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Pregnancy-related pelvic girdle pain and its relation to muscle function

Jenny Sjö Dahl

Division of Physiotherapy
Department of Medical and Health Sciences
Linköping University, Sweden



Linköping University
FACULTY OF HEALTH SCIENCES

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Jenny.sjodahl@liu.se

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Optimus Parentibus

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ABSTRACT

Pregnancy-related lumbopelvic pain affects approximately 50% of all pregnant women. For the majority the pain disappears during the first months after delivery; however, for a significant number of women, the pain is persistent, with little improvement for more than three months after delivery. Moreover, women who experience persistent lumbopelvic pain three months postpartum are at substantial risk for new episodes or for chronic lumbopelvic pain later in life. Hence, pregnancy-related lumbopelvic pain should be considered a major public health issue. In order to develop and offer specific treatment strategies, it is important to identify different subgroups of lumbopelvic pain based on different clinical presentations. Pelvic girdle pain (PGP) is one of the major subgroups of pain related to pregnancy. There is no consensus regarding the underlying mechanisms although instability in the pelvis has been proposed as one of the possible mechanism; thus, further studies are necessary to determine how to treat these women. The local lumbopelvic muscle system, including the pelvic floor muscles (PFM) is thought to contribute to the stabilization of the pelvis and they are also the target for many treatment strategies for lumbopelvic pain.

The overall aim of this thesis was to improve rehabilitation for women with persistent postpartum PGP by investigating three areas, including: 1) the postural response of the PFM, 2) the effect of home-based specific stabilizing exercises (SSE) that target the local lumbopelvic muscle system and, 3) predictors for disability at 15 months postpartum.

The thesis comprises three studies: A) a methodological study, B) an experimental study, and C) a clinical randomized controlled trial (RCT). The data is mainly based on muscle function, including recordings of electromyographic (EMG) activation, muscle endurance, and muscle strength. We also collected subjective ratings of disability, health-related quality of life, and pain.

The methodological study showed that the designed protocol, which included limb movements performed at a comfortable speed in both standing and supine positions, was useful for detecting a postural response in the PFM. The experimental study demonstrated that women with persistent postpartum PGP and those free of pain exhibited a feed-forward mechanism in the PFM that responded in anticipation to leg lifts performed in a supine position. However, we cannot rule out the possibility that women with difficulties in transferring load between the trunk and legs (i.e., those with functional pelvic instability) might have a different postural response in the PFM. In the present study, one woman with persistent postpartum PGP failed to present a feed-forward mechanism in the PFM, in agreement with previous studies on other parameters of the PFM from other similar groups.

The clinical RCT demonstrated that the concept of home-based SSE with visits every second week with the treating physiotherapist was not more effective than the clinical natural course for improving subjective ratings or muscle function in women with persistent postpartum PGP.

A linear regression analysis revealed a complex picture that suggests that disability 15 months postpartum in women with persistent PGP could be partially predicted by two interaction effects comprising factors from different dimensions: biological, physical functioning, and self-rated function. The proposed association between muscle function and PGP was strengthened. New approaches are most likely needed to further identify subgroups of patients with persistent postpartum PGP that can be considered homogeneous for treatment.

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LIST OF PUBLICATIONS

This thesis is based on the following papers, which are referred to in the text with Roman numerals:

- I. **Jenny Sjødahl**, Joanna Kvist, Annelie Gutke, Birgitta Öberg. The postural response of the pelvic floor muscles during limb movements: a methodological electromyography study in parous women without lumbopelvic pain. *Clinical Biomechanics* 2009; 24(2):183-189.
- II. **Jenny Sjødahl**, Joanna Kvist, Annelie Gutke, Birgitta Öberg. The postural response of the pelvic floor muscles during active straight leg raise test in women with and without persistent postpartum pelvic girdle pain: an experimental study. *Manuscript*.
- III. Annelie Gutke, **Jenny Sjødahl**, Birgitta Öberg. Specific muscle stabilizing as home exercise for persistent pelvic girdle pain after pregnancy. A randomized controlled clinical trial. *Accepted in Journal of Rehabilitation Medicine*.
- IV. **Jenny Sjødahl**, Annelie Gutke, Birgitta Öberg. Predictors for disability in women with persistent postpartum pelvic girdle pain. *Manuscript*.

DESCRIPTION OF CONTRIBUTIONS

Paper I

Study Design	Öberg B, Kvist J, Sjö Dahl J, Gutke A
Data Collection	Sjö Dahl J
Data Reduction	Sjö Dahl J
Data Analysis	Sjö Dahl J, Kvist J, Öberg B, Gutke A
Manuscript Writing	Sjö Dahl J
Manuscript Revision	Sjö Dahl J, Öberg B, Kvist J, Gutke A

Paper II

Study Design	Öberg B, Kvist J, Sjö Dahl J, Gutke A
Data Collection	Sjö Dahl J
Data Reduction	Sjö Dahl J
Data Analysis	Sjö Dahl J, Kvist J, Öberg B, Gutke A
Manuscript Writing	Sjö Dahl J
Manuscript Revision	Sjö Dahl J, Öberg B, Kvist J, Gutke A

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Study Design	Gutke A, Öberg B, Östgaard HC
Data Collection	Sjö Dahl J, Gutke A
Data Analysis	Sjö Dahl J, Gutke A, Öberg B
Manuscript Writing	Gutke A, Sjö Dahl J
Manuscript Revision	Gutke A, Sjö Dahl J, Öberg B

Paper IV

Study Design	Gutke A, Öberg B
Data Collection	Sjö Dahl J, Gutke A
Data Analysis	Sjö Dahl J, Gutke A, Öberg B
Manuscript Writing	Sjö Dahl J
Manuscript Revision	Sjö Dahl J, Öberg B, Gutke A

ABBREVIATIONS

ASLR	Active Straight Leg Raise
BMI	Body Mass Index; kg/m ²
CI	Confidence Interval
CV	Coefficient of Variations
EMG	Electromyography/electromyographic
EQ-5D	European Quality of Life 5-Dimensional Questionnaire
HRQL	Health-Related Quality of Life
IAP	Intra-Abdominal Pressure
ICC	Intraclass Correlation Coefficient
LBP	Low Back Pain
MDT	Mechanical Diagnosis and Therapy
MVC	Maximal Voluntary Contraction
N	Newton
ODI	Oswestry Disability Index
P4-test	Posterior Pelvic Pain Provocation test
PGP	Pelvic Girdle Pain
PFM	Pelvic Floor Muscles
RCT	Randomized Controlled Trial
RMS	Root Mean Square
SD	Standard Deviation
SIJ	Sacroiliac Joint
SSE	Specific Stabilizing Exercises
μV	Microvolt
VAS	Visual Analog Scale

DEFINITIONS

Background activity	The activity observed in an electromyographic recording in the absence of movement or voluntary muscle contraction.
Baseline	The part of an electromyographic recording when no movement or muscle contraction is yet voluntarily performed; i.e. only the background activity is observed.
Baseline activity	The electromyographic activity observed during 2 s of a 30 s reference file.
Clinical natural course	The course the disease takes without directed intervention except an evaluation of low back pain. ¹¹⁸
Combined pain	The compound pain that arises from two syndromes in a single person: pelvic girdle pain and lumbar pain. ⁵³
Compliance	A patient's adherence to a treatment prescription.
Contralateral limb movement	Limb movement performed on the opposite side of the torso from where the electrodes on the abdominal wall are placed.
Disability	A general term for impairment, activity limitation, and participation restrictions from the problematic aspect, according to International Classification of Functioning, Disability, and Health (ICF). ¹⁷⁷
Dynamic test movement	Umbrella term for different dynamic movements used in the electromyography studies, including limb movements in the supine or standing position, jumping, and heavy lifting.
Electromyographic onset	The start of a 50 ms period where the electromyographic activity exceeds the mean baseline activity by 2.5 standard deviations. The electromyographic burst must exceed 25 microvolts to be accepted as an onset in recordings of the rectus femoris muscle and the deltoid muscle.
Feed-forward mechanism	The postural responses that are made in advance of imposed forces that perturb the trunk.

Ipsilateral limb movement	Limb movement performed on the side of the torso that the electrodes on the abdominal wall are placed.
Lack of onset	Defined as either the lack of detection of an electromyographic onset by computerized software or an electromyographic onset that occur ≥ 400 ms after the start of limb movement.
Low back pain	Pain and discomfort localized below the costal margin and above the inferior gluteal folds, with or without leg pain. ¹⁶⁶
Lumbar pain	Pain perceived to arise from anywhere within a region bounded superiorly by an imaginary transverse line through the tip of the last thoracic spinous process, inferiorly by an imaginary transverse line through the tip of the first sacral spinous process, and laterally by vertical lines tangential to the lateral borders of the lumbar erector spinae. ¹⁰⁹
Lumbopelvic pain	Including pelvic girdle pain and/or lumbar pain without differentiation. ¹⁷⁸
Pelvic girdle pain	Pain experienced between the posterior iliac crest and the gluteal fold, particularly in the vicinity of the sacroiliac joints. The pain may radiate to the posterior thigh and can also occur in conjunction with/or separately from pain in the symphysis. ¹⁶⁹
Persistent postpartum pelvic girdle pain	Pain that is present most of the time or occurs in episodes over a period of ≥ 12 weeks after giving birth.
Postural response	A muscle response to counteract the dynamic reactive forces produced by movements or perturbations.
Postpartum	After giving birth.
Prognostic factor	Explanatory variable.
Resting file	Electromyographic recording taken in a supine or standing position, where the woman remains absolutely still and relaxed. This file was used as reference for detecting electromyographic onset.

BACKGROUND

Pelvic girdle pain

Nearly 50% of all pregnant women experience lumbopelvic pain.¹⁷⁸ For the majority of women, the lumbopelvic pain disappears within the first 1-3 months after delivery,^{2,122} however, approximately 25% of women experience persistent pain, and in 7%, the pain is severe.¹⁷⁸ Moreover, women who experience persistent lumbopelvic pain 3 months postpartum are at substantial risk for new episodes or chronic lumbopelvic pain later in life.^{27,122}

Pelvic girdle pain (PGP) is one of the major subgroups of lumbopelvic pain related to pregnancy.⁵⁵ The reported prevalence of PGP during pregnancy was found to be 14 to 33%.^{3,56,84,113} According to European guidelines,¹⁶⁹ the classification of PGP can only be made after lumbar causes have been excluded. Nevertheless, the majority of studies does not differentiate between PGP and lumbar pain^{110,120,121,130,161} and do not exclude women that report only lumbar pain.^{84,116} It is important to distinguish different subgroups of lumbopelvic pain, because different subgroups exhibit different presentations.^{52,54-56,125,159} Moreover, research suggests different treatment strategies for PGP and lumbar pain in relation to pregnancy.^{125,134} Pregnancy-related lumbopelvic pain is assessed and diagnosed either by clinical examination^{53,146,156} or with self-reports through questionnaires or interviews.^{110,120,121,130,161}

PGP often starts during pregnancy or shortly postpartum^{13,16} but it can also occur after a traumatic incidence to the pelvis¹²⁸ or in connection with a rheumatic disease.⁵¹ Women with PGP experience deep uni- or bilateral pain in the buttocks between the iliac crest and the gluteal fold, particularly in the vicinity of the sacro-iliac joints (SIJ) and distal to the lumbar spine. It may radiate to the posterior thigh and can also occur with or separately from pain in the symphysis.¹⁶⁹ Functionally, the pain can limit the ability to maintain prolonged positions and activities; in particular, endurance is diminished for standing, walking, and sitting.¹⁶⁹ Clinical findings include catching of the leg,¹⁵⁹ delayed pain response, and no positive nerve root tests. In addition, the pain or functional disturbances in relation to PGP must be reproducible in specific clinical tests.^{85,169}

No specific underlying mechanism has been identified for most cases of PGP. The pathogenesis may include a variety of contributing factors, including biomechanical, anatomic, psychosocial, neurophysiologic, genetic, or hormonal disorders.^{127,169} The role of relaxin in humans is not well understood. MacLennan et al⁹⁵ have proposed that relaxin has the ability to remodel connective tissues; they hypothesized that a side effect of this activity might be a predisposition to pain in the pelvic area. Some studies

have shown that a high level of the hormone relaxin was correlated with pregnancy-related PGP^{83,94} but this was not confirmed in other studies.^{4,136}

Another hypothesis proposed that PGP may be due to increased mobility of the SIJ. However, roentgen stereophotogrammetry has shown that the degree of SIJ mobility was similar in patients with SIJ pain.¹⁵⁸ A recent review pointed out that women with pregnancy-related lumbopelvic pain exhibited larger motions in the pubic symphysis during pregnancy and ≤ 3 weeks postpartum than women without lumbopelvic pain.¹⁰³ However, the results should be interpreted with caution due to the large overlap between women with and without pregnancy-related lumbopelvic pain. The increased motion did not remain at 3 weeks after delivery.¹⁰³

The origin of PGP is nearly impossible to determine, because many structures can be stressed during pelvic pain provocation tests.⁹⁶ The clinical diagnosis of PGP of SIJ origin is difficult, given the variety of clinical tests and the absence of a gold standard. Double anesthetic blocks of the SIJ have been proposed as a gold standard.⁹⁶ However, it has been argued that these only are effective for diagnosing intra-articular pathology; and that they do not cover the ligamentous apparatus that surrounds the joint (i.e., the long dorsal ligament, the interosseous SIJ ligaments, or other dorsally located ligaments of the joint, which are also important sources of pain).^{85,114} The SIJ have been shown to cause pain over the joints and to refer pain down the posteriorlateral buttock and thigh.^{46,47} However, pain in the buttock region can also originate from the discs and facet joints of the lumbar spine.^{18,80}

Moreover, identifying the anatomical source of pain does not automatically explain why a particular tissue is painful. To understand why a tissue is stressed, it is necessary to focus on functional kinematic relationships and the integration of bones, joints, and ligaments with movement generators (muscles) and control systems (neural regulation).^{88,131,176} In recent years, several groups have discussed the role of the muscles in providing pelvic stability. Functional instability of the pelvis is thought to be a potential cause of PGP.^{127,169} However, a corticosteroid injection in the sacrospinous ligament on the ischial spine was shown to relieve pain in women with persistent pregnancy-related sacral low back pain (LBP).¹⁶² This indicated that pain in the stabilizing structures may not always involve instability, per se.

Lumbopelvic instability

Instability of the SIJ is defined as an impairment of the ability of the SIJ to transfer a load between the trunk and legs.¹⁵¹ The active straight leg raise (ASLR) test evaluates the mechanism in the pelvic girdle that is responsible for transferring the load.^{106,108} Joint stability is only possible when the passive, the active, and the neural subsystems are working together (Fig. 1).^{131,151,152} *The passive subsystem* refers to the osseoligamentous structures and the passive mechanical properties of the muscles. *The active subsystem* consists of the muscles that surround the joint in question. *The neural*

subsystem includes various force and motion transducers located in the ligaments, tendons, muscles, and neural control centers.¹³¹

Previous studies have described a biomechanical model of a self-locking mechanism of the SIJ that is based on the principles of *form closure* and *force closure*.^{153,168} The self-locking mechanism of the SIJ is a nutation (i.e., a flexion of the sacrum in relation to the ilium) or a posterior rotation of the ilium.¹⁶⁸ *Form closure* refers to the stable situation, caused by closely fitting joint surfaces, where no extra forces are needed from the surrounding muscles and ligaments to maintain stability in the actual load situation. An increased tension in most of the ligaments in the pelvis can be observed during nutation of the sacrum, which pulls the ilium bones together, thus enhancing the compression and the stiffness of the SIJ.¹⁶⁸

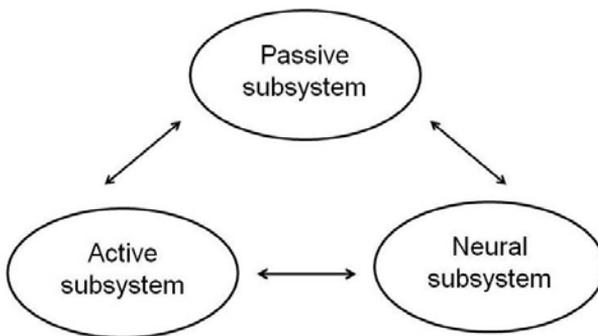


Figure 1. The three subsystems in Panjabi's spinal stability model (adapted from Panjabi, 1992)¹³¹

If the sacrum were perfectly fitted into the pelvis, no lateral forces would have been needed to maintain stability. However, this would have made mobility in the pelvis nearly impossible. The SIJ are flat joints that are relatively vulnerable to shear forces. Therefore, loading stability cannot be achieved solely on the basis of closely fitted joints, but must rely on the surrounding structures.¹⁵¹ *Force closure* refers to the compressive forces produced by the surrounding muscles, ligaments, and thoracolumbar fascias that maintain stability during movement, when the SIJ are exposed to shear forces.

Muscle function in relation to PGP

Another hypothesis proposed an association between muscle dysfunction and PGP.^{54,55,76,128,138} There is growing interest in how the neuromuscular system supports and controls lumbopelvic stability. No single muscle crosses the pelvic joints, but various muscles are thought to contribute to force closure.^{61,137,139,151,167,170} The

muscles linked to lumbopelvic stability can be divided into two functional systems: a global system and a local system.¹⁷

Global muscle system

The global muscle system comprises primarily large, torque-producing muscles that are located more distally from the joint than the local muscle system. The global muscles are important for controlling lumbopelvic movement, orientation, and balance.¹⁷ Women with postpartum PGP had lower trunk muscle endurance,^{54,117} hip muscle strength^{54,105-107,117} and gait speed⁵⁴ compared to women without LBP.

It is important to understand how individual muscles connect and function together. When a specific muscle contracts, it produces forces that spread to its own origin and insertion and to surrounding tissues that are connected both in series and in parallel.⁸⁸ Four different slings of muscle systems have been described that stabilize the pelvis regionally.^{151,171} The longitudinal sling connects peronei, the biceps femoris, the sacrotuberous ligament, the deep lamina of the thoracolumbar fascia, and the erector spinae. The lateral sling comprises the gluteus medius, the gluteus maximus, and the tensor fascia latae, which are the prime stabilizers of the hip joint. The posterior oblique sling contains connections between the latissimus dorsi and the gluteus maximus through the thoracolumbar fascia. The anterior oblique sling contains connections between the external oblique abdominal muscle, the anterior abdominal fascia, the contralateral internal oblique abdominal muscle, and the thigh adductors. Doppler imaging has shown that contraction of the erector spinae, the latissimus dorsi, the biceps femoris, and the gluteus maximus increased the stiffness of the SIJ;¹⁶⁷ however, none of these muscles directly crosses the SIJ.

Local muscle system

In recent years, interest has focused on the role of the local lumbopelvic muscle system in stabilizing the pelvis and spine. Together, the transverse abdominal muscle and the lumbar multifidus muscle form a corset to support the lumbopelvic region. The diaphragm and the pelvic floor muscles (PFM) constitute the roof and the floor, respectively, of the abdominal cavity. Lumbopelvic stability is achieved through several mechanisms, including increasing the intra-abdominal pressure (IAP),^{33,64,65} increasing tension of the thoracolumbar fascia,^{59,75,66} and/or increasing the articular stiffness.^{66,75,143}

The transverse abdominal muscle does not cross the SIJ directly, but it impacts the stiffness of the SIJ¹⁴³ due to its attachment to the middle layer and the deep lamina of the posterior layer of the thoracolumbar fascia.⁸ Prior to the initiation of rapid arm movements, a recruitment of the transverse abdominal muscle,⁷⁵ the deep fibers of the multifidus muscle,¹¹² and the diaphragm⁶³ has been observed in anticipation of lumbar and pelvic stabilization.¹⁴³ Moreover, contraction of the transverse abdominal muscle

has been found to stiffen the SIJ,¹⁴³ and co-contraction of the transverse abdominal muscle and the multifidus muscle improved the stability of the lumbar spine.¹³⁹

The pelvic floor muscles

The pelvic floor is a complex structure of muscles, ligaments, and fasciae with multiple functions. The PFM are crucial in preventing pelvic organ prolapse and maintaining continence during IAP elevation and motions associated with daily physical activities.^{6,155} However, it must also permit micturition and evacuation; in females, it also forms part of the birth canal.⁶

The PFM comprise the pelvic diaphragm and urogenital diaphragm.¹³³ These muscles are located inside the pelvis and form the floor of the abdominal cavity. The pelvic diaphragm includes the levator ani muscle (pubococcygeus, puborectalis and iliococcygeus) and the coccygeus muscle. The urogenital diaphragm is a triangle-shaped plate that consists of two layers of muscles and fasciae. The PFM maintain constant muscle tone with type I striated muscle fibers, and are innervated by S1-S3 neurons.¹³³ It is also possible to voluntarily contract the PFM; this causes an inward lift and squeeze around the urethra, vagina, and anus.²³

The PFM is thought to contribute to stabilizing the spine and the pelvic girdle.^{137,151,152} The PFM, together with other muscles surrounding the abdominal cavity, act to increase and control the IAP.¹⁹ A biomechanical analysis of the upright standing posture has shown that co-contraction of the PFM and the transverse abdominal muscle could effectively reduce vertical SIJ shear forces, and thus increase SIJ stability,¹³² despite the fact that neither muscle crosses the SIJ.

Pregnancy and vaginal delivery can lead to problems in the pelvic floor. Pelvic floor dysfunction can cause urinary and fecal incontinence, pelvic organ prolapse, pain, and sexual disorders.⁶ Neuromuscular disturbance of the PFM has been observed in women with pregnancy-related lumbopelvic pain.^{128,138} For example, the PFM showed a significant increase in EMG activity during prolonged contractions and pushing in women with pregnancy-related lumbopelvic pain compared with healthy controls.¹³⁸ This increase in PFM activity might be an attempt to compensate for functional pelvic instability.¹³⁸ In addition, some studies have reported a relation between urinary incontinence and LBP; urinary incontinence was observed in 52% to 78% of women with lumbopelvic pain.^{38,138} This strengthened the hypothesis that the PFM might play an important role in stabilizing the lumbopelvic region.

Feed-forward mechanism

Joint stability was shown to be controlled in a feed-forward manner.^{70,71,73,75} A feed-forward mechanism is considered to be an anticipatory postural response that occurs in advance of imposed forces that perturb the trunk. For instance, activity in the

transverse abdominal muscle, the oblique abdominal muscles,^{71-73,98} and diaphragm⁶³ occurred prior to the primary mover for rapid single or repetitive movements of the upper limb in a standing position. Pre-activation was also observed in the transverse abdominal muscle, oblique abdominal muscles, and the multifidus muscle prior to fast hip movements^{70,76} and prior to loading mass onto the trunk.³³ The feed-forward response is also thought to occur in response to other types of external loading; for example, different kinds of movements and movements performed at various speeds.

Electromyography

Surface electromyography (EMG) is defined as “*the study of the muscle function through the inquiry of the electrical signal the muscle emanates*”.¹¹ The EMG signal is the electrical signal of neuromuscular activation; it is the sum of all action potentials from motor units that can be detected by the electrodes.¹⁰ The EMG is analyzed to assess the magnitude and timing of muscle activation. Unlike needle or wire EMG, surface EMG is an easily applied, non-invasive method. Surface electrodes mainly focus on the superficial motor units; thus, surface EMG reflects motor units from a larger area than needle electrodes. One disadvantage in surface EMG is the risk of crosstalk; i.e., overhearing activity from adjacent muscles.⁹

EMG onset is a temporal parameter commonly used to evaluate neuromuscular function during movements and postures.⁶² The EMG onset is defined as the point in time when an EMG burst occurs in relation to the initiation of a movement or the burst in a muscle considered being the prime mover (Fig. 2). Thus EMG onsets can be used to study timing of muscle reactions in relation to different movements, including the feed-forward mechanism. Visual analyses^{76,89,98} or computer-based methods^{72,73,98} can both be used to detect EMG onsets and the two methods have been found to be comparable.⁶²

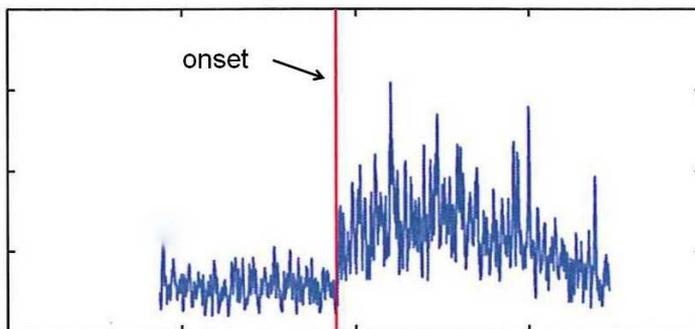


Figure 2. Illustration of an electromyographic onset, indicated with the vertical line.

Predictors

Pregnancy is a risk factor for developing LBP later in life. In the general population, it has been found that 10 to 28% of women with recurrent LBP relate their first episode to pregnancy.^{22,160} Several predictors have been identified that mark the development of, and recovery from, pregnancy-related lumbopelvic pain; however, no clear picture has been presented.¹⁶⁹ In a review, Wu et al.¹⁷⁸ identified 12 potential risk factors for postpartum lumbopelvic pain, and they found strong evidence for strenuous work, previous lumbopelvic pain, and previous PGP. They also concluded that maternal age, number of pregnancies and maternal ethnicity could not be established as risk factors due to conflicting results.¹⁷⁸ Other factors that have been found to be predictive for postpartum lumbopelvic pain are body mass index (BMI), hyper-mobility, pain onset, and pain level.¹¹⁰ In addition, pain location has been proposed as an important predictor for postpartum PGP.^{5,55} PGP in combination with lumbar pain (combined pain) early in pregnancy has been identified as a predictor for PGP 3 months postpartum.⁵⁵ Furthermore, women with bilateral posterior pelvic pain in combination with pain in the symphysis showed a slower postpartum recovery rate compared to women that had fewer sites with pain.² Work dissatisfaction⁵⁵ and lack of belief in improvement¹⁷² are also factors that have been identified as predictors for postpartum PGP.

Recent studies have shown that clinical signs in women with PGP can predict postpartum PGP⁵⁵ as well as disability and pain in women with PGP late in pregnancy¹⁴⁶ and postpartum.^{145,172} Factors that were predictive included low trunk flexor endurance,⁵⁵ the sum of the provocation tests^{145,146} and the ASLR test.¹⁷² In addition, a positive posterior pelvic pain provocation (P4)-test is predictive for disability and pain in women with PGP late in pregnancy.¹⁴⁶

Recent studies on predictors have defined subgroups in pregnancy-related lumbopelvic pain and focused on the PGP subgroup.^{55,145,146,172} However, there is a need for more studies on predictors for persistent postpartum PGP. All but one previous study¹⁷² on postpartum PGP investigated predictors identified during pregnancy. Because the majority of women recover within the first months after delivery,¹²² there is a need to investigate whether the same predictors are valid for persistent postpartum PGP.

Treatment of PGP

The knowledge on how to treat postpartum PGP is limited. Two randomized controlled trials (RCTs) have studied treatment for postpartum PGP.^{104,156} In the first study, Stuge et al.¹⁵⁶ compared physical therapy with focus on specific stabilizing exercises (SSE) and physical therapy without SSE. After 20 weeks of intervention and 6 months later, the SSE group showed lower pain intensity, less disability, and higher health-related quality of life (HRQL) compared to the group without SSE. Significant

differences between the groups were retained after 2 years, with continued low levels of pain and disability in the SSE group.¹⁵⁷ In the second study, Mens et al.¹⁰⁴ compared a group of women that performed video-instructed exercises for the diagonal trunk muscles to groups that performed either placebo exercises or no exercises. None of the three groups received individualized or supervised exercises. No significant differences were found among groups after 8 weeks of intervention. In addition, acupuncture was tested as a treatment for PGP, and it was found to be as effective as SSE for treating pain in pregnant women with PGP.³⁷ The European guidelines for PGP¹⁶⁹ recommend individualized treatment programs that focus on SSE as a part of a multifactorial treatment concept for women with postpartum PGP.

Specific stabilizing exercises

SSE that focuses on local lumbopelvic muscles have been widely used in the management of LBP and pelvic pain.^{26,28,37,49,58,81,82,115,129,142,156} A stabilizing exercise is designed to dynamically control the lumbar segments and the pelvic joints by activating the local muscles in coordination with the global muscles. The aim of SSE is to control pain by supporting and protecting the spinal segment from re-injury. SSE also re-establish and enhance muscle control to compensate for any loss of segmental stiffness caused by injury or degenerative changes.⁷⁹ The form and force closure model is applied in SSE for treating women with PGP.¹⁶⁸ Fitts and Posner reported three stages in learning a new motor skill;¹⁴⁹ in their simplest form, SSE can be said to represent this process of motor learning.¹⁴⁴

The three stages of SSE are:¹⁴⁴

First stage: The aim is to train the local muscles (i.e. transverse abdominal muscle, PFM, deep lumbar multifidus muscle, and diaphragm) to make specific isometric co-contractions at low levels of maximal voluntary contraction. The muscles must contract independent of the global muscles and the patient should maintain regular breathing. A high level of awareness is demanded of the patients in order to isolate the local muscles and perform co-contractions without interference from the global muscles; thus, this is a highly cognitive stage.

Second stage: The aim is to maintain the co-contractions of the local muscles while gradually increasing the load with weight-bearing closed-chain exercises.

Third stage: The aim is to continue to develop segmental control at the individual joints during open-chained exercises. In addition, steps are taken to progress on to functional movements, which involve movements of the trunk with higher loads and speed.

SSE appear to reduce disability and pain in patients with chronic LBP and pelvic pain.^{44,93} However, it is not clear whether these improvements are associated with changes in the pattern of muscle activation.⁴⁴

Rationale for the thesis

PGP is common during pregnancy and a substantial number of women experience persistent PGP after giving birth. There is no consensus regarding the underlying mechanisms of persistent postpartum PGP or how to treat the condition. Consequently, this study proposed to investigate the underlying mechanisms of persistent postpartum PGP in order to facilitate the development of effective and early treatment strategies. The study focused on the muscles', including the PFM, role in PGP. In addition, we aimed to identify factors that were prognostic for disability in women with persistent postpartum PGP. The goal was to identify diagnostic and practical markers that could be used to adjust rehabilitation strategies for women with persistent postpartum PGP.

AIMS OF THE THESIS

General aim

The overall aim of this thesis was to improve rehabilitation strategies for women with persistent postpartum pelvic girdle pain. To that end, we investigated the following:

- (a) The postural response of the pelvic floor muscles in women with and without persistent postpartum pelvic girdle pain.
- (b) The effect of home-based specific stabilizing exercises, with a focus on the local lumbopelvic muscle system in women with persistent postpartum pelvic girdle pain.
- (c) Predictors of disability in women with persistent postpartum pelvic girdle pain.

Specific aims

Study I (Paper I): To develop a method, based on surface electromyography and computer-based analysis, to detect the postural response in the pelvic floor muscles during limb movements performed at a comfortable speed.

Study II (Paper II): To evaluate the postural responses, measured with surface electromyography, in the pelvic floor muscles during leg lifts in the supine position at a comfortable speed in women with and without persistent postpartum pelvic girdle pain.

Study III (Paper III): To investigate if home-based specific stabilizing exercises focusing on the local lumbopelvic muscle system are sufficient for improving disability, pain, health-related quality of life, and muscle function in women with persistent postpartum pelvic girdle pain.

Study III (Paper IV): To identify predictors for disability in women with persistent pelvic girdle pain 15 months postpartum.

MATERIALS AND METHODS

Design

The thesis comprises three studies:

- **A methodological study (study I)** that included healthy women and aimed to develop a method for evaluating the postural responses of the PFM during limb movements performed at a comfortable speed in supine and standing positions.
- **An experimental study (study II)** that included women with and without persistent postpartum PGP and aimed to evaluate the postural response of the PFM during leg lifts performed in the supine position at a comfortable speed.
- **A clinical randomized controlled trial (study III)** that included women with persistent postpartum PGP and aimed to: a) evaluate home-based SSE that focused on the local lumbopelvic muscle system and b) identify predictors for disability at 15 months postpartum.

Overview of the studies

The thesis is mainly based on data that describe: a) muscle function, including EMG recordings of muscle activity, muscle endurance, and muscle strength, and b) subjective assessments of disability, HRQL, and pain.

Study I

EMG activation of the PFM, trunk, leg, and arm muscles was measured in women with no lumbopelvic pain. A test protocol was developed for evaluating the postural response of the PFM during limb movements performed at a comfortable speed. The results are presented in Paper I.

Study II

EMG activation of the PFM, trunk, and leg muscles was measured in women with and without persistent postpartum PGP. The test protocol developed in study I was used to evaluate the postural response of the PFM during leg lifts in the supine position. The results are presented in Paper II.

Study III

Women with persistent postpartum PGP or combined pain were included in a RCT approximately 3 months postpartum. In addition to a clinical examination, subjective ratings of the condition and the function of the PFM, trunk, and hip extensor muscles were evaluated at inclusion and again after 3-, 6-, 12-, and 24-months in follow-ups. The results from the 3- and 6-month follow-ups are presented in Paper III. A linear regression analysis was used to identify predictors for long-term disability at the 12-month follow-up. Those results are presented in Paper IV. The 24-month follow-up is not included in this thesis.

Table 1. Women included in the studies

Study	Paper	Number of subjects	PGP*/pain-free	Mean age, y (min-max)	Mean BMI [†] kg/m ² (min-max)	Mean parity, n (min-max)
I	I	10	Pain-free women	37 (32-40)	23 (19-28)	2 (1-3)
II	II	8	Women with PGP	28 (26-33)	26 (20-32)	2 (1-2)
		9	Pain-free women	30 (22-36)	25 (20-34)	1 (1-3)
III	III	88	Women with PGP or combined pain [‡]	31 (18-41)	26 (18-42) ^{††}	2 (1-5)
III	IV	50	Women with PGP or combined pain	30 (18-41)	27 (18-42) ^{††}	2 (1-5)

*PGP = pelvic girdle pain; [†]BMI = Body Mass Index; [‡]Combined pain = PGP in combination with lumbar pain; ^{††}n = 77; ^{††}n = 46

Subjects

These studies included women with persistent postpartum PGP and women with no lumbopelvic pain (i.e. pain-free women; Table 1). Inclusion criteria and exclusion criteria for the participants are presented in Table 2 and 3, respectively.

Study I

This study included a sample of 10 women with a history of at least one delivery, but with no lumbopelvic pain. More than 12 months had elapsed since their last delivery. They were recruited by advertisements posted at the local university and the local university hospital.

Study II

This study included a sample of 8 women with persistent postpartum PGP and 9 women with no lumbopelvic pain. The women with PGP and the women with no lumbopelvic pain were tested within a median of 23 weeks postpartum (range 13-40) and within 31 weeks postpartum (range 17-50), respectively. They were recruited by advertisements posted in the waiting rooms of children's health care clinics.

Table 2. Inclusion criteria for the women in studies I-III

Study I	Study II	Study III
<ul style="list-style-type: none">• Age 20-40 years• Latest delivery occurred >12 months prior to this study• The latest delivery was vaginal	<ul style="list-style-type: none">• Age 20-40 years• Latest delivery occurred 3-12 months prior to this study• The latest delivery was vaginal• Women with pelvic girdle pain also fulfilled the criteria for pelvic girdle pain	<ul style="list-style-type: none">• All women were 3 months postpartum• All women fulfilled the criteria for pelvic girdle pain or combined pain*

*combined pain = pelvic girdle pain in combination with lumbar pain

Table 3. Exclusion criteria for the women in studies I-III

<p>All women:</p> <ul style="list-style-type: none">• Insufficient Swedish language skills• Ongoing pregnancy• Diagnosed with a neurologic or rheumatic disease• Fracture, surgery, or neoplasm of the femur, pelvis, or spine• History of gynecological operation• Treatment with specific stabilizing exercises that focused on the local lumbopelvic system in the 3 months prior to this study <p>Women without lumbopelvic pain</p> <ul style="list-style-type: none">• Recurrent lumbopelvic pain in the previous 12 months (study I)• Recurrent lumbopelvic pain in the previous 12 months and/or during their latest pregnancy (study II)

Study III

This study recruited 88 women with PGP or combined pain at approximately 12 weeks postpartum from two different geographical areas. Sixty-five and 60 women performed the 3- and 6-month follow-ups, respectively. Fifty-eight women completed the 12-month follow-up and 50 of those were included in the multiple linear regression analysis. A flow-chart of the included women is presented in Figure 3.

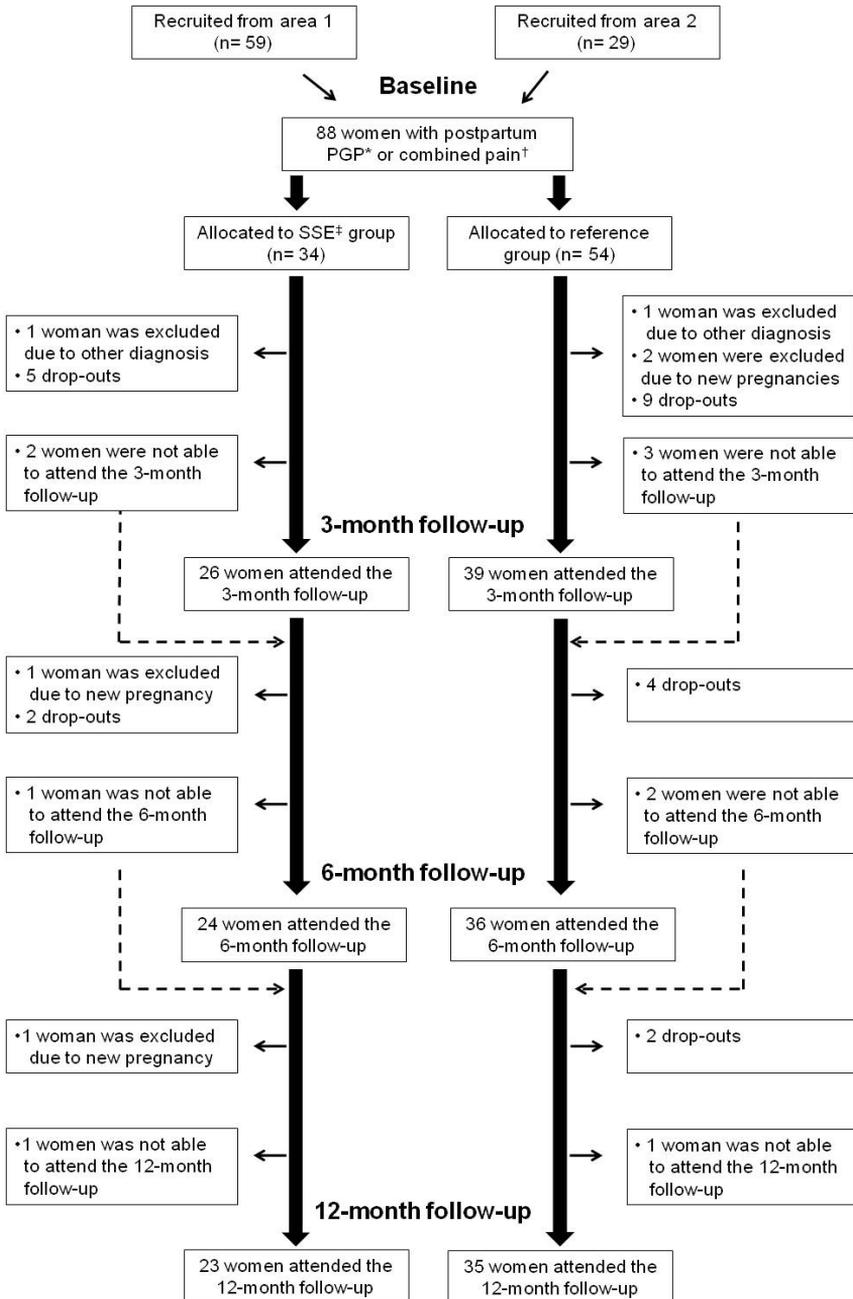


Figure 3. Flowchart of the participants in study III, baseline \approx 3 months postpartum
 *pelvic girdle pain, †pelvic girdle pain in combination with lumbar pain, ‡ specific stabilizing exercises

Classification of PGP

A clinical examination was performed to determine whether the women fulfilled the criteria for PGP (studies II & III) or combined pain (study III). The criteria for PGP and combined pain are presented in Table 4. The examination started with a standard history that focused on known characteristics of lumbar pain, including positions and effects on daily life activities. The positions included bending, sitting, standing, walking, and lying down. Pain location was self-assessed by subjects on a pain drawing.¹⁴¹ Range of motion of the back was evaluated while standing with back flexion, extension, and lateral flexions.

Five pelvic pain provocation tests were performed in the sequence described below. A positive result on a pelvic pain provocation test was reported when the test could reproduce the woman's familiar pain in both location and quality.

1. **Distraction test:** The participant lies supine. The examiner applies a posterior directed force to the anterior superior iliac spines on both sides of the pelvis.⁸⁶
2. **Posterior pelvic pain provocation test:** The participant lies supine with 90° of flexion at the hip and knee on the tested side. The examiner stabilizes the contralateral side of the pelvis over the superior anterior iliac spine. A light manual pressure is applied on the patient's flexed knee, along the longitudinal axis of the femur. The test is performed bilaterally.¹²⁴
3. **Gaenslen's test:** The participant lies supine near the edge of the table. One leg hangs over the edge of the table and the hip and knee of the other leg are flexed towards the patient's chest. The examiner applies pressure to the flexed knee towards the chest and a counter pressure to the knee of the hanging leg towards the floor. The test is performed bilaterally.⁸⁶
4. **Compression test:** The participant is lying on one side with the hip and knees flexed to approximately right angles. The examiner kneels behind the participant on the table. The examiner applies a pressure vertically downward on the upper iliac crest.⁸⁶
5. **Sacral thrust:** The participant lies prone. The examiner applies a light pressure vertically downward on the sacrum.⁸⁶

In order to exclude problems associated with the hip, a rotational range of motion test was performed in the prone position. The mechanical assessment of the lumbar spine was based on the Mechanical Diagnosis and Therapy (MDT) protocol.¹⁰⁰ The participant performed flexion and extension in standing and lying positions in sets of 5-10 repetitions. If necessary, lateral flexion was added to the protocol. The data included the baseline symptoms and the effects on symptoms during and immediately following the movements. When the patients reported that radiating symptoms regressed proximally (centralization) or distally (peripheralization) as a result of repeated movements or positions, the symptoms were considered discogenic³⁶ and thus, lumbar pain. Previously reports of responses to these movements have shown that the method is promising for use in pain classifications.⁹⁹ The mechanical assessment was followed by the ASLR test, a neurological examination that included

muscle testing, reflex testing in the lower extremities, sensation, and the straight leg raise test. The inter-rater reliability of the classification procedure was investigated on pregnant women, and the agreement between two examiners was 87%, giving a substantial kappa coefficient of 0.79 (95% CI: 0.60-0.98).⁵³

Table 4. Criteria for being assigned to the pelvic girdle pain group or the combined pain group

Pelvic girdle pain:

- Pain experienced between the posterior iliac crest and the gluteal fold, with or without radiation to the posterior thigh and calf, and with or without pain in the symphysis.¹⁶⁹
- Pain that is reproducible in at least 2 out of the 5 pelvic pain provocation tests (2 tests bilaterally).⁸⁵
- No centralization or peripheralization phenomena and no change in the degree of pain or range of motion with repeated movements or different positions of the lumbar spine, according to the MDT* classification.¹⁰⁰
- Onset of pain was during pregnancy or within 3 weeks after delivery.

Combined pain:

- Pain experienced both in the lumbar region and between the posterior iliac crest and the gluteal fold, with or without radiation to the posterior thigh and calf, and with or without pain in the symphysis.¹⁶⁹
- Positive results on two or more pelvic pain provocation tests.⁸⁵
- Changes in the degree of pain and/or a change in range of motion with repeated movements or different positions of the lumbar spine, or the presence of centralization and/or peripheralization phenomena, according to the MDT classification.¹⁰⁰
- Onset of pain was during pregnancy or within 3 weeks after delivery.

*MDT = *Mechanical Diagnosis and Therapy*

ASLR test

The ASLR test was used to evaluate the ability to transfer load between the trunk and legs.^{106,108} The ASLR test was not used as an inclusion criterion, but to describe the severity of pain in terms of a possible load transfer problem. The ASLR test was performed in the supine position with straight legs and the feet placed 20 cm apart. The test was performed after the instruction: “Try to raise your legs, one after the other, above 10-20 cm without bending the knee”.¹⁰⁸ The women were then asked to score impairment on a 4-point scale:

- 0 = the woman felt no restriction
- 1 = the woman reported decreased ability to raise the leg, but the examiner observed no signs of impairment
- 2 = the woman reported decreased ability to raise the leg, and the examiner observed signs of impairment
- 3 = inability to raise the leg

The inter-examiner reliability of the ASLR test score was shown to be high (Kendall’s Tb = 0.81).¹⁰⁸

Equipment

Electromyography

Muscle activation was recorded with a surface EMG. The EMG signals were used to investigate the postural responses in the PFM, abdominal, back, leg, and arm muscles. The responses were then related to the initiation of limb movements performed at a comfortable speed (studies I & II). The muscles recorded are showed in Table 5. Furthermore, surface EMG was used to study isolated activation of the PFM (study III).

Table 5. Muscles assessed with electromyography

Muscle	Study
Pelvic floor muscle	I, II, III
Hip adductor muscles	I
Rectus femoris muscle	I, II
Muscles of the lower lateral abdominal wall ¹	I, II
Rectus abdominal muscle	I, II
Erector spinae muscle	I
Deltoid muscle	I

Pilot study

A pilot study that included two women was conducted to investigate possible methodological errors, including crosstalk, artifacts, and potential alterations in background activity in the PFM during a test session.

Crosstalk and artifact

The maximal voluntary contraction (MVC) was recorded with the women in different positions. The MVC was recorded for the PFM, the muscles of the lower lateral abdominal wall, and the hip adductors. For example, the MVC for the PFM was performed in the standing position, in the supine position with the legs extended, and in the supine position with the knees flexed approximately 90° and the feet hip-width apart. A risk of crosstalk was suspected in the recording of the EMG activity of the

¹ Transversus abdominis muscle is used instead of the muscles of the lower lateral abdominal wall when describing the electrode site in paper I.

PFM when agreement was visually detected between the EMG activation of the PFM and that of the muscles from the two other electrode sites. However, we did not detect any agreements, either between the PFM and the muscles of the lower lateral abdominal wall or between the PFM and the hip adductors. This suggested that the risk of crosstalk was minimal (unpublished data).

Visual analyses of both the raw EMG signals and the root mean square (RMS) EMG signals showed the presence of artifacts in the recordings from the erector spinae, the rectus abdominal muscle, and the muscles of the lower lateral abdominal wall due to heartbeats (unpublished data). Therefore, EMG signals from these muscles were filtered to minimize the disturbance from heartbeats when analyzing EMG onsets. Artifacts were also present in the recordings of the erector spinae when women were placed in a supine position; thus, the erector spinae recordings were excluded from the analyses of the leg lifts.

Alterations in background activity in the PFM

Potential alterations in background activity in the PFM during test sessions could lead to problems in detecting the onset of the PFM response, particularly when a separate recording, the resting file, was used as a reference.

The test sessions lasted approximately 120 min. The mean baseline activity of the PFM was extracted from each baseline in all the dynamic test movement recordings, the resting files, and the MVC recordings. A total of 52 recordings were completed for the first woman; of these recordings, 20 were recorded in the supine position, and 32 were completed in the standing position. For the second woman, there were a total of 51 recordings; of these recordings, 15 were recorded in the supine position, and 36 were recorded in the standing position.

For woman 1, the difference in mean background activity in the PFM between the first and last recording was 2.5% and 5% of the MVC in the supine and standing positions, respectively (Fig. 4). For woman 2, the difference in mean background activity in the PFM was 3% and 5% in the supine and standing positions, respectively (Fig. 4).

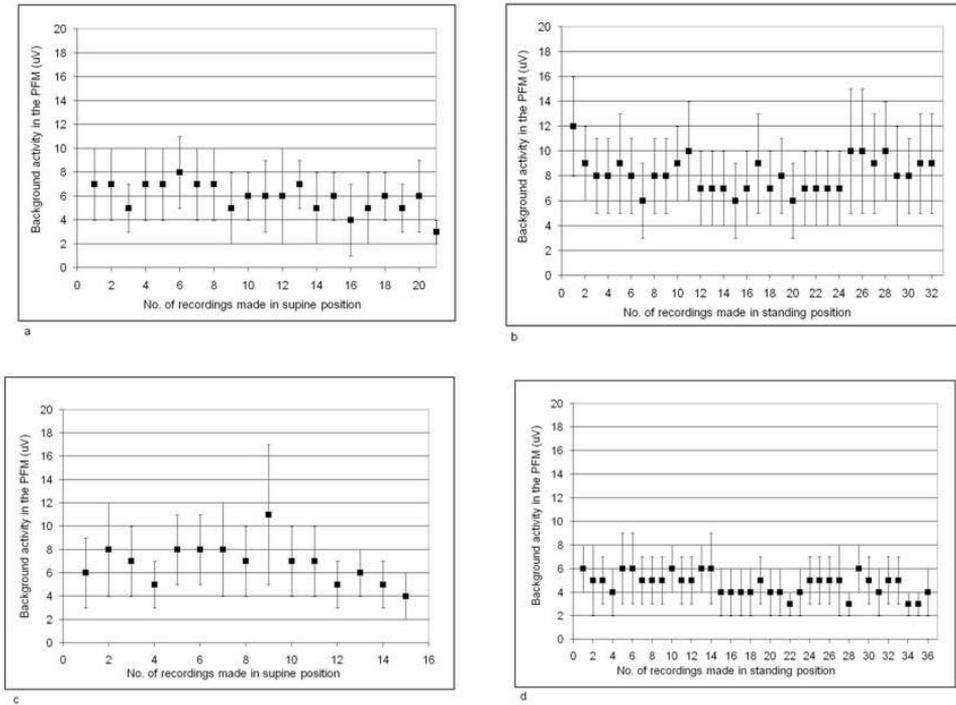


Figure 4. Illustration of the alterations in pelvic floor muscle (PFM) activity. Results are from the pilot study for a) woman 1 in the supine position, b) woman 1 in the standing position, c) woman 2 in the supine position, and d) woman 2 in the standing position. Symbols and error bars represent the mean and SD, respectively, for each recording.

Study I & Study II

The PeriformTM vaginal probe (Neen HealthCare, Dereham, UK) was used to record the EMG activity of the PFM (Fig. 5). The probe was 7.5 cm long and had a circumference of 10 cm. It was equipped with two longitudinal recording plates embedded along the sides of the probe that were 1.5 cm wide and 3.5 cm long. The distances between the tip of the probe and the two recording plates and the base and the two recording plates were 1.5 cm and 3.0 cm, respectively.¹⁷³ The between-trial reliability was found to be good to high for surface EMG of the PFM with the PeriformTM vaginal probe; the intra-class correlation coefficient ($ICC_{(3,1)}$) was 0.80-0.98 and the coefficient of variations (CV) was 9.6-19.5%.⁷ The women inserted the probe into the vagina, up to the ring at the introitus. A ground electrode and an amplifier were placed on the right iliac in order to reduce noise in the PFM recordings.

Skin preparation and electrode placements were made according to recommendations from “Surface EMG for the Non Invasive Assessment of Muscles” (SENIAM)⁵⁷ for the other recorded muscles. The muscles were located by palpation during a submaximal isometric contraction and the electrodes were placed at the most

prominent site on the muscle. The skin at each electrode site was first prepared by shaving and cleaning with 70% alcohol to facilitate electrode adherence and conduction of EMG signals. On the skin above each muscle, two pre-gelled AgCl recording electrodes (Blue sensor, M-00-S, Medicotest, Denmark, diameter of active part 10 mm) (Fig. 5) were placed 2 cm apart, center-to-center, and one ground electrode with an amplifier placed about 10 cm from the measuring area. The electrode placement was verified by performing a functional test and observing the recording on the computer screen. EMG signals were sampled at 1000Hz with the ME 6000 EMG unit system (study I) and MESPEC 4000 EMG unit system (study II). Both EMG unit systems were from MEGA Electronics Ltd., Kuopio, Finland.

Study III

The EMG activity of the PFM was recorded with the Periform™ vaginal probe (Neen HealthCare, Dereham, UK; Fig. 5). A ground electrode was placed on the right iliac in order to reduce noise from the recordings. The EMG signals were acquired with the NeuroTrac™ ETS (Verity Medical Ltd., Lightwater Surrey, England).

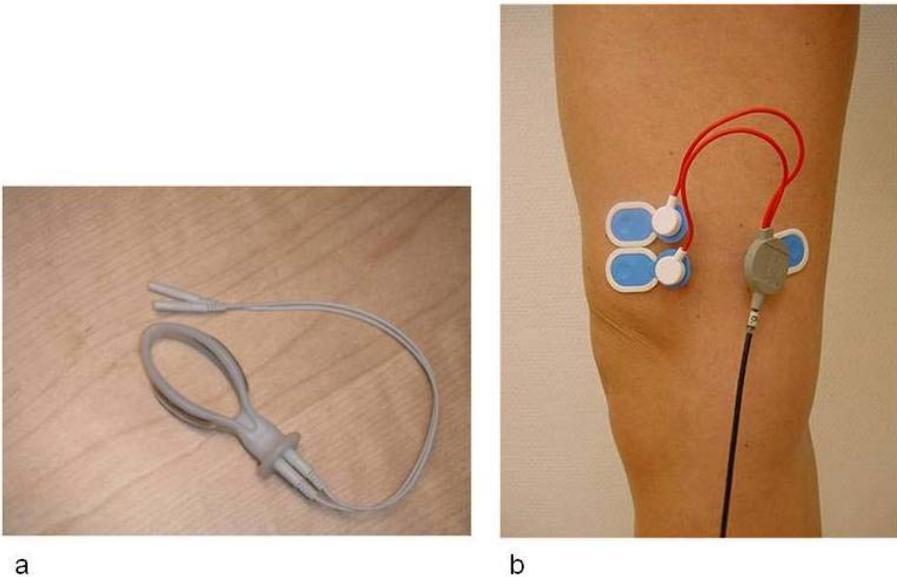


Figure 5. Photographs of the electrodes used to record the electromyographic activity: a) the pelvic floor muscles were recorded with an oval probe inserted into the vagina; b) the trunk, leg, and arm muscles were recorded with two surface electrodes (anterior) placed close together on the skin, and a ground electrode with an amplifier (posterior) placed nearby.

Dynamometer

Maximal voluntary isometric hip extension strength was measured with a dynamometer with a fixed sensor (Chatillon CSD 500 strength dynamometer, Ametek, Largo, FL). The reliability of the hip muscle extension test was investigated in a pilot test-retest study (n=20) conducted by Gutke (unpublished data). Spearman's r was 0.82 for the right leg and 0.88 for the left leg; the ICC (model 2) was 0.87 for the right leg and 0.85 for the left leg. The measurement error was 53 N on the right leg and 50 N on the left leg. The measurement error was 15% of the mean values of extension strength.

Self-reported questionnaires

Basic questionnaires were performed to collect data on age, BMI, number of parity, and number of children. The women also answered questions on the mode of the latest pregnancy, injuries in the pelvic floor during delivery, breastfeeding, weight of the newborn, if the lumbopelvic pain hindered taking care of the baby, lumbopelvic pain during pregnancy, treatment for lumbopelvic pain during latest pregnancy, current exercise frequency (never/sometime per month, 1-2 times/week, or >2 times/week), physical activity level (1-6; 6 = most active; 1-3 = manage all household duties, including gardening and light physical activity; or 4-6: the aforementioned activities + exercises at increasing intensity),⁴⁸ urinary leakage, symptom satisfaction (delighted, pleased, mostly satisfied, mixed feelings, mostly dissatisfied, unhappy, terrible),³⁰ expectations of treatment (be completely restored, quite improved, no expectations of being restored but to get some relief, no expectations of being restored or to get some relief), and postpartum depressive symptoms.³² In addition, the women used different measures (described below) to rate their disability, HRQL, wellbeing, and pain (Table 6).

Oswestry Disability Index

The Oswestry Disability Index (ODI), version 2.0 was used to measure back-specific disability.^{42,102} The perceived disability was rated on 10 different items: pain intensity, personal care, lifting, walking, sitting, standing, sleeping, sexual life, social life, and traveling. The items were scored from 0 to 5. The scores of all items were summed, giving a total maximum score of 50 points. The total score was doubled and expressed as a percentage, where 0% represented no disability. The ODI scores of patients could be divided into categories: minimal or no disability (0-20%), moderate disability (20-40%), severe disability (40-60%), crippled (60-80%), or bed bound/exaggeration of the symptoms (80-100%).⁴² Good reliability has been reported for the ODI.^{43,50}

Table 6. Overview of the questions used in this thesis

<i>Variable</i>	<i>Scale levels</i>	<i>Paper</i>
Age (y)	Continuous	I-III
Body mass (kg)	Continuous	I-III
Height (cm)	Continuous	I- III
Body mass index (kg/cm ²)	Continuous	I -III
Number of parity	Continuous	III
Number of children	Continuous	I-III
Urinary leakage	Nominal	I-III
Exercise frequency	Ordinal	III
Activity level (1-6) ⁴⁸	Ordinal	III
Lumbopelvic pain during latest pregnancy	Nominal	II, III
Treatment for lumbopelvic pain during pregnancy	Nominal	III
Delivery mode	Nominal	III
Injuries during delivery	Nominal	II-III
Weight of newborn (g)	Continuous	III
Breastfeeding	Nominal	III
Postpartum depressive symptoms measured with Edinburgh Postnatal Depression Scale	Ordinal	III
Expectation of treatment (1-4)	Ordinal	III
Symptom satisfaction (1-7) ³⁰	Ordinal	II
Lumbopelvic pain hindered taking care of the baby	Nominal	II
Pain frequency (1-5)	Ordinal	III
Pain drawing (cm ²)	Continuous	III
Pain intensity (mm on the VAS) ⁷⁷	Continuous	II-IV
Oswestry Disability score ⁴²	Continuous	II-IV
Wellbeing (1-6)	Ordinal	III
General health (mm on the VAS)	Continuous	III
EQ-5D score ¹	Ordinal	II, III
EQ-VAS (mm) ¹	Continuous	II, III

HRQL and wellbeing

The European Quality of Life 5-Dimensional Questionnaire (EQ-5D) was used for measuring HRQL.^{1,140} This is a generic HRQL measurement, and it can be used regardless of disease or illness. The EQ-5D consisted of two parts that measured the HRQL. The first part involved a state of health classification scheme that included mobility, self care, usual activities, pain/discomfort, and anxiety/depression. Each

dimension had 3 response categories (1 = no problems, 2 = moderate problems, and 3 = severe problems). There were 243 (3^5) possible health states and each had a preference value attached to it with values that ranged from -0.59 to 1.0, where 1.0 was optimal health. The second part of the EQ-5D was a 20 cm, vertical, visual analog scale (VAS) ranging from 0 (“worst possible health status”) to 100 (“best possible health status”); the respondent rated their perceived health on that particular day. Wellbeing was measured on a horizontal 100 mm VAS that ranged from 0 (“best imaginable wellbeing”) to 100 (“worst imaginable wellbeing”).

Pain

Pain intensity was measured with a horizontal VAS (0-100 mm), where 0 = “no pain” and 100 = “worst imaginable pain”.⁷⁷ The pain intensity was assessed for current pain and average pain during the previous week.³⁵ Pain intensity was also measured with a plastic VAS ruler before and after the test protocol and after each set of leg lifts in study II. Pain intensity was also measured before and after each test of function in the protocol used in the follow-ups for study III. A previous study showed that changes of 10-18 mm in the VAS score had the best cut-off points for discriminating between improvement and no improvement.²⁰ Another study reported a decrease in pain when a pain score was least 7 mm less than the preceding assessment.²⁹ Pain location was self-assessed by women on a pain drawing.¹⁴¹ The distribution and extent of pain reported on pain drawings were found to be reasonably stable over time⁹⁷ and they have high criterion, construct, and content validity.¹¹⁹ Pain frequency was measured with one question that had five possible answers (never, sometimes, several times per week, daily, always).

Assessments

Electromyographic activation

Study I & Study II

EMG signals were acquired from the PFM and muscles of the trunk, leg, or arm (Table 5) during limb movements. The different limb movements are displayed in Table 7. A switch was placed under the limb that performed the movement. The switch generated a signal when the lift was initiated, and EMG onsets were related to this time point. Each limb movement was repeated 5 times with approximately 40 s of rest between each repetition. Each repetition was performed on verbal command. The subjects were instructed to perform the movements at a comfortable speed, i.e. the movement was performed at a self-paced speed.

A randomization procedure was used to decide which leg/arm was to perform the contralateral limb movements; i.e., movements performed with the limb on the *opposite side of the torso from the abdominal electrodes*. In study II, the leg that did not perform the contralateral leg lift was used to perform the ipsilateral leg lift. For example, when the left leg was randomized to perform the contralateral leg lifts, the right one performed the ipsilateral leg lift.

Table 7. Test movements used in the electromyographic studies

Test movement	Study	
	I	II
Contralateral* leg lift (ASLR [‡])	X	X
Contralateral leg lift (ASLR) with an extra weight	X	X
Ipsilateral leg lift (ASLR)		X
Contralateral arm lift	X	

**Contralateral lift = the lift was performed with the leg/arm on the opposite side of the torso from the abdominal electrodes*

[‡]*ASLR = Active Straight Leg Raise*

EMG activity was also acquired at rest in the standing position (study I) and in the supine position (studies I & II). The recording lasted 30 s when the women were relaxed and performed no movements. Two of these seconds served as reference when analyzing EMG onsets.

In study I, MVCs were performed for each recorded muscle. The peak value recorded during the MVC served as a reference value for calculating relative EMG activity.

Leg lift

The leg lift was performed as an ASLR. Women rested in the supine position with arms placed next to the torso. They were asked to raise their leg 10-20 cm from the examination table with the knee extended (Fig. 6). The contralateral leg lift was performed both with and without an extra weight strapped to the ankle (studies I & II); the ipsilateral leg lift (study II) was performed with no extra weight.

The activity from the rectus femoris muscle was always recorded from the leg performing the lift. The activity from the hip adductors was also recorded from the leg performing the leg lift (study I).

Arm lift

The arm lift was performed with the arm contralateral to the electrodes on the trunk. The lift was performed as a forward flexion at the shoulder with a 5-kg weight strapped to the wrist (Fig. 6). Activity from the deltoid muscle was recorded from the arm performing the lift. Activity from the hip adductors was also recorded from the side performing the arm lift.

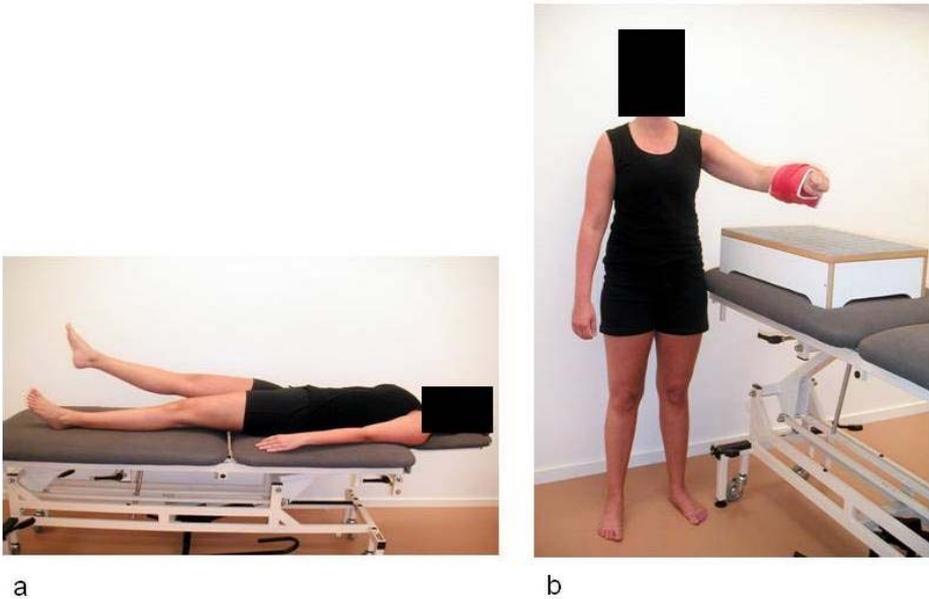


Figure 6. The limb movements performed in the electromyographic studies: (a) the leg lift (active straight leg raise (ASLR)), (b) the arm lift.

Relative activation level

MVCs were performed in two repetitions, each 4-5 s, for each recorded muscle. The MVCs were performed as follows:

PFM: performed in the supine and standing positions. Instruction: contract the PFM and lift the pelvic floor towards the abdominal cavity.

Muscles of the lower lateral abdominal wall: performed in the supine position with legs extended. Instruction: tighten the lower abdomen by drawing the umbilicus against the back.

Rectus abdominal muscle: performed in the supine position with knees flexed at approximately 90°, feet hip-width apart. Arms were aligned next to the torso; the upper body was restrained with a strap. Instruction: tighten the lower abdomen by drawing the umbilicus against the back and lift the upper body from the table against the strap.

Erector spinae muscle: performed in the prone position with the arms next to the torso; the upper body was restrained with a strap. Instruction: perform a back extension against the strap.

Hip adductor muscles: performed in the supine position with knees flexed at approximately 90°, feet hip-width apart. Arms were aligned next to the torso; the test examiner fixed the pelvis on the contralateral side by holding it against the table. Instruction: perform an adduction against the manual resistance placed on the inside of the knee by the test examiner.

Rectus femoris muscle: performed in the supine position. The contralateral foot was placed on the table; the ipsilateral knee was flexed at approximately 30° and restrained with a strap. Instruction: perform a knee extension against the resistance.

Deltoid muscle: performed in the standing position. The elbow was flexed at 90°, and the shoulder was abducted by approximately 20°. Instruction: perform abduction against the resistance placed on the outside of the elbow by the test examiner.

Study III

In this study, women rested on an examination table in the supine position with the legs extended. They were asked to contract the PFM as much as possible for 5 s, and then to relax for 5 s. This sequence was repeated 5 times.

Trunk flexor endurance

To test the isometric endurance of the trunk flexor muscles, the women laid supine with arms crossed over the chest, hands on the opposite shoulders, hips bent, and knees and feet apart. The women were asked to nod forward and to continue to lift their head and shoulders until the inferior angle of the scapula was lifted from the examination bench modified from McQuade et al.¹⁰¹ The time that the position was maintained was recorded in seconds up to a maximum of 120 s. The maximal time was based on values for healthy women and women with nonspecific LBP.^{91,92} No encouragement was given during the test. The isometric trunk flexor endurance test was reported to have low (ICC 0.51) reliability in some studies^{92,111} and high reliability in one study (ICC 0.90-0.95).⁷⁸

Trunk extensor endurance

To test the isometric endurance of the trunk extensor muscles, the women laid prone with arms crossed over the chest, and the trunk was maintained in a horizontal position off the examination bench. The pelvis was fixed to the examination bench with straps and the lower legs were fixed by the test examiner, modified from Biering-Sørensen.²¹ The time that the trunk position was maintained was recorded in seconds up to a

maximum of 120 s. The maximal time was based on values for healthy women and women with nonspecific LBP.^{91,92} No encouragement was given during the test. ICCs for subjects with current LBP, previous LBP, and no LBP were 0.88, 0.77, and 0.83 respectively.⁸⁷

Hip extensor strength

Maximal voluntary isometric hip extension strength was measured with a dynamometer with a fixed sensor (Chatillon CSD 500 strength dynamometer, Ametek, Largo, FL). Women laid their torso on the table in a prone position, feet on the floor, bent at the waist. A sling fastened to the table leg was placed around the distal part of the femur, and the knee was bent to maintain the sling in place. The women pulled against the sling to extend the hip (Fig. 7). The instruction was “pull as hard as you can until I stop you after 5 seconds”. All women started with the right leg, and two training repetitions were performed. The mean of the 3 following repetitions was analyzed. Each repetition consisted of 5 s of work and 5-10 s of rest. The same procedure was performed on the left leg. No encouragement was given during the test.

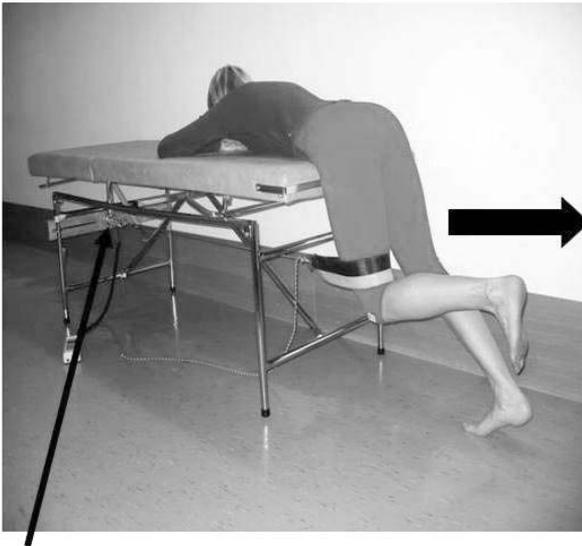


Figure 7. The hip extension test for the left side

dynamometer
sensor

Gait analysis

Limitations in walking were studied in a gait test, modified from Ljungqvist et al.⁹¹ The women were timed while walking barefoot for a distance of 20 m “at a comfortable speed” on a horizontal floor. Women with PGP often have increased pain and stabs of pain while turning. Therefore, the turning and the 20 m walk back were excluded in order to eliminate pain provocation. The time it took to walk 20 m was recorded. No encouragement was given during the test. Reliability for comfortable gait speed has been reported to be good ($r=0.90$).²⁵

Intervention

The women assigned to the treatment group were instructed to exercise at home ≥ 2 times per day and to perform each exercise with 10 repetitions. The training consisted of SSE and focused on the transversely oriented abdominal muscles, the lumbar multifidus, and the PFM.¹⁴⁴ The SSE model includes principles of motor learning theory and consists of three stages: (1) local segmental control, (2) closed chain segmental control, and (3) open chain segmental control.¹⁴⁴ An individual program was prepared for each woman, where exercises were chosen among 15 standardized predesigned exercises. The loading during the exercises was progressively increased during the treatment period with the goal of reaching stage 3.¹⁴⁴ In addition to the home training, individual guidance and adjustments in the exercise program were performed every second week by one of two treating physiotherapists. To measure compliance, a self-maintained daily training diary was used during the training period.

The women in the reference group were allowed one telephone contact with a physiotherapist. They received information about PGP and combined pain, including the fact that it is a common problem during pregnancy and that it disappears within a couple of months postpartum in the majority of cases. They were instructed to resume their normal activities.

Data analysis

Electromyography

The EMG amplitude was calculated with continuous RMS averaging within a moving window of 10 ms with MegaWin software. The highest window across all MVCs was used to represent the maximal voluntary activation amplitude for each muscle. The peak value during the limb movements was normalized to the peak value of the MVC

for each muscle (relative value of one muscle = peak value during a limb movement/peak value during MVC in that muscle).

To study EMG onset, continuous RMS averaging was first computed across each recording of the limb movement within a moving window of 1 ms and filtered at 50 Hz with MegaWin software. The EMG onset was defined as the start of a 50 ms period, where the activity exceeded the mean baseline activity by 2.5 standard deviations (SD). This algorithm was used for all muscles, except the deltoid muscle (study I) and the rectus femoris muscle (studies I & II); in the latter muscles, the EMG activity had to exceed 25 μV for a period of 50 ms to be accepted as an EMG onset.

To minimize the disturbance from heartbeats that we observed in the pilot study, we compared the electrocardiogram rhythm and the EMG signals with MATLAB® version 7.1.0.246 (R14) Service Pack 3 (The MathWorks Inc., Natick, US). Clear periodic peaks appeared in EMG signals at points that corresponded to the electrocardiogram rhythm. The y-value of the point that corresponded to the heart rhythm indicated the strength of the correlation between the points, and the x-value specified the time between the points. The first point, from the covariance function, gave the interval between the heartbeats; it was used to detect the heartbeats. However, heartbeats do not necessarily occur at constant time intervals; therefore, the algorithm was programmed to identify the point in an interval when a heartbeat should occur. This point of interest was then replaced with the mean between the previous point and the present point.

EMG onsets that occurred ≥ 400 ms after the initiation of movement were not defined as onsets. If an EMG onset occurred earlier than 400 ms prior to the initiation of the limb movement, the onset was defined as an increase in the background activity and excluded due to difficulties in detecting onsets. Based on the PFM, the two most extreme recordings in the five repetitions were excluded. The remaining three repetitions were used to analyze the EMG onsets and the relative activation amplitudes for all muscles.

Statistical analysis

The statistical methods used in the four papers are shown in Table 8. Statistics were calculated with SPSS (version 15.0-17.00; SPSS Inc., Chicago, IL). In all studies, a significance level of $P < 0.05$ was used for all variables.

Sample size calculation in study III was executed based on the ODI, which was the primary outcome. That calculation estimated that 21 women would be required per group for a 10% difference to be considered significant ($\alpha = 0.05$, $\beta = 0.20$).

Descriptive statistics were used for demographic data. These were presented as the mean and SD when the assumptions of normality and homogeneity of variance were

met and the studied variables were measured at the ratio level. Data measured at the interval, ordinal, or nominal levels were analyzed with nonparametric tests and were presented as median values with quartiles or ranges or, when appropriate, they were presented as a percentage.

Differences between two groups were measured with the independent samples t-test when the variable was normally distributed and was measured at the ratio level. For analysis of non-parametric data measured at the ordinal level, the Mann Whitney U test was used for group comparisons. For data measured at the nominal level, the chi squared test or Fisher’s exact test was performed when appropriate. Due to the skewed distribution of data in the EMG variables, the EMG data in study II was evaluated with the Mann Whitney U test.

Within-group comparisons were made with the paired samples t-test for variables measured at the ratio level and with the Wilcoxon Signed Rank test for non-parametric variables measured at the ordinal level. For dichotomous variables, the McNemar test was performed.

Table 8. *Statistical methods used in the studies.*

Statistical method	Paper			
	I	II	III	IV
Descriptive analyses	x	x	x	x
Independent samples t-test			x	
Mann-Whitney U test		x	x	
Paired samples t-test			x	
Wilcoxon Signed Ranks test			x	
Chi-square test			x	
Fisher’s exact test			x	
Linear regression analyses				x

In Paper IV, multiple linear regression analysis was performed on measures taken 3 months postpartum. These analyses were used to determine predictors of disability in women with persistent PGP at 15 months postpartum. The initial choice of independent variables was based on the hypothesis of an association between muscle dysfunction and PGP, and was supported by reports in the literature.^{5,12,54,55,172,175,178}

With multiple linear regression analysis, it is crucial that all subjects included respond to all the questions in the model. In this study, subjects were also required to perform all the physical tests. These requirements reduced the sample size to 50 participants. In

order to minimize the risk of multicollinearity, a correlation matrix was analyzed. The multiple linear regression model was then executed in two steps.

1) A forward stepwise procedure was used to identify two-way interaction effects after entering all main effects in the regression model. A significance level of $P < 0.01$ was used. Two interaction effects were identified.

2) The two interaction effects and their main effects were entered in the regression model and a forward stepwise procedure was used on the remaining 14 predictors. A significance level of $P < 0.05$ was used. No significant predictors were found in addition to the two interaction effects identified in step 1.

A ROC (Receiver Operating Characteristic) curve was used to evaluate the predictive models ability to discriminate between sick and healthy in ODI 15 months postpartum, dichotomized as $\geq 10\%$ and $< 10\%$.

Ethical considerations

All participants received written and oral information about the aim of the study and the test procedures. The women in study III also received information about the two alternatives in the trial. All individuals in study I and study II provided written informed consent before participation in the study. In study III, participants provided oral informed consent before participation in the study. They were informed that participation was voluntary, that they could discontinue participation at any point without explanation, and that any test could be discontinued when increased pain or onset of pain occurred during the test, or when any discomfort was experienced with the vaginal probe. No other risks to the women in the studies were identified. Participation in study II and study III presented the possibility of an evaluation of the participant's lumbopelvic pain. Ethical approval was granted by the local Ethics Committee (study I and study II Dnr M81-06, and study III Dnr Ö414-00, T018-07).

RESULTS

Additional results are presented in the separate papers.

Muscle activation in healthy women during limb movements (study I)

Electromyographic onset

During the contralateral leg lift tests with and without the extra weight, the median onset of EMG activity in all recorded muscles occurred before the initiation of the lifts (Fig. 8). The same pattern for the onsets was observed during the contralateral arm lift test for all muscles, except the rectus abdominal muscle. The onset for the deltoid muscle was not analyzed due to an increased background activity in the majority of files.

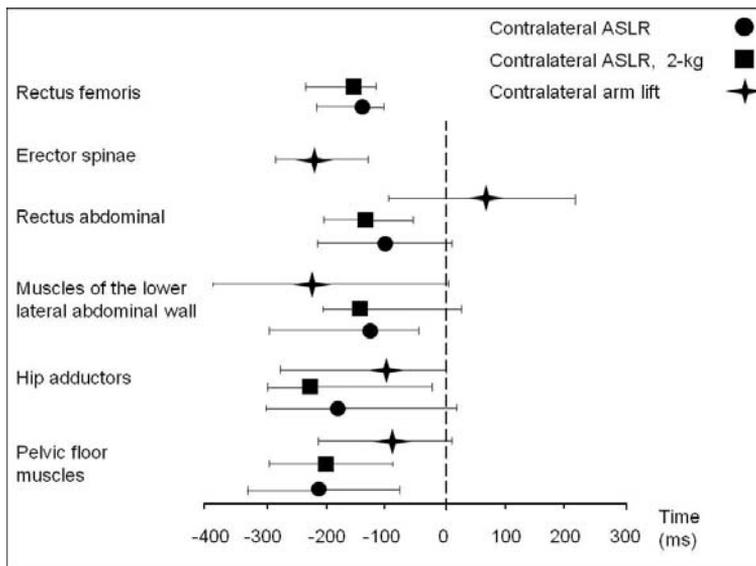


Figure 8. The median electromyographic onsets during the contralateral leg lift tests and the contralateral arm lift test. The lift was performed with the limb on the opposite side of the torso from the electrodes placed on the trunk. The rectus femoris and hip adductors were recorded from the leg that performed the lift. Whiskers represent the 25th and 75th percentiles.

The relative activation level

During the contralateral leg lift tests, the median relative activation level of the PFM was 38% (range 14-125%) and 20% (range 13-71%) of the MVC when performed with and without extra weight, respectively. During the contralateral arm lift test, the median activation level was 23% of the MVC with a range of 9-36% (Fig. 9).

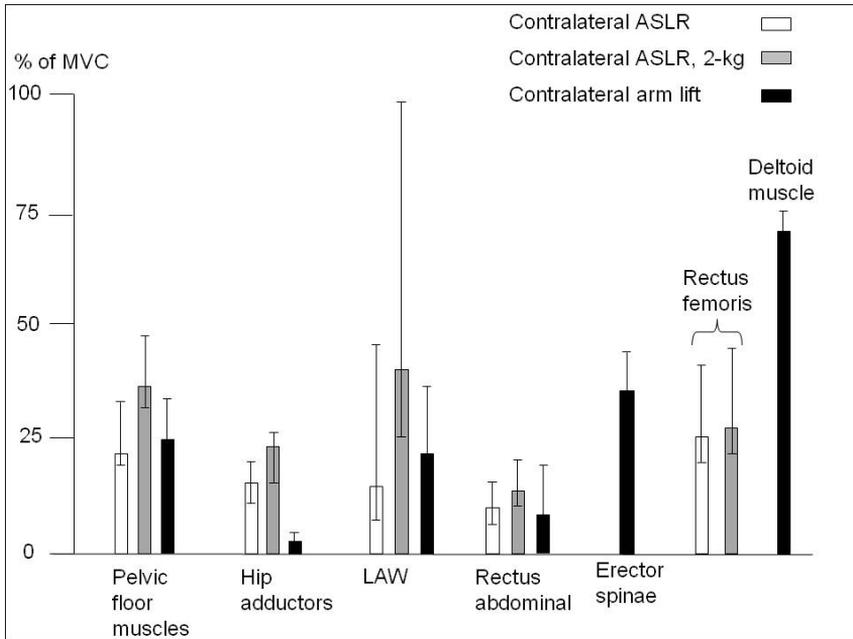


Figure 9. The median relative activation level (% of MVC) during the contralateral leg lift tests and the contralateral arm lift test. The lift was performed with the limb on the opposite side of the torso from the electrodes placed on the trunk. The rectus femoris, the hip adductors and the deltoid muscle were recorded from the limb that performed the lift.

MVC = maximal voluntary contraction; LAW = muscles of lower lateral abdominal wall. Error bars represent the 25th and 75th percentiles.

The postural response during leg lifts (study II)

Characteristics of the PGP group

The median pain intensity on the VAS was 34 mm (range 14-61 mm) at inclusion and 46 mm (range 14-67 mm) for the previous week. The median ODI score was 25% (range 10-34%).

All women experienced bilateral PGP. The median number of positive pelvic pain provocation tests was 4 (range 2-6). The ASLR test showed that only one woman experienced difficulties with load transfer between the trunk and legs; she scored 4 out of 6 points on the ASLR test during the clinical examination. All the remaining women scored 0.

Electromyographic onset

The EMG onsets in the recorded muscles of women with persistent postpartum PGP and of pain-free women are presented in Figure 10.

The median EMG onset for the PFM occurred before the initiation of the three leg lift tests in women with and without persistent postpartum PGP. There was no significant difference between the two groups ($P>0.05$).

The median EMG onset of the rectus femoris muscle occurred earlier in women with persistent postpartum PGP than in pain-free women during the contralateral leg lift tests with ($P=0.02$) and without ($P=0.04$) the extra weight. There was no significant difference between the two groups' onset of the rectus femoris muscle during the ipsilateral leg lift test ($P>0.05$).

The median EMG onset of the muscles of the lower lateral abdominal wall occurred earlier in women with persistent postpartum PGP than in pain-free women during the contralateral leg lift test with no extra weight ($P=0.02$). There was no significant difference between the two groups' onsets of the rectus abdominal muscle during the contralateral leg lift test with no extra weight ($P>0.05$). There were no significant differences between the two groups' onsets of the muscles of the lower lateral abdominal wall or the onsets of the rectus abdominal muscle during the contralateral leg lift test with an extra weight or the ipsilateral leg lift test ($P>0.05$).

Load transfer difficulties

One woman with persistent postpartum PGP exhibited an EMG onset of the PFM after the initiation of the three leg lift tests. In addition, this subject also lacked EMG onset in the muscles of the lower lateral abdominal wall during the three leg lift tests and in the rectus abdominal muscle during the two leg lift tests with no extra weight, i.e. the contralateral leg lift test with no extra weight and the ipsilateral leg lift test.

This woman was not different from the other 7 women with persistent postpartum PGP regarding pain onset, localization of the pain, pain intensity, or disability. However, she had the highest number of positive pelvic pain provocation tests (6 out of 7), and she scored 4 out of 6 on the ASLR test during the clinical examination.

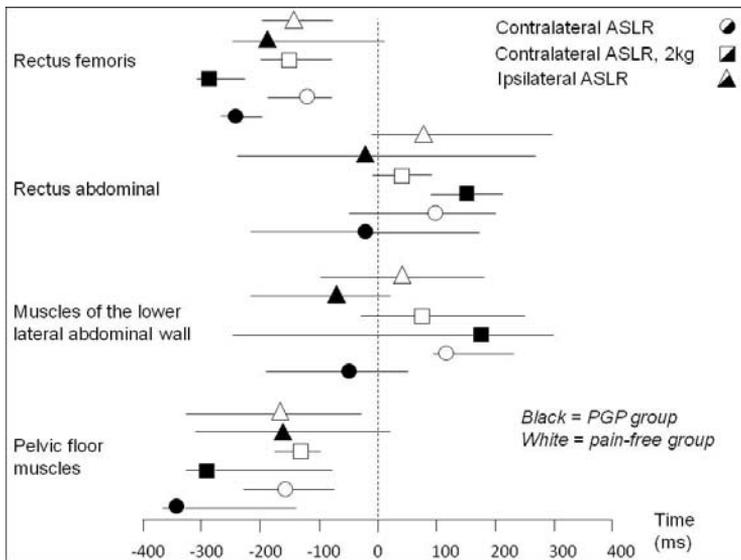


Figure 10. The median electromyographic onsets during the three leg lift tests. The contralateral leg lift test was performed with the leg on the opposite side of the body from the electrodes placed on the abdominal wall. The rectus femoris was recorded from the leg that performed the lift. ASLR = Active Straight Leg Raise. Whiskers represent the 25th and 75th percentiles.

The effect of SSE (study III)

All included women except one scored ≤ 2 points on the ASLR test, one woman scored 4 points. On average 5 (SD 3) physiotherapy sessions were performed. No woman trained 2 times/day in average during their training period, 10 woman trained ≥ 1.5 times/day in average and 15 woman trained < 1.5 times/day. Seven diaries were not handed in; in addition, two women did not receive allocated intervention and did not

receive or hand in any diaries. Seventy-eight percent of the women in the treatment group reached stage 3 in the treatment program.

Oswestry Disability Index

No difference could be demonstrated in the ODI scores between the treatment group and the reference group at the 3- or 6-month follow-up. Compared to baseline, there were improvements in the ODI score for both the treatment group and the reference group (Table 9).

Pain, symptom satisfaction, HRQL, and wellbeing

The pain frequency was lower in the treatment group compared to the reference group at the 3-month follow-up. No differences could be detected between the groups regarding pain intensity, symptom satisfaction, HRQL, or wellbeing at the 3- or 6-month follow-up (Table 9).

The pain intensity and symptom satisfaction had improved in both groups compared to baseline. No differences over time could be detected for HRQL or wellbeing in either of the two groups (Table 9).

Muscle function

No differences were detected between the two groups for trunk muscle endurance, hip extension strength, activity in the PFM, or gait speed at the two follow-ups. Within-group comparisons showed improvements in several of the global muscles at both follow-ups compared to baseline (Table 10).

Table 9. Between-group comparisons and within group comparisons of ODI, Wellbeing VAS, EQ-5D instrument, and Pain intensity VAS based on mean differences at 3- and 6- month follow-ups. Symptom satisfaction and Pain frequency are presented as proportions at the 3- and 6- month follow-ups.

Variable	Based on mean difference from baseline median (25th, 75th percentiles)					
	Baseline		3-month follow-up		6-month follow-up	
	Treatment group (n=32-33)	Reference group (n=52-53)	Treatment group (n=25-26)	Reference group (n=34-39)	Treatment group (n=23-24)	Reference group (n=32-35)
ODI %	18 (13-27)	18 (10-27)	-4 (-1;4)*	-2 (-6;4)	-8 (-20;3)*	-4 (-12;2)*
Wellbeing VAS mm	19 (10-35)	16 (11-32)	-2(-9;11)	-1.5(-10;6)	0 (-14;5)	-3 (-14;4)
EQ-5D Score	0.73 (0.70-0.80)	0.80 (0.73-0.80)	0.0 (-0.1;0.1)	0.0 (0.0;0.06)	0.0(-0.1;0.1)	0.0 (0.0;0.1)
EQ-VAS mm	79 (70-88)	77 (70-85)	5 (-1;10)	3 (-4;13)	4 (-2;11)	5 (0;12)*
Pain intensity at moment VAS mm	30 (13-48)	35 (17-55)	-12 (-30;3)**	-14 (-31;2)**	-16 (-28;3)**	-19 (-41;-1)**
Average pain intensity over the previous week VAS mm	36 (23-50)	35 (20-59)	-21(-34;6)**	-14(-35;7)*	-20 (-31;8)**	-19(-48;0)**
Symptom satisfaction, n (%)						
Delighted-mostly satisfied	9 (27)	17 (33)	14 (54)*	17 (44)	15 (63)*	27 (77)*
Mixed feelings-terrible	24 (73)	35 (67)	12 (46)	22 (56)	9 (38)	8 (21)
Pain frequency, n (%)						
Always, day and night, several times per week	26 (79)	45 (87)	14 (58)#	33 (87)	13 (54)	20 (59)*
Occasionally-never	7 (21)	7 (13)	10 (42)	5 (13)	11 (46)	14 (41)

between group comparison $p < 0.05$; * within group comparison $p < 0.05$; ** within group comparison $p < 0.001$

Table 10. Between group comparisons and within group comparisons of the muscle function tests based on mean differences
Based on mean difference from baseline
mean (SD)

Variable	Baseline		3-month follow-up		6-month follow-up	
	Treatment group (n=19-32)	Reference group (n=35-52)	Treatment group (n=15-24)	Reference group (n=16-37)	Treatment group (n=12-23)	Reference group (n=17-35)
Trunk flexor endurance s	31.1 (28.8)	32.3 (29.1)	2 (27.3)	0.8(15.2)	4.6 (23.5)	5.0 (27.2)
Trunk extensor endurance s	51.6 (36.2)	40.4 (30.6)	6.6 (15.3)	20.4 (26.3)**	18.6 (14.8)*	17.3 (33.1)*
Gait speed m/s	1.24(0.19)	1.28 (0.14)	0.07 (0.12)*	0.07 (0.12)**	0.08 (0.15)*	0.05 (0.16)
Mean hip extension right leg N	210 (101)	203 (82)	41 (70)*	20 (57)*	35(60)*	28 (68)*
Peak hip extension right leg N	249 (111)	250 (95)	41 (72)*	14 (63)	30 (733)	29 (80)*
Mean hip extension left leg N	208 (94)	197 (82)	26 (54)*	2 (64)#	30 (41)*	8 (68)
Peak hip extension left leg N	245 (103)	226 (84)	30 (70)	11 (60)	32 (43)*	18 (66)
Work average in the PFM µV	34 (20)	34 (22)	4 (14)	4 (17)	0.3 (20)	2 (13)
Rest average in the PFM µV	9 (6)	8 (5)	0.2 (4.2)	0.3(4.5)	-1.1 (4.3)	-1.5 (4)
Work peak in the PFM µV	71 (42)	70 (45)	4.8 (25.1)	0.6 (30.3)	1.7 (36.9)	2 (25.5)
Average onset in the PFM ms	229 (174)	211 (337)	0.0 (0.2)	0.1 (0.6)	0.0 (0.2)	0.01 (0.21)
Average release in the PFM ms	268 (518)	106 (610)	0.1 (0.4)	0.3 (0.8)	-0.1 (0.4)	0.5 (0.9)*

between group comparison $p < 0.05$; * within group comparison $p < 0.05$; ** within group comparison $p < 0.001$

Predictors for long-term disability (study III)

The linear regression model included 50 women; 37 were classified into having PGP and 13 into having combined pain at 3 months postpartum. Eighteen of the 50 women had been treated with SSE postpartum. There was a significant improvement in disability measured with ODI between 3 and 15 months postpartum (Fig. 11). Two two-way interaction effects whose main effects were collected 3 months postpartum were significantly associated with disability at 15 months postpartum, including: a) age + trunk flexor endurance, and b) hip extensor strength + disability level. The final model explained 52% of the variation in the ODI 15 months postpartum (Table 11).

Table 11. Predictors for disability measured with Oswestry Disability Index in women with persistent pelvic girdle pain 15 months postpartum

Independent variables	Dependent variable: Continuous Oswestry Disability Index (ODI) at 15 months postpartum			
	β -Coefficient	95% CI	t	P
Constant	58.49			
Age	-1.36	-2.11 - (-)0.60	-3.63	< 0.01
Trunk flexor endurance ^a	-1.23	-1.83 - (-)0.62	-4.10	< 0.01
Oswestry Disability Index ^b	-1.14	-2.04 - (-)0.24	-2.56	0.01
Hip extensor strength ^c	-0.05	-0.11 - (-)0.01	-1.74	0.09
Interaction effect: age + trunk flexor endurance ^e	0.04	0.02 - 0.06	4.15	< 0.01
Interaction effect: disability + hip extensor strength ^f	0.01	< 0.01 - 0.01	3.83	< 0.01

Multiple linear regression analysis with Oswestry Disability Index (ODI) at 15 months postpartum as dependent variable. The independent variables were collected at baseline evaluation 3 months postpartum.

Unstandardized β -Coefficient, 95% CI = 95% confidence interval and P value given for β -Coefficients. Adjusted R^2 was 0.52. $N = 50$

^a Trunk flexor endurance 0-120 seconds

^b ODI: 0-100%: High value indicating high disability.

^c Hip extensor strength measured in Newtons.

^d Interaction effect comprising age and trunk flexor endurance.

^e Interaction effect comprising disability measured with ODI and hip extensor strength

Using ≥ 10 % and < 10 % as a cut-off for sick and healthy on ODI 15 months postpartum and the predictive values from the model resulted in a sensitivity of 73% and a specificity of 75%. The AUC (Area under the ROC curve) was 0.80 (± 0.13)

(Fig. 12). Pain intensity, number of pain sites, combined pain, wellbeing, HRQL, occurrence of stress-induced urinary incontinence, treatment with SSE, expectations of treatment, symptom satisfaction, gait speed, and the ASLR test score were not significant predictors for disability at 15 months postpartum ($P>0.05$).

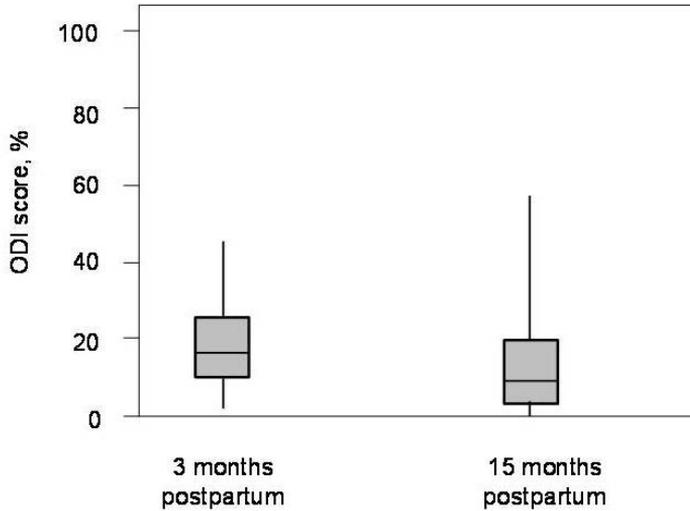


Figure 11. Distribution of Oswestry Disability Index (ODI) score, approximately 3 months postpartum and 15 months postpartum. Median values given by horizontal line, boxes show the interquartiles and whiskers the range. $P<0.01$; $n = 50$; scale range from 0-100%, 0 = no disability.

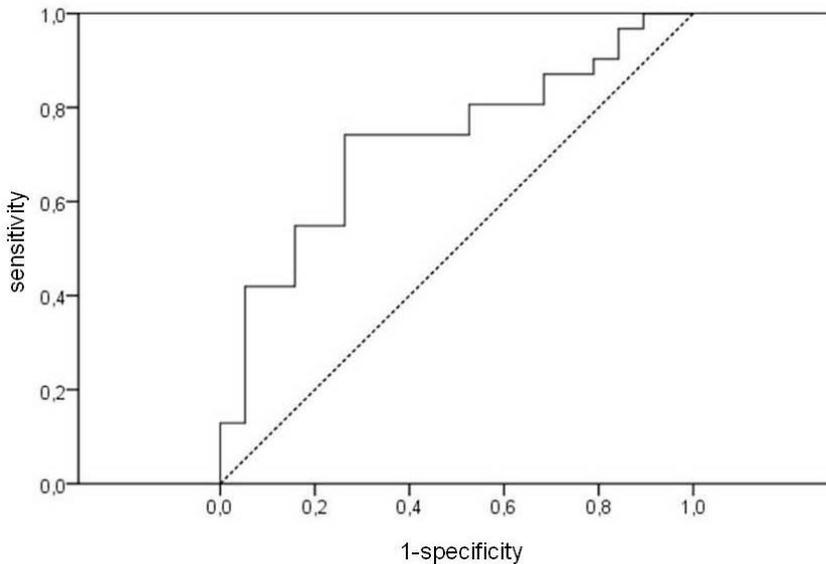


Figure 12. ROC curve for the predictive model's ability to discriminate between sick and healthy in ODI 15 months postpartum, dichotomized as $\geq 10\%$ and $<10\%$.

DISCUSSION

Main findings

The methodological study showed that the designed protocol, including limb movements performed at a comfortable speed in standing and supine positions, could successfully detect postural responses in the PFM. The first main finding of this thesis was that women with persistent postpartum PGP and pain-free women exhibited a feed-forward mechanism in the PFM in an anticipatory response to leg lifts performed in the supine position. The second main finding was that home-based SSE that focused on the local lumbopelvic muscle system did not provide any benefits over the clinical natural course in women with persistent postpartum PGP. The third main finding was that disability in women with persistent PGP 15 months postpartum could be partially predicted by two two-way interaction effects whose main effects can be found in different dimensions, including biological, physical functioning, and self-rated function.

In contrast to the first main finding, we found one woman with persistent postpartum PGP who lacked a feed-forward mechanism in the PFM and the muscles of the lower lateral abdominal wall. Moreover, this woman experienced more difficulties with load transfer between the trunk and legs, as indicated by a higher ASLR score than the other women. This suggested that the results described in this thesis may not be applicable to all women with persistent postpartum PGP.

A feed-forward mechanism in response to limb movements

Our hypothesis was that women with persistent postpartum PGP would lack a feed-forward mechanism in the PFM in relation to a functional instability in the pelvis. The hypothesis was based on the assumption that instability of the pelvis is one of the mechanisms behind PGP^{127,169} and the fact that one of the components responsible for joint stability in the pelvis is the local lumbopelvic muscle system, including the PFM.¹³¹ However, our hypothesis was not supported by the data. We found that all but one of the women tested with persistent postpartum PGP exhibited a feed-forward mechanism in the PFM.

The woman that failed to demonstrate a feed-forward response in the PFM and in the muscles of the lower lateral abdominal wall was also the only woman that presented a positive ASLR test during the clinical examination. Because instability of the pelvis

has been defined as an impairment in the ability of the SIJ to transfer load between the trunk and legs,¹⁵¹ we can assume that the ASLR test can be used to assess the mechanism responsible for the load transfer¹⁰⁸ and thus, the stability of the pelvis. Therefore, we reasoned that the woman with no feed-forward mechanism may have had functional pelvic instability that was manifested by an impaired ability to transfer load. Thus, we assumed that the functional pelvic instability was due to the lack of a feed-forward mechanism in the PFM and the muscles of the lower lateral abdominal wall. This assumption is in line with the proposed hypothesis that women with pregnancy-related lumbopelvic pain who present a negative ASLR test are successful in compensating for functional pelvic instability, in contrast to women with a positive ASLR test.¹³⁸ In addition, the ASLR test was found to be a useful tool for identifying women with severe persistent PGP, defined as high disability and evening pain 12 months postpartum.¹⁷²

To our knowledge, this is the first study to investigate the EMG onset of PFM in women with persistent postpartum PGP during leg lifts performed as ASLRs. However, other parameters of the pelvic floor have been investigated previously during ASLRs. Results from those studies indicated that there is a dysfunction in the pelvic floor in people with PGP and similar conditions. Increased pelvic floor descent has been demonstrated in people with SIJ pain compared to pain-free subjects;¹²⁸ similarly, a greater depression of the pelvic floor was found in women with persistent PGP¹⁴ compared to pain-free women.¹⁵ In addition, increased EMG activity was found in the PFM in women with pregnancy-related lumbopelvic pain.¹³⁸ Moreover altered motor control patterns were detected in the EMG for muscles other than the PFM in subjects with SIJ or PGP during ASLRs.^{14,76}

The majority of studies that found altered motor control patterns in various muscles, including the PFM, used a positive ASLR test as an inclusion criterion.^{14,31,34,76,126,128,138} Therefore it cannot be ruled out that those women who have persistent postpartum PGP and difficulty with the load transfer may have functional instability in the pelvis in relation to insufficient motor control strategies. However, this hypothesis requires further exploration. Our results support the notion that functional pelvic instability only represents part of the mechanism underlying persistent postpartum PGP.^{127,169} Thus, PGP might be studied more effectively by identifying subgroups; for example, one subgroup would comprise subjects with load transfer difficulties. Studies with larger sample sizes are needed to explore the mechanisms that give rise to different subgroups.

It is currently recognized that motor control impairments detected with the EMG commonly co-exist with lumbopelvic pain disorders.^{76,128,138} However, the mere presence of those impairments does not establish cause and effect. Motor control impairments can occur secondary to the presence of pain. For example, alterations in coordination of the knee muscle activity can be caused by an injection of hypertonic saline (5%); i.e., pain unassociated with a muscle origin.⁶⁷ Hodges et al.⁶⁸ have demonstrated that experimentally induced pain may replicate some of the motor control changes that are observed in people with LBP. This argued that pain may cause

the changes in motor control, at least in some cases; however, the findings did not exclude the possibility that motor control changes may also lead to pain.⁶⁸ Therefore, it is possible that the women with persistent postpartum PGP that did not demonstrate a delayed onset of the PFM in the present study might exhibit motor control changes in the future.

Postural demands

Different postures were used as starting point in study I when the leg and arm lift tests were performed. To our knowledge, this is the first study to investigate the temporal activation pattern in terms of EMG onsets in the PFM during different postures, i.e., supine and standing. A feed-forward mechanism was exhibited in the PFM in an anticipatory response to both leg lift performed in supine position and arm lift performed in standing position in the pain-free women included in study I.

A direction independent activation has been observed in the transverse abdominal muscle during rapid upper limb movements performed in the standing position⁷¹ and during expected and unexpected perturbations performed while laying on one side.⁴⁰ However, the pre-activation that was found during limb movements in the standing position⁷¹ could not be demonstrated while laying on one side.⁴⁰ Thus, the recruitment pattern of the transverse abdominal muscle appears to be different for standing and side-laying positions. It is possible that gravity poses specific postural demands on the transverse abdominal muscle during standing and that these specific postural demands are absent when laying on one side.⁴¹

The EMG onsets recorded from the two electrode sites on the abdominal wall, i.e. the rectus abdominal muscle and the muscles of the lower lateral abdominal wall, differed between the two groups of pain-free women during the leg lift in the supine position. A pre-activation was present in the pain-free women of study I, but not in those of study II. Thus, the temporal activation pattern in the muscles of the lower lateral abdominal wall was both consistent and inconsistent with the pattern observed when laying on one side.^{40,41} One explanation could be that the elapsed time after pregnancy differed between the two pain-free groups due to the inclusion criterion. One can speculate that the recovery of the abdominal muscles, and thus, the activation pattern in the abdominal muscles, were influenced by the elapsed time from pregnancy. In addition, there was wide variability among EMG onsets of the included women. Due to the rather small number of women included, this might explain the contradictory results to some degree.

Methodological issues regarding the EMG studies

The protocol used for detecting the postural response in the PFM had several strengths. It allowed a comfortable speed when performing the limb movements and used a structured classification system for women with persistent postpartum PGP. According

to the European guidelines for PGP,¹⁶⁹ the ASLR test is the only test available for assessing pelvic function. Based on current knowledge, it would have been interesting to have used the ASLR test as an inclusion criterion in the present study in order to study different subgroups of women with persistent postpartum PGP.

A pilot study was conducted prior to the methodological study to investigate potential methodological problems. The main potential problem when recording surface EMG activity of the PFM is crosstalk,⁹ and overhearing from adjacent muscles has been suggested as a possible source of crosstalk.^{24,135,148} Consistent with Hodges et al⁷⁴ and Smith et al,¹⁵⁰ the results of the pilot study indicated that overhearing from adjacent muscles did not appear to be a source of disturbance in the EMG recordings of the PFM in the present study. Activity of the PFM is generally accompanied by contractions of the abdominal and hip muscles; this can potentially lead to an erroneous interpretation of crosstalk.

The background activity in the PFM might shift slightly during the test session due to the women being unaccustomedness to the vaginal sensor at the start of the test session. To our knowledge, no other studies that used a vaginal probe have discussed this possibility. However, there were no indications from the pilot study that the background activity in the PFM changed during the test session. Nevertheless, we excluded a few women from each limb movement test due to increases in the background activity of the PFM in the recordings of leg and arm lifts. The women were reminded to remain relaxed until they received the verbal command to perform the lift; however, the women may have involuntarily prepared themselves for the task. This might have caused the activity to increase in the baseline and made it difficult to detect the EMG onsets.

Speed of the limb movements

Previous studies of the feed-forward mechanism in different muscles have mostly been investigated during rapid limb movements.^{60,63,71,73} A delayed postural contraction of the transverse abdominal muscle was demonstrated in people with LBP during rapid hip⁶⁹ and arm movements⁶⁰ performed in the standing position. However, we chose to use limb movements performed at a comfortable speed for two reasons: 1) we did not want to risk increasing the pain, and 2) movements performed at a comfortable speed better simulate the speed used in everyday tasks.

Clearly, movements performed at a comfortable speed or at a “natural speed”^{72,147} are somewhat arbitrarily defined. Thus, the speed can be interpreted differently by each participant performing the movement; this can result in a wide range of movement velocities. However, it is similarly arbitrary when a participant is asked to perform a movement as fast as possible, i.e. self-paced rapid movements.^{60,63,70,71,73} The speed of the movement is not more controlled than during movements performed at a comfortable speed and interpretations can be different among different participants. In both cases, some participants might hesitate, due to pain or other reasons, to move the

limb at the designated speed. Furthermore, attempts to control the speed of a movement might cause alterations in the sequence of muscle contractions and the temporal features of the postural response.⁹⁰ One reason why we attempted to avoid increasing the women's pain during the leg lifts was that pain has the ability to alter the coordination of muscle activity.⁶⁷ However, one can speculate that people with pain perform limb movements at a different velocity than people without pain. The velocity (°/s) of rapid shoulder flexion performed in the standing position without controlling the speed was previously investigated by Hodges et al. as a part of a larger study.⁷³ They found no significant difference in the velocities of rapid shoulder flexions among people with and without LBP. Therefore, we assume that large variations in velocity between people with and without LBP is most likely neither a problem when performing movements at a comfortable speed.

The speed of limb movement is likely to influence the EMG onset detected with a computer-based method. More precisely, the rate of increase in the activation level¹⁷⁴ is likely to influence the EMG onset. The initiation of slow movement occurs with a slow increase in EMG amplitude; in contrast, rapid movements are associated with large EMG bursts. Therefore, the delay in the increase of EMG activity may cause a delay and variability in the identified onset⁹⁰ during limb movements performed at a comfortable speed that are not observed to the same extent during rapid limb movements. Despite the differences in speed of EMG amplitude increases, pre-programmed trunk muscle activity has been associated with upper limb movements, whether performed rapidly or at a "natural speed".⁷²

The extra loading

We used extra loading to: 1) to determine a more distinct onset of the PFM in the standing position, and 2) validate the response in terms of the relative activation level (% of MVC). The 5-kg weight was used during the arm lift in the standing position because, in that position, a relatively high background activity is present due to constant muscle tone in the PFM.¹³³ The 5-kg weight highlighted the distinction between the activity increase in the PFM and the background activity; this facilitated the detection of activity increases in the PFM. A 2-kg weight was used to validate the response in terms of the relative activation level (% of MVC) during the contralateral leg lift performed in the supine position in study I. The relative activation amplitude was higher with the extra 2-kg weight compared to no extra weight in all recorded muscles during the lift. This variation in the relative activation level with the extra 2-kg loading verified the method's usefulness in detecting variations in relative activation levels. In addition, the temporal activation pattern did not differ among the two pain-free groups and the group with persistent postpartum PGP during the contralateral leg lifts with and without the 2-kg weight.

Specific stabilizing exercises

We found that this concept of home-based SSE with visits every second week with the treating physiotherapist did not provide any benefits over the clinical natural course in women with persistent postpartum PGP. This contrasted with findings from Stuge et al.¹⁵⁶ However, the two studies differed in inclusion criteria, type of intervention, dosage, duration of the intervention, and the amount of guidance.

First, the women included in the two studies had different levels of severity in terms of disability. In our study, baseline disability ranged from no disability to moderate disability according to the ODI. In the Stuge et al. study,¹⁵⁶ baseline disability ranged from no disability to crippled. Moreover, the different levels of disability in the two studies led to different possible ranges for improvement. Second, the two study groups differed in terms of difficulties with load transfer between the trunk and legs. In our study, few women experienced difficulties with load transfer. In the Stuge et al. study,¹⁵⁶ a positive ASLR test was used as an inclusion criterion; i.e., all the women included experienced difficulties with load transfer. Thus, in our study, the participants did not exhibit functional instability in the pelvis; in contrast, all the women exhibited functional pelvic instability in the Stuge et al. study.¹⁵⁶ The low ASLR scores found in our study suggested that, either the women could compensate for functional instability in the pelvis,¹³⁸ or a different mechanism underlies the PGP.^{127,169} The latter case opens the possibility that the women in our study did not have functional instability in the pelvis; in that case, another type of treatment may have been more effective. Koumantakis et al.⁸² found that SSE did not provide any additional benefit to general exercises in people with subacute or chronic non-specific LBP with no clinical signs of spinal instability. Thus, the ASLR test might be useful for identifying women that would benefit from SSE treatment.

In the Stuge et al.¹⁵⁶ study, the intervention focused on SSE for specific activation of both the local lumbopelvic and global muscle systems, with an emphasis on motor control of coordinated muscle recruitment. In addition, they focused on information, body awareness, and ergonomic advice in specific real-life situations, and when indicated, the patients received relaxation, massage, stretching, and joint mobilization therapies. Thus, the Stuge et al. study provided a multifactorial treatment including SSE, which is recommended by the European guidelines for PGP.¹⁶⁹ In contrast, our study was a home-based design that prescribed SSE that only focused the local lumbopelvic muscle system.

The SSE model is designed to restore stability based on assumptions of how pain may occur in the spinal area.¹³¹ SSE have been demonstrated to reduce disability and pain in patients with chronic LBP and pelvic pain.^{44,93} However, there is limited evidence that the subjective improvements are associated with changes in the pattern of muscle activation.⁴⁴ Recent studies with small groups of subjects have provided initial evidence that the temporal aspects of activity in the transverse abdominal muscle can be modified with SSE.^{45,163,164} Tsao and Hodges¹⁶⁴ have demonstrated that the EMG onset of the transverse abdominal muscle occurred earlier during rapid arm flexion and

extension, after *a single treatment session*. The treatment emphasized isolation of the transverse abdominal muscle in a group of patients with recurrent LBP. In another study by the same research group,¹⁶⁵ persistent improvements in the EMG onset of the transverse abdominal muscle were observed after *4 weeks of training* patients with recurrent LBP to isolate the transverse abdominal muscle. Those changes were retained after 6 months. In the third study, improvements in recruiting the transverse abdominal muscle were measured by changes in muscle thickness detected with ultrasonography in patients with chronic LBP.⁴⁵ After adjusting for baseline values, recruitment was found to be greater in patients that performed motor control exercises than in patients that performed general exercises or spinal manipulative therapy. In addition, preliminary evidence showed that motor learning interventions had beneficial effects on pelvic floor and diaphragm kinematics during ASLR in subjects with SIJ pain.¹²⁶

Dosage of SSE & home-training

A home-based approach was chosen for the RCT, because it was a common approach used at clinics in Sweden at the time the present study was initiated. In addition, our goal was to apply the SSE in daily living, and the home-based approach without any training equipment was thought to be better for this purpose. However, with a home-based approach, it was more difficult to control for compliance, quality training and exercise frequency. It is possible that the home-training concept used in the present study did not provide sufficient support for achieving optimal results. Although Stuge et al.¹⁵⁶ also used a home-based approach, those patients met with a physiotherapist 11 times on average; more than twice as often as the women in our study. In addition, the exercise doses were different; in our study, women were instructed to train twice or more per day; in the Stuge et al. study, patients trained 30 to 60 min, 3 times per week. There was also a difference in the length of the training period. Our study was pragmatic, designed to resemble the typical clinical setting. Thus, we did not define the intervention period, but allowed the treating physiotherapist and the women to decide when the instructions and guidance were sufficient to continue independent home-training. At that time, the patient no longer visited any physiotherapist within the study more than on the follow-ups. No consensus has been reached on the most appropriate frequency-response rate for achieving significant results; the “one-size-fits-all” approach to exercise therapy is not based on research⁷⁹ and the most appropriate frequency-response rate need to be further investigated.

According to the self-maintained diaries, none of the patients reached the prescribed training frequency of 2 times per day. However, 78% of women in the treatment group reached stage 3 in the treatment program. Thus, more frequent visits with the physiotherapist could maybe have improved both compliance and the quality of training. Mens et al.¹⁰⁴ could not demonstrate that eight weeks of training the diagonal trunk muscles provided any benefit over training the longitudinal trunk muscles or no training at all in women with postpartum PGP. They discussed whether the results

might have been influenced by the way the training instructions were provided; i.e., in a 30 min videotape without individual guidance.

According to the guidelines from the Swedish Council on Health Technology Assessments on rehabilitation,¹⁵⁴ patients with persistent pain require multimodal rehabilitation that lasts for a prolonged period of time. The focus on multimodal rehabilitation is consistent with the European guidelines for PGP; they advocate multifactorial treatment, but they do not define it precisely.¹⁶⁹ A multimodal approach might also be recommended due to the frequent co-morbidity observed between postpartum depression and persistent postpartum PGP and lumbar pain.⁵²

Predictors of long-term disability

We identified two two-way interaction effects 3 months postpartum that were significantly associated with disability at 15 months postpartum, i.e. age + trunk flexor endurance, and level of disability + hip extensor strength. The main effects can be classified into three different dimensions: biological (age), physical functioning (trunk flexor endurance and hip extensor strength), and self-rated function (disability).

Women that experience persistent lumbopelvic pain at 3 months postpartum are at substantial risk for new episodes or long-term lumbopelvic pain.^{27,121,123} The recovery rates and the predictors are likely to differ between women with *postpartum PGP* and those with *persistent postpartum PGP*. Thus, when predicting consequences for women with persistent postpartum PGP, it is reasonable to include women with a built-in risk for long-term disability, etc. Therefore, when predicting for consequences in women with persistent postpartum PGP, it is important to use measurements taken postpartum and not rely solely on measurements taken during pregnancy. The time elapsed from pregnancy has been correlated to the result from the ASLR. When the ASLR test was performed postpartum, it could predict disability and evening pain in women with persistent PGP at 12 months postpartum;¹⁷² on the other hand, when the ASLR test was performed during pregnancy, it could not predict pain or disability late in pregnancy¹⁴⁶ or 3 months postpartum.¹⁴⁵ In addition, interaction effects can be important in identifying predictors of long-term disability. Robison et al did not detect any significant interaction effects between factors collected during pregnancy that predicted disability or pain in women with PGP late in pregnancy¹⁴⁶ or 3 months postpartum.¹⁴⁵ It is possible that long-term disability in women with postpartum PGP arises from different mechanisms than those involved in short-term outcomes and that this is partly revealed by the presence by interaction effects. However, Vollestad & Stuge collected factors postpartum and they did not identify any significant interaction effects when predicting for disability and evening pain at 12 months postpartum in women with persistent PGP.¹⁷²

Previous studies have found age to be a predictor for postpartum lumbopelvic pain. However, there are inconsistent results regarding age; thus, age has been proposed as a bimodal factor.¹⁷⁸ Both younger age¹⁶⁵ and older age^{55,161} have been reported as risk

factors. We found that the interaction effect comprising age + trunk flexor endurance was a stronger predictor of disability at 15 months postpartum than age alone. Based on our finding that age is a part of an interaction effect and the proposal of age as a bimodal factor,¹⁷⁸ we recommend caution in interpreting age as a sole predictor of disability in women with persistent postpartum PGP.

Previous studies have suggested an association between muscle function and PGP.^{117,156} Low endurance of the trunk flexors was identified as a predictor for PGP at 3 months postpartum.⁵⁵ The two identified interaction effects which both comprise muscle function, strengthen the suggested association between muscle function and PGP.^{54,167}

SSE were previously found to improve disability and evening pain in women with persistent postpartum PGP.¹⁷² However, our data did not support that home-based SSE were effective for reducing disability in women with persistent PGP at 15 months postpartum. It is possible that our RCT included too small a sample in the regression analysis to enable the identification of SSE. As discussed previously, it is also possible that the compliance and/or the prescribed dose were insufficient to achieve the quality of SSE required for improvement. However, the aim of the SSE is to improve muscle function; therefore, to some degree, our results confirmed those of Vollestad & Stuge,¹⁷² because we identified muscle function as an important main effect in the interaction effects. ODI is a measurement of self-rated function and partly a subjective measure of physical capacity. Higher disability measured with ODI was found to be predictive for disability both at 1-year and 5-year follow-ups for primary care patients with LBP.³⁹

The ASLR test performed postpartum was previously shown to be a predictor for disability and evening pain in women with persistent postpartum PGP.¹⁷² Our results could not confirm this finding. However, this discrepancy might be due to the fact that our study sample had lower ASLR scores than that of Vollestad & Stuge.¹⁷² In the present study, only 8% of women had ≥ 1 out of 6 points and none scored >2 points on the test; in the Vollestad & Stuge study, 60% had more than 4 out of 8 points. Due to the low scores in our RCT, it is possible that we underestimated the impact of the ASLR test as a predictor for disability in women with persistent postpartum PGP. Several factors did not emerge as significant predictors for disability at 15 months postpartum. This does not mean that they are of no importance for predicting disability in women with persistent postpartum PGP but merely that other factors were more important in this study population.

Methodological comments on the RCT

This RCT had several strengths. The study had a prospective design, used a structured classification system for PGP, and used multivariable statistics for identifying predictors. We used a classification system with good accuracy for differentiating between PGP and lumbar pain.⁵³ This promoted the inclusion of women with PGP and

exclusion of those with lumbar pain. However, as discussed earlier, if we had included women with persistent postpartum PGP that also demonstrated clinical signs of functional pelvic instability, i.e. a positive ASLR test, we might have drawn a different conclusion regarding the effect of home-based SSE on persistent postpartum PGP. Furthermore, the results are clinically generalizable, because women were included from different geographical areas and more than one physiotherapist monitored the training.

This study also had some methodological limitations. The women in our study had quite good functional status at baseline, which limited the possibility for improvement. Another limitation of the study was the relatively small number of women included in the follow-ups. Twenty-six percent and 32% were lost to the 3- and 6-month follow-ups, respectively. Furthermore, it was not possible to adjust for the uneven randomization of the two arms when it was identified in the ongoing study. Finally, in critical review of the design of the home-based SSE intervention, we could not rule out that the dosage, duration of the treatment period, the amount of guidance from the treating physiotherapist, and the quality of the exercises might have influenced the results in a negative way. Our linear regression analysis also had some limitations. It is crucial that all subjects respond to all questions and undergo all physical tests that are included in the analysis. Our regression analysis included only 50 out of the 54 women that had attended the 12-month follow-up, due to missing data. Furthermore, multivariate analysis is sensitive to small deviations in the data, and thus, to sampling error.

Clinical implications

Persistent postpartum PGP appears to be a heterogeneous condition and there is a need to define distinct subgroups. One clinical implication from the laboratory study is that it might be important to include an analysis of PFM activity in women with clinical signs of functional pelvic instability; i.e., a positive ASLR test. Other parameters of the pelvic floor have been investigated previously and results from those studies indicate that there is a dysfunction in the pelvic floor in subjects with PGP and similar conditions who demonstrate difficulties with the load transfer.^{14,15,128} Furthermore, our results provide some support for using the ASLR test to identify one subgroup of women with persistent postpartum PGP.¹⁰⁵ In addition, it might be possible to define PGP subgroups based on the presence or absence of a feed-forward mechanism in the PFM.

The concept of home-based SSE targeting the local lumbopelvic muscle system with physiotherapist visits every second week did not provide any benefit over the clinical natural course. Nevertheless, SSE were previously demonstrated to be effective at reducing pain and disability and improving HRQL in patients with chronic LBP and pelvic pain.^{44,93} Perhaps is SSE more appropriate for women with clinical signs of functional pelvic instability, based on high ASLR scores or, perhaps, for women that

lack a feed-forward mechanism in the PFM. Furthermore, women with persistent postpartum PGP might benefit from more supervised training,¹⁵⁶ particularly because they are at high risk for long-term problems.^{27,122} Finally, it might be important to consider multimodal rehabilitation in treating women with persistent postpartum PGP.¹⁶⁹

The identified predictors of disability in women with persistent PGP at 15 months postpartum can be evaluated clinically with questions concerning age and disability, and with methods for measuring hip extensor strength and trunk flexor endurance postpartum. In addition, the identified predictors demonstrate the importance of investigating different dimensions in order to understand which women with persistent PGP are at risk for disability at 15 months postpartum.

Future research

Further investigations are needed to explore the underlying mechanisms of persistent postpartum PGP and to identify subgroups within PGP. More studies are needed on the roles of the global and local lumbopelvic muscle systems in persistent postpartum PGP. The laboratory study was relatively small and should be repeated in order to confirm the result that the postural response of the PFM is similar among women with and without persistent postpartum PGP. Because one woman with persistent postpartum PGP failed to demonstrate a feed-forward response of the PFM, we will continue to investigate whether this woman represented a subgroup within persistent postpartum PGP. If we do identify this subgroup, we intend to investigate whether we can change the temporal activation pattern in the PFM to reduce disability and pain. In addition, more studies are required to investigate the mechanisms that govern the impact of SSE, and to identify subgroups of PGP and LBP that would be most likely to benefit from SSE treatment. Moreover, it is also important to consider and to continue to investigate whether all women with persistent postpartum PGP can benefit from SSE or whether some subgroups would benefit more from other types of treatments.

CONCLUSIONS

- Limb movements performed at a comfortable speed can be used to detect electromyographic onset of the pelvic floor muscles.
- Electromyographic onsets have demonstrated that a feed-forward mechanism is present in the pelvic floor muscles as an anticipatory response to leg lift tests performed at a comfortable speed in the supine position in women with and without persistent postpartum pelvic girdle pain. However, we cannot rule out that there might be subgroups within persistent postpartum pelvic girdle pain that have a different postural response of the pelvic floor muscles.
- This home-based concept of specific stabilizing exercises that focused on the local lumbopelvic muscle system with visits at the treating physiotherapist every second week did not add any benefit over the clinical natural course for treating persistent postpartum pelvic girdle pain.
- The results from the linear regression analysis demonstrated the importance of investigating different dimensions in order to understand which women with persistent postpartum pelvic girdle pain are most likely to be at risk for disability at 15 months postpartum. The results strengthened the proposed association between muscle function and pelvic girdle pain; but it also revealed a complex picture suggesting that interaction effects might be important when predicting for disability in women with persistent postpartum pelvic girdle pain.

SUMMARY IN SWEDISH

Ryggsmärtor i samband med graviditet är vanligt förekommande. Hälften av alla gravida drabbas av ryggsmärta och även om den avklingar inom tre månader från förlossningen för majoriteten av kvinnorna så blir inte alla besvärsfria. De kvinnor som har kvarstående ryggbesvär tre månader efter förlossningen löper en ökad risk att få besvär av mer långdragen natur eller upprepade episoder av ryggbesvär senare i livet. Studier har visat att graviditet verkar vara en väsentlig riskfaktor för kronisk ryggsmärta. Tio till tjugoprocent av medelålders kvinnor med upprepade episoder av ryggbesvär kan härleda sin första episod till en graviditet. För att kunna erbjuda effektiv behandling är det viktigt att precisera och undergruppera graviditetsrelaterade ryggbesvär för att kunna rikta rätt behandling till rätt grupp. Bäckensmärta är en av de största undergrupperna och 2/3 av de graviditetsrelaterade ryggbesvären anses komma från bäckenet. Det finns i dag inte tillräcklig kunskap om varför kvinnor drabbas av kvarstående bäckensmärta efter förlossning. En teori är att de har en minskad stabilitet i bäckenet. Stabiliteten i en led är beroende av hur en led är utformad samt funktionen i de omkringliggande ledbanden och musklerna. I tidigare studier har man funnit att ett flertal djupa buk- och ryggmuskler samt bäckenbottenmusklerna kan vara viktiga för stabiliteten i bäckenet. Kunskap om hur en effektiv behandling skall genomföras för kvarstående bäckensmärta efter förlossningen är också begränsad. En vanlig behandlingsmetod för ryggbesvär generellt är specifik stabiliseringssträning som syftar till att förbättra funktionen i de djupa buk- och ryggmusklerna samt bäckenbottenmusklerna.

Det övergripande syftet med denna avhandling är att ge underlag för förbättrad rehabilitering för kvinnor med kvarstående bäckensmärta efter förlossningen genom ökade kunskaper om: 1) aktivitetsmönstret i bäckenbottenmusklerna, 2) effekten av specifik stabiliseringssträning och 3) faktorer som kan förutspå funktionsnedsättning. Avhandlingen består av tre studier: A) en metodologisk studie som syftade till att utveckla en metod för att identifiera aktiveringsmönstret i bäckenbottenmusklerna i förhållande till starten av en ben- respektive armrörelse, B) en laborativ studie där metoden tillämpades på kvinnor med och utan kvarstående bäckensmärta efter förlossningen och C) en klinisk randomiserad kontrollerad studie som syftade till att undersöka effekten av ett hemträningprogram med specifik stabiliseringssträning av de djupa buk- och ryggmusklerna samt bäckenbottenmusklerna hos kvinnor med kvarstående bäckensmärta efter förlossningen. Träningen utfördes som hemträning med besök hos sjukgymnast varannan vecka. Ytterligare ett syfte i denna studie var att undersöka vilka faktorer som kan förutspå funktionsnedsättning 15 månader efter förlossningen.

Den utvecklade metoden är användbar för att identifiera aktiveringsmönstret i bäckenbottenmusklerna i förhållande till starten av en ben- respektive armrörelse. Både kvinnor med och utan kvarstående bäckensmärta efter förlossning aktiverar bäckenbottenmusklerna innan ett benlyft påbörjas. Eftersom bäckenbottenmusklerna är en av de komponenter som tros bidra till att stabilisera bäckenet så skulle denna

föraktivering kunna vara ett sätt att öka stabiliteten i bäckenet som svar på det ökade krav på stabilitet som en rörelse utgör. Vissa resultat samt litteraturuppgifter indikerar dock att de kvinnor som uppvisar kliniska fynd på minskad stabilitet i bäckenet inte har en föraktivering av bäckenbottenmuskulaturen och därmed en sämre stabiliseringsfunktion.

Konceptet med hembaserad specifik stabiliseringsträning med besök hos sjukgymnast varannan vecka var inte bättre än det kliniska naturalförloppet när det gällde att förbättra självskattad funktion, smärta och hälsa eller muskelfunktion hos kvinnor med kvarstående bäckensmärta efter förlossning. Det är möjligt att dosen inte var tillräcklig för att få effekt på musklerna. Det är också möjligt att det krävs andra behandlingsmetoder i kombination med träning av de djupa buk- och ryggmusklerna samt bäckenbottenmusklerna.

Resultaten från en sambandsanalys visar att funktionsnedsättning hos kvinnor med kvarstående bäckensmärta 15 månader efter förlossningen kan förutspås av olika faktorer som samverkar: ålder, muskelfunktion och självskattad funktion. Resultaten visar på en komplex bild som indikerar att hänsyn till flera samverkande faktorer är nödvändig för att förstå prognosen. Fortsatta studier krävs för att identifiera undergrupper av kvinnor med kvarstående bäckensmärta efter förlossningen och därmed ge underlag för att kunna erbjuda effektiva behandlingsmetoder.

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