52
	Asymptomatic pregnant	8.1 (7.2, 9.0)	
	Asymptomatic non-pregnant	7.5 (6.6, 8.4)	
	Pregnant with PGP	8.1 (7.2, 9.1)	
Pelvic sagittal plane RoM (°)			0.85
	Asymptomatic pregnant	3.3 (2.9, 3.7)	
	Asymptomatic non-pregnant	3.3 (3.0, 3.7)	
	Pregnant with PGP	3.5 (3.1, 3.9)	

Pelvic frontal plane RoM (°)			0.003
	Asymptomatic pregnant	10.9 (9.9, 11.8)	
	Asymptomatic non-pregnant	10.6 (9.6, 11.6)	
	Pregnant with PGP	8.5 (7.5, 9.5)	
Pelvic transversal plane RoM (°)			0.16
	Asymptomatic pregnant	14.2 (12.3, 16.0)	
	Asymptomatic non-pregnant	13.2 (11.3, 15.1)	
	Pregnant with PGP	11.4 (9.5, 13.4)	
Pelvic lateral translation (%Inter ASIS distance/2)[6] RoM			0.70
	Asymptomatic pregnant	44.1 (39.8, 48.3)	
	Asymptomatic non-pregnant	44.2 (39.7, 48.6)	
	Pregnant with PGP	41.4 (36.6, 46.2)	
Hip sagittal plane RoM (°)			0.002
	Asymptomatic pregnant	48.3 (46.7, 49.9)	
	Asymptomatic non-pregnant	47.7 (46.0, 49.3)	
	Pregnant with PGP	44.1 (42.4, 45.7)	
Hip frontal plane RoM (°)			0.01
	Asymptomatic pregnant	17.3 (16.0, 18.7)	
	Asymptomatic non-pregnant	17.1 (15.7, 18.5)	
	Pregnant with PGP	14.5 (13.1, 15.9)	
Hip transversal plane RoM (°)			0.56
	Asymptomatic pregnant	15.4 (14.1, 16.8)	
	Asymptomatic non-pregnant	16.1 (14.8, 17.5)	
	Pregnant with PGP	14.8 (13.3, 16.3)	
Thoracic kinematics at specific events			
Thoracic sagittal plane angle[7] at heel strike (°)			0.50
	Asymptomatic pregnant	-2.1 (-3.6, -0.7)	
	Asymptomatic non-pregnant	-1.0 (-2.5, 0.5)	
	Pregnant with PGP	-1.1 (-2.7, 0.4)	

Thoracic frontal plane angle[8] at heel strike (°)			0.38
	Asymptomatic pregnant	-0.4 (-1.2, 0.4)	
	Asymptomatic non-pregnant	-1.0 (-1.8, -0.2)	
	Pregnant with PGP	-1.1 (-1.9, -0.3)	
Thoracic transversal plane angle[9] at heel strike(°)			0.92
	Asymptomatic pregnant	-1.1 (-2.6, 0.4)	
	Asymptomatic non-pregnant	-1.4 (-2.9, 0.2)	
	Pregnant with PGP	-0.9 (-2.5, 0.7)	
Thoracic sagittal plane angle at mid-stance (°)			0.53
	Asymptomatic pregnant	-2.5 (-4.0, -1.0)	
	Asymptomatic non-pregnant	-1.4 (-3.0, 0.1)	
	Pregnant with PGP	-1.6 (-3.2, -0.05)	
Thoracic frontal plane angle at mid-stance (°)			0.36
	Asymptomatic pregnant	0.9 (0.08, 1.7)	
	Asymptomatic non-pregnant	0.07 (-0.8, 0.9)	
	Pregnant with PGP	0.6 (-0.3, 1.4)	
Thoracic transversal plane angle at mid-stance (°)			0.30
	Asymptomatic pregnant	2.7 (1.4, 4.0)	
	Asymptomatic non-pregnant	4.0 (2.6, 5.3)	
	Pregnant with PGP	3.8 (2.4, 5.1)	
Thoracic sagittal plane angle at peak hip adduction (°)			0.38
	Asymptomatic pregnant	-3.6 (-5.2, -2.0)	
	Asymptomatic non-pregnant	-2.0 (-3.6, -0.4)	
	Pregnant with PGP	-2.8 (-4.5, -1.1)	
Thoracic frontal plane angle at peak hip adduction (°)			0.57
	Asymptomatic pregnant	1.2 (0.5, 1.9)	
	Asymptomatic non-pregnant	0.7 (-0.08, 1.5)	
	Pregnant with PGP	0.9 (0.1, 1.6)	
Thoracic transversal plane angle at peak hip adduction (°)			0.79
	Asymptomatic pregnant	-0.7 (-2.1, 0.7)	
	Asymptomatic non-pregnant	-0.03 (-1.5, 1.4)	
	Pregnant with PGP	-0.2 (-1.7, 1.3)	

Thoracic sagittal plane angle at toe off (°)			0.51
	Asymptomatic pregnant	-4.2 (-5.8, -2.7)	
	Asymptomatic non-pregnant	-3.1 (-4.7, -1.5)	
	Pregnant with PGP	-3.1 (-4.8, -1.5)	
Thoracic frontal plane angle at toe off (°)			0.51
	Asymptomatic pregnant	-0.3 (-1.2, 0.5)	
	Asymptomatic non-pregnant	-1.0 (-1.9, -0.1)	
	Pregnant with PGP	-0.9 (-1.8, 0.1)	
Thoracic transversal plane angle at toe off (°)			0.006
	Asymptomatic pregnant	-0.4 (-1.7, 1.1)	
	Asymptomatic non-pregnant	2.9 (1.4, 4.3)	
	Pregnant with PGP	1.3 (-0.2, 2.8)	
Pelvic kinematics at specific events			
Pelvic sagittal angle[10] at heel strike (°)			0.52
	Asymptomatic pregnant	11.2 (8.9, 13.5)	
	Asymptomatic non-pregnant	9.4 (7.1, 11.7)	
	Pregnant with PGP	10.0 (7.8, 12.3)	
Pelvic frontal plane angle[11] at heel strike (°)			0.20
	Asymptomatic pregnant	-0.7 (-1.5, -0.01)	
	Asymptomatic non-pregnant	-0.1 (-0.8, 0.7)	
	Pregnant with PGP	-1.0 (-1.8, -0.3)	
Pelvic transversal plane angle[12] at heel strike (°)			0.31
	Asymptomatic pregnant	5.8 (4.6, 7.1)	
	Asymptomatic non-pregnant	4.5 (3.2, 5.9)	
	Pregnant with PGP	4.8 (3.4, 6.2)	
Pelvic lateral translation at heel strike (%Inter ASIS distance/2)			0.20
	Asymptomatic pregnant	43.4 (38.7, 48.1)	
	Asymptomatic non-pregnant	49.4 (44.3, 54.4)	
	Pregnant with PGP	45.2 (39.8, 50.5)	
Pelvic sagittal angle at mid-stance (°)			0.57
	Asymptomatic pregnant	11.5 (9.2, 13.8)	
	Asymptomatic non-pregnant	9.8 (7.5, 12.1)	
	Pregnant with PGP	10.3 (8.1, 12.6)	

Pelvic frontal plane angle at mid-stance (°)			0.20
	Asymptomatic pregnant	1.2 (0.5, 2.0)	
	Asymptomatic non-pregnant	1.4 (0.7, 2.2)	
	Pregnant with PGP	0.5 (-0.3, 1.2)	
Pelvic transversal plane angle at mid-stance (°)			0.61
	Asymptomatic pregnant	2.1 (1.1, 3.0)	
	Asymptomatic non-pregnant	1.7 (0.7, 2.7)	
	Pregnant with PGP	2.5 (1.4, 3.5)	
Pelvic lateral translation at mid-stance (%Inter ASIS distance/2)			0.37
	Asymptomatic pregnant	22.9 (17.9, 27.9)	
	Asymptomatic non-pregnant	27.6 (22.3, 32.9)	
	Pregnant with PGP	26.6 (21.0, 32.1)	
Pelvic sagittal plane angle at peak hip adduction (°)			0.58
	Asymptomatic pregnant	10.8 (8.4, 13.1)	
	Asymptomatic non-pregnant	9.3 (6.9, 11.6)	
	Pregnant with PGP	9.2 (6.9, 11.6)	
Pelvic frontal plane angle at peak hip adduction (°)			0.006
	Asymptomatic pregnant	5.3 (4.4, 6.2)	
	Asymptomatic non-pregnant	5.5 (4.7, 6.4)	
	Pregnant with PGP	3.5 (2.6, 4.4)	
Pelvic transversal plane angle at peak hip adduction (°)			0.48
	Asymptomatic pregnant	3.5 (2.3, 4.7)	
	Asymptomatic non-pregnant	2.5 (1.3, 3.7)	
	Pregnant with PGP	3.0 (1.8, 4.3)	
Pelvic lateral translation at peak-hip adduction (%Inter ASIS distance/2)			0.32
	Asymptomatic pregnant	29.4 (25.0, 33.8)	
	Asymptomatic non-pregnant	34.1 (29.4, 38.8)	
	Pregnant with PGP	31.7 (26.7, 36.6)	
Pelvic sagittal plane angle at toe off (°)			0.72
	Asymptomatic pregnant	10.7 (8.4, 12.9)	
	Asymptomatic non-pregnant	9.7 (7.4, 11.9)	
	Pregnant with PGP	9.5 (7.2, 11.7)	

Pelvic frontal plane angle at toe off (°)			0.42
	Asymptomatic pregnant	-3.9 (-4.9, -3.2)	
	Asymptomatic non-pregnant	-3.2 (-4.0, -2.5)	
	Pregnant with PGP	-3.8 (-4.5, -3.0)	
Pelvic transversal plane angle at toe off (°)			0.61
	Asymptomatic pregnant	-4.5 (-5.8, -3.3)	
	Asymptomatic non-pregnant	-4.3 (-5.6, -3.0)	
	Pregnant with PGP	-3.6 (-4.9, -2.2)	
Pelvic lateral translation at toe off (%Inter ASIS distance/2)			0.32
	Asymptomatic pregnant	40.8 (35.1, 46.6)	
	Asymptomatic non-pregnant	46.4 (40.3, 52.4)	
	Pregnant with PGP	45.8 (39.4, 52.2)	
Hip kinematics at specific events			
Hip sagittal plane angle[13] at heel strike (°)			0.052
	Asymptomatic pregnant	38.8 (35.9, 41.6)	
	Asymptomatic non-pregnant	36.1 (33.2, 39.0)	
	Pregnant with PGP	33.1 (31.0, 36.6)	
Hip frontal plane angle[14] at heel strike (°) [7]			0.48
	Asymptomatic pregnant	-0.4 (-1.5, 0.8)	
	Asymptomatic non-pregnant	0.6 (-0.6, 1.8)	
	Pregnant with PGP	0.2 (-1.0, 1.4)	
Hip transversal plane angle[15] at heel strike (°)			0.34
	Asymptomatic pregnant	4.9 (2.5, 7.4)	
	Asymptomatic non-pregnant	7.3 (4.8, 9.8)	
	Pregnant with PGP	6.4 (3.8, 8.9)	
Hip sagittal plane angle at mid-stance (°)			0.71
	Asymptomatic pregnant	8.9 (5.9, 11.9)	
	Asymptomatic non-pregnant	7.2 (4.1, 10.2)	
	Pregnant with PGP	7.7 (4.7, 10.7)	
Hip frontal plane angle at mid-stance (°)			0.56
	Asymptomatic pregnant	6.8 (5.7, 7.9)	
	Asymptomatic non-pregnant	6.0 (4.9, 7.1)	
	Pregnant with PGP	6.3 (5.2, 7.4)	

Hip transversal plane angle at mid-stance (°)			0.08
	Asymptomatic pregnant	9.7 (7.3, 12.0)	
	Asymptomatic non-pregnant	12.9 (10.5, 15.3)	
	Pregnant with PGP	9.3 (7.0, 11.8)	
Hip sagittal plane angle at peak hip adduction (°)			0.03
	Asymptomatic pregnant	28.0 (24.8, 31.3)	
	Asymptomatic non-pregnant	26.4 (23.1, 29.7)	
	Pregnant with PGP	21.6 (18.2, 25.0)	
Hip frontal plane angle at peak hip adduction (°)			0.10
	Asymptomatic pregnant	10.7 (9.6, 11.9)	
	Asymptomatic non-pregnant	10.6 (9.4, 11.7)	
	Pregnant with PGP	9.0 (7.8, 10.2)	
Hip transversal plane angle at peak hip adduction (°)			0.52
	Asymptomatic pregnant	8.0 (5.3, 10.6)	
	Asymptomatic non-pregnant	8.3 (5.6, 11.0)	
	Pregnant with PGP	10.1 (7.3, 12.8)	
Hip sagittal plane angle at toe-off (°)			0.12
	Asymptomatic pregnant	-1.8 (-4.8, 1.1)	
	Asymptomatic non-pregnant	-5.0 (-8.0, -2.1)	
	Pregnant with PGP	-0.9 (-3.9, 2.0)	
Hip frontal plane angle at toe-off (°)			0.72
	Asymptomatic pregnant	-4.3 (-5.5, -3.1)	
	Asymptomatic non-pregnant	-3.8 (-5.0, -2.6)	
	Pregnant with PGP	-3.7 (-4.9, -2.5)	
Hip transversal plane angle at toe-off (°)			0.25
	Asymptomatic pregnant	1.8 (-0.8, 4.3)	
	Asymptomatic non-pregnant	4.6 (2.0, 7.2)	
	Pregnant with PGP	2.2 (-0.4, 4.7)	

Kinematic values denote joint range of motion (RoM) during gait cycle and angles at the time of heel strike, mid-stance, peak hip adduction and toe-off during stance phase of gait, [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]range of motion, [3]translation of C7 spinal vertebra in relation to the laboratory coordinate system given in cm, [4]translation of L3 spinal vertebra in relation to the laboratory coordinate system given in cm, [5]degrees, [6]pelvic lateral translation represents the position of foot placement (calcaneus marker) relative to the midline of the participant (0% represent a position of the calcaneus directly under the midline and 100%

directly under the anterior superior iliac spines), [7]thoracic flexion is positive, [8]thoracic ipsilateral lean is positive, [9]thoracic ipsilateral forward rotation is positive [10]pelvic anterior tilt is positive [11]pelvic obliquity indicates the contralateral pelvis is dropped relative to the stance limb, [12]pelvic ipsilateral forward rotation is positive, [13]hip flexion is positive, [14]hip adduction is positive, [15]hip internal rotation is positive

Table S3 Reliability of spatiotemporal variables over the four gait trials presented by the intraclass correlation coefficient (ICC 1,1) and intra-individual standard deviation (SD) for asymptomatic pregnant women (n=24), asymptomatic non-pregnant women (n=24) and pregnant women with PGP (n=25)

Spatiotemporal variables	Group	ICC (95% CIs)[1]	SD (Median)[2]
Speed[3]			
	Asymptomatic pregnant	0.95 (0.91, 0.98)	0.03
	Asymptomatic non-pregnant	0.89 (0.80, 0.95)	0.03
	Pregnant with PGP	0.95 (0.90, 0.97)	0.03
Contralateral step length[4,5]			
	Asymptomatic pregnant	0.92 (0.85, 0.96)	0.012
	Asymptomatic non-pregnant	0.87 (0.78, 0.94)	0.014
	Pregnant with PGP	0.89 (0.81, 0.95)	0.016
Stance time[6]			
	Asymptomatic pregnant	0.93 (0.87, 0.96)	0.014
	Asymptomatic non-pregnant	0.92 (0.86, 0.96)	0.009
	Pregnant with PGP	0.94 (0.86, 0.97)	0.015
Stance phase[7]			
	Asymptomatic pregnant	0.75 (0.60, 0.87)	0.6
	Asymptomatic non-pregnant	0.57 (0.37, 0.78)	0.6
	Pregnant with PGP	0.68 (0.51, 0.82)	0.9
Double limb support[8]			
	Asymptomatic pregnant	0.83 (0.72, 0.92)	0.8
	Asymptomatic non-pregnant	0.74 (0.59, 0.87)	0.8
	Pregnant with PGP	0.84 (0.74, 0.92)	1.2

This table shows the variable speed and the spatiotemporal variables with statistical significant between-group difference when adjusted for speed. [1]95% confidence intervals, [2]median value within each group, [3]meter per second, [4]denoting step length on the non-affected or less affected (non-test side for the asymptomatic women), [5]meter, [6]second, [7]stance phase calculated as % of gait cycle, [8]double limb support calculated as % of gait cycle

Table S4 Reliability of kinematic variables over the four gait trials presented by the intraclass correlation coefficient (ICC 1,1) and intra-individual standard deviation (SD) for asymptomatic pregnant women (n=24), asymptomatic non-pregnant women (n=24) and pregnant women with PGP (n=25)

Kinematic variables	Group	ICC (95% CIs)[1]	SD (°)[2] (Median)[3]
RoM[4] during gait cycle			
Pelvic frontal plane RoM			
	Asymptomatic pregnant	0.91 (0.84, 0.96)	0.7
	Asymptomatic non-pregnant	0.89 (0.81, 0.95)	0.7
	Pregnant with PGP	0.84 (0.74, 0.92)	0.8
Hip sagittal plane RoM			
	Asymptomatic pregnant	0.96 (0.92, 0.98)	1.0
	Asymptomatic non-pregnant	0.81 (0.68, 0.90)	1.4
	Pregnant with PGP	0.85 (0.75, 0.92)	1.5
Hip frontal plane RoM			
	Asymptomatic pregnant	0.93 (0.87, 0.97)	0.9
	Asymptomatic non-pregnant	0.89 (0.81, 0.95)	0.9
	Pregnant with PGP	0.91 (0.84, 0.95)	0.9
Thoracic transversal plane angle at toe off			
	Asymptomatic pregnant	0.82 (0.70, 0.91)	1.3
	Asymptomatic non-pregnant	0.88 (0.80, 0.94)	1.0
	Pregnant with PGP	0.80 (0.67, 0.89)	1.2
Pelvic frontal plane angle at peak hip adduction			
	Asymptomatic pregnant	0.97 (0.94, 0.98)	0.5
	Asymptomatic non-pregnant	0.89 (0.81, 0.95)	0.5
	Pregnant with PGP	0.89 (0.81, 0.95)	0.6
Hip sagittal plane angle at peak hip adduction			
	Asymptomatic pregnant	0.91 (0.83, 0.95)	1.6
	Asymptomatic non-pregnant	0.96 (0.92, 0.98)	1.4
	Pregnant with PGP	0.93 (0.87, 0.96)	1.8

This table shows the kinematic variables with statistical significant between-group difference when adjusted for speed. [1]95% confidence intervals, [2]degrees, [3]median value within each group, [4]range of motion

Paper III

Lene Christensen, Nina K. Vøllestad, Marit B. Veierød, Vidar E. Jakobsen, Britt Stuge, Eva S. Bakke, Jan Cabri and Hilde Stendal Robinson. *Trunk, pelvic and hip kinematics during the Stork test in pregnant women with pelvic girdle pain, asymptomatic pregnant and non-pregnant women.* Clinical Biomechanics; Submitted 17th of January 2020

III

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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Abstract:

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 functional test, including visual observation of movement responses. 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 were included in 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 [1-3]. In addition, a large number of pregnant women develop pelvic girdle pain (PGP) [3-6], a musculoskeletal disorder with pain located in the posterior pelvis between the iliac crest and gluteal folds and/or the pubic symphysis [5]. Although the etiology of PGP is multifactorial, dysfunctional load transfer is considered a significant contributor [5, 7, 8]. Moreover, pregnant women with PGP have reduced ability to perform weight-bearing activities such as standing and walking [9].

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) [10]. 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 [10]. Pregnant women with PGP also walked with less pelvic frontal plane and hip sagittal and frontal plane movements, as well as greater lateral trunk translation [10]. 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 [11]. 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 [12]. SLS tests are commonly used to assess loading strategies in patients with lower limb disorders [13, 14]. The clinician evaluates and identifies movement responses during SLS tests by visual observation [14]. Key movement responses are lateral pelvic tilt and shift as well as lateral trunk motion relative to the stance leg [15] during transition to [13] and in SLS [13, 15]. The Stork test is a SLS test widely used in patients with PGP. 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 increased posterior pelvic tilt during the Stork test. However, 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 [12, 16]. Of these, none reported kinematics in pregnant women. To inform the clinical interpretation of the Stork test in pregnant women with PGP, quantification of trunk, pelvic and hip kinematics and investigation of the influence of both pregnancy and PGP on Stork performance are important.

Asymptomatic pregnant women also report disability [3] and demonstrate gait alterations [10, 17-19]. The progressive weight gain primarily localized in the anterior lower-trunk and pelvic region [1] is a unique feature of pregnancy with a likely impact on biomechanics. We therefore aimed to investigate the influence of both pregnancy and PGP

in the 2nd trimester on trunk, pelvic and hip kinematics during the Stork test by comparing kinematics in pregnant women with PGP, asymptomatic pregnant and non-pregnant women. Based on our findings in gait analysis and clinical experience, we hypothesized that Stork kinematics would be less influenced by pregnancy than by PGP. Moreover, we hypothesized that pregnant women with PGP would lift their leg slower and demonstrate less hip adduction and contralateral pelvic drop, as well as greater lateral trunk translation during this test compared to asymptomatic 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 [20]. 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 [5], onset in current pregnancy, a positive posterior pelvic pain provocation (P4) test [21] and an active straight leg raise (ASLR) test score >0 on clinical examination [22]. The ASLR test is assumed to assess load transfer [22]. 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 [20]. 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 movement analysis, reflective markers were placed on the participants [10]. 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 [23]. 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 [10] 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 [24]. Lateral pelvic translation was calculated according to Allison et al [25], 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 [26].

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 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 [25]. 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 [25]. 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 (min-max). 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 ($P_{interaction}$=0.03) and pelvic frontal plane angle during SLS ($P_{interaction}$=0.03), we found no significant interaction effects in the analyses of kinematic variables ($0.15 \leq P_{interaction} \leq 0.97$). 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 [27]. 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 [10]. 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-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, asymptomatic pregnant and non-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 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 with the same effect size when adjusted for pelvic width (Table 2). In contrast, Bussey and colleagues [12] found slower leg lift and altered hip-spine kinematics in individuals with PGP compared to asymptomatic controls during a SLS. However, comparisons are limited as participants lifted their leg as fast as possible and the PGP participants were non-pregnant and had a long lasting condition [12]. Since we wanted to mimic clinical practice, we instructed participants to lift their leg at self-selected speed. However, 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, however it is unknown if one is easier than the other is. Comparable to the influence of speed on biomechanics during gait [28-32], it seems reasonable that different strategies regarding 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 [12], 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 on PGQ (10-73%), NRS for pain intensity (0-7) and ASLR (1-8) [10]. Importantly, the affliction of our participants is comparable with a large Norwegian pregnant cohort [3]. 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 [33]. Although self-reported "preferred leg to kick a ball" is often used to decide leg dominance [33], the literature reports different methods to determine leg dominance [34, 35]. Leg dominance may also vary between tasks [33], such as bilateral mobilizing tasks (e.g. kicking a ball) and unilateral stabilizing tasks (e.g. SLS) [33, 35]. In SLS the standing leg has been suggested to be the dominant leg [34], 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 performing subgroup analyses. The adjustment for dominant leg tested did not change the results (Table 2 and 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. However, lifting the leg to 30° of hip flexion might better resemble hip flexion excursion during walking. It has been advocated that lifting the leg to 90° in contrast to 30° of hip flexion facilitates an excessive elevation of the contralateral pelvis [15]. 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. Hence, the Stork test apparently did not reveal between-group kinematic differences in contrast to our findings during gait in the same study sample [10]. This is clinically important 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 et al [14] found that trunk movements during SLS tasks were small in asymptomatic, young women. As noted in Fig. 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 [17, 19, 30, 36], and proposed to reflect that adaptation to pregnancy is unique to each individual [17, 19].

Interestingly, we found large inter-individual variation in all three groups (Fig. 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 [15]. This has clinical relevance, suggesting that trunk, pelvic and hip movements as during by the Stork test are not specific to pregnancy and/or PGP in the 2nd trimester. Accordingly, the clinician cannot anticipate specific movement patterns on visual observation of trunk, pelvic and hip kinematics during this test in pregnant women with and without PGP. Interestingly, de Groot and colleagues [37] 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-group differences in gait kinematics in this sample [10]. Finally, soft tissue artefacts is a common source of error in kinematic analyses [38].

5. Conclusion

We found few and small significant differences between pregnant women with PGP, asymptomatic pregnant and non-pregnant women as regards trunk, pelvic and hip kinematics during the Stork test. However, the large variation 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 implications, indicating that trunk, pelvic and hip movements during the Stork test are not specific to pregnancy and/or PGP in the 2nd trimester. Since movement strategies appear unique to each individual, clinicians should change focus from movement patterns to individual movement responses if the Stork test is used in the examination of pregnant women in the 2nd trimester.

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Conflicts of interest

None

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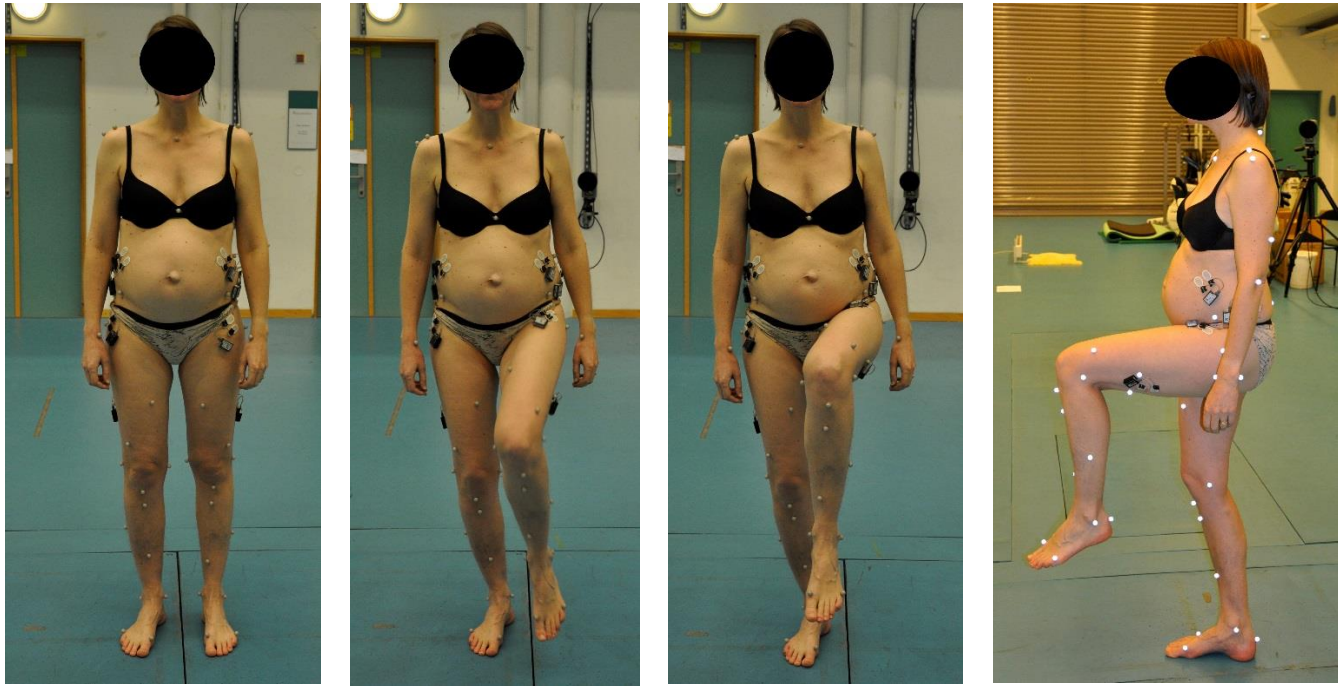
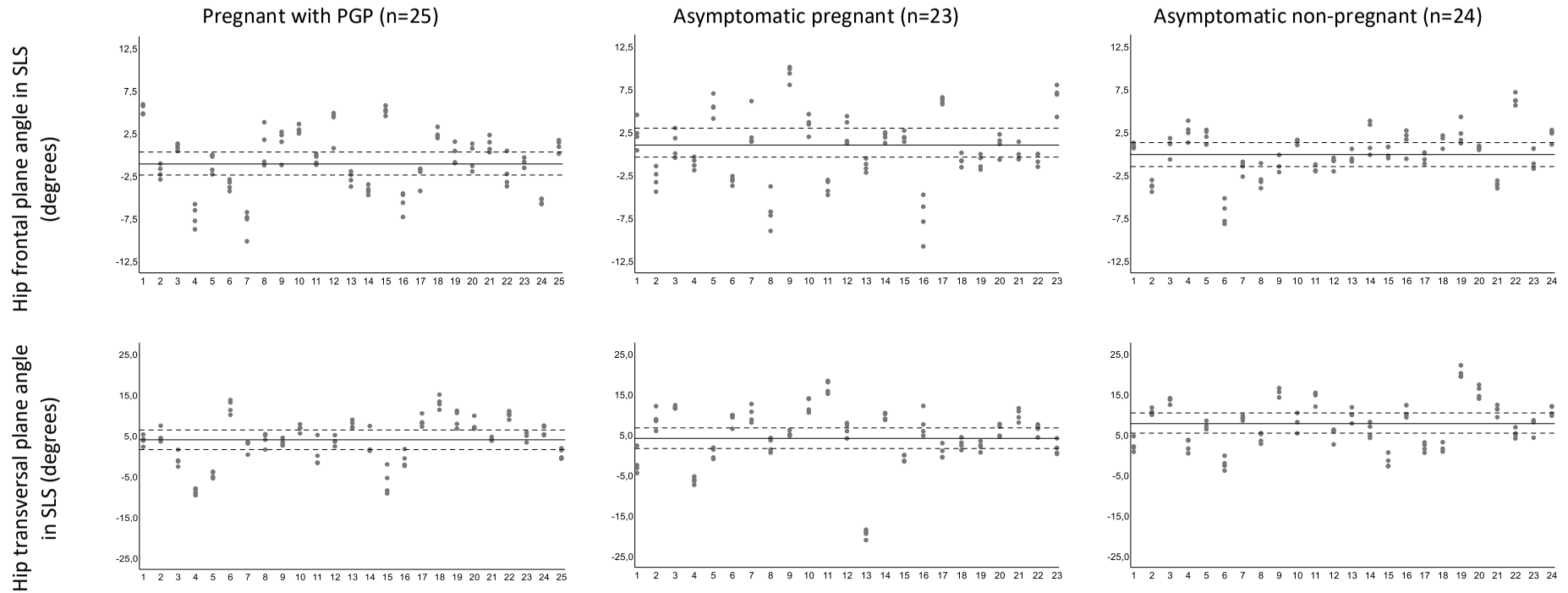
Fig. 1. Pregnant participant performing the Stork test



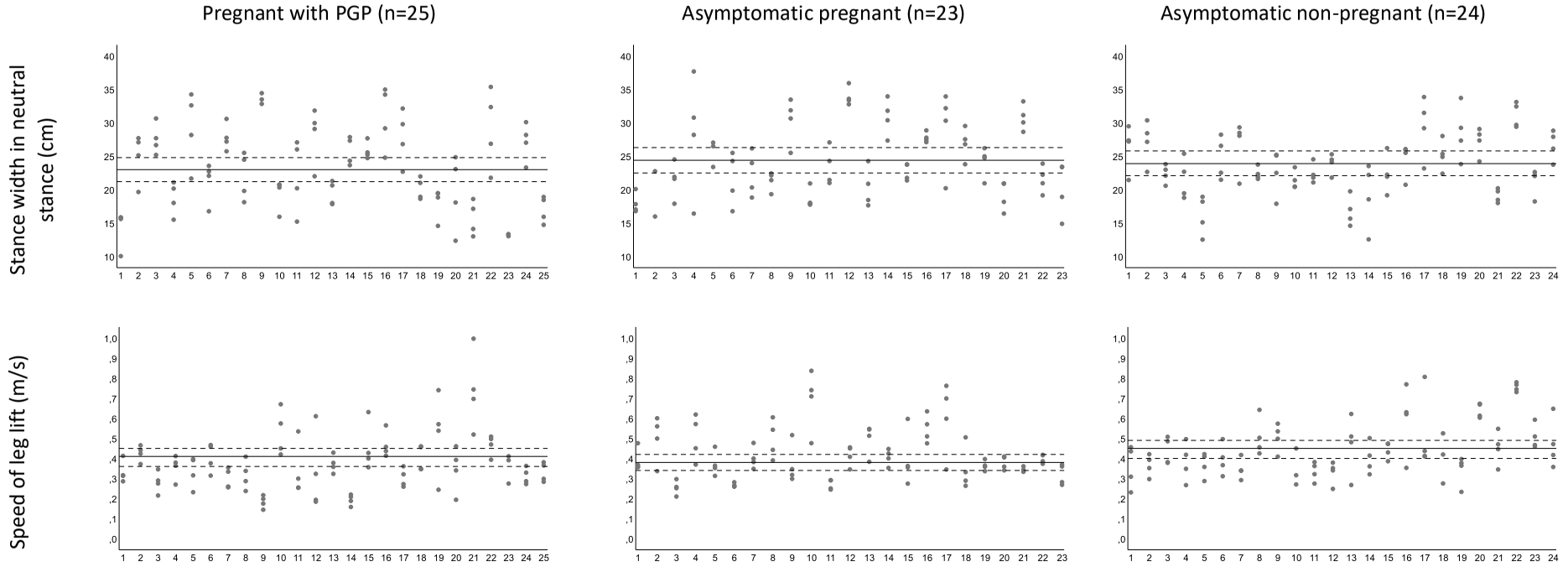
(a) Self-selected stance (b) Lifting phase (c) Single leg stance (d) Single leg stance

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.



Peak hip flexion angle of the lifted leg (degrees)

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.



Pelvic frontal plane angle in SLS (degrees)

Trunk translation in SLS (cm)

Thoracic frontal plane angle in SLS (degrees)

Pelvic translation in SLS
(% inter ASIS distance/2)

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)	30.9 (2.2)	31.1 (3.3)	31.4 (4.0)	0.90 [1]
Height (m), mean (SD)	1.67 (0.07)	1.67 (0.07)	1.66 (0.06)	0.85[1]
Weight (kg), mean (SD)	68.7 (8.0)	67.7 (7.7)	63.4 (6.7)	0.04[1]
Pre-pregnancy BMI[2] 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[1]
Pelvic width[3] (cm), median (min-max)	26 (22-31)	26 (21-29)	23 (21-26)	<0.001[4]
Trochanter major distance[5] (cm), median (min-max)	39 (33-44)	39 (33-43)	38 (35-42)	0.15[4]
Test side[6] (right), n (%)	11 (44)	15 (65)	12 (50)	0.32[8]
Dominant leg tested[7] (yes), n (%)	13 (52)	16 (70)	17 (71)	0.27[8]
Pain duration (weeks), mean (SD)	7 (5)			
PGQ[9], mean (SD)[10]	42.7 (16.0)			
NRS for pain intensity[11], mean (SD)[10]	2.5 (1.9)			
One substitute question for TSK[12], median (min-max)[10]	6.5 (1-10)			
ASLR[13] score, median (min-max)	3 (1-8)			

[1]One way analysis of variance, [2]body mass index, self-reported, [3]determined by the distance between the anatomical landmarks anterior spina iliaca superior on the pelvis, [4]Kruskal-Wallis test, [5]distance between trochanter major on the right and left femur, [6]side of symptomatic posterior pelvic pain, designated in asymptomatic participants by a coin toss, [7]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)), [8]chi-square test, [9]Pelvic Girdle Questionnaire, [10]n=24, [11]numeric rating scale, [12]fear of movement measured by one substitute question for the Tampa Scale of Kinesiophobia, [13]active straight leg raise test

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

Supplementary table S1

Estimated marginal means (EMMs) with 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)

VARIABLES	Group	Crude[1]		Adjusted[2]		Adjusted[3]	
		EMM (95% CI)	P_{group}[4]	EMM (95% CI)	P_{group}[4]	EMM (95% CI)	P_{group}[4]
Stance width in neutral stance (cm)			0.57		0.64		0.73
	Asymptomatic pregnant	24.4 (22.5, 26.3)		24.4 (21.2, 25.1)		24.3 (22.3, 26.3)	
	Asymptomatic non-pregnant	23.9 (22.1, 25.8)		23.7 (21.6, 25.8)		23.6 (21.4, 25.7)	
	Pregnant with PGP	23.0 (21.2, 24.8)		23.2 (22.5, 26.4)		23.2 (21.2, 25.2)	
Lifted leg							
Speed of leg lift (m/s)[5]			0.10		0.13		0.13
	Asymptomatic pregnant	0.38 (0.34, 0.42)		0.41 (0.36, 0.45)		0.41 (0.36, 0.45)	
	Asymptomatic non-pregnant	0.45 (0.40, 0.49)		0.45 (0.40, 0.50)		0.45 (0.40, 0.50)	
	Pregnant with PGP	0.41 (0.36, 0.45)		0.38 (0.33, 0.42)		0.38 (0.33, 0.42)	
Stance leg							
Neutral stance							
Thoracic sagittal plane angle[6] (°)[7]			0.68		0.92		0.86
	Asymptomatic pregnant	-5.7 (-7.1, -4.4)		-5.6 (-6.9, -4.2)		-5.7 (-7.1, -4.3)	
	Asymptomatic non-pregnant	-4.9 (-6.3, -3.6)		-5.2 (-6.6, -3.7)		-5.3 (-6.8, -3.9)	
	Pregnant with PGP	-5.4 (-6.7, -4.1)		-5.3 (-6.6, -3.9)		-5.2 (-6.6, -3.9)	
Thoracic frontal plane angle[8] (°)			0.47		0.47		0.46
	Asymptomatic pregnant	0.2 (-0.5, 0.9)		0.3 (-0.5, 1.0)		0.2 (-0.6, 0.9)	
	Asymptomatic non-pregnant	-0.4 (-1.1, 0.3)		-0.4 (-1.2, 0.4)		-0.5 (-1.2, 0.3)	
	Pregnant with PGP	0.02 (-0.7, 0.7)		0.06 (-0.7, 0.8)		0.06 (-0.7, 0.8)	
Thoracic transversal plane angle[9] (°)			0.42		0.51		0.64
	Asymptomatic pregnant	0.2 (-1.0, 1.4)		0.3 (-0.9, 1.5)		0.4 (-0.8, 1.7)	
	Asymptomatic non-pregnant	1.3 (0.1, 2.5)		0.9 (-0.4, 2.1)		1.0 (-0.4, 2.3)	

	Pregnant with PGP	0.9 (-0.3, 2.0)		1.2 (0.01, 2.4)		1.2 (-0.03, 2.4)	
Trunk translation[10] (cm)			0.87		0.84		0.84
	Asymptomatic pregnant	12.5 (11.3, 13.7)		12.4 (11.2, 13.7)		12.4 (11.2, 13.7)	
	Asymptomatic non-pregnant	12.8 (11.7, 14.0)		13.0 (11.7, 14.3)		12.9 (11.6, 14.3)	
	Pregnant with PGP	12.8 (11.7, 14.0)		12.8 (11.5, 14.0)		12.8 (11.5, 14.0)	
Pelvic sagittal plane angle[11] (°)			0.65		0.64		0.43
	Asymptomatic pregnant	11.7 (9.4, 14.0)		11.7 (9.4, 14.0)		12.2 (9.9, 14.6)	
	Asymptomatic non-pregnant	10.6 (8.4, 12.8)		10.8 (8.3, 13.2)		11.3 (8.8, 13.8)	
	Pregnant with PGP	10.3 (8.1, 12.5)		10.2 (7.0, 12.5)		10.1 (7.8, 12.4)	
Pelvic frontal plane angle[12] (°)			0.64		0.81		0.89
	Asymptomatic pregnant	-0.3 (-1.1, 0.6)		-0.3 (-1.1, 0.5)		-0.2 (-1.1, 0.6)	
	Asymptomatic non-pregnant	-0.4 (-1.2, 0.4)		-0.4 (-1.2, 0.5)		-0.3 (-1.2, 0.6)	
	Pregnant with PGP	0.09 (-0.7, 0.9)		0.04 (-0.8, 0.9)		0.03 (-0.8, 0.9)	
Pelvic transversal plane angle[13] (°)			0.35		0.36		0.10
	Asymptomatic pregnant	1.0 (-0.1, 2.2)		1.0 (-0.9, 2.2)		1.6 (0.5, 2.7)	
	Asymptomatic non-pregnant	-0.04 (-1.1, 1.1)		-0.01 (-1.2, 1.2)		0.5 (-0.7, 1.6)	
	Pregnant with PGP	0.2 (-0.8, 1.3)		0.2 (-0.9, 1.4)		0.1 (-1.0, 1.1)	
Pelvic translation (% inter ASIS distance/2)[14]			0.26		0.99		0.95
	Asymptomatic pregnant	101 (92, 110)		102 (93, 110)		104 (94, 113)	
	Asymptomatic non-pregnant	107 (99, 116)		102 (93, 112)		103 (93, 112)	
	Pregnant with PGP	97 (88, 106)		102 (93, 111)		102 (93, 110)	
Hip sagittal plane angle[15] (°)			0.80		0.84		0.73
	Asymptomatic pregnant	4.7 (1.8, 7.6)		4.7 (1.8, 7.7)		5.1 (2.1, 8.2)	
	Asymptomatic non-pregnant	4.6 (1.8, 7.4)		4.5 (1.4, 7.7)		4.9 (1.6, 8.1)	
	Pregnant with PGP	3.5 (0.8, 6.3)		3.6 (0.6, 6.5)		3.5 (0.6, 6.5)	
Hip frontal plane angle[16] (°)			0.74		0.55		0.60
	Asymptomatic pregnant	-1.9 (-3.3, -0.6)		-2.0 (-3.4, -0.7)		-2.1 (-3.5, -0.7)	
	Asymptomatic non-pregnant	-2.6 (-3.9, -1.2)		-2.0 (-3.4, -0.6)		-2.0 (-3.5, -0.6)	
	Pregnant with PGP	-2.6 (-3.8, -1.2)		-3.0 (-4.3, -1.6)		-3.0 (-4.3, -1.6)	

Hip transversal plane angle[17] (°)			0.23		0.53		0.37
	Asymptomatic pregnant	6.4 (3.8, 9.1)		6.8 (4.2, 9.4)		6.2 (3.6, 8.9)	
	Asymptomatic non-pregnant	9.6 (7.0, 12.3)		8.2 (5.4, 11.0)		7.7 (4.9, 10.6)	
	Pregnant with PGP	7.7 (5.2, 10.3)		8.8 (6.2, 11.4)		8.8 (6.2, 11.4)	
Weight shift[18]							
Thoracic sagittal plane RoM[19] (°)			0.82		0.97		0.97
	Asymptomatic pregnant	2.2 (1.8, 2.6)		2.2 (1.8, 2.6)		2.2 (1.8, 2.6)	
	Asymptomatic non-pregnant	2.2 (1.8, 2.6)		2.3 (1.8, 2.7)		2.3 (1.8, 2.8)	
	Pregnant with PGP	2.3 (1.9, 2.7)		2.2 (1.8, 2.7)		2.2 (1.8, 2.7)	
Thoracic frontal plane RoM (°)			0.53		0.79		0.75
	Asymptomatic pregnant	1.7 (1.3, 2.0)		1.6 (1.3, 2.0)		1.7 (1.4, 2.0)	
	Asymptomatic non-pregnant	1.4 (1.1, 1.7)		1.5 (1.1, 1.8)		1.5 (1.2, 1.9)	
	Pregnant with PGP	1.6 (1.3, 1.9)		1.6 (1.3, 1.9)		1.6 (1.3, 1.9)	
Thoracic transversal plane RoM (°)			0.08		0.17		0.25
	Asymptomatic pregnant	2.6 (2.0, 3.2)		2.6 (2.0, 3.2)		2.7 (2.1, 3.2)	
	Asymptomatic non-pregnant	2.3 (1.8, 2.9)		2.4 (1.7, 3.0)		2.4 (1.8, 3.0)	
	Pregnant with PGP	3.2 (2.6, 3.7)		3.1 (2.6, 3.7)		3.1 (2.6, 3.7)	
Trunk translation (cm)			0.39		0.75		0.76
	Asymptomatic pregnant	11.3 (10.3, 12.3)		11.3 (10.3, 12.3)		11.2 (10.2, 12.2)	
	Asymptomatic non-pregnant	10.5 (9.5, 11.4)		10.7 (9.6, 11.8)		10.6 (9.5, 11.8)	
	Pregnant with PGP	11.2 (10.3, 12.2)		10.1 (10.0, 12.1)		11.1 (10.0, 12.1)	
Pelvic sagittal plane RoM (°)			0.63		0.43		0.32
	Asymptomatic pregnant	2.6 (2.1, 3.1)		2.7 (2.0, 3.1)		2.7 (2.1, 3.2)	
	Asymptomatic non-pregnant	2.4 (1.9, 3.0)		2.6 (2.0, 3.1)		2.7 (2.1, 3.2)	
	Pregnant with PGP	2.2 (1.7, 2.8)		2.1 (1.6, 2.7)		2.1 (1.6, 2.7)	
Pelvic frontal plane RoM (°)			0.12		0.051		0.08
	Asymptomatic pregnant	1.9 (1.5, 2.2)		1.9 (1.5, 2.3)		1.9 (1.6, 2.3)	
	Asymptomatic non-pregnant	2.1 (1.7, 2.4)		1.9 (1.6, 2.3)		2.0 (1.6, 2.4)	
	Pregnant with PGP	2.4 (2.0, 2.7)		2.5 (2.1, 2.8)		2.4 (2.1, 2.8)	

Pelvic transversal plane RoM (°)			0.23		0.27	0.36
	Asymptomatic pregnant	2.9 (2.2, 3.5)		2.9 (2.2, 3.6)	3.0 (2.3, 3.7)	
	Asymptomatic non-pregnant	2.7 (2.0, 3.3)		2.7 (1.9, 3.4)	2.7 (2.0, 3.5)	
	Pregnant with PGP	3.4 (2.8, 4.1)		3.5 (2.8, 4.1)	3.5 (2.8, 4.2)	
Pelvic translation (% inter ASIS distance/2)			0.56		0.78	0.83
	Asymptomatic pregnant	79 (71, 86)		79 (72, 87)	78 (70, 86)	
	Asymptomatic non-pregnant	79 (71, 86)		76 (68, 84)	74 (66, 83)	
	Pregnant with PGP	74 (67, 81)		76 (68, 84)	76 (69, 84)	
Hip sagittal plane RoM (°)			0.67		0.99	0.99
	Asymptomatic pregnant	4.7 (3.8, 5.6)		4.6 (3.7, 5.5)	4.6 (3.6, 5.5)	
	Asymptomatic non-pregnant	4.3 (3.4, 5.2)		4.7 (3.7, 5.6)	4.6 (3.6, 5.7)	
	Pregnant with PGP	4.8 (4.0, 5.7)		4.6 (3.7, 5.5)	4.5 (3.6, 5.5)	
Hip frontal plane RoM (°)			0.56		0.63	0.79
	Asymptomatic pregnant	6.6 (5.7, 7.6)		6.6 (5.6, 7.6)	6.4 (5.4, 7.3)	
	Asymptomatic non-pregnant	6.0 (5.0, 6.9)		6.1 (5.1, 7.2)	5.9 (4.9, 6.9)	
	Pregnant with PGP	6.1 (5.2, 7.0)		6.0 (5.0, 6.7)	6.0 (5.1, 7.0)	
Hip transversal plane RoM (°)			0.60		0.70	0.74
	Asymptomatic pregnant	4.6 (4.0, 5.2)		4.4 (3.9, 5.0)	4.6 (4.0, 5.2)	
	Asymptomatic non-pregnant	4.8 (4.3, 5.4)		4.8 (4.2, 5.4)	4.8 (4.2, 5.4)	
	Pregnant with PGP	4.4 (3.9, 5.0)		4.4 (3.9, 5.0)	4.4 (3.9, 5.0)	
Lifting phase[20]						
Thoracic sagittal plane RoM (°)			0.57		0.55	0.66
	Asymptomatic pregnant	2.1 (1.8, 2.4)		2.1 (1.8, 2.4)	2.1 (1.8, 2.4)	
	Asymptomatic non-pregnant	2.0 (1.7, 2.3)		1.9 (1.6, 2.3)	2.0 (1.6, 2.3)	
	Pregnant with PGP	2.2 (1.9, 2.5)		2.2 (1.9, 2.5)	2.2 (1.9, 2.5)	
Thoracic frontal plane RoM (°)			0.45		0.99	0.99
	Asymptomatic pregnant	2.6 (2.1, 3.1)		2.6 (2.1, 3.1)	2.6 (2.1, 3.1)	
	Asymptomatic non-pregnant	2.4 (1.9, 2.8)		2.6 (2.1, 3.1)	2.6 (2.1, 3.1)	
	Pregnant with PGP	2.8 (2.3, 3.2)		2.6 (2.1, 3.1)	2.6 (2.2, 3.1)	

Thoracic transversal plane RoM (°)			0.19		0.27	0.35
	Asymptomatic pregnant	2.9 (2.5, 3.4)		3.0 (2.5, 3.4)	3.0 (2.6, 3.5)	
	Asymptomatic non-pregnant	3.5 (3.0, 3.9)		3.4 (2.9, 3.8)	3.4 (3.0, 3.9)	
	Pregnant with PGP	3.3 (2.9, 3.7)		3.4 (2.9, 3.8)	3.3 (2.9, 3.8)	
Trunk translation (cm)			0.71		0.71	0.77
	Asymptomatic pregnant	6.2 (5.6, 6.9)		6.2 (5.6, 6.9)	6.3 (5.6, 7.0)	
	Asymptomatic non-pregnant	6.5 (5.9, 7.2)		6.5 (5.8, 7.2)	6.5 (5.8, 7.3)	
	Pregnant with PGP	6.6 (6.0, 7.2)		6.6 (5.9, 7.3)	6.6 (5.9, 7.3)	
Pelvic sagittal plane RoM (°)			0.29		0.41	0.62
	Asymptomatic pregnant	5.6 (4.7, 6.5)		5.6 (4.7, 6.5)	5.8 (4.9, 6.7)	
	Asymptomatic non-pregnant	5.2 (4.4, 6.1)		5.2 (4.3, 6.2)	5.4 (4.5, 6.4)	
	Pregnant with PGP	6.2 (5.3, 7.0)		6.2 (5.2, 7.1)	6.1 (5.2, 7.0)	
Pelvic frontal plane RoM (°)			0.88		0.53	0.66
	Asymptomatic pregnant	7.4 (6.6, 8.3)		7.5 (6.7, 8.3)	7.7 (6.8, 8.5)	
	Asymptomatic non-pregnant	7.4 (6.6, 8.2)		7.2 (6.3, 8.0)	7.3 (6.4, 8.1)	
	Pregnant with PGP	7.6 (6.9, 8.4)		7.8 (7.0, 8.6)	7.8 (7.0, 8.6)	
Pelvic transversal plane RoM (°)			0.23		0.22	0.28
	Asymptomatic pregnant	3.0 (2.6, 3.5)		3.0 (2.6, 3.5)	3.1 (2.6, 3.5)	
	Asymptomatic non-pregnant	3.5 (3.0, 3.9)		3.5 (3.0, 4.0)	3.6 (3.1, 4.0)	
	Pregnant with PGP	3.5 (3.1, 3.9)		3.5 (3.0, 3.9)	3.5 (3.0, 3.9)	
Pelvic translation (% inter ASIS distance/2)			0.12		0.39	0.46
	Asymptomatic pregnant	30 (26, 33)		31 (27, 35)	31 (27, 35)	
	Asymptomatic non-pregnant	36 (32, 40)		34 (29, 38)	34 (30, 38)	
	Pregnant with PGP	32 (28, 36)		34 (30, 38)	34 (30, 38)	
Hip sagittal plane RoM (°)			0.41		0.66	0.84
	Asymptomatic pregnant	4.9 (4.0, 5.7)		4.8 (4.0, 5.7)	5.0 (4.2, 5.9)	
	Asymptomatic non-pregnant	4.8 (4.0, 5.7)		5.1 (4.1, 6.0)	5.3 (4.3, 6.2)	
	Pregnant with PGP	5.5 (4.7, 6.4)		5.4 (4.5, 6.2)	5.4 (4.5, 6.2)	
Hip frontal plane RoM (°)			0.47		0.51	0.51

	Asymptomatic pregnant	5.7 (4.9, 6.6)		5.8 (4.8, 6.7)		5.7 (4.8, 6.7)
	Asymptomatic non-pregnant	5.2 (4.3, 6.1)		5.1 (4.2, 6.1)		5.1 (4.1, 6.1)
	Pregnant with PGP	5.9 (5.0, 6.7)		5.9 (5.0, 6.8)		5.9 (5.0, 6.8)
Hip transversal plane RoM (°)			0.71		0.70	0.68
	Asymptomatic pregnant	6.9 (6.1, 7.6)		6.9 (6.1, 7.6)		6.9 (6.2, 7.7)
	Asymptomatic non-pregnant	6.6 (5.9, 7.3)		6.5 (5.7, 7.3)		6.5 (5.7, 7.3)
	Pregnant with PGP	6.5 (5.8, 7.6)		6.5 (5.8, 7.3)		6.5 (5.8, 7.3)
Single leg stance						
Thoracic sagittal plane angle[6] (°)			0.69		0.70	0.54
	Asymptomatic pregnant	-5.9 (-7.3, -4.6)		-5.9 (-7.3, -4.5)		-6.2 (-7.6, -4.8)
	Asymptomatic non-pregnant	-5.4 (-6.7, -4.1)		-5.4 (-6.9, -3.9)		-5.6 (-7.2, -4.1)
	Pregnant with PGP	-5.1 (-6.4, -3.8)		-5.1 (-6.5, -3.7)		-5.1 (-6.5, -3.7)
Thoracic frontal plane angle[8] (°)			0.48		0.58	0.55
	Asymptomatic pregnant	3.1 (2.1, 4.1)		3.1 (2.1, 4.1)		3.2 (2.1, 4.2)
	Asymptomatic non-pregnant	2.3 (1.3, 3.3)		2.4 (1.3, 3.5)		2.5 (1.3, 3.6)
	Pregnant with PGP	2.6 (1.6, 3.6)		2.5 (1.4, 3.5)		2.5 (1.4, 3.5)
Thoracic transversal plane angle[9] (°)			0.48		0.53	0.59
	Asymptomatic pregnant	1.9 (0.5, 3.3)		2.0 (0.5, 3.4)		2.1 (0.6, 3.6)
	Asymptomatic non-pregnant	3.0 (1.7, 4.4)		2.9 (1.3, 4.4)		3.0 (1.4, 4.6)
	Pregnant with PGP	2.8 (1.5, 4.2)		3.0 (1.5, 4.4)		3.0 (1.5, 4.4)
Trunk translation[10] (cm)			0.63		0.96	0.98
	Asymptomatic pregnant	-5.4 (-6.4, -4.8)		-5.4 (-6.2, -4.6)		-5.5 (-6.4, -4.7)
	Asymptomatic non-pregnant	-5.1 (-5.9, -4.3)		-5.3 (-6.2, -4.4)		-5.4 (-6.3, -4.5)
	Pregnant with PGP	-5.6 (-6.4, -4.8)		-5.5 (-6.3, -4.6)		-5.5 (-6.3, -4.6)
Pelvic sagittal plane angle[11] (°)			0.88		0.89	0.84
	Asymptomatic pregnant	3.5 (1.5, 5.6)		3.5 (1.5, 5.6)		3.8 (1.6, 5.9)
	Asymptomatic non-pregnant	3.8 (1.8, 5.8)		3.8 (1.6, 6.1)		4.1 (1.7, 6.3)
	Pregnant with PGP	3.1 (1.1, 5.1)		3.1 (1.0, 5.2)		3.1 (1.0, 5.2)
Pelvic frontal plane angle[12] (°)			0.41		0.27	0.28

	Asymptomatic pregnant	-2.6 (-5.6, 0.4)		-2.5 (-5.5, -0.6)		-2.5 (-5.6, 0.5)	
	Asymptomatic non-pregnant	-5.2 (-8.1, -2.2)		-5.8 (-9.1, -2.6)		-5.8 (-9.2, -2.5)	
	Pregnant with PGP	-3.1 (-5.9, -0.2)		-2.6 (-5.6, 0.5)		-2.5 (-5.6, 0.7)	
Pelvic transversal plane angle[13] (°)			0.62		0.79		0.56
	Asymptomatic pregnant	3.1 (1.5, 4.6)		3.0 (1.5, 4.5)		3.4 (1.8, 4.9)	
	Asymptomatic non-pregnant	2.1 (0.6, 3.5)		2.6 (0.9, 4.2)		3.0 (1.4, 4.6)	
	Pregnant with PGP	2.7 (1.2, 4.1)		2.3 (0.7, 3.8)		2.3 (0.7, 3.7)	
Pelvic translation (% inter ASIS distance/2)[14]			0.59		0.55		0.47
	Asymptomatic pregnant	-15 (-21, -10)		-15 (-21, -10)		-14 (-19, -8)	
	Asymptomatic non-pregnant	-19 (-24, -14)		-20 (-25, -14)		-18 (-24, -12)	
	Pregnant with PGP	-18 (-23, -12)		-17 (-23, -12)		-17 (-23, -12)	
Hip sagittal plane angle (°)[15]			0.55		0.81		0.78
	Asymptomatic pregnant	3.8 (1.0, 6.6)		3.7 (0.9, 6.5)		3.9 (1.0, 6.8)	
	Asymptomatic non-pregnant	1.9 (-0.8, 4.6)		2.4 (-0.6, 5.5)		2.7 (-0.4, 5.8)	
	Pregnant with PGP	3.1 (0.5, 5.8)		2.8 (-0.1, 5.6)		2.7 (-0.1, 5.6)	

[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*-values for group, [5]meter per second, [6]positive values denote thoracic flexion, [7]degrees, [8]positive values denote ipsilateral thoracic lean, [9]positive values denote ipsilateral thorax is rotated forward on the stance leg, [10]trunk translation represents the marker on the 7th cervical vertebra relative to the stance leg, given in cm, [11]positive values denote anterior pelvic tilt, [12]positive values denote that the contralateral pelvis is dropped relative to the stance leg, [13]positive values denote that the ipsilateral pelvis is rotated forward on the side of the stance leg, [14]lateral pelvic translation represents the position of foot placement (calcaneus marker) relative to the midline of the participant (0% represent a position of the calcaneus directly under the midline and 100% directly under the anterior superior iliac spines (ASIS) on the pelvis), [15]positive values denote hip flexion, [16]positive values denote hip adduction, [17]positive values denote hip internal rotation, [18]weight-shift denotes the phase between neutral stance and contralateral foot-off, [19]range of motion, [20]lifting phase denotes the phase between toe-off and end of lift

Supplementary table S2

Sensitivity analyses of kinematic variables, estimated marginal means (EMMs) with 95% confidence intervals (CIs) comparing asymptomatic pregnant women (n = 23), asymptomatic non-pregnant women (n = 24) and pregnant women with PGP (n = 25)

VARIABLES	Group	Adjusted[1] EMM (95% CI)	P_{group}[3]	Adjusted[2] EMM (95% CI)	P_{group}[3]
Lifted leg					
Peak hip flexion angle in SLS (°)[4]					0.06
	Asymptomatic pregnant			80.4 (77.0, 83.9)	
	Asymptomatic non-pregnant			74.2 (70.5, 78.0)	
	Pregnant with PGP			78.0 (74.2, 81.2)	
Stance leg					
Lifting phase[5]					
Thoracic sagittal plane RoM[6] (°)[7]			0.58		0.63
	Asymptomatic pregnant	2.1 (1.7, 2.4)		2.1 (1.8, 2.4)	
	Asymptomatic non-pregnant	2.0 (1.6, 2.3)		2.0 (1.6, 2.3)	
	Pregnant with PGP	2.2 (1.9, 2.5)		2.2 (1.9, 2.5)	
Thoracic frontal plane RoM (°)			0.91		0.91
	Asymptomatic pregnant	2.5 (2.0, 3.0)		2.6 (2.1, 3.1)	
	Asymptomatic non-pregnant	2.7 (2.2, 3.2)		2.6 (2.0, 3.1)	
	Pregnant with PGP	2.6 (2.1, 3.0)		2.6 (2.1, 3.1)	
Thoracic transversal plane RoM (°)			0.25		0.22
	Asymptomatic pregnant	2.9 (2.5, 3.4)		2.9 (2.5, 3.4)	
	Asymptomatic non-pregnant	3.4 (2.9, 3.8)		3.4 (3.0, 3.9)	
	Pregnant with PGP	3.3 (2.9, 3.8)		3.3 (2.9, 3.8)	
Trunk translation (cm)			0.70		0.69
	Asymptomatic pregnant	6.2 (5.5, 6.9)		6.2 (5.5, 6.9)	
	Asymptomatic non-pregnant	6.5 (5.8, 7.3)		6.5 (5.7, 7.2)	
	Pregnant with PGP	6.2 (5.5, 6.9)		6.6 (5.9, 7.3)	

Pelvic sagittal plane RoM (°)			0.32		0.38
	Asymptomatic pregnant	5.3 (4.4, 6.2)		5.6 (4.7, 6.5)	
	Asymptomatic non-pregnant	5.5 (4.5, 6.4)		5.2 (4.2, 6.2)	
	Pregnant with PGP	6.2 (5.3, 7.1)		6.2 (5.3, 7.1)	
Pelvic frontal plane RoM (°)			0.58		0.55
	Asymptomatic pregnant	7.3 (6.5, 8.1)		7.5 (6.7, 8.3)	
	Asymptomatic non-pregnant	7.3 (6.4, 8.1)		7.1 (6.3, 8.0)	
	Pregnant with PGP	7.8 (7.0, 8.6)		7.8 (7.0, 8.6)	
Pelvic transversal plane RoM (°)			0.23		0.19
	Asymptomatic pregnant	3.0 (2.6, 3.5)		3.0 (2.6, 3.5)	
	Asymptomatic non-pregnant	3.5 (3.0, 4.0)		3.6 (3.1, 4.0)	
	Pregnant with PGP	3.5 (3.0, 4.0)		3.4 (3.0, 3.9)	
Pelvic translation (% inter ASIS distance/2)			0.34		0.46
	Asymptomatic pregnant	30 (26, 34)		31 (27, 35)	
	Asymptomatic non-pregnant	34 (29, 38)		33 (29, 38)	
	Pregnant with PGP	34 (30, 38)		34 (30, 38)	
Hip sagittal plane RoM (°)			0.35		0.63
	Asymptomatic pregnant	4.6 (3.7, 5.4)		4.8 (4.0, 5.7)	
	Asymptomatic non-pregnant	5.3 (4.4, 6.2)		5.0 (4.1, 6.0)	
	Pregnant with PGP	5.4 (4.5, 6.3)		5.4 (4.5, 6.3)	
Hip frontal plane RoM (°)			0.86		0.46
	Asymptomatic pregnant	5.5 (4.6, 6.4)		5.7 (4.8, 6.6)	
	Asymptomatic non-pregnant	5.5 (4.5, 6.5)		5.1 (4.1, 6.1)	
	Pregnant with PGP	5.8 (4.9, 6.7)		5.9 (5.0, 6.9)	
Hip transversal plane RoM (°)			0.70		0.68
	Asymptomatic pregnant	6.8 (6.1, 7.6)		6.9 (6.1, 7.6)	
	Asymptomatic non-pregnant	6.5 (5.7, 7.3)		6.5 (5.7, 7.3)	
	Pregnant with PGP	6.5 (5.8, 7.3)		6.5 (5.8, 7.3)	
Single leg stance					

Thoracic sagittal plane angle[7] (°)			0.59		0.73
	Asymptomatic pregnant	-6.0 (-7.4, -4.7)		-5.9 (-7.3, -4.5)	
	Asymptomatic non-pregnant	-5.3 (-6.8, -3.8)		-5.4 (-6.9, -3.9)	
	Pregnant with PGP	-5.1 (-6.5, -3.7)		-5.1 (-6.6, -3.7)	
Thoracic frontal plane angle[8] (°)			0.65		0.53
	Asymptomatic pregnant	3.1 (2.0, 4.1)		3.1 (2.1, 4.1)	
	Asymptomatic non-pregnant	2.5 (1.4, 3.6)		2.4 (1.2, 3.4)	
	Pregnant with PGP	2.5 (1.4, 3.5)		2.5 (1.5, 3.5)	
Thoracic transversal plane angle[9] (°)			0.52		0.55
	Asymptomatic pregnant	2.0 (0.5, 3.4)		2.0 (0.5, 3.4)	
	Asymptomatic non-pregnant	2.9 (1.3, 4.4)		2.9 (1.4, 4.4)	
	Pregnant with PGP	3.0 (1.5, 4.4)		2.9 (1.5, 4.4)	
Trunk translation[10] (cm)			0.97		0.38
	Asymptomatic pregnant	-5.4 (-6.2, -4.5)		-5.5 (-6.2, -4.8)	
	Asymptomatic non-pregnant	-5.3 (-6.2, -4.4)		-5.7 (-6.5, -5.0)	
	Pregnant with PGP	-5.5 (-6.5, -4.6)		-6.1 (-6.8, -5.4)	
Pelvic sagittal plane angle[11] (°)			0.90		0.84
	Asymptomatic pregnant	3.6 (1.5, 5.7)		3.5 (1.5, 5.6)	
	Asymptomatic non-pregnant	3.8 (1.5, 6.1)		3.9 (1.7, 6.2)	
	Pregnant with PGP	3.1 (0.9, 5.2)		3.1 (0.9, 5.2)	
Pelvic frontal plane angle[12] (°)			0.26		0.28
	Asymptomatic pregnant	-2.5 (-5.5, 0.5)		-2.4 (-5.5, 0.6)	
	Asymptomatic non-pregnant	-5.9 (-9.1, -2.6)		-5.8 (-9.0, -2.6)	
	Pregnant with PGP	-2.6 (-5.6, 0.5)		-2.6 (-5.6, 0.5)	
Pelvic transversal plane angle[13] (°)			0.76		0.78
	Asymptomatic pregnant	3.0 (1.5, 4.6)		3.0 (1.5, 4.5)	
	Asymptomatic non-pregnant	2.5 (0.9, 4.1)		2.5 (0.9, 4.2)	
	Pregnant with PGP	2.3 (0.7, 3.8)		2.3 (0.7, 3.8)	
Pelvic translation (% inter ASIS distance/2)[14]			0.50		0.62

	Asymptomatic pregnant	-15 (-20, -10)		-15 (-21, -10)	
	Asymptomatic non-pregnant	-20 (-23, -12)		-19 (-25, -13)	
	Pregnant with PGP	-17 (-23, -12)		-17 (-23, -12)	
Hip sagittal plane angle[15] (°)			0.75		0.79
	Asymptomatic pregnant	3.8 (0.9, 6.8)		3.7 (1.0, 6.5)	
	Asymptomatic non-pregnant	2.2 (-0.9, 5.4)		2.5 (-0.5, 5.6)	
	Pregnant with PGP	2.8 (-0.2, 5.8)		2.7 (-0.2, 5.5)	
Hip frontal plane angle[16] (°)			0.02		0.03
	Asymptomatic pregnant	1.0 (-0.4, 2.3)		0.8 (-0.6, 2.2)	
	Asymptomatic non-pregnant	0.5 (-0.9, 2.0)		0.8 (-0.7, 2.2)	
	Pregnant with PGP	-1.6 (-3.0, -0.2)		-1.6 (-3.0, -0.3)	
Hip transversal plane angle[17] (°)			0.83		0.74
	Asymptomatic pregnant	4.8 (2.4, 7.1)		4.6 (2.3, 7.0)	
	Asymptomatic non-pregnant	5.8 (3.3, 8.3)		6.0 (3.4, 8.5)	
	Pregnant with PGP	5.4 (3.0, 7.8)		5.4 (3.0, 7.8)	

[1]Linear mixed model with group and Stork trial (1 to 4) in the model adjusted for pelvic width and maximum hip flexion of the lifted leg. The estimated marginal means describe the level within the three groups over the four repeated Stork trials, [2]model adjusted for pelvic width and speed of leg lift, [3]*P*-values for group, [4]lifting phase denotes the phase between toe-off and end of lift, [5]range of motion, [6]degrees, [7]positive values denote thoracic flexion, [8]positive values denote ipsilateral thoracic lean, [9]positive values denote ipsilateral thorax is rotated forward on the stance leg, [10]trunk translation represents the marker on the 7th cervical vertebra relative to the stance leg, given in cm, [11]positive values denote anterior pelvic tilt, [12]positive values denote that the contralateral pelvis is dropped relative to the stance leg, [13]positive values denote that the ipsilateral pelvis is rotated forward on the side of the stance leg, [14]lateral pelvic translation represents the position of foot placement (calcaneus marker) relative to the midline of the participant (0% represent a position of the calcaneus directly under the midline and 100% directly under the anterior superior iliac spines on the pelvis), [15]positive values denote hip flexion, [16]positive values denote hip adduction, [17]positive values denote hip internal rotation

Supplementary table S3

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

VARIABLES	Group	Crude[1] EMM (95% CI)	P_{group}[3]	Adjusted[2] EMM (95% CI)	P_{group}[3]
Stance width in neutral stance (cm)			0.67		0.31
	Asymptomatic pregnant	24.3 (22.6, 26.1)		24.4 (22.9, 26.9)	
	Asymptomatic non-pregnant	23.8 (22.1, 25.5)		23.5 (21.6, 25.3)	
Lifted leg					
Speed of leg lift (m/s)[4]			0.18		0.26
	Asymptomatic pregnant	0.41 (0.4, 0.45)		0.41 (0.36, 0.46)	
	Asymptomatic non-pregnant	0.45 (0.41, 0.49)		0.45 (0.40, 0.50)	
Peak hip flexion angle in SLS (°)[5]			0.01		0.03
	Asymptomatic pregnant	80.3 (77.0, 83.6)		80.7 (77.0, 84.5)	
	Asymptomatic non-pregnant	74.5 (71.2, 77.7)		74.2 (70.6, 77.8)	
Stance leg					
Neutral stance					
Thoracic sagittal plane angle[6] (°)[7]			0.38		0.22
	Asymptomatic pregnant	-5.7 (-6.9, -4.4)		-6.1 (-7.5, -4.6)	
	Asymptomatic non-pregnant	-4.9 (-6.2, -3.7)		-4.7 (-6.1, -3.4)	
Thoracic frontal plane angle[8] (°)			0.33		0.51
	Asymptomatic pregnant	0.2 (-0.5, 0.9)		0.2 (-0.6, 0.9)	
	Asymptomatic non-pregnant	-0.3 (-1.0, 0.4)		-0.2 (-0.9, 0.5)	
Thoracic transversal plane angle[9] (°)			0.22		0.35
	Asymptomatic pregnant	0.3 (-0.8, 1.4)		0.3 (-0.9, 1.6)	
	Asymptomatic non-pregnant	1.3 (0.2, 2.4)		1.2 (-0.01, 2.4)	
Trunk translation[10] (cm)			0.73		0.76
	Asymptomatic pregnant	12.6 (11.4, 13.8)		12.6 (11.4, 13.9)	
	Asymptomatic non-pregnant	12.9 (11.7, 14.1)		13.0 (11.6, 14.3)	

Pelvic sagittal plane angle[11] (°)			0.48		0.56
	Asymptomatic pregnant	11.7 (9.5, 13.8)		11.6 (9.1, 14.0)	
	Asymptomatic non-pregnant	10.6 (8.5, 12.7)		10.5 (8.2, 12.9)	
Pelvic frontal plane angle[12] (°)			0.87		0.91
	Asymptomatic pregnant	-0.4 (-1.2, 0.4)		-0.4 (-1.3, 0.6)	
	Asymptomatic non-pregnant	-0.3 (-1.1, 0.5)		-0.3 (-1.2, 0.6)	
Pelvic transversal plane angle[13] (°)			0.19		0.78
	Asymptomatic pregnant	1.0 (-0.2, 2.2)		0.5 (-0.7, 1.7)	
	Asymptomatic non-pregnant	-0.02 (-1.2, 1.1)		0.3 (-0.9, 1.4)	
Pelvic translation (% inter ASIS distance/2)[14]			0.37		0.46
	Asymptomatic pregnant	102 (92, 112)		108 (98, 118)	
	Asymptomatic non-pregnant	107 (98, 117)		103 (93, 112)	
Hip sagittal plane angle[15] (°)			0.86		0.95
	Asymptomatic pregnant	4.7 (2.0, 7.5)		4.4 (1.3, 7.6)	
	Asymptomatic non-pregnant	4.4 (1.7, 7.1)		4.3 (1.3, 7.3)	
Hip frontal plane angle[16] (°)			0.52		0.53
	Asymptomatic pregnant	-2.1 (-3.5, -0.7)		-2.9 (-4.3, -1.4)	
	Asymptomatic non-pregnant	-2.7 (-4.0, -1.3)		-2.2 (-3.6, -0.8)	
Hip transversal plane angle[17] (°)			0.1		0.78
	Asymptomatic pregnant	6.6 (4.1, 9.2)		7.8 (5.1, 10.6)	
	Asymptomatic non-pregnant	9.5 (7.0, 12.0)		8.4 (5.8, 11.0)	
Weight shift[18]					
Thoracic sagittal plane RoM[19] (°)			0.81		0.53
	Asymptomatic pregnant	2.2 (1.8, 2.6)		2.1 (1.7, 2.5)	
	Asymptomatic non-pregnant	2.2 (1.8, 2.5)		2.3 (2.0, 2.6)	
Thoracic frontal plane RoM (°)			0.48		0.72
	Asymptomatic pregnant	1.6 (1.3, 2.0)		1.6 (1.2, 2.0)	
	Asymptomatic non-pregnant	1.5 (1.2, 1.8)		1.5 (1.2, 1.8)	
Thoracic transversal plane RoM (°)			0.23		0.23
	Asymptomatic pregnant	2.6 (2.3, 3.0)		2.6 (2.2, 3.1)	

	Asymptomatic non-pregnant	2.3 (2.0, 2.7)		2.3 (1.9, 2.7)	
Trunk translation (cm)			0.08		0.13
	Asymptomatic pregnant	11.5 (10.5, 12.5)		11.5 (10.4, 12.6)	
	Asymptomatic non-pregnant	10.3 (9.4, 11.3)		10.3 (9.3, 11.4)	
Pelvic sagittal plane RoM (°)			0.70		0.76
	Asymptomatic pregnant	2.5 (2.0, 3.0)		2.4 (1.8, 2.9)	
	Asymptomatic non-pregnant	2.4 (1.9, 2.9)		2.5 (2.0, 3.0)	
Pelvic frontal plane RoM (°)			0.38		0.69
	Asymptomatic pregnant	1.9 (1.5, 2.2)		1.9 (1.5, 2.3)	
	Asymptomatic non-pregnant	2.1 (1.7, 2.4)		2.1 (1.7, 2.4)	
Pelvic transversal plane RoM (°)			0.46		0.42
	Asymptomatic pregnant	2.9 (2.5, 3.3)		2.9 (2.4, 3.4)	
	Asymptomatic non-pregnant	2.7 (2.2, 3.1)		2.6 (2.2, 3.1)	
Pelvic translation (% inter ASIS distance/2)			0.70		0.20
	Asymptomatic pregnant	80 (72, 88)		83 (74, 92)	
	Asymptomatic non-pregnant	78 (70, 86)		75 (67, 83)	
Hip sagittal plane RoM (°)			0.31		0.51
	Asymptomatic pregnant	4.8 (3.9, 5.6)		4.8 (3.9, 5.6)	
	Asymptomatic non-pregnant	4.2 (3.4, 5.0)		4.4 (3.6, 5.2)	
Hip frontal plane RoM (°)			0.24		0.18
	Asymptomatic pregnant	6.8 (5.8, 7.7)		7.0 (5.9, 8.0)	
	Asymptomatic non-pregnant	6.0 (5.1, 7.0)		6.0 (5.0, 7.0)	
Hip transversal plane RoM (°)			0.63		0.63
	Asymptomatic pregnant	4.6 (4.1, 5.1)		4.6 (4.0, 5.2)	
	Asymptomatic non-pregnant	4.8 (4.3, 5.3)		4.8 (4.2, 5.3)	
Lifting phase[20]					
Thoracic sagittal plane RoM (°)			0.63		0.91
	Asymptomatic pregnant	2.1 (1.8, 2.3)		2.0 (1.7, 2.4)	
	Asymptomatic non-pregnant	1.9 (1.7, 2.3)		2.0 (1.7, 2.3)	
Thoracic frontal plane RoM (°)			0.59		0.76

	Asymptomatic pregnant	2.6 (2.1, 3.0)		2.4 (1.9, 2.9)	
	Asymptomatic non-pregnant	2.4 (1.9, 2.8)		2.5 (2.1, 3.0)	
Thoracic transversal plane RoM (°)			0.06		0.32
	Asymptomatic pregnant	3.0 (2.5, 3.4)		3.1 (2.6, 3.6)	
	Asymptomatic non-pregnant	3.5 (3.1, 4.0)		3.5 (3.0, 3.9)	
Trunk translation (cm)			0.60		0.58
	Asymptomatic pregnant	6.5 (5.8, 7.1)		6.2 (5.5, 7.0)	
	Asymptomatic non-pregnant	6.2 (5.5, 6.9)		6.5 (5.8, 7.3)	
Pelvic sagittal plane RoM (°)			0.63		0.54
	Asymptomatic pregnant	5.6 (4.7, 6.4)		5.6 (4.7, 6.6)	
	Asymptomatic non-pregnant	5.2 (4.4, 6.1)		5.2 (4.3, 6.1)	
Pelvic frontal plane RoM (°)			0.89		0.60
	Asymptomatic pregnant	7.5 (6.7, 8.2)		7.6 (6.7, 8.4)	
	Asymptomatic non-pregnant	7.6 (6.6, 8.1)		7.3 (6.4, 8.1)	
Pelvic transversal plane RoM (°)			0.15		0.10
	Asymptomatic pregnant	3.0 (2.6, 3.5)		3.0 (2.5, 3.5)	
	Asymptomatic non-pregnant	3.5 (3.0, 3.9)		3.5 (3.1, 4.0)	
Pelvic translation (% inter ASIS distance/2)			0.04		0.25
	Asymptomatic pregnant	30 (26, 34)		31 (27, 36)	
	Asymptomatic non-pregnant	36 (32, 40)		35 (31, 39)	
Hip sagittal plane RoM (°)			0.41		0.90
	Asymptomatic pregnant	4.9 (4.0, 5.7)		4.8 (4.0, 5.7)	
	Asymptomatic non-pregnant	4.8 (4.0, 5.7)		5.0 (4.1, 5.8)	
Hip frontal plane RoM (°)			0.47		0.17
	Asymptomatic pregnant	5.7 (4.9, 6.6)		5.8 (5.0, 6.7)	
	Asymptomatic non-pregnant	5.2 (4.3, 6.1)		5.0 (4.1, 5.8)	
Hip transversal plane RoM (°)			0.41		0.42
	Asymptomatic pregnant	6.9 (6.1, 7.6)		6.9 (6.1, 7.6)	
	Asymptomatic non-pregnant	6.4 (5.7, 7.1)		6.4 (5.7, 7.2)	
Single leg stance					

Thoracic sagittal plane angle[5] (°)			0.59		0.27
	Asymptomatic pregnant	-5.9 (-7.3, -4.6)		-6.4 (-7.9, -5.0)	
	Asymptomatic non-pregnant	-5.4 (-6.7, -4.1)		-5.2 (-6.5, -3.8)	
Thoracic frontal plane angle[7] (°)			0.82		0.37
	Asymptomatic pregnant	3.3 (2.4, 4.2)		3.1 (2.1, 4.0)	
	Asymptomatic non-pregnant	2.1 (1.3, 3.0)		2.4 (1.5, 3.3)	
Thoracic transversal plane angle[8] (°)			0.09		0.09
	Asymptomatic pregnant	1.8 (0.8, 2.9)		1.7 (0.5, 2.9)	
	Asymptomatic non-pregnant	3.0 (2.0, 4.1)		3.2 (2.1, 4.4)	
Trunk translation[9] (cm)			0.46		0.98
	Asymptomatic pregnant	-5.4 (-6.3, -4.6)		-5.3 (-6.2, -4.3)	
	Asymptomatic non-pregnant	-5.0 (-5.8, -4.2)		-5.3 (-6.1, -4.4)	
Pelvic sagittal plane angle[10] (°)			0.73		0.73
	Asymptomatic pregnant	3.5 (1.5, 5.6)		3.4 (1.1, 5.9)	
	Asymptomatic non-pregnant	4.0 (2.0, 6.1)		4.0 (1.8, 6.3)	
Pelvic frontal plane angle[11] (°)			0.12		0.01
	Asymptomatic pregnant	-1.9 (-4.8, 1.1)		-0.3 (-3.5, 2.8)	
	Asymptomatic non-pregnant	-5.0 (-8.0, -2.1)		-5.9 (-8.9, -2.9)	
Pelvic transversal plane angle[12] (°)			0.20		0.58
	Asymptomatic pregnant	3.1 (1.8, 4.3)		2.3 (1.0, 3.5)	
	Asymptomatic non-pregnant	2.0 (0.8, 3.2)		2.8 (1.6, 4.0)	
Pelvic translation (% inter ASIS distance/2)[13]			0.23		0.58
	Asymptomatic pregnant	-15 (-20, -9)		-16 (-22, -10)	
	Asymptomatic non-pregnant	-19 (-25, -14)		-19 (-24, -13)	
Hip sagittal plane angle[14] (°)			0.49		0.70
	Asymptomatic pregnant	3.5 (0.8, 6.3)		3.3 (0.2, 6.4)	
	Asymptomatic non-pregnant	2.2 (-0.4, 5.0)		2.4 (-0.6, 5.4)	
Hip frontal plane angle[15] (°)			0.26		0.81
	Asymptomatic pregnant	0.9 (-0.6, 2.3)		0.4 (-1.0, 1.8)	
	Asymptomatic non-pregnant	-0.2 (-1.6, 1.2)		0.2 (-1.2, 1.5)	

Hip transversal plane angle[16] (°)			0.03		0.72
	Asymptomatic pregnant	4.1 (1.3, 6.8)		5.7 (2.9, 8.5)	
	Asymptomatic non-pregnant	8.2 (5.5, 10.9)		6.5 (3.8, 9.1)	

[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 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)), [3]*P*-values for group, [4]meter per second, [5]peak of leg lift of the lifted leg, [6]positive values denote thoracic flexion, [7]degrees, [8]positive values denote ipsilateral thoracic lean, [9]positive values denote ipsilateral thorax is rotated forward on the stance leg, [10]trunk translation represents the marker on the 7th cervical vertebra relative to the stance leg, given in cm, [11]positive values denote anterior pelvic tilt, [12]positive values denote that the contralateral pelvis is dropped relative to the stance leg, [13]positive values denote that the ipsilateral pelvis is rotated forward on the side of the stance leg, [14]lateral pelvic translation represents the position of foot placement (calcaneus marker) relative to the midline of the participant (0% represent a position of the calcaneus directly under the midline and 100% directly under the anterior superior iliac spines (ASIS) on the pelvis), [15]positive values denote hip flexion, [16]positive values denote hip adduction, [17]positive values denote hip internal rotation, [18]weight-shift denotes the phase between neutral stance and contralateral foot-off, [19]range of motion, [20]lifting phase denotes the phase between toe-off and end of lift

Supplementary table S4

Estimated marginal means (EMMs) with 95% confidence intervals (CIs) for kinematic variables comparing asymptomatic pregnant women (n=8), asymptomatic non-pregnant women (n=8) and pregnant women with PGP (n=7)

VARIABLES	Group	Crude[1] EMM (95% CI)	P_{group}[3]	Adjusted[2] EMM (95% CI)	P_{group}[3]
Stance width in neutral stance (cm)			0.07		0.02
	Asymptomatic pregnant	22.4 (19.2, 25.5)		21.2 (17.9, 24.5)	
	Asymptomatic non-pregnant	24.9 (21.8, 28.0)		26.5 (22.9, 30.2)	
	Pregnant with PGP	27.4 (24.0, 30.7)		26.7 (23.4, 30.0)	
Lifted leg					
Speed of leg lift (m/s)[4]			0.49		0.77
	Asymptomatic pregnant	0.44 (0.34, 0.55)		0.47 (0.35, 0.58)	
	Asymptomatic non-pregnant	0.49 (0.38, 0.59)		0.45 (0.32, 0.58)	
	Pregnant with PGP	0.40 (0.29, 0.51)		0.42 (0.30, 0.53)	
Peak hip flexion in SLS (°)[5]			0.46		0.69
	Asymptomatic pregnant	80.0 (72.1, 87.2)		77.1 68.9, 85.3)	
	Asymptomatic non-pregnant	73.2 (65.6, 80.8)		78.0 (68.5, 87.5)	
	Pregnant with PGP	75.5 (67.4, 83.6)		73.4 (65.2, 81.6)	
Stance leg					
Neutral stance					
Thoracic sagittal plane angle[6] (°)[7]			0.35		0.15
	Asymptomatic pregnant	-4.0 (-6.7, -1.2)		-2.6 (-5.6, 0.4)	
	Asymptomatic non-pregnant	-4.4 (-7.2, -1.7)		-6.1 (-9.5, -2.8)	
	Pregnant with PGP	-6.6 (-9.6, -3.7)		-6.2 (-9.2, -3.2)	
Thoracic frontal plane angle[8] (°)			0.63		0.63
	Asymptomatic pregnant	0.1 (-1.2, 1.5)		0.3 (-1.3, 1.8)	
	Asymptomatic non-pregnant	-0.5 (-1.9, 0.8)		-0.7 (-2.5, 1.0)	
	Pregnant with PGP	0.3 (-1.1, 1.7)		0.4 (-1.1, 1.9)	
Thoracic transversal plane angle[9] (°)			0.005		0.03

	Asymptomatic pregnant	-1.7 (-3.1, -0.4)		-1.7 (-3.2, -0.2)	
	Asymptomatic non-pregnant	1.6 (0.2, 2.9)		1.5 (-0.2, 3.3)	
	Pregnant with PGP	0.2 (-1.2, 1.6)		0.2 (-1.3, 1.8)	
Trunk translation[10] (cm)			0.21		0.22
	Asymptomatic pregnant	12.1 (10.2, 14.1)		11.8 (9.6, 14.0)	
	Asymptomatic non-pregnant	14.4 (12.5, 16.4)		14.9 (12.5, 17.4)	
	Pregnant with PGP	13.4 (11.4, 15.5)		13.2 (11.0, 15.4)	
Pelvic sagittal plane angle[11] (°)			0.44		0.45
	Asymptomatic pregnant	11.7 (7.6, 15.9)		12.1 (7.4, 16.8)	
	Asymptomatic non-pregnant	8.4 (4.2, 12.5)		7.6 (2.3, 13.0)	
	Pregnant with PGP	8.8 (4.4, 13.2)		9.2 (4.5, 14.0)	
Pelvic frontal plane angle[12] (°)			0.95		0.87
	Asymptomatic pregnant	-0.3 (-1.8, 1.2)		-0.4 (-2.1, 1.2)	
	Asymptomatic non-pregnant	-0.1 (-1.6, 1.4)		0.1 (-1.8, 2.1)	
	Pregnant with PGP	-0.5 (-0.7, 0.9)		-0.6 (-2.3, 1.1)	
Pelvic transversal plane angle[13] (°)			0.57		0.69
	Asymptomatic pregnant	0.07 (-1.7, 1.9)		-0.3 (-2.4, 1.7)	
	Asymptomatic non-pregnant	-1.1 (-3.0, 0.7)		-0.4 (-2.7, 1.9)	
	Pregnant with PGP	-1.0 (-2.9, 1.0)		-1.3 (-3.4, 0.7)	
Pelvic translation (% inter ASIS distance/2)[14]			0.06		0.22
	Asymptomatic pregnant	88 (75, 101)		89 (74, 105)	
	Asymptomatic non-pregnant	110 (97, 124)		108 (91, 125)	
	Pregnant with PGP	103 (88, 117)		104 (89, 119)	
Hip sagittal plane angle[15] (°)			0.51		0.29
	Asymptomatic pregnant	5.7 (0.1, 11.2)		2.0 (1.4, 2.6)	
	Asymptomatic non-pregnant	1.9 (-3.6, 7.5)		2.7 (1.9, 3.3)	
	Pregnant with PGP	1.7 (-4.2, 7.6)		2.0 (1.4, 2.6)	
Hip frontal plane angle[16] (°)			0.03		0.005
	Asymptomatic pregnant	0.2 (-1.6, 2.0)		0.1 (-2.0, 2.2)	
	Asymptomatic non-pregnant	-2.6 (-3.9, -1.2)		-2.1 (-4.4, 0.2)	

	Pregnant with PGP	-4.6 (-6.5, -2.6)		-4.7 (-6.8, -2.6)	
Hip transversal plane angle[17] (°)			0.14		0.55
	Asymptomatic pregnant	4.9 (3.8, 9.1)		5.5 (1.8, 9.2)	
	Asymptomatic non-pregnant	9.4 (6.1, 12.7)		8.4 (4.3, 12.6)	
	Pregnant with PGP	6.9 (3.4, 10.4)		7.3 (3.6, 11.0)	
Weight shift[18]					
Thoracic sagittal plane RoM[19] (°)			0.68		0.30
	Asymptomatic pregnant	2.3 (1.7, 3.0)		2.0 (1.4, 2.6)	
	Asymptomatic non-pregnant	2.0 (1.4, 2.6)		2.7 (2.0, 3.3)	
	Pregnant with PGP	2.5 (1.8, 3.2)		2.0 (1.4, 2.6)	
Thoracic frontal plane RoM (°)			0.99		0.76
	Asymptomatic pregnant	1.4 (1.0, 1.9)		1.3 (0.8, 1.8)	
	Asymptomatic non-pregnant	1.4 (1.0, 1.9)		1.6 (1.1, 2.2)	
	Pregnant with PGP	1.5 (1.0, 2.0)		1.4 (0.9, 1.9)	
Thoracic transversal plane RoM (°)			0.09		0.14
	Asymptomatic pregnant	2.4 (1.8, 3.0)		2.3 (1.6, 2.9)	
	Asymptomatic non-pregnant	2.4 (1.8, 3.0)		2.6 (1.9, 3.4)	
	Pregnant with PGP	3.2 (2.6, 3.9)		3.1 (2.5, 3.8)	
Trunk translation (cm)			0.31		0.95
	Asymptomatic pregnant	11.9 (10.0, 13.7)		11.2 (9.3, 13.5)	
	Asymptomatic non-pregnant	10.4 (8.5, 12.2)		11.5 (9.3, 13.7)	
	Pregnant with PGP	12.0 (10.1, 14.0)		11.6 (9.6, 13.5)	
Pelvic sagittal plane RoM (°)			0.20		0.11
	Asymptomatic pregnant	2.6 (1.6, 3.5)		2.3 (1.3, 3.4)	
	Asymptomatic non-pregnant	2.8 (1.8, 3.8)		3.2 (2.0, 4.4)	
	Pregnant with PGP	1.7 (0.7, 2.7)		1.6 (0.5, 2.6)	
Pelvic frontal plane RoM (°)			0.03		0.05
	Asymptomatic pregnant	1.6 (1.1, 2.1)		1.5 (1.0, 2.1)	
	Asymptomatic non-pregnant	1.6 (1.1, 2.0)		1.7 (1.1, 2.2)	
	Pregnant with PGP	2.4 (1.9, 2.9)		2.3 (1.8, 2.8)	

Pelvic transversal plane RoM (°)			0.19		0.21
	Asymptomatic pregnant	2.6 (1.9, 3.3)		2.6 (1.8, 3.4)	
	Asymptomatic non-pregnant	2.9 (2.2, 3.6)		2.9 (2.0, 3.8)	
	Pregnant with PGP	3.4 (2.8, 4.2)		3.5 (2.7, 4.3)	
Pelvic translation (% inter ASIS distance/2)			0.92		0.46
	Asymptomatic pregnant	79 (66, 92)		75 (60, 89)	
	Asymptomatic non-pregnant	82 (69, 95)		89 (72, 105)	
	Pregnant with PGP	82 (68, 96)		79 (65, 94)	
Hip sagittal plane RoM (°)			0.16		0.53
	Asymptomatic pregnant	5.2 (3.5, 7.0)		4.5 (2.7, 6.3)	
	Asymptomatic non-pregnant	3.9 (2.1, 5.6)		5.1 (2.9, 7.2)	
	Pregnant with PGP	6.3 (4.4, 8.1)		5.8 (4.0, 7.7)	
Hip frontal plane RoM (°)			0.87		0.05
	Asymptomatic pregnant	7.0 (5.3, 8.7)		5.9 (4.3, 7.5)	
	Asymptomatic non-pregnant	7.5 (5.8, 9.2)		9.2 (7.4, 11.1)	
	Pregnant with PGP	6.9 (5.1, 8.7)		6.4 (4.8, 8.0)	
Hip transversal plane RoM (°)			0.36		0.35
	Asymptomatic pregnant	4.6 (3.5, 5.7)		4.4 (3.2, 5.7)	
	Asymptomatic non-pregnant	5.2 (4.1, 6.3)		5.5 (4.0, 6.9)	
	Pregnant with PGP	4.1 (2.9, 5.3)		4.0 (2.8, 5.3)	
Lifting phase[20]					
Thoracic sagittal plane RoM (°)			0.02		0.03
	Asymptomatic pregnant	1.6 (1.1, 2.1)		1.6 (1.1, 2.1)	
	Asymptomatic non-pregnant	2.2 (1.8, 2.7)		2.2 (1.6, 2.9)	
	Pregnant with PGP	2.5 (2.1, 3.1)		2.6 (2.0, 3.1)	
Thoracic frontal plane RoM (°)			0.41		0.13
	Asymptomatic pregnant	2.2 (1.5, 2.9)		1.9 (1.2, 2.6)	
	Asymptomatic non-pregnant	2.5 (1.8, 3.2)		3.0 (2.2, 3.8)	
	Pregnant with PGP	2.8 (2.1, 3.5)		2.6 (1.9, 3.3)	
Thoracic transversal plane RoM (°)			0.47		0.57

	Asymptomatic pregnant	2.7 (2.1, 3.4)		2.9 (2.1, 3.6)	
	Asymptomatic non-pregnant	3.2 (2.5, 3.9)		2.9 (2.0, 3.8)	
	Pregnant with PGP	3.3 (2.5, 4.0)		3.3 (2.6, 4.1)	
Trunk translation (cm)			0.004		0.001
	Asymptomatic pregnant	5.0 (4.1, 5.9)		4.7 (3.7, 5.6)	
	Asymptomatic non-pregnant	7.2 (6.3, 8.2)		7.9 (6.8, 9.0)	
	Pregnant with PGP	6.9 (6.0, 7.9)		6.6 (5.7, 7.6)	
Pelvic sagittal plane RoM (°)			0.52		0.39
	Asymptomatic pregnant	5.6 (4.1, 7.1)		6.1 (4.4, 7.7)	
	Asymptomatic non-pregnant	5.4 (3.9, 7.0)		4.6 (2.7, 6.5)	
	Pregnant with PGP	4.5 (2.9, 6.1)		4.8 (3.1, 6.4)	
Pelvic frontal plane RoM (°)			0.99		0.99
	Asymptomatic pregnant	7.1 (5.7, 8.5)		7.1 (5.4, 8.7)	
	Asymptomatic non-pregnant	7.1 (5.7, 8.5)		7.2 (5.4, 9.0)	
	Pregnant with PGP	7.1 (5.6, 8.7)		7.1 (5.4, 8.7)	
Pelvic transversal plane RoM (°)			0.50		0.63
	Asymptomatic pregnant	2.8 (2.1, 3.5)		2.9 (2.1, 3.7)	
	Asymptomatic non-pregnant	3.3 (2.6, 4.0)		3.2 (2.3, 4.1)	
	Pregnant with PGP	3.3 (2.6, 4.0)		3.4 (2.6, 4.1)	
Pelvic translation (% inter ASIS distance/2)			<0.001		0.02
	Asymptomatic pregnant	23 (17, 28)		22 (16, 28)	
	Asymptomatic non-pregnant	44 (38, 50)		44 (37, 51)	
	Pregnant with PGP	31 (25, 37)		31 (25, 37)	
Hip sagittal plane RoM (°)			0.83		0.99
	Asymptomatic pregnant	4.7 (3.2, 6.2)		4.8 (3.2, 6.5)	
	Asymptomatic non-pregnant	5.2 (3.7, 6.7)		5.0 (3.0, 6.9)	
	Pregnant with PGP	4.8 (3.1, 6.3)		4.8 (3.1, 6.5)	
Hip frontal plane RoM (°)			0.98		0.96
	Asymptomatic pregnant	5.0 (3.6, 6.5)		4.9 (3.3, 6.6)	
	Asymptomatic non-pregnant	5.2 (3.8, 6.7)		5.3 (3.4, 7.2)	

	Pregnant with PGP	5.0 (3.5, 6.6)		4.9 (3.3, 6.6)	
Hip transversal plane RoM (°)			0.77		0.54
	Asymptomatic pregnant	6.8 (5.2, 8.1)		7.0 (5.4, 8.6)	
	Asymptomatic non-pregnant	6.0 (4.5, 7.5)		5.5 (3.6, 7.4)	
	Pregnant with PGP	6.5 (4.9, 8.0)		6.6 (5.0, 8.3)	
Single leg stance					
Thoracic sagittal plane angle[6] (°)			0.44		0.39
	Asymptomatic pregnant	-3.9 (-6.3, -1.4)		-3.5 (-6.3, -0.7)	
	Asymptomatic non-pregnant	-4.9 (-7.3, -2.4)		-5.5 (-8.7, -2.3)	
	Pregnant with PGP	-6.1 (-8.7, -3.4)		-5.8 (-8.5, -3.1)	
Thoracic frontal plane angle[8] (°)			0.64		0.38
	Asymptomatic pregnant	2.1 (0.6, 3.7)		2.6 (0.9, 4.3)	
	Asymptomatic non-pregnant	2.0 (0.5, 3.6)		1.3 (-0.6, 3.2)	
	Pregnant with PGP	2.9 (1.3, 4.6)		3.1 (1.4, 4.8)	
Thoracic transversal plane angle[9] (°)			0.015		0.06
	Asymptomatic pregnant	0.7 (-0.6, 1.9)		0.6 (-0.8, 2.0)	
	Asymptomatic non-pregnant	3.3 (2.1, 4.5)		3.4 (1.8, 5.0)	
	Pregnant with PGP	2.1 (0.8, 3.4)		2.1 (0.7, 3.5)	
Trunk translation[10] (cm)			0.98		0.92
	Asymptomatic pregnant	-4.9 (-6.5, -3.4)		-5.3 (-7.0, -3.5)	
	Asymptomatic non-pregnant	-5.1 (-6.7, -3.5)		-4.7 (-6.7, -2.7)	
	Pregnant with PGP	-5.0 (-6.7, -3.3)		-5.0 (-6.8, -3.3)	
Pelvic sagittal plane angle[11] (°)			0.32		0.37
	Asymptomatic pregnant	5.6 (1.3, 9.8)		5.8 (0.9, 10.7)	
	Asymptomatic non-pregnant	1.6 (-2.8, 5.9)		1.2 (-4.5, 6.9)	
	Pregnant with PGP	1.7 (-3.0, 6.3)		1.8 (-3.2, 6.7)	
Pelvic frontal plane angle[12] (°)			0.13		0.15
	Asymptomatic pregnant	-0.4 (-4.3, 5.1)		-1.2 (-4.1, 6.5)	
	Asymptomatic non-pregnant	-5.5 (-10.2, -0.8)		-6.8 (-12.6, -1.0)	
	Pregnant with PGP	-1.4 (-6.4, 3.5)		-0.9 (-6.1, 4.4)	

Pelvic transversal plane angle[13] (°)			0.91		0.99
	Asymptomatic pregnant	1.9 (0.3, 3.6)		1.8 (-0.07, 3.7)	
	Asymptomatic non-pregnant	1.6 (-0.1, 3.3)		1.8 (-0.4, 3.9)	
	Pregnant with PGP	2.1 (0.3, 3.8)		2.0 (0.05, 3.9)	
Pelvic translation (% inter ASIS distance/2)[14]			0.31		0.65
	Asymptomatic pregnant	-19 (-28, -9)		-19 (-30, -8)	
	Asymptomatic non-pregnant	-27 (-37, -17)		-26 (-39, -13)	
	Pregnant with PGP	-18 (-28, -7)		-18 (-29, -7)	
Hip sagittal plane angle[15] (°)			0.33		0.67
	Asymptomatic pregnant	5.3 (-0.1, 10.7)		4.6 (-1.5, 10.6)	
	Asymptomatic non-pregnant	0.1 (-5.3, 5.6)		1.3 (-5.6, 8.1)	
	Pregnant with PGP	1.9 (-3.8, 7.7)		1.6 (-4.4, 7.6)	
Hip frontal plane angle[16] (°)			0.02		0.02
	Asymptomatic pregnant	3.9 (1.8, 6.0)		2.9 (0.7, 5.1)	
	Asymptomatic non-pregnant	1.1 (-1.1, 3.2)		2.6 (0.1, 5.1)	
	Pregnant with PGP	-0.5 (-2.7, 1.8)		-1.0 (-3.1, 1.2)	
Hip transversal plane angle[17] (°)			0.27		0.39
	Asymptomatic pregnant	5.5 (2.3, 8.6)		6.0 (2.6, 9.4)	
	Asymptomatic non-pregnant	6.4 (3.3, 9.5)		5.6 (1.8, 9.4)	
	Pregnant with PGP	3.2 (-0.05, 6.5)		3.4 (0.2, 6.8)	

[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]*P*-values for group, [4]meter per second, [5]peak hip flexion of the lifted leg during SLS, [6]Positive values denote thoracic flexion, [7]degrees, [8]positive values denote ipsilateral thoracic lean, [9]positive values denote ipsilateral thorax is rotated forward on the stance leg, [10]trunk translation represents the marker on the 7th cervical vertebra relative to the stance leg, given in cm, [11]positive values denote anterior pelvic tilt, [12]positive values denote that the contralateral pelvis is dropped relative to the stance leg, [13]positive values denote that the ipsilateral pelvis is rotated forward on the side of the stance leg, [14]lateral pelvic translation represents the position of foot placement (calcaneus marker) relative to the midline of the participant (0% represent a position of the calcaneus directly under the midline and 100% directly under the anterior superior iliac spines (ASIS) on the pelvis), [15]positive values denote hip flexion, [16]positive values denote hip adduction, [17]positive values denote hip internal rotation, [18]weight-shift denotes the phase between neutral stance and contralateral foot-off, [19]range of motion, [20]lifting phase denotes the phase between toe-off and end of lift.

Appendices

Appendix 1

Table S1 Detailed overview of papers on spatiotemporal and kinematic gait characteristics including pregnant women in the 2nd trimester

Study	Participants	Methods/ Statistics	Outcome variables	Results[1]
Aguiar et al (2015) [1]	18 pregnant women 18 non-pregnant women	Cross-sectional study: Comparing pregnant women in 2nd trimester (27.3 (SD=3) w.p.[1]) and non-pregnant with and without experimental added load Self-selected gait speed Equipment: 12-camera optoelectronic system (Qualisys), Force plates (Kistler) Statistics: Student t-test and Mann-Whitney U-test. Paired-samples t-test, Wilcoxon non-parametric test	Velocity, stride width, step length, step time, stance time, double limb support time Ankle, knee, hip joint as well as pelvic angles and ROM over the gait cycle	2nd trimester compared to non-pregnant; significant longer stance phase time and double limb support time, increased left step time and wider stride width. Significant less ankle eversion, but greater ankle inversion/eversion ROM, less knee extension and flexion during stance, but greater knee flexion/extension ROM. Greater hip flexion during stance, less hip extension. Greater anterior and posterior pelvic tilt, less right pelvic obliquity angle and less pelvic obliquity ROM, less left pelvic transversal rotation
Bird et al (1999) [2]	25 pregnant women	Longitudinal study: Comparing the same women in 12, 16, 20, 24, 28 and 36 w.p. Equipment: Footprint assessment on cardboard walkway Statistics: Multivariate repeated-measures analysis of variance (ANOVA)	Stride length, step length, foot length, angle of gait, base of gait (i.e. stride width)	Significant trend for increased base of gait during pregnancy. No other footprint parameters changed during pregnancy. Specific differences in the 2nd trimester not given
Bertuit et al (2015) [3]	58 healthy pregnant women divided into 4 groups 9 healthy post-partum 23 healthy nulliparous	Cross sectional study: Comparing groups of women in: 25-28 w.p. (8 women), 29-32 w.p. (17 women), 33-36 w.p. (23 women), 37-41 w.p. (10 women), 9 post-partum, 23 nulliparous Preferred, fast and slow gait speed Equipment: Electronic walkway GAITrite Statistics: Analysis of variance for repeated measures (ANOVA)	Gait and stride velocity, step and stride length, step width, toe out/in, cadence, step and gait cycle time, stance and swing phase, double and single support	Reduced gait speed, step length, cadence, swing phase and single support phase as well as longer cycle time, stance phase and double support phase were observed during pregnancy. Comparisons between 2nd trimester and post-partum or non-pregnant women are not provided
Branco et al (2013) [4]	22 pregnant women	Longitudinal study: Comparing the same women in the end of 2nd trimester, 3rd	Velocity, cycle time, step time, double limb	Most spatiotemporal parameters remained unchanged between trimesters and between

	12 non-pregnant women	trimester and also a non-pregnant control group Natural and comfortable speed Equipment: 10 infrared high-speed cameras (Qualisys), Force plates (Kistler) Statistics: Repeated measures and Manova tests for comparisons	support time, time of support and flight phases, stride width, stride length, step length Sagittal, frontal and transversal plane ankle, knee, hip and pelvic angles	pregnant and controls. Stride and right/left step lengths decreased significantly as well as significant increased double limb support, decreased right hip extension and adduction, increased left knee flexion and decreased ankle plantarflexion between trimesters. 2nd trimester compared to non-pregnant; significant increased double limb support, decreased right hip extension and adduction
Branco et al (2016) [5]	11 healthy pregnant women	Longitudinal study: Comparing the same women in 1st, 2nd, 3rd trimesters and post-partum Natural and comfortable speed Equipment: 12 infrared high-speed cameras (Qualisys). Force plates (Kistler) Statistics: Repeated measures ANOVA Friedman and Wilcoxon tests	Velocity, stride length, stride width, cycle time, double limb support time, step length, step time, stance time, swing time Sagittal, frontal and transversal plane ankle, knee, hip and pelvic angles	The longitudinal effect of pregnancy was not observed in any spatiotemporal parameters. The longitudinal effect of pregnancy was observed for most joint kinematics. Between 1st and 2nd trimesters; significant increase in anterior pelvic tilt and increase in hip internal rotation. Between 2nd trimester and post-partum; significant decrease in hip extension, increase in hip flexion and hip internal rotation
Carpes et al (2008) [6]	7 healthy pregnant women	Longitudinal study: Comparing the same women in 2nd trimester (22-28 w.p.), 3rd trimester (34-40 w.p.), 4 months postpartum (PP) Self-selected gait speed Equipment: Video analysis (Peak Motus) Statistics: Student t-test Repeated measures ANOVA	Step length, stride length, gait cycle time, single, stance time, swing time, single and double support time, hip and knee flexion/extension angles	2nd trimester compared to PP; increased double support, longer single leg support time, longer step length and stride length. No significant difference in hip flexion/extension. The study suggest that gait alterations persisted 4 months after pregnancy.
Eldeeb et al (2016) [7]	20 healthy pregnant women	Longitudinal study: Comparing the same women in 1st (12 w.p.), 2nd (22-24 w.p.), 3rd trimester (33-34 w.p.) Self-selected gait speed Equipment: 3 dimensional gait analysis system (Qualisys) and 6 pro-reflex cameras Statistics: Repeated measures analysis of variance (ANOVA)	Velocity Maximum anterior pelvic tilt, maximum trunk flexion during stance phase, pelvic tilt, obliquity and rotation, trunk flexion-extension, lateral bending and rotation were measured	Significant increase in max anterior pelvic tilt, decrease in pelvic obliquity, max trunk flexion, trunk lateral bending, trunk rotation No significant difference in walking velocity, pelvic tilt, pelvic rotation and trunk tilt Between 1st and 2nd trimester; significant decrease in maximum trunk flexion and no significant changes in the frontal and transversal plane pelvic

		Pearson`s correlation coefficient		and trunk kinematics as well as maximum anterior pelvic tilt. In the 2nd trimester; Significant negative correlation between maximum anterior pelvic tilt and maximum trunk flexion, positive correlation between pelvic and trunk obliquity and no correlation between pelvic and trunk rotation
Forczek et al (2019) [8]	30 healthy pregnant women	Longitudinal study: Comparing the same women in 1st trimester (12 w.p.), 2nd trimester (25 w.p.), 3rd trimester (36 w.p.) Barefoot at self-selected speed Equipment: 5-camera video-based motion capture system (Vicon) Statistics: Repeated measures ANOVA for multiple measurements	Speed, cadence, single support duration, stride length, base of support, ROM of ankle, knee, hip and pelvis joints (in the sagittal plane)	No significant differences during pregnancy for speed, cadence and stride length. Base of support increased significantly between trimesters. 2nd trimester compared to 1st trimester; significant larger hip flexion, more anterior pelvic tilt and pelvic ROM. The above kinematics were also increased in 3rd trimester compared to 2nd trimester.
Gilleard et al (2013) [9]	9 healthy pregnant 12 non-pregnant	Longitudinal study: Comparing the same women in 18 (data not included), 24, 32 and 38 w.p. and 8 weeks post-partum and also with non-pregnant women Self-determined gait speed Equipment: 8-camera Motion Analysis Corporation Expert Visions system Force platform (Kistler) Statistics: Repeated measures ANOVA with planned contrasts, Bonferroni	Velocity, step width, stride length Pelvic and thoracic spine ROM Motion between pelvis and thorax Linear trends during pregnancy investigated	Significant linear trends for increased step width, decreased stride length, decreased transverse plane ROM of the pelvis and thoracolumbar spine, decreased pelvic frontal plane ROM during pregnancy. No significant linear trends for velocity, sagittal plane thoracic, pelvic and thoracolumbar ROM. Specific comparisons between pregnant women in 24 w.p. and post-partum were not provided
Gutke et al (2008) [10]	99 pregnant with PGP, 32 pregnant with lumbar pain, 54 pregnant with combined PGP and lumbar pain, 116 healthy pregnant	Longitudinal/cohort study: Comparing the same women in 12-18 w.p. and 3 months postpartum Comfortable gait speed Equipment: Stopwatch Statistics: One way analysis of variance	Velocity	Pregnant women with PGP (within the 2nd trimester) walked at a slower speed both during pregnancy and postpartum compared to pregnant women without pain
Huang et al (2002) [11]	10 pregnant women divided into 3 groups. Some	Cross-sectional study: Comparing different groups of women: Pregnant ≤12, 13-28 and 29-40 w.p. and non-pregnant	Joint angles, moments and powers of the hip, knee and ankle	When comparing pregnant women in the different gestational stages; significant increased hip extension and knee adduction moments, decreased

	reported LBP and SIJ pain (no further information given) 10 non-pregnant	Level walking in normal pattern (no information regarding speed) Equipment: EVA motion analysis system and an optimization method to define the hip joint center Statistics: Information not provided		knee extension and ankle planter flexion moments. Pregnant women compared to non-pregnant; significant differences in knee abduction angle, knee and hip internal rotation angles, hip extension moment and hip power. Specific differences in the 2nd trimester not given
Kerbourc`h et al (2017) [12]	66 pregnant women with PGP 61 healthy pregnant 22 non-pregnant women	Cross-sectional study: Comparing different groups of women; Pregnant between 18-27 w.p. and non-pregnant Preferred, slow and fast gait speed Equipment: GAITRite walkway Statistics: Analysis of variance for repeated measures	Stance time Center of pressure (COP) excursion, mean COP velocity, COP length and width	Stance time was significantly increased in all speeds and most COP parameters were significantly modified for both pregnant with and without PGP compared to non-pregnant women. No effect of PGP on stance time. Only anteroposterior COP displacement was significantly modified by PGP
McCrory et al (2011) [13]	29 healthy pregnant 40 non-pregnant	Longitudinal/cross-sectional study: Comparing the same women in 2nd trimester (20.9 (1.2) w.p.) and 3rd trimester (35.8 (1.5) w.p.) and a group of non-pregnant women Freely-chosen gait speed Equipment: VICON workstation system, force plate Statistics: Two-factor analyses of variance (ANVOVA) and co-variance (ANCOVA), adjustment for velocity	Velocity Ground reaction forces (GRFs) Center of pressure (COP)	Walking velocity differed significantly between conditions; pregnant women in the 2nd trimester walked slower than non-pregnant and pregnant women in their 3rd trimester walked slower than women in the 2nd trimester No differences were seen in the GRFs or COP movements between trimesters or between pregnant women characterized as fallers and those characterized as non-fallers
McCrory et al (2014) [14]	29 healthy pregnant 40 non-pregnant	Longitudinal/cross-sectional study: Comparing the same women in 2nd trimester (20.9 (1.2) w.p.) and 3rd trimester (35.8 (1.5) w.p.) and a group of non-pregnant women Freely-chosen gait speed Equipment: 8-camera motion capture system (Vicon), force plates Statistics: Multivariate analysis of covariance (MANCOVA), adjustment for velocity	Stride width, pelvis and thorax angles and ROM in sagittal, frontal and transversal planes Lateral translation of markers at the C7 and L4 vertebrae	2nd trimester compared to non-pregnant; Significant increased frontal plane translation of C7 and L4 markers, increased thorax extension 3rd compared to 2nd trimester; Significant increased step width, frontal plane translation of C7 and L4 markers, thorax extension at HS, decreased sagittal thorax ROM 3rd trimester compared to non-pregnant; Significant increased step width, ant. pelvic tilt, decreased sagittal thorax ROM,

Mei et al (2018) [15]	16 healthy pregnant	Longitudinal study: Comparing the same women in 2nd trimester, 3rd trimester, 4 month post-partum (PP) Self-selected comfortable speed Equipment: 8-camera 3-dimensional motion analysis system (VICON), force plate (Novel EMED) Statistics: Repeated measures analysis of variance (ANOVA)	Peak pelvis, hip, knee and ankle angles in 3 planes during stance phase, joint angle curves during gait cycle Center of pressure (COP)	2nd trimester compared to post-partum: Significantly decreased peak ankle eversion, less hip adduction, decreased hip flexion 3rd trimester compared to 2nd trimester; Significantly decreased peak ankle eversion, greater pelvic anterior tilt angle, greater external rotation angle
Sawa et al (2015) [16]	27 healthy pregnant women	Cross sectional study: Comparing different groups of women: Pregnant before 28 w.p., pregnant after 28 w.p. Preferred gait speed Equipment: Wireless motion-recording-sensor units, Accelerometers, Stopwatch Statistics: Mann-Whitney U, multiple regression analyses	Stride time coefficient of variation, RMS and autocorrelation coefficient, coefficient of attenuation of acceleration Functional ability of the trunk	No significant difference in velocity, stride length, stride time, gait variability and in amplitude of acceleration of the upper trunk between 2nd and 3rd trimester. Significant smaller root mean square in the anterior-posterior direction at the lower trunk and lower coefficient of attenuation of acceleration in anterior-posterior direction in pregnant women after 28 w.p. than before
Yoo et al (2015) [17]	19 pregnant 15 non-pregnant	Cross sectional, longitudinal study: Comparing the same women in 2nd and 3rd trimester and a group of non-pregnant women Self-selected comfortable speed Equipment: GAITrite Statistics: Repeated measures analysis of variance (ANOVA), One-way ANOVA	Velocity, cadence,	Gait velocity and cadence was significantly decreased in both 2nd and 3rd trimesters compared to non-pregnant women Gait velocity and cadence were significantly decreased between the 3rd and 2nd trimesters

[1]*weeks pregnant*

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Appendix 2

Relevant psychometric properties of measures used in the thesis are reported for pelvic girdle pain (PGP) and/or pregnancy when available. For other measures, properties are reported for the condition most relevant for PGP and/or pregnancy (Table S2). For the Slump test, P4 test and ASLR test, sensitivity and specificity are reported, as these clinical tests were used to assist recruitment of participants in accordance with the study`s inclusion and exclusion criteria (Table S2).

Table S2 Overview of relevant psychometric properties of measures used in the thesis

Functional tests	
Gait at self-selected speed	We studied reliability of our spatiotemporal and kinematic gait data, by calculating the intraclass correlation coefficient (ICC; 1,1) with 95 % CI [1] of the four gait trials used (paper II). To improve interpretability, we also calculated the intra-individual SD over the four gait in each group as an absolute measure of measurement variation [2]. Results are given on page 65 and in Paper II, Supplementary material, Table S3-4.
The Stork test	We studied reliability of our spatiotemporal and kinematic Stork data, by calculating the intraclass correlation coefficient (ICC; 1,1) with 95 % CI [1] of the Stork trials used (paper III). To improve interpretability, we also calculated the intra-individual SD over the four gait in each group as an absolute measure of measurement variation [2]. Results are given on page 65 and in Appendix 4, Table S4.
The Timed Up and Go (TUG) test[1]	Test-retest reliability was excellent with ICC = 0.88 ((95 % CI), 0.70-0.95), with SEM (absolute reliability) and MDC_{95} values of 0.42 and 1.16 seconds, respectively. Inter-tester reliability was excellent with ICC = 0.95 ((95 % CI), 0.84-0.98) with SEM (absolute reliability) and MDC_{95} values of 0.36 and 1.00 seconds, respectively. Assessed in pregnant women with PGP in the 2nd and 3rd trimester (n = 17) [3, 4]. Convergent validity tested by Spearman rank correlation, strong correlation between the TUG test and the ASLR test; r_s= 0.73, p=0.001 and moderate correlations between the TUG test and the PGQ; r_s= 0.41-0.52, p≤ 0.089. Assessed in pregnant women with PGP in the 2nd and 3rd trimester (n = 18) [4].
Active straight leg raise (ASLR) test	Test-retest reliability in the ASLR (sum score of both sides) in non-pregnant women with lumbopelvic pain (n=50) showed a Pearson`s correlation coefficient of 0.87 and an ICC of 0.83 [5] . For an ASLR (sum score of both sides), with a cut-off between 0 and 1, sensitivity was 0.87 and specificity was 0.94 in patients with posterior pelvic pain since pregnancy (n=200) and healthy controls (n=50) [5]. The ASLR (sum score of both sides), with a cut-off between 0 and 1, has been reported to have a sensitivity of 54 % and specificity of 88 % in a population of pregnant women with lumbopelvic pain (n=110) and without lumbopelvic pain (n=72) [6]. Sensitivity of the ASLR test was larger (68%) in combination with the P4 test, and when levels of pain and/or disability were higher. For diagnostic use the best cut-off for the ASLR test in pregnancy is between score 0 and 1 (reported AUC value of 0.71).
Posterior pelvic pain provocation (P4) test	The P4 has been suggested as a valid and reliable test to diagnose pregnancy-related PGP [7, 8]. A strong correlation was found between a history of posterior pelvic pain and a positive pain reaction when performing the P4 in pregnant women (n=72), with a sensitivity of 81% and

	specificity of 80% of the P4 test [7]. Mens et al [6] reported a sensitivity of 44% and specificity of 93% in a population of pregnant women with lumbopelvic pain (n=110) and without lumbopelvic pain (n=72). P4 test (named painful femoral compression) had a sensitivity of 69% and specificity of 90% in pregnant women with and without pain located in the sacral spine (n=200) [9].
Slumps test	A systematic review [10] reported sensitivity (0.44 – 0.84) and specificity (0.58-0.83) of the Slump test in identifying radiculopathy. Another recent systematic review [11] reported sensitivity (1.00) and specificity (0.83) from one additional study for the diagnostic accuracy in the Slump test in detecting nerve root impingement.
Beighton score for general joint hypermobility *	A recent systematic review [12], reported limited positive to conflicting evidence for the reliability of the Beighton score, but concluded that inter-rater reliability was acceptable for clinical use with uniformity of testing procedures. Shortcomings were found in studies on validity. Recently, inter-rater reliability for total Beighton score was reported to be good with ICC = 0.72 ((95 % CI), 0.55-0.83) and a SEM (absolute reliability) of 0.7. Intra-rater reliability was excellent with ICC = 0.76 ((95 % CI), 0.54-0.88) and a SEM (absolute reliability) of 0.7. Assessed in a population of women and men working in Swedish rehabilitation company (n = 39 and n = 29) [13].
Single-item questions and questionnaires	
Self-reported weight/ body mass index (BMI)	Among demographics, questions on self-reported weight and height to calculate BMI and weight-gain during pregnancy are relevant to our study. A recent systematic review [14] reported high correlations, r = 0.90-0.99, between self-reported and measured weight, based on nine studies with short/medium lengths of recall (≤1 year post-pregnancy), using gold standard weight references. They reported that women underreported their pre-pregnancy weight by 0.34-2.94 kg (SD range; 2.2-5 kg), and concluded that the magnitude of error was small. In a Norwegian sample of middle-aged women (n=1873) [15], self-reported height and weight was reported to provide a valid ranking of BMI; Substantial agreement was found between values measured by medical staff and self-reported values with weighted kappa-values of 0.73 ((95%CI) 0.67-0.80).
Hopkins symptom checklist – 10 items (SCL-10) *	The short-form SCL-10 was derived from the SCL-25 [16]. Reliability of the SCL-10 has been reported as Cronbach`s alpha and found to be 0.88 (using data from Statistics Norway`s (SSB) Survey of Level of Living 1998) [17]. Correlation between SCL-10 and SCL-25 was 0.97. Correlation between the original anxiety and depression scores was 0.73, 0.69 between the corresponding SCL-10 scores [17]. Correlation between the short form and original anxiety score was 0.91, and 0.96 between the depression scores (HUNT-study population data) [18]. Moreover, sensitivity of 89 % and specificity of 98 % were found for the SCL-10 (cut-off value of 1.85) with the SCL-25 (cut-off value of 1.75) as a criterion. The areas under the ROC curve with SCL-25 cut-off value of 1.75, as a criterion was 0.99 for SCL-10 [17].
Pelvic Girdle Questionnaire (PGQ)	PGQ has shown high test-retest reliability and validity in a pregnant and non-pregnant women with PGP [19]; ICC (95 % CI) for PGQ-total score; 0.93 (0.87-0.96), PGQ-activity score; 0.93 (0.86-0.96) and PGQ-symptom score; 0.91 (0.84-0.95). Good internal consistency was reported for PGQ-activity score with Cronbach alpha value of 0.86 and construct validity with high correlations between PGQ-activity and most instruments assessing activity limitations and physical functioning, as well as relatively high correlations to PGQ-symptom score. Moreover, MDCs on the individual level have been identified for PGQ-total score; 14.9, PGQ-activity score; 14.4 and PGQ-symptom score; 19.6. MDC values on group were reported for PGQ-total score; 2.3, PGQ-activity score; 2.2 and PGQ-symptom score; 3.0 [19]. In addition, PGQ also has shown acceptable responsiveness in pregnant women with PGP, LBP or both [20].

Pain intensity, score on an 11-point numeric rating scale (NRS) *	A recent systematic review [21] reported that test-retest reliability and responsiveness of pain measures, including NRS pain intensity, are difficult to evaluate due to the inherent fluctuation in pain. Moreover, as pain is a subjective experience and since no gold standard comparator exists, estimating validity of pain measures, including NRS pain intensity, is difficult. Recently, an 11-point NRS pain intensity was used to assess convergent validity of the Swedish PGQ. High correlations were found between NRS pain intensity and PGQ total score, PGQ activity score and PGQ symptom score; Spearman`s correlation coefficients of 0.68, 0.66 and 0.74, respectively (pregnant women reporting LBP and/or PGP, n = 174-177) [22]. Responsiveness for NRS (0-10) evening pain has been reported, AUC (95 % CI) = 0.80 (0.75-0.86) and MIC value of 1.5 points, in pregnant women recruited from maternity care units in Norway, (n = 411) [20]. Responsiveness for NRS (0-10) mean of three pain severity measures has been reported, AUC (95% CI) 0.90 (0.84-0.97) and MIC value of 1.3 points, in treatment-seeking pregnant women with LBP and PGP in England (n = 90) [23].
Fear of movement by one question from Tampa Scale for Kinesiophobia, score on an 11-point numeric rating scale (NRS) *	One substitute question for the TSK showed moderate correlation with the TSK 17-items in a Dutch, non-pregnant population with sciatica in primary care (n=135) [24]; Pearson correlation coefficient, r=0.46 ($p<0.001$). Acceptable test-retest reliability was indicated by a r = 0.65 between mean score of the substitute question at 3 weeks follow up and at 6 weeks follow up. The Dutch TSK 17-items questionnaire has shown construct validity with moderate correlation coefficients with self-reported measures of pain-related fear, pain catastrophizing and disability in patients with chronic low back pain (LBP) [25]. A high level of internal consistency, Cronbach`s alpha values of 0.81 and 0.79 for the total score, was found in chronic low back pain patients (n=225) and patients with fibromyalgia (n=391) [25] .

[1]*TUG undertaken at maximal pace, * It seems plausible, that the reliability and/or validity of this measure are not expected to differ in a pregnant population.*

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Appendix 3

According to our study protocol, muscle activation was recorded with wireless surface EMG from 5 muscles bilaterally. The muscles measured in each clinical test/activity are detailed in Table S3.

Table S3 Overview of muscles measured bilaterally with electromyography during the functional tasks/activities. Data not used in the papers

Muscles	**ASLR[1]**	**Upright standing[2]**	**Gait[3]**	**Stork test**	**Modified Stork test**	**Sit-to-stand-to-sit**
M. obliques internus	X					
M. obliques externus	X	X	X	X	X	X
M. tensor fascia latae	X	X	X	X	X	X
M. gluteus medius		X	X	X	X	X
M. biceps longus	X	X	X	X	X	X

[1]active straight leg raise, [2]upright standing for 30 seconds, [3]gait at self-selected speed

Prior to the data collection, we performed a pilot study on two non-pregnant women and one pregnant woman to validate the positioning and standardized procedure of the EMG electrodes and amplifiers. The validation was done using ultrasound assisted positioning of the EMG equipment. This thesis does not include EMG data, hence details regarding the EMG data will not be described further.

Appendix 4

Table S4 Reliability of kinematic variables over the four Stork trials presented by the intraclass correlation coefficient (ICC 1,1) and intra-individual standard deviation (SD) for asymptomatic pregnant women (n = 23), asymptomatic non-pregnant women (n = 24) and pregnant women with PGP (n = 25)

Kinematic variables	**Group**	**ICC (95 % CIs)[1]**	**SD (median value within each group)**
Hip frontal plane angle (°)[2]			
	Asymptomatic pregnant	0.95 (0.91, 0.98)	0.03
	Asymptomatic non-pregnant	0.89 (0.80, 0.95)	0.03
	Pregnant with PGP	0.95 (0.90, 0.97)	0.03
Hip transversal plane angle (°)			
	Asymptomatic pregnant	0.92 (0.85, 0.96)	0.012
	Asymptomatic non-pregnant	0.87 (0.78, 0.94)	0.014
	Pregnant with PGP	0.89 (0.81, 0.95)	0.016
Peak hip flexion angle of the lifted leg (°)			
	Asymptomatic pregnant	0.93 (0.87, 0.96)	0.014
	Asymptomatic non-pregnant	0.92 (0.86, 0.96)	0.009
	Pregnant with PGP	0.94 (0.86, 0.97)	0.015

[1]95 % confidence intervals, [2] degrees

Appendix 5

Written informed consent

Forespørsel om deltakelse i forskningsprosjektet

"Bekkenleddsmerter hos gravide – underliggende mekanismer"

Bakgrunn og hensikt

Dette er et spørsmål til deg om å delta i et forskningsprosjekt som skal studere underliggende mekanismer ved bekkenløsning hos gravide. Bekkenløsning, (også kalt bekkenleddsmerter) rammer ca 50 % av alle gravide. Grad av smerter og nedsatt funksjon varierer sterkt. Det er vist at bekkenet normalt får økt leddbevegelighet under svangerskap på grunn av hormonell påvirkning, men sammenhengen mellom bevegelighet, smerte og nedsatt funksjon hos gravide er fortsatt uklar. Vi ønsker derfor å undersøke hvordan gravide beveger seg og belaster bekkenet, samt se på muskelfunksjon hos gravide kvinner. Prosjektet tar sikte på å gi økt kunnskap om bekkenløsning hos gravide, for å bedre fysioterapeuters diagnostisering og behandlingstilbud til disse kvinnene.

Vi vil undersøke gravide kvinner både *med* og *uten* bekkenløsning i svangerskapet, samt en kontrollgruppe med friske, ikke-gravide kvinner. Avdeling for helsefag ved Universitetet i Oslo har samarbeid med helsestasjoner og fysioterapeuter som behandler gravide i Oslo området. Kvinner som går til rutinemessig svangerskapskontroll ved helsestasjonene, eller oppsøker fysioterapeut, og som er aktuelle for deltagelse, vil bli invitert til å delta i prosjektet.

Hva innebærer studien?

Studien innebærer at du møter til én undersøkelse. Først vil du svare på noen spørsmål om din helse og daglige funksjon på et nettbrett. Deretter, vil du bli undersøkt av en fysioterapeut, som vurderer funksjon, bevegelighet og smerte i bekkenet ditt. Dersom du inkluderes videre, skal du så utføre fem enkle funksjonstester, mens vi måler hvordan du beveger deg og hvordan musklene dine arbeider. Undersøkelsen utføres på Norges Idrettshøgskole (NIH) og vil ta ca 3 timer. Selve funksjonstestene tar ca 30 minutter. Undersøkelsen er nærmere beskrevet i vedlegget. For at vi skal kunne gjøre målingene, er det nødvendig at du kan ta av deg til undertøyet, det vil si truse og BH. Vi serverer drikke, kjeks og nøtter. Det er gode parkeringsmuligheter ved Sognsvann og t-banen stanser rett ved NIH (Sognsvann stasjon). Vi har dessverre ikke midler til å dekke utgifter til transport. Tid for testing vil bli avtalt per telefon. Det kan bli aktuelt å kontakte deg igjen på et senere tidspunkt og vi ber om lov til det.

Mulige fordeler og ulemper

Alle undersøkelser som benyttes er kjente og godt etablerte, og benyttes daglig i undersøkelse og behandling av gravide kvinner. Dersom du har bekkenløsning, kan undersøkelsen medføre at du får noe økte smerter under, eller rett etter undersøkelsen. Smertene vil oftest gå raskt over, og oppstår fordi strukturer i og rundt bekkenet ditt blir belastet under undersøkelsen. Det er vanlig at en undersøkelse hos fysioterapeut kan utløse kortvarige og forbigående smerter fordi fysioterapeuten forsøker å finne årsaken til smertene dine. De testene som benyttes i dette prosjektet anses ikke å være mer belastende enn vanlige, daglige aktiviteter. Du vil bli bedt om å utføre testene på den måten du best klarer det, slik at du kan ta hensyn til om noe gir deg smerter. Du kan også ta pauser underveis ettersom du har behov for det. Alle undersøkelser, målinger og evt. smerter som følge av undersøkelsene i denne studien, anses som ufarlige og uten risiko for deg, eller fosteret. Dersom du ønsker videre utredning og behandling hos fysioterapeut, vil vi kunne formidle kontakt til fysioterapeut.

Hva skjer med informasjonen om deg

Informasjonen som registreres om deg skal kun brukes slik som beskrevet i hensikten med studien. Svarene du gir oss på nettbrettet vil bli sendt automatisk og elektronisk til en sikker database. Data fra spørreskjemaer og undersøkelser vil lagres på en sikker server på Universitetet i Oslo. Informasjonen om deg vil bli behandlet av forskerne uten ditt navn, fødselsnummer, eller andre direkte gjenkjennbare opplysninger om deg. Noen helseopplysninger vil samles på papir, disse vil scannes og lagres elektronisk med et deltakernummer, på den samme sikre serveren ved Universitetet i Oslo. Papirkopien vil deretter makuleres. Etter prosjektets slutt i 2020, vil alle data anonymiseres, og lagres i inntil 15 år før de blir slettet. Alle opplysningene om deg vil til enhver tid bli behandlet konfidensielt, og det vil ikke være mulig å identifisere deg i resultatene av studien når denne publiseres.

Frivillig deltakelse

Det er frivillig å delta i studien. Du kan når som helst, og uten å oppgi noen grunn, trekke ditt samtykke til å delta i studien. Dette vil ikke få noen konsekvenser for deg. Dersom du ønsker å delta, undertegner du samtykkeerklæringen på siste side. Om du sier ja til å delta, kan du senere trekke tilbake samtykket ditt, uten at det får konsekvenser for din oppfølging på helsestasjonen. Dersom du skulle ønske å trekke deg på et senere tidspunkt, eller har spørsmål vedrørende studien, kan du kontakte doktorgradsstipendiat Lene Christensen (se nedenfor).

Rett til innsyn og sletting av opplysninger om deg

Hvis du sier ja til å delta i studien, har du rett til å få innsyn i hvilke opplysninger som er registrert om deg. Du har videre rett til å få korrigert eventuelle feil i de opplysningene vi har registrert. Dersom du trekker deg fra studien, kan du kreve å få slettet resultater fra tester og opplysninger, med mindre disse allerede er inngått i analyser eller brukt i vitenskapelige publikasjoner.

Økonomi og Fond til etter- og videreutdanning av fysioterapeuters rolle

Studien er finansiert gjennom forskningsmidler fra Fond til etter- og videreutdanning av fysioterapeuter. Det er ingen kjente interessekonflikter.

Forsikring

Du er i denne studien dekket av Pasientskadeloven.

Informasjon om utfallet av studien

Studien vil bli publisert i internasjonale og nasjonale fagtidsskrifter
Ytterligere informasjon om studien finnes i vedlegg. Samtykkeerklæring følger etter vedlegget.

Med vennlig hilsen

Lene Christensen, Fysioterapeut/ manuellterapeut/ Phd-stipendiat
Tlf 93 65 06 97 (med telefonsvarer) /e-post: lene.christensen@medisin.uio.no

Vedlegg: Utdypende forklaring av hva studien innebærer

Kriterier for deltakelse

For å delta i studien må du være kvinne, mellom 18 og 50 år, og gravid til og med graviditetsuke 26. Du kan delta dersom du **er** plaget med, eller **ikke er** plaget med smerter i bekkenområdet. Har du bekkenløsning må to undersøkelsestester være positive ved den første undersøkelsen, for at du skal kunne delta i den neste delen. For å delta i kontrollgruppen, må du være kvinne, mellom 18 og 50 år, samt **ikke** være gravid, og det må ha gått minst 6 måneder etter siste fødsel. Alle deltakere må beherske norsk språk muntlig og skriftlig.

Du kan **ikke delta** dersom du har et potensielt risikofylt svangerskap, venter mer enn ett barn, har en KMI (kroppsmasse index) før graviditet på over 27, eller dersom du har hatt ryggplager, som har ført til nedsatt fysisk funksjon, eller sykemelding i løpet av de siste 6 månedene. Du kan **ikke delta** dersom du tidligere har hatt en traumatisk hodeskade, er tidligere operert i bena, eller operert i rygg, mage, eller bekken i løpet av de siste 6 månedene. Du kan heller **ikke delta** dersom du har, eller har hatt en inflammatorisk, eller nevrologisk systemsykdom, eller har nevrologiske funn ved klinisk undersøkelse. Du kan **ikke delta** i **kontrollgruppene**, dersom du har hatt smerter i bekkenområdet i løpet av de siste 6 månedene.

Undersøkelse/Testprotokoll

Under undersøkelsen, vil du først besvare noen spørsmål knyttet til din helse og daglige funksjon på et nettbrett. Noen av spørsmålene vil omhandle din bakgrunn, eksempelvis alder, høyde, antall barn, utdanning etc., og andre vil måle arbeidsstatus- og evne, livskvalitet, begrensninger i aktivitet, plager og smerter, samt mosjon/trening og redsel for bevegelse. Det tar ca 15 minutter å svare, og du vil få hjelp underveis hvis det er noe du lurer på. Deretter, vil en fysioterapeut undersøke deg med åtte kliniske tester for å vurdere funksjon, bevegelighet og smerter i bekkenet ditt. Testene benyttes daglig i undersøkelse og behandling av pasienter med bekkenløsning. Undersøkelsen tar ca 15-20 minutter.

Du vil så utføre fem enkle funksjonstester, der vi måler hvordan du beveger deg og hvordan musklene dine arbeider. For å kunne måle dette, vil vi benytte oss av måleutstyr i bevegelseslaboratoriet ved Norges Idrettshøgskole. For å måle bevegelse vil vi benytte 3D videoanalyse, og vi vil plassere refleksmarkører på definerte punkter på overkroppen, bekkenet, armene og bena dine. For å måle aktivitet i muskulatur vil vi benytte EMG (elektromyografi) med overflateelektroder, som plasseres over noen utvalgte mage-, lår-, og setemuskler. For å måle kreftene som virker på hofte, kne og ankelleddene dine vil du utføre

testene stående på en kraftplate. Elektroder og markører vil bli plassert på huden din av en fysioterapeut før testene gjennomføres. Måleinstrumentene benyttes mye i forskning, og det er ingen kjent risiko ved disse målemetodene verken for den gravide, eller fosteret. Selve testingen tar ca 30 minutter. Hele prosedyren, inkludert å svare på spørreskjemaer, bli undersøkt av fysioterapeut, få satt på markører og elektroder, samt gjennomføre funksjonstestene, tar ca 3 timer.

Du vil utføre følgende fem funksjonstester:

- *Stå i oppreist stilling i 30 sekunder*
- *Gå frem og tilbake*: Du skal gå en strekning på 5 meter ca 5-6 ganger.
- *Sette og reise seg:* Dette er en test der du skal reise deg opp fra sittende til stående stilling, og sette deg ned igjen.
- *Stork test:* Dette er en test hvor du skal stå på ett ben av gangen.
- *Active straight leg raise – ASLR:* Dette er en test hvor du ligger på ryggen og løfter ett og ett ben 20 cm opp fra underlaget.

Samtykke til deltakelse i studien

Jeg har lest informasjonen om forskningsprosjektet ”Bekkenleddsmerter hos gravide – underliggende mekanismer”, inklusive vedlegget, og er villig til å delta i studien.

(Signert av prosjektdeltaker, dato)

Navn skrevet i blokkbokstaver

Jeg bekrefter å ha gitt informasjon om studien

(Lene Christensen, doktorgradsstipendiat, dato)