Deadlift training for patients with mechanical low back pain

A comparison of the effects of a high-load lifting exercise and individualized low-load motor control exercises

Lars Berglund

Department of Community Medicine and Rehabilitation, Physiotherapy
Department of Surgical and Perioperative Sciences, Orthopaedics
Umeå University, Sweden
Umeå 2016

"If it doesn't challenge you, it doesn't change you"

Fred DeVito

Table of Contents

Abstract

Disability due to low back pain is common. While evidence exist that exercise is effective in reducing pain and disability, it is still largely undetermined which kind of exercises that are most effective. The overall aim of this thesis was to evaluate and compare the effects of a high-load lifting exercise and individualized low-load motor control exercises for patients with nociceptive mechanical low back pain. A secondary aim was to evaluate which patients benefit from training with a high-load lifting exercise.

All four papers in this thesis were based on a randomized controlled trial including 70 participants with nociceptive mechanical low back pain as their dominating pain pattern. Participants were randomized into training with either a high-load lifting exercise (HLL), the deadlift, (n=35) or individualized low-load motor control exercises (LMC) (n=35). Both interventions included aspects of pain education. All participants were offered twelve sessions during an eight week period. The effects of the interventions were evaluated directly after and twelve months after the end of the intervention period. Outcome measures were pain intensity, activity, disability, physical performance, lumbo-pelvic alignment and lumbar multifidus muscle thickness.

There was a significant between-group effect in favour of the LMC intervention regarding improvements in activity, movement control tests and some tests of trunk muscle endurance. For pain intensity there were no significant differences between groups. A majority of participants in both intervention groups showed clinically meaningful improvements from baseline to two and twelve month follow-up regarding pain intensity and activity. There were no significant differences between HLL and LMC regarding the effect on lumbo-pelvic alignment or lumbar multifidus thickness. The participants who benefit the most from the HLL intervention were those with a low pain intensity and high performance in the Biering-Sørensen test at baseline.

The results of this thesis showed that the HLL intervention was not more effective than the LMC intervention. The LMC was in fact more effective in improving activity, performance in movement control tests and some tests of trunk muscle endurance, compared to the HLL intervention.

The results imply that the deadlift, when combined with education, could be considered as an exercise to produce clinically relevant improvements on pain intensity in patients who prefer a high-load exercise. However, before considering deadlift training, the results suggest that pain intensity and performance in the Biering-Sørensen test should be evaluated.

Sammanfattning på svenska

Ländryggssmärta är ett vanligt och för individen begränsande tillstånd. Det finns många olika typer av ländryggssmärta och det finns olika sätt att undersöka och kategorisera patienter med ländryggssmärta. I denna avhandling ingår patienter som kategoriserats med mekanisk ländryggssmärta, det vill säga en smärta som påverkas av patienternas hållnings- och rörelsemönster.

Man vet att träning är effektivt för att behandla ländryggssmärta men det är ännu oklart vilken typ av träning eller vilka övningar som är mest effektiva. Rörelsekontrollträning är en typ av träning som ofta används. När man tränar rörelsekontroll är målet att individen ska förstå hur hållning och rörelseutförande påverkar smärtbilden. Målet är också att bli bättre på att kontrollera sina rörelser i ländryggen och intilliggande leder, exempelvis höfterna, för att på så sätt minska smärta och förbättra funktionen i rörelser och i vardagliga aktiviteter. Hittills har träning av rörelsekontroll inom rehabilitering företrädesvis skett med individanpassade lågbelastande övningar. Träning med högbelastande övningar, exempelvis marklyft, har inte tidigare utvärderats i någon större omfattning.

Det huvudsakliga syftet med denna avhandling var att jämföra effekterna av en högbelastande övning, marklyft, med individanpassade lågbelastande övningar för rörelsekontroll. Anledningen till varför marklyft utvärderades var att övningen fokuserar både på rörelseutförande och engagerar samtlig rygg- och höftmuskulatur. En annan fördel med marklyft som tränas med skivstång och vikter är att man enkelt kan stegra belastningen för att uppnå en styrkeökning. Ett ytterligare syfte var att undersöka vilka patienter som blev mest hjälpta av att träna marklyft. Skälet var att även om resultat på gruppnivå kan påvisa att en träningsform är effektiv, kan det finnas individer som inte uppnår ett gott resultat. Eftersom marklyft aldrig tidigare utvärderats i en större studie var det viktigt att ta reda på om denna träningsform passar för alla patienter med mekanisk ländryggssmärta.

Samtliga delstudier i avhandlingen baseras på en och samma studie. Studien, som är en randomiserad kontrollerad studie, inkluderade sjuttio patienter som rekryterats från företagshälsovården. Deltagarna erbjöds tolv träningstillfällen under åtta veckor och under dessa tillfällen fick de också utbildning om hur de själva kunde påverka sin ländryggssmärta.

Denna avhandling är den första som utvärderar marklyftsträning för patienter med mekanisk ländryggssmärta. Resultatet visar att marklyft inte

är en mer effektiv träningsform än individanpassad lågbelastande rörelsekontrollträning. Däremot verkar marklyft, i likhet med, de individanpassade lågbelastande övningarna, kunna ge positiva effekter på smärta och tester av fysisk prestation samt kunna påverka hållningen i ländryggen och tjockleken på ländryggens djupa muskellager. Det bör dock tilläggas att individanpassade lågbelastande övningar för rörelsekontroll förefaller vara nödvändiga för att förbättra funktionen i rörelser och i vardagliga aktiviteter. Vid jämförelse gav de individanpassade lågbelastande övningarna en klart överlägsen effekt för mått på rörelsekontroll och funktion i vardagliga aktiviteter jämfört med marklyftsträningen. Resultatet visade också att de patienter som blev mest hjälpta av att träna marklyft var de med låg smärtnivå och hög prestation i ett test av uthållighet i rygg- och höftmuskulatur (Biering-Sørensen).

Slutligen tyder resultaten på att marklyft i kombination med utbildning kan användas för att uppnå kliniskt relevanta förbättringar på smärta för patienter som föredrar en högbelastande övning. Resultaten visar dock att det är viktigt att utvärdera smärtintensitet och uthållighet i rygg- och höftmuskulatur innan man påbörjar den högbelastande marklyftsträningen.

Abbreviations

LBP – low back pain

RCT – randomized controlled trial

m. TA – musculus transversus abdominis

HLL – high-load lifting exercise

LMC – low-load motor control exercises

BMI – body mass index

VAS – visual analogue scale

PSFS – patient-specific functional scale

RMDQ – Roland and Morris Disability Questionnaire

TSK – Tampa scale of kinesiophobia

B-S – Biering-Sørensen

RUSI – rehabilitative ultrasound imaging

$LOW_{lu/sa}$ – participants below the 25th percentile for lumbar lordosis or sacral angle

$MID_{lu/sa}$ – participants between the 25th and 75th percentile for lumbar lordosis or sacral angle

$HIGH_{lu/sa}$ – participants above the 75th percentile for lumbar lordosis or sacral angle

Original Papers

This thesis is based on the following papers, referred to in the text by their Roman numeral I-IV

I. Aasa B, **Berglund L**, Michaelson P, Aasa U. Individualized low-load motor control exercises and education versus a high-load lifting exercise and education to improve activity, pain intensity, and physical performance in patients with low back pain: a randomized controlled trial. J Orthop Sports Phys Ther. 2015 Feb;45(2):77-85, B1-4. doi: 10.2519/jospt.2015.5021.

II. **Berglund L**, Aasa B, Michaelson P, Aasa U. Sagittal lumbo-pelvic alignment in patients with low back pain and the effects of a high-load lifting exercise and individualized low-load motor control exercises – a randomized controlled trial. (Submitted)

III. **Berglund L**, Aasa B, Michaelson P, Aasa U. The effects of low-load motor control exercises and a high-load lifting exercise on lumbar multifidus thickness – a randomized controlled trial. (Submitted)

IV. **Berglund L**, Aasa B, Hellqvist J, Michaelson P, Aasa U. Which Patients With Low Back Pain Benefit From Deadlift Training? J Strength Cond Res. 2015 Jul;29(7):1803-11. doi: 10.1519/JSC.0000000000000837.

The original papers have been reprinted for this thesis with the kind permission of the publishers.

Preface

Low back pain has been a persistent topic for me before I even started my education to be a physiotherapist until today as I write this doctoral thesis. On a personal level, musculoskeletal problems of different sorts have been an element of my own sports career from when I played soccer as a teenager, to the present where I occupy myself with the sport of powerlifting. In competitive sports on the elite-level, pain and discomfort are commonly accepted and almost a necessity as the saying goes; "no pain, no gain".

Doing sports and, ironically, being injured, founded and fueled my interest in physiotherapy. In a sense, my own previous low back pain problems have shaped my mindset as a physiotherapist. Through these I have learned the importance of proper movement strategies and their impact on the musculoskeletal system. In my own training, coaching, clinical work as well as in my continuous education as a physiotherapist this perspective has been a central part.

Throughout my studies at an advanced level I have had the opportunity to continue to deepen my knowledge within the topic of low back pain in a research setting. For this I am grateful to my main supervisor, Ulrika Aasa, supervising me both during my master's thesis as well as this doctoral thesis.

Simultaneously as I have worked on my master's and my doctoral thesis I have also worked in primary health care clinics in Boden and Umeå, mainly with patients presenting with different neuromusculoskeletal disorders. Through my clinical work I feel that I have had a perfect opportunity to implement the knowledge I gained during my studies and research. However, I have also experienced the many difficulties that exist regarding the assessment and treatment of neuromusculoskeletal disorders in general, and specifically low back pain.

In my relatively short career as a physiotherapist I believe I have covered a lot of ground regarding the subject of this thesis, i.e. low back pain and exercise. From the perspectives of an athlete, coach, physiotherapy student, clinician and researcher, I have learned many valuable lessons which I will carry with me in my future career.

Introduction

Low back pain (LBP) is a highly prevalent, costly and disabling condition. LBP is also one of the most common reasons for patients to consult physiotherapists in primary health care [3, 31]. While LBP can arise as a consequence of specific pathology (e.g. osteoporosis, infections or fractures) or diseases, LBP is most often not attributable to these conditions [12]. There are many proposed risk factors for developing persistent/chronic (i.e. symptoms lasting longer than three months) LBP [3, 62], however, there is no single and solid explanation to how and why persistent LBP develops. During the last years, the importance of posture and movement patterns have been highlighted. Some researchers and clinicians hypothesize that persistent LBP can be linked to unfavorable posture and/or movement patterns which invoke micro-trauma to the various tissues in the low back, thus over time leading to LBP or persistence of LBP related symptoms [71, 81]. Regardless of the origin of persistent LBP, current evidence based guidelines state that exercise in combination with education is the most effective treatment approach [77].

Theoretical framework for the thesis

In physiotherapy, movement is the overarching theme of the profession, whether it may be in regard to the neurological, respiratory or musculoskeletal fields of practice, to name a few [17]. Although movement is also of importance and in focus in other modern professions and research fields, physiotherapy is the only profession within the health care system that explicitly uses movement as an approach for describing health, pathology, assessments and interventions [17, 108]. As a physiotherapist, movement is a central concept in relation to health from a physical, psychological, emotional and social point of view [107], i.e. considering an individuals' health within a biopsychosocial model [101].

In this thesis, movement and movement patterns have a significant place in relation to the assessment and classification of patients with LBP, outcome measures and the interventions evaluated. The biopsychosocial model [24, 100] was primarily used as a basis for the clinical reasoning process when screening the participants but also during the interventions.

The movement continuum theory of physiotherapy

The movement continuum theory of physiotherapy by Cott et al. [17] was first presented in 1995 with the aim to define physiotherapy by highlighting

the unique perspectives of how physiotherapy incorporates movement in describing health, pathology, function and disability. Within the framework, movement is described as an entity within several levels of an individual, from a cellular level where movement will have effects on the movement of the individual in a social context, and vice versa [17]. To illustrate, a deviating posture could be the adaptive response to LBP in order to alleviate stress on aggravated tissues, but it could also be the opposite, i.e. a posture which repeatedly puts abnormal stress on tissue thus causing LBP. The reason for adapting different postures in the first place could also be influenced by social or environmental factors, e.g. workers on an assembly line or in an office will adopt the posture necessary to perform the occupational tasks required and a depressed individual might also change his/her posture as an effect to their state of mind. In either case, movement undoubtedly have a myriad of effects on tissue and social levels and therefore also physiotherapy have a role in each of these levels.

Ultimately, physiotherapy involves assessment of movement and different modalities to improve qualities related to movement with the goal of improving movement capabilities and health [17]. In this thesis, the concept of a movement continuum becomes relevant in several ways but mainly in terms of assessment of movement patterns in patients with LBP and the interventions, consisting of exercise in combination with education, which are evaluated.

The biopsychosocial model

The biopsychosocial model was first presented in the 1970's and intended to contribute with a broadened perspective on health and disease in comparison with the traditional biomedical model [24]. In essence, it states that to understand illness one must consider the impact of all factors surrounding the individual, from biological, to psychological and social factors [24]. The model therefore also contributes with an explanation why a certain disease could be experienced in different ways and create a different impact on health for different patients [24].

As detailed in the biopsychosocial model, all health conditions including LBP, affects an individual on all levels from biological to psychological and social [6]. Therefore, clinicians are recommended to assess patients with LBP in regard to all levels [71, 77], and through a process of clinical reasoning and diagnostic triage, determine which components that primarily needs to be addressed in order to meet the patients goals.

In the clinic, patients with LBP mainly seek out a physiotherapist with the goal to decrease the pain and disability associated with LBP [2]. Pain has been defined by the International Association for the Study of Pain (IASP) as *"An unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage"* [46]. This definition also indicates that pain is a complex sensation for the patient to describe, for the clinician to ask about and interpret, and for the researcher to measure. Besides pain, disability or limitations in activity are other main complaints in patients with LBP. It is not uncommon for patients to become so disabled that they need to be on sick-leave [54].

In this thesis, the inclusion and exclusion of participants were performed with the aim to include participants within a specific sub-group of patients with LBP. This process of assessment included the consideration of biological, psychological and social factors of the participant's LBP. Also, during the interventions, the physiotherapists did not solely provide exercises but also addressed the participant's thoughts and beliefs about their LBP in relation to movement. This education was performed on an individual basis, as it is also commonly performed in clinical practice.

Epidemiology of low back pain

The prevalence of LBP in the north of Sweden has been reported to be 44 %, of which 55 % were women and 45 % men [11]. The prevalence of LBP was most common in the age group 55-64 years [11]. These figures have also been found in a systematic review, including studies from different populations over the world, which aimed to investigate the prevalence of LBP from a global perspective [45]. The incidence for first time LBP during one year is estimated to be between 6.3 % and 15.4 % and the incidence for LBP including recurrent episodes of LBP up to 36 % [45]. The national economic burden of LBP in Sweden was calculated to 1860 million EURO in 2001, for which 84 % were indirect costs, i.e. related to loss of productivity [23]. In a systematic review which aimed to determine the societal economic burden of LBP from an international perspective the authors concluded that the total burden of LBP must be considered significant in most countries [18].

Definitions and classifications of low back pain

In the literature, the most common definition of LBP is defined based on the anatomical location of symptoms, i.e. *"pain and discomfort localized below the costal margin and above the inferior gluteal folds, with or without leg pain"* [12].

LBP is also further commonly classified by the duration of symptoms. A duration of pain lasting up to six weeks is classified as acute, six to twelve weeks as sub-acute and a duration beyond twelve weeks as chronic or persistent [12]. Furthermore, LBP usually appears in an episodic manner, i.e. a period of symptom relief in between periods of persistent symptoms, and in those cases defined as recurrent LBP [12].

Beyond the definition and classification based on localization and duration of symptoms, several attempts to classify LBP into further sub-groups have been described. Some classification systems incorporate the same broad division of LBP which separates LBP disorders originating from specific red flag conditions, e.g. fractures, tumors or inflammatory diseases, from what is defined as non-specific conditions whereas the LBP cannot be attributed to a specific pathological tissue or condition [12]. In the literature, non-specific LBP is used interchangeable with 'common' LBP as this subtype is considered the most prevalent.

However, the lack of clear cut results in randomized controlled trials (RCT) evaluating the effects of different interventions for non-specific LBP has shaped a new direction in the research [28]. Instead of solely focusing on efficacy trials, there are now an emphasis on investigating whether there are factors related to heterogeneity of the etiology and presentation of symptoms in patients with non-specific LBP that contribute to the lack of strong treatment effects in trials.

Therefore, based on the proposed heterogeneity, researchers [25, 71, 105] have suggested that there might in fact exist sub-groups of patients, within the broad definition of non-specific LBP, that have certain factors related to the presentation of signs and symptoms in common. These sub-groups are also believed to be more likely to respond to individualized treatment based on their specific classification [28].

As for the basis of classification, some of the different systems used to classify LBP differ fundamentally regarding their theoretical background and approach when assessing the patients' history and signs and symptoms in the physical examination. For example, some systems rely on the physiotherapists ability to define specific anatomical structures as pain generators/origin of symptoms [75], others classify patients in relation to the risk of poor prognosis [8], some rely on assessment of signs and symptoms to define the dominating pain mechanisms [88-90], and some classify patients based on examination of movement impairments related to the patients symptoms as reported in the history and observed in physical examination [71, 105]. While a number of these systems have more aspects

in common, others follow completely different paradigms, e.g. a pathoanatomical approach compared to a movement system impairment syndrome approach [50]. Nevertheless, while the main aim for all systems are to describe the patients' specific impairments in order to improve treatment outcomes, there is no clear consensus as to which classification system is the best to describe meaningful sub-groups of patients with LBP [29]. However, a review of the most commonly used classification systems show that classification systems based on assessing posture and movement patterns and pain mechanisms have the best inter-rater reliability of the different systems [50].

As mentioned, all health conditions affect individuals on biological, psychological and social levels, and no component can be disregarded when assessing and classifying patients with LBP [71]. Still, the aim of the classification process is to, through clinical reasoning, assess which components dominate the patients' LBP problem. For the purpose of this thesis, patients were classified using a mechanism-based approach in regard to the patients' dominating pain mechanism [71, 76, 90]. Specifically, patients with a dominating pain pattern of nociceptive mechanical LBP were sought. These patients present with pain localized to the area of injury/dysfunction (low back) which have a proportionate response to aggravating and easing factors such as sustained postures or specific movements [76, 90]. Consideration to psychological components were taken during physical examination at it was ascertained that mechanical factors and not negative beliefs dominated the patients experience of pain according to the definition of nociceptive mechanical LBP [76, 90].

Structure and function of the low back and impairments associated with low back pain

The low back could be considered mainly comprised of the motion segments of the lumbar spine, i.e. the vertebraes, facet joints, ligaments, nerves and the muscles attached to the vertebrae as well as surrounding the lumbar spine. However, the structures and movements of the low back are closely interconnected, through joint connections and soft-tissue structures (muscle, fascia), with the thoracic area, pelvis and hip joint, i.e. the adjacent motion segments [49].

When describing the structure and function of the low back in relation to LBP, much attention has been directed to the control of movements in the lumbar spine, earlier referred to as stability [10, 73]. Movement control/stability can be defined in several ways, however, in the eyes of a physician or physiotherapist, it could be defined as the ability to limit

patterns of displacement during load to avoid damage to anatomical structures [10]. Almost two decades ago, Panjabi [73] proposed that a majority of LBP could be a consequence of "clinical instability", i.e. a mechanical origin where the lumbar spine has lost its normal pattern of motion which in turn causes pain. In an attempt to further define and study this condition of LBP, Panjabi [73] describes a model for the stability of the spine. In this model there are three components that together provide stability to the spine: the spinal column which provides the passive support, the muscles of the spine providing active stabilization, and the neural control unit which evaluates and coordinates muscle response to meet demands of stabilization in relation to e.g. outer forces [73]. The seminal work by Bergmark in 1989 [10], was the first to denominate and classify muscles surrounding the spine and trunk according to their role in creating control of spinal movements in the low back. In his article [10], muscles that have their origin or insertion at a vertebrae and act to create stiffness between lumbar spine segments, e.g. lumbar multifidus muscles, are classified as muscles belonging to the local system. According to Bergmark [10], muscles that connect the thoracic cage, low back and pelvis and act to increase intra-abdominal pressure and transfer load between the thoracic cage and pelvis are classified as muscles in the global system.

The work by Bergmark [10], even though influential, mainly takes a mechanical standpoint when considering the functional anatomy of the low back in relation to muscle function. Due to the extensive research that has progressed in the area of assessment and treatment of LBP since the original work of Bergmark [10], several researchers and physiotherapists [15, 71, 81] have emphasized a more comprehensive approach in the assessment of the structure and function of the low back. In these approaches, the structure and function of the low back is examined in detail but also as a whole and in relation to adjacent movement segments. For example, a patient with LBP that is worsened during tasks involving lifting above shoulder height, i.e. shoulder flexion, and upon assessment, display an increased movement in lumbar spine extension during these tasks might have several dysfunctions. The m. obliquus externus ability to counteract the extension moments to the lumbar spine might be impaired, but there could also be presence of muscular restrictions in the m. latissimus dorsi. This relationship between increased movement and restrictions causes movement to take the path of least resistance, i.e. to the lumbar spine. Similarly, a patient with LBP during forward bending might have a tendency to move with a larger magnitude in the lumbar spine than in the hip joint due to decreased stiffness in the lumbar spine and muscular or articular restrictions in the hip joints. This concept of chain reactions in adjacent movement segments is described by Sahrmann [81] as the concept of relative flexibility.

In the clinic, physiotherapists assessing patients with LBP examine specific aspects of the function of the low back such as; alignment, relative stiffness, flexibility, movement control, muscle activation patterns, strength, endurance, etc. [76]. As mentioned before, there is no consensus regarding the best way to classify patients with LBP but it should be noted that several impairments related to the structure and function of the low back has been shown in patients with LBP.

Patients with LBP and asymptomatic individuals have been shown to have differences in their seated lumbo-pelvic alignment [20] and muscle activation pattern in sitting [19]. Furthermore, the movement control of the lumbo-pelvic area has been studied in a number of ways in patients with LBP. A study by Porter et al. [78] showed that during forward bending of the trunk, patients with persistent LBP moved relatively more in the lumbar spine than in the hips, compared to asymptomatic individuals. Patients with LBP also seem to have an impaired ability to maintain the lumbar spine in a neutral position while performing active movements in adjacent joints compared with asymptomatic individuals [58]. The performance in tests of endurance and isometric strength of the trunk muscles have also been shown to differentiate patients with LBP and asymptomatic individuals [55, 65, 84]. Regarding the structure of the low back, several studies have shown that the muscles surrounding the lumbar spine (especially the local stabilizers, e.g. lumbar multifidus muscles) have a decreased size and symmetry compared to asymptomatic individuals [9, 37, 41].

A couple of explanations regarding the cause of the mentioned impairments have been suggested in the literature. The most prominent explanation is that the experience and presence of pain affects motor performance on several levels, for example resulting in an altered distribution of muscle activity within and between muscles, changes to proprioception and decreased maximal force output [4, 43]. Another theory is that patients with persistent LBP have a general deconditioning of tissues, either as a consequence of their first LBP episode or as a result of the persistence of symptoms [91]. According to Steele et al. [91] one of the most noticeable tissue changes, i.e. deconditioning, in patients with LBP are atrophy and fatigability of the lumbar extensors, e.g. the lumbar multifidus muscles. However, there is also the theory that the mentioned impairments, observed in patients with LBP, could in fact be caused by non-ideal alignment and movement patterns which, in turn, could also be associated to the original cause of the patient's LBP [81]. All in all, it is difficult to dismiss any of these theories since most of the mentioned studies regarding different impairments have a cross-sectional design.

Evidence based guidelines for the treatment of low back pain

Currently, evidence based guidelines for the treatment of persistent LBP recommend that patients are initially examined through a diagnostic triage [51, 77] within a biopsychosocial framework [71]. The aim of the triage is to identify and classify the patients' LBP disorder in terms of non-specific (i.e. pain not attributable to a specific anatomical structure), specific pathology (e.g. spondylolisthesis), serious pathology (i.e. red flag disorders such as tumors, fractures or infections) or due to a nerve lesion [51, 77]. Moreover, an assessment of psychosocial factors, such as fear of movement, anxiety or poor coping strategies, is also recommended in order to prioritize the need for a more cognitively oriented treatment strategy [77]. Further, an assessment of signs and symptoms of ongoing pain and tissue mechanisms can be included in the triage process in order to further classify the LBP disorder in relation to further management [71, 76, 87].

After the screening process and classification of a LBP disorder, that is consistent with non-specific LBP, the present guidelines emphasize the importance of patient education regarding diagnosis, prognosis, self-care advice and prevention [77]. A study by Moseley [66] illustrated this importance and showed that education regarding pain physiology resulted in a change in pain cognition that was associated with improvements in physical performance. The evidence based guidelines also indicate that in combination with education, exercise have the greatest support as the most effective intervention [77].

Several kinds of exercise interventions have been evaluated in RCTs and also systematically reviewed regarding their efficacy on pain and disability. For example walking [70], yoga [83], pilates [74, 111], specific resistance exercise of lumbar extensors [92], motor control exercises [82] and resistance training [53] have been evaluated. Overall, these exercise interventions show low to moderate quality evidence for being more effective than minimal/control intervention, however, no specific exercise intervention seem more effective than others, when evaluated for the effect on pain and disability [70, 82, 83, 111]. These results are confirmed by two other reviews of the effects of exercise interventions, defined as any physical exercise [85, 106]. The review by Searle et al. [85] also concluded that there are beneficial effects for resistance training and coordination/stabilization exercise interventions and that cardiovascular interventions are ineffective. Notably, the patients included in most studies in the mentioned reviews were not classified beyond persistent LBP.

Finally, guidelines also stress the importance of describing specific sub-group of patients with persistent LBP that benefit from certain exercise interventions [77].

Research gaps – related to exercise and low back pain

Exercise interventions are effective in reducing pain and disability in patients with persistent LBP. However, it is largely unknown which exercise interventions are the most effective and if certain interventions could be more effective for certain sub-groups of patients with persistent LBP [106]. A reason for this could be that very few studies have described the underlying signs and symptoms of the mechanisms related to the patients' LBP. One systematic review concluded that this needs to be done, since an individualized approach produces favorable results compared to interventions that are not directed to a specific sub-group [29]. Beyond these issues, the question of how different exercise interventions reduce pain and disability in patients with LBP remains unanswered, even though several theories exist [36, 94].

One theory which explains how exercise interventions can reduce pain and disability is that the LBP is associated with the mentioned impairments to the structure and function of the low back. Subsequently, by performing exercises which address these impairments, e.g. atrophy of local stabilizing muscles surrounding the spine or impaired movement control, the pain, disability and recurrence of symptoms for patients with persistent LBP will be reduced [79, 81]. In conjunction to this theory, several approaches have been evaluated, for example motor control exercises with special emphasis on targeting the impairments of local stabilizing muscles [39], movement control exercises oriented to correcting faulty movement patterns [57] or isolated resistance training of back extensors [93]. These exercise interventions have been proven to reduce pain and disability with a concurrent effect on several of the mentioned impairments, for example, lumbo-pelvic movement control [57], muscle size of the lumbar multifidus muscles [39], and strength of lumbar extensors [93]. Despite these mentioned positive effects regarding pain, disability and impairments related to the function of the low back, the details regarding the optimal exercise approach for re-training have not been fully explored.

However, a rationale for motor control training has been described in textbooks [42, 79] and evaluated in several studies [38, 40, 98, 99].

Low-load motor control exercises

Low-load motor control exercises have been used in clinical practice for some time and evaluated in research studies [16, 27, 60]. Motor control exercises are most often described as low-load isometric exercises targeting individual stabilizing muscles of the spine [82], e.g. the lumbar multifidus muscles or the transversus abdominis muscle (m. TA). In some studies, low-load motor control exercises also include exercises emphasizing movement patterns during daily activities, coordination between muscles, and target posture [16]. Regardless of definition, the aim of low-load motor control exercises is to correct motor control (sometimes also called movement) impairments in order to minimize the load to the tissues that signal pain.

When using motor control exercises as treatment for patients with LBP, certain principles are often accentuated. Exercises should be performed pain-free in order to emphasize pain control and avoiding compensatory actions and tissue stress [79]. Also, exercises should initially be performed with a low-load in order to highlight activation of targeted muscles of the local system and preventing muscles of the global system to "take over".[79, 98, 99]. Finally, exercises should be specific in their design in order to stimulate the desired specific effect [79]. For example, a study by Tsao and Hodges [98] compared the onset for the m. TA during a single arm lift before and after having patients either train a sit-up exercise or specific activation of the m. TA. Patients in both groups achieved comparable activation amplitudes of the m. TA during training, however, only the patients who trained the specific m. TA exercise had an effect on the onset for the m. TA [98].

To sum up, there is evidence that low-load motor control exercises, performed with the aforementioned principles in mind, are effective for patients with persistent LBP [82]. However, the basis for some of these principles, for example if the same, or greater, effects of exercises can be achieved by performing them with a high-load while also emphasizing proper movement patterns and posture, have not been thoroughly evaluated in clinical trials.

A high-load lifting exercise, the deadlift

One high-load exercise which could be used as a comparison to the low-load motor control exercises is the deadlift exercise. The deadlift exercise is a popular resistance training exercise where a barbell is lifted from the ground. It is also an event in the sport of powerlifting where the athletes attempt to lift the highest load possible in a single attempt [47]. Traditionally, the

deadlift is used in resistance training to increase muscle mass, strength and power in the back, hip and thigh muscles [21].

To perform the deadlift within the recommendations for safe practice, the lumbar spine should be kept in a neutral position at all times and the bar should be lifted close to the body [68]. In order to attain this lifting technique, several demands are put on the individual. Firstly, since the principal movements during the deadlift are done in the hip, knee and ankle joints, coordination between joints is necessary in order to dissociate movements in the hip, knee and ankle joints from those in the lumbo-pelvic region. Secondly, the individual needs to activate stabilizing muscles of the spine in order to prevent deviation from the neutral position due to the external moments which are imposed on the low back while lifting [14]. The activation of the back extensor muscles have been shown to be substantial and even greater than when performing commonly used trunk stabilizing exercises [34, 69].

Seeing that the deadlift involves important aspects of both movement control, muscle activation and strength, the deadlift exercise could be a valid exercise to improve pain and disability by addressing the mentioned impairments observed in patients with LBP. Compared to low-load motor control exercises, the deadlift exercise could have some advantages. When using the deadlift the potential to progress the intensity is well above the needs of patients and healthy individuals. This could be advantageous in order to increase strength and contribute to hypertrophy of atrophied back extensor muscles, i.e. addressing the proposed deconditioning of tissues as mentioned earlier [91]. Also, resistance training has been demonstrated to induce post-exercise hypoalgesia in healthy individuals [67], which could be a potential benefit with deadlift training rather than low-load motor control exercises. Training with the deadlift, as a rehabilitative exercise for patients with persistent LBP, have so far only been evaluated in one small pilot study, showing positive effects on pain and disability [44].

Rationale to the thesis

The rationale behind this thesis comes from the present need of studies evaluating specific exercise interventions for specific sub-groups of LBP [77, 106]. As described above, there is a lack of knowledge whether the positive effects seen in studies using low-load motor control exercises also can be found when using a high-load lifting exercise, such as the deadlift.

In my personal experience, I have met some patients with persistent LBP who indicate that they would prefer more challenging or physically taxing rehabilitative exercises than which are normally prescribed to them by their physiotherapist. At the same time I have also met physiotherapists that believe that such exercises, for example the deadlift, might be detrimental to the low back and should be avoided. Contrary to such beliefs, the mentioned pilot study, evaluating deadlift training for patients with persistent LBP, did in fact show positive effects on pain and disability, and did not result in any adverse events [44]. However, the pilot study did not include a control group and there are no other previous trials comparing the effects of deadlift training to other interventions, such as individualized low-load motor control exercises, for patients with nociceptive mechanical LBP.

Therefore, there was a rationale to compare training with a high-load lifting exercise, the deadlift, with individualized low-load motor control exercises, to see how the effects compared. Subsequently, since the effects of deadlift training had not previously been evaluated in an RCT it was also indicated, in line with present guidelines [77], to evaluate which patients benefit from training with a high-load lifting exercise.

Aim

The overall aim of this thesis was to evaluate and compare the effects of a high-load lifting exercise and individualized low-load motor control exercises for patients with nociceptive mechanical LBP.

Specific aims

i.   Compare the effects of a high-load lifting exercise and individualized low-load motor control exercises for patients with nociceptive mechanical LBP on pain intensity, activity, physical performance, lumbar multifidus thickness and lumbo-pelvic alignment (Paper I-III)

ii. Investigate the effects of a high-load lifting exercise and individualized low-load motor control exercises on lumbo-pelvic alignment in patients with nociceptive mechanical LBP with a special emphasis on patients with extreme variations of lumbo-pelvic alignment (Paper II)

iii. Evaluate which patients with nociceptive mechanical low back pain benefit from training with a high-load lifting exercise (Paper IV)

Materials and methods

Design

This thesis was based on data from an RCT including patients (n=70) with a dominating pain pattern of nociceptive mechanical LBP. The study protocol was registered in the Clinical Trial Registry of the U.S. National Institute of Health (NCT00791596) (available at https://www.clinicaltrials.gov/ct2/show/NCT01061632). The interventions consisted of a high-load lifting exercise (HLL), i.e. the deadlift exercise, and individualized low-load motor control exercises (LMC). Details regarding study design are found in Table 1.

Table 1. Overview of study design.

	Paper I	Paper II	Paper III	Paper IV
Design	RCT	RCT	RCT	Secondary analysis
Outcome measures	Pain intensity, activity and physical performance	Lumbo-pelvic alignment	LM muscle thickness	Pain intensity, disability, activity
Data Collection	Baseline, 2 and 12 months	Baseline and 2 months	Baseline and 2 months	Baseline and 2 months
Sample size, n	70	66	65	35 (HLL group)

Abbreviations: RCT = Randomized Controlled Trial, LM = lumbar multifidus, HLL = High-Load Lifting exercise

Ethical considerations

All studies included in this thesis were approved by the Regional Ethical Review Board in Umeå, Sweden (09-200M). All participants gave their written consent and were informed that they could at any time end their participation without further explanation. Risk of harm or injury to participants were minimized by encouraging patients to report any discomfort or pain during or between sessions. All participants provided written informed consent before the final eligibility verification.

Recruitment and eligibility screening

Initial recruitment was performed through referral from physiotherapists working at two occupational health care services. Patients seeking care for pain and/or discomfort from the low back for three months or longer, with or without referred leg pain, and diagnosed by their physiotherapist with a dominating pain pattern of nociceptive mechanical character [76, 90], were

asked whether they wanted to participate in a study about LBP and exercise. Through a process of diagnostic triage [77] the physiotherapist ensured that the patients did not have any acute or evident red flag disorders, psychiatric or mental deficits, ongoing claims for compensation or contraindications to exercise.

After agreeing to participate, patients were contacted by the study administrator who then performed an additional screening, on the telephone, to ensure that the patient understood the Swedish language in speech and writing, was not pregnant, did not suffer from any systemic illness, for example psychiatric, endocrine, neurological, rheumatoid or other serious co-morbidities, or in any way had contraindications to exercise. Participants were then given more information about the study, a written informed consent form and questionnaires which they were to bring to the first data collection session.

Before performing the baseline data collection, participants were examined for a final verification of eligibility by a physiotherapist with a specialty in orthopaedic manual therapy and over 20 years of clinical experience of patients with neuromusculoskeletal disorders and chronic pain, with respect to the inclusion and exclusion criteria (Table 2). Through a process of diagnostic triage with consideration given to red flags and psychosocial factors, the physiotherapist made an assessment of the participant's pain disorder. The aim was to ascertain that the LBP was of a dominantly nociceptive mechanical character [76, 90] and that signs and symptoms of other pain mechanisms (e.g. peripheral neurogenic pain [89] or central sensitization [88]) were absent. Regarding negative and faulty pain perceptions and/or non-ideal coping strategies, they were not reasons for exclusion, however, during the physical examination it was ensured that the participants LBP could be provoked or eased through movement or manual tests.

The physical examination was carried out by first assessing the movements or postures that the participants had mentioned as being associated as aggravating or easing of their LBP. During the movement and posture examination, the participants preferred and pain provocative movement or postural strategies were first examined regarding symptom provocation. Thereafter, the participant was instructed or guided by the physiotherapist in order to examine whether a change in the way the participant moved or aligned their lumbo-pelvic region during the provocative movement or posture could be associated with a decrease in pain [81, 103, 104].

After this final eligibility verification, participants were included or excluded depending on meeting the inclusion/exclusion criteria as described in Table 2. The number of excluded participants, reasons for exclusion, number of participants included in respective paper and drop-outs, are shown in Figure 1.

Table 2. Summary of inclusion and exclusion criteria.

| Inclusion	Exclusion
Age 25–60 years	Red flag disorders
Pain located to the low back	(e.g. fractures, acute disc herniation)
Dominating mechanism of	Other dominating pain mechanism
nociceptive mechanical pain	(peripheral neurogenic, central sensitization)
Duration of pain ≥three months	Present or prior psychiatric or mental deficits
Understands spoken and written Swedish	Fibromyalgia
	Rheumatic disease
	Inflammatory disease
	Endocrine disease
	Neurologic disease
	Connective tissue disease
	Psychiatric disease
	Cancer disease
	Pregnancy
	Ongoing claims for compensation
	Contraindication to exercise
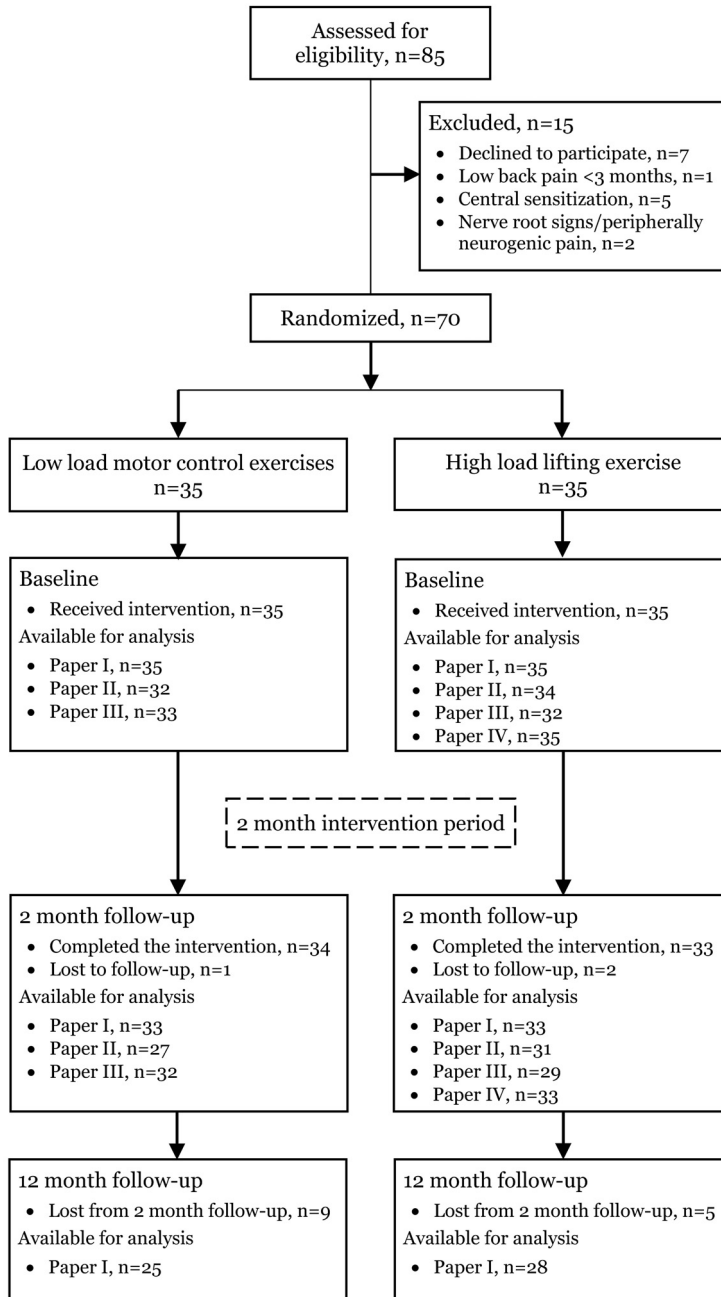
Figure 1. Showing the participants flow, from recruitment to twelve-month follow-up as well as number of participants available at baseline and follow-up for each paper.

Description of participants

After the final examination, 70 participants were included. Two participants had prior experience of resistance training. The participants (n=70) self-reported physical activity at moderate intensity was a mean 171.6, SD 153.1 minutes per week. Regarding work status, all participants worked full or part time and no participants were on full-time sick leave. Most participants worked in industry, on assembly-lines or with administrative duties, i.e. desk jobs. For a description of the participants characteristics at baseline, see Table 2 below.

Table 2. Background characteristics of participants in Papers I–IV, presented with mean and standard deviation if not otherwise indicated.

	All n=70	HLL n=35	LMC n=35	Men n=30	Women n=40
Sex (n, men)	30	15	15	n/a	n/a
Age (years)	42.2±10.2	41.9±9.9	42.5±	44.5±10.0	40.5±10.1
BMI (kg*m⁻²)	25.3±3.4	24.4±2.7	26.3±3.7	26.1±3.1	24.8±3.4
VAS (mm)	45.0±25.5	42.6±23.5	47.3±27.5	38.2±23.5	50.1±26.1
PSFS (0-10)	4.3±1.5	4.8±1.3	3.8±1.4	4.6±1.6	4.1±1.3
RMDQ (0-24))	7.2±4.3	7.1±4.1	7.3±4.6	6.7±4.6	7.6±4.1
TSK (17-68)	32.6±7.0	31.6±7.1	33.6±6.9	33.7±6.8	31.8±7.1
Prone bridge (seconds)	63.7±39.9	71.9±45.7	55.6±31.6	78.9±39.1	52.4±37.0
Side-bridge (right) (seconds)	40.7±27.7	45.1±28.2	36.3±26.9	58.1±23.6	27.6±23.1
Side-bridge (left) (seconds)	42.2±29.1	46.1±28.4	38.3±29.5	60.7±23.0	28.4±25.3
B-S test (seconds)	81.1±39.8	87.1±43.4	75.0±35.4	87.1±37.9	76.6±41.0
Lift strength (Newton)	915.0±416.8	935.6±415.8	894.4±422.7	1312.1±272.6	616.8±199.1
MC test battery (0-7)	3.4±1.7	3.9±1.6	2.9±1.6	3.0±1.7	3.7±1.6
LM thickness, small side(cm)	2.4±0.4 (n=65)	2.3±0.5 (n=32)	2.5±0.4 (n=33)	2.5±0.5 (n=28)	2.3±0.4 (n=37)
LM thickness, large side(cm)	2.6±0.5 (n=65)	2.6±0.5 (n=32)	2.7±0.4 (n=33)	2.8±0.4 (n=28)	2.5±0.4 (n=37)
Lumbar lordosis (degrees)	59.0±11.5 (n=66)	62.1±10.7 (n=34)	55.7±11.6 (n=32)	59.0±10.9 (n=29)	59.0±12.2 (n=37)
Sacral angle (degrees)	42.0±9.6 (n=66)	43.8±10.1 (n=34)	40.2±8.8 (n=32)	41.7±7.7 (n=29)	42.3±10.9 (n=37)
Posterior bend (mm)	22.3±21.1 (n=66)	20.3±16.0 (n=32)	24.2±25.1 (n=34)	25.5±19.5 (n=29)	19.8±22.3 (n=37)

Abbreviations: HLL = High-Load Lifting exercise, LMC = Individualized Low-Load Motor Control exercises, BMI = Body Mass Index, VAS = Visual Analogue Scale, PSFS = Patient-Specific Functional Scale, RMDQ = Roland and Morris Disability Questionnaire, TSK = Tampa Scale of Kinesiophobia, B-S = Biering-Sørensen, MC = Movement Control, LM = Lumbar Multifidus

Randomization and allocation

All the papers in this thesis are based on the same sample. Upon inclusion, participants were assigned consecutive numbers from one to 70. After the inclusion process and baseline data collection, the randomization was performed by an investigator blinded to participants' characteristics. Randomization was stratified by sex (male or female) and age (young ≤42 or old 43≥ years) forming four groups (young males, young females, old males, and old females). From these four groups, the randomization was performed by a computer-generated procedure of n out of N which randomly drew n cases from a population of N, thus forming the intervention groups. The investigator performing the randomization then sent the list of randomized numbers back to the investigator in charge of recruitment who had a list of numbers corresponding to each participant. Allocation was then finalized by each physiotherapist in charge of respective intervention.

Blinding

In order to ensure blinding as far as possible in a study evaluating exercise interventions, key investigators were blinded to participant allocation and characteristics. Essentially, the investigators collecting the data were blinded to participant allocation and characteristics except for the primary outcome data collection at the two-month follow-up in Paper III, rehabilitative ultrasound imaging, whereas the person performing the data collection also administered the LMC intervention. The reason for this was due to economic and time constraints within the study.

Participants were also blinded to the specifics regarding their assigned exercise intervention. The only information they received was that one intervention would be conducted at a sports centre and the other at a primary health care clinic. Additionally, all participants were asked not to reveal their test results or which intervention they had performed to any assessor throughout the data collection processes.

Interventions

Participants in both intervention groups were offered twelve supervised training sessions, twice per week for the first four weeks and once per week for the last four weeks, during an eight week period. The interventions were administered by one physiotherapist per intervention group, both experienced in using the respective exercise/exercises in their clinical practice for patients with LBP as well as explaining pain and tissue mechanisms in relation to movement and muscle recruitment patterns.

Both interventions included elements of education, implemented on an individual basis, where the physiotherapists explained how non-ideal movement and alignment patterns could lead to increased tissue stress and symptoms. Furthermore, they explained how the exercises performed in each intervention group would lead to decreased pain. In the HLL intervention, the participants were taught about how weak muscles decrease stability of the lumbar spine and thereby increasing stress on the low back. The physiotherapist also emphasized the importance of maintaining the spine in a neutral position during daily activities to decrease stress on the low back. In the LMC intervention the therapist focused on explaining how the way the participant performed their self-reported pain provocative activities was associated with their LBP. Thereafter, the therapist explained that the exercises used in the LMC intervention were designed to improve the participant's movement pattern in a way that would lead to decreased pain sensitization. The time spent on education regarding pain and tissue mechanisms or cognitive behaviours that influenced the pain and/or movement pattern, such as kinesiophobia, varied depending on the therapist's judgment of the participant's need of more or less thorough explanations.

High-load lifting exercise – the deadlift

The HLL intervention was carried out in the resistance training section of a sports centre. Sessions were conducted in groups of three to five participants and each session lasted about 60 minutes.

In the HLL intervention, the barbell deadlift exercise (Figure 2A-F) was the only exercise performed. The main purpose of the exercise was to improve the participants' control of the neutral position of their lumbar spine during lifting as well as strengthening muscles around the spine and hip. The participants were instructed in a lifting technique with emphasis on activation of stabilizing muscles prior and during the lifts while maintaining control of the neutral position of the lumbar spine. The ideal lifting technique demonstrated by the physiotherapist is depicted in Figure 2B-F, however, in the prior to the lift Figure 2A, participants were instructed to take a deep breath, performing the Valsalva manoeuver [33] in combination with abdominal bracing [63] in order to create a high intra-abdominal pressure [33] and co-activation of all stabilizing muscles of the spine and in this way increasing the stability of the lumbar spine [32] during the entire lift. Subsequently, while maintaining the lumbar spine neutral position throughout, the lift was initiated by simultaneous hip and knee extension until the barbell passed the knee where the ascending part of the lift was completed through knee and hip extension. During the following descending

part, the barbell was lowered slowly, initially through hip flexion, until passing the knee where simultaneous hip and knee flexion concluded the descent. Before initiating the next repetition, the participant let go of the barbell and stood up for a brief moment before repeating the process for the following repetitions.

Before progressing the load, the physiotherapist ensured that the participants could maintain proper lumbar spine alignment throughout the lift. The training progressed in two phases. In the initial phase focus was neural adaption to the exercise, i.e. improving the participants' ability to coordinate activation of stabilizers, agonists and antagonists and maintaining proper lifting technique. However, all participants started the training period with a load of ten kg, performing about three to five sets of about ten repetitions each. In the second phase, the training was progressed to stimulate hypertrophy and/or maximal strength whereas the physiotherapist increased the load and volume (total lifted weight/session) for the participant in an individualized manner. In this phase the load varied between 20 and 200 kg for male participants and between 17.5 and 102.5 kg for the female participants; sets were kept between three to eight and repetitions between three to five, with a total number of repetitions per session of about 20–60. Those participants who were apprehensive about performing the exercise with regards to putting stress on their low back were assured that the risk of symptom provocation was very low since the load of 10 kg lifted with both arms could be considered equivalent to carrying groceries from the store, and that the training could be progressed with a slow pace of 2.5 kg increments. During the training sessions, participants were told that a pain intensity below 50 mm on the visual analogue scale was fine, as long as the participants did not deviate from the proper lifting technique initially taught and that the pain did not linger after each set or after the training session.

In addition to the supervised training sessions, participants were also encouraged to use the lifting technique and stabilization strategies which the physiotherapist had instructed in activities outside the gym.
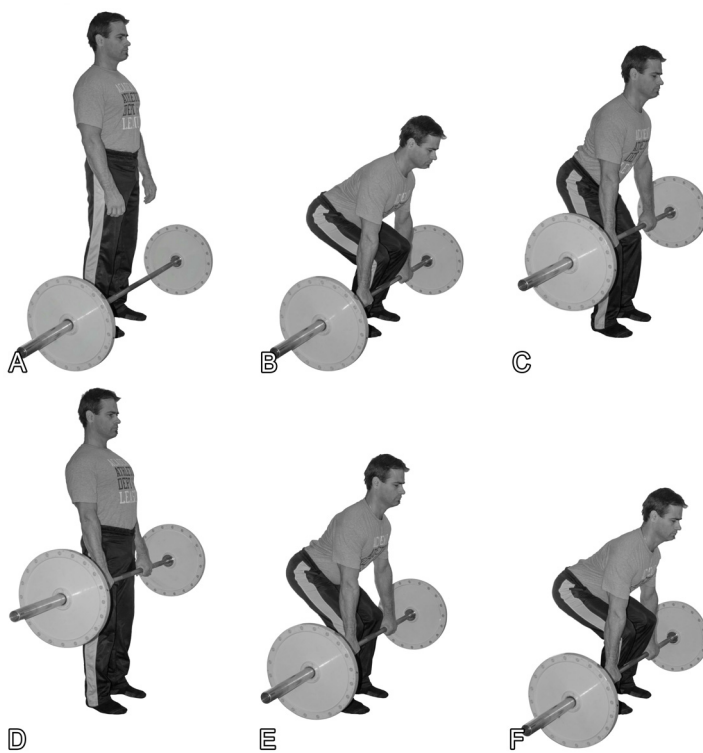
Figure 2A-F. Showing the ideal lift technique of the deadlift exercise as instructed in the HLL intervention. Reprinted with permission from Aasa B, Berglund L, Michaelson P, Aasa U. Individualized low-load motor control exercises and education versus a high-load lifting exercise and education to improve activity, pain intensity, and physical performance in patients with low back pain: a randomized controlled trial. J Orthop Sports Phys Ther. 2015;45:77-85. http://dx.doi.org/10.2519/jospt.2015.5021. Copyright ©Journal of Orthopaedic & Sports Physical Therapy

Individualized low-load motor control exercises

The LMC intervention was carried out individually in a physiotherapy clinic at a primary health care centre and sessions lasted for about 30 minutes.

In the LMC intervention, the exercises were chosen based on the examination of the participant with the aim to normalize the participants dominating movement impairment. The training progressed in three stages (Figure 3A-C). In stage one (Figure 3A), the participants were taught to find the neutral position of their spine in supine, four-point kneeling, sitting and standing positions and maintain this position while simultaneously moving arms or legs. The exercises were performed in a controlled manner with focus on the patient's awareness of alignment and muscle activation in order

to promote low load holding in stabilizing muscles and control of the lumbar spine neutral position. In stage two (Figure 3B), the exercises were progressed to match the individual activities that the participants had reported the most difficulty in performing due to their LBP. In stage three (Figure 3C), the exercises focused on dynamic stability. For example, bending forward with a correct movement pattern of an initial hip flexion followed by a controlled flexion movement of the spine with simultaneous activation of stabilizing trunk muscles.

Throughout the intervention the physiotherapist used several feedback techniques in order to facilitate re-training. Participants were instructed to watch the therapist perform the exercise, perform the exercise while watching themselves in a mirror, palpate the lumbar spine and/or muscles during the exercises. Also, since the exercises targeted the participants' provocative movement patterns, the participant also received immediate internal feedback if they performed the exercise in a non-ideal manner thus provoking their pain, and vice versa.

Aside from the individual sessions with the physiotherapist, the participants in the LMC group were also encouraged to perform home-exercises two to three times per day with ten repetitions per exercise. The purpose of the home exercises was to fortify the movement and muscle activation patterns taught during the sessions in daily living.
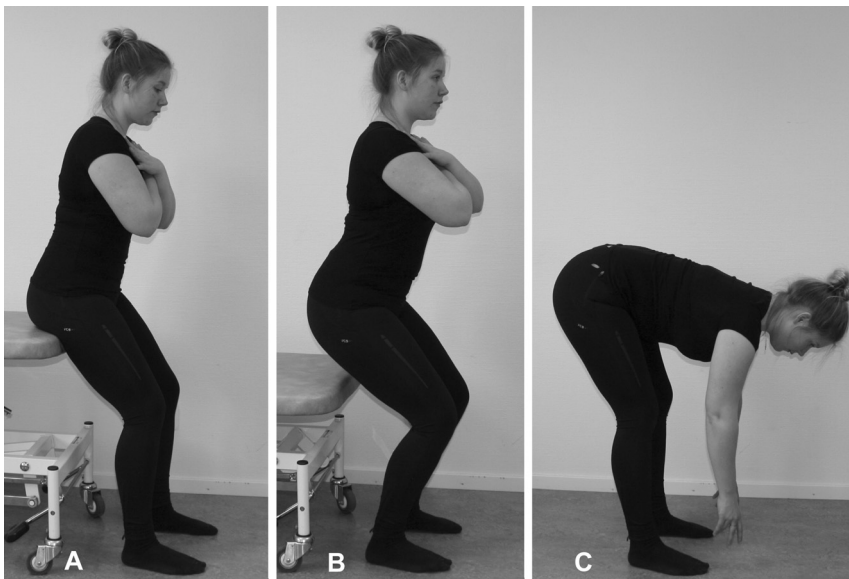

Figure 3A-C. Showing an example of exercise progressions used in the LMC intervention in stage 1 (A), stage 2 (B) and stage 3 (C).

Data collection and outcome measures

Before and directly after the intervention period, questionnaires were collected and physical performance tests, rehabilitative ultrasound imaging (RUSI) and radiographic imaging were performed. Twelve months after the end of the intervention, questionnaires and physical performance test data was collected once again. All questionnaires and test were collected during the same session, except for the radiographic imaging which was performed at a separate occasion. Detailed information about the characteristics of outcome measures and instruments used and how they were measured in this thesis is provided below. All measures or instruments listed below were used as outcome measures in Papers I-III, except for the Roland and Morris Disability Questionnaire, the Tampa Scale of Kinesiophobia and the measure of posterior bend. In Paper IV, the Visual Analogue Scale, the Patient-Specific Functional Scale and Roland and Morris Disability Questionnaire were used as outcome measures and predictors, while the age, sex and Body Mass Index, Tampa Scale of Kinesiophobia and physical performance tests (prone bridge, side bridge, Biering-Sørensen test and movement control test battery) were included only as predictive variables. An overview of the instruments used in each paper of this thesis is shown in Table 3.

Table 3. Instruments used in the thesis.

Instrument	Paper
Questionnaires	
Visual Analogue Scale	I, III, IV
Patient-Specific Functional Scale	I, IV
Roland and Morris Disability Questionnaire	I, IV
Tampa Scale of Kinesiophobia	I, IV
Physical performance tests	
Movement control test battery	I, IV
Prone bridge	I, IV
Side bridge	I, IV
Biering-Sørensen	I, IV
Lift strength	I, IV
Imaging methods	
Radiographic imaging: Lumbar lordosis, sacral angle, posterior bend	II
Rehabilitative ultrasound: Thickness of lumbar multifidus muscle	III

Questionnaires

Pain intensity was measured with the Visual Analogue Scale (VAS), rating average pain intensity over the last seven days on a 0-100 millimetre (mm) scale. A rating of "0" represents "no pain at all" and "100" "the worst imaginable pain". The VAS for measuring pain intensity is used extensively in chronic pain research and is considered both a reliable and valid measurement [22].

Self-rated activity limitation was measured with the Patient-Specific Functional Scale (PSFS) which is an activity specific questionnaire. The patient is asked to list three activities that they are unable to perform due to their low back pain. Patients are also asked to rate on a 0-10 scale the current level of difficulty of performing each activity. A score of "10" represents the level of activity "pre-injury" and "0" represents not being able to perform the activity at all [95]. The PSFS is considered a reliable and valid measurement of activity [95].

Disability was assessed with the Roland and Morris Disability Questionnaire (RMDQ) which is a condition specific questionnaire which consists of 24 yes/no questions regarding activities relevant to patients with low back pain. Every "yes" answer equals one point on the 0–24 point scale where a higher total score indicates a higher level of disability. The RMDQ is considered a reliable and valid measurement of disability [48].

Kinesiophobia/fear of movement was assessed with the questionnaire Tampa Scale of Kinesiophobia (TSK). TSK consists of 17 statements which the patient rates on a scale of 1–4 where "1" represents "strongly disagree" and "4" "strongly agree". The statements are constructed to reflect different aspects of fear of movement, fear of injury and/or re-injury and pain catastrophizing. A total score of 17–68 is calculated where a higher total score indicates a higher degree of pain-related fear of movement. The TSK is considered both a reliable and valid measurement [56].

Physical performance tests

Movement control of the lumbo-pelvic area was measured with a battery of tests which challenge the patients' ability to control the lumbar spine in neutral position and prevent deviating movements in flexion, extension and rotation, i.e. dissociation tests [58]. The tests used are called, "waiter's bow" (Figure 4), "sitting knee extension" (Figure 5) and "prone knee flexion" (Figure 6) [59]. The sitting knee extension test and prone knee flexion test were performed bilateral and unilateral. Participants performed three trials of each exercise and three correctly performed trials were noted as a correct test. Test results were summed together ranging from "0" (no correct test) to "7" (all correct tests). The individual tests have been evaluated for reliability with good results [59] and a similar test battery has also shown to be able to discriminate between patients with persistent LBP and healthy controls [58]. One test included in the test battery, the "waiter's bow", has been shown to have some predictive validity regarding the development of future LBP in dancers [80].

Figure 4. Showing the test "waiters bow".

Figure 5. Showing the test "sitting knee extension".
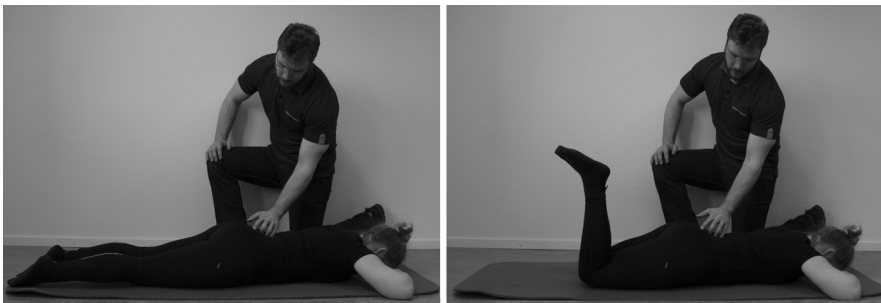
Figure 6. Showing the test "prone knee flexion".

Endurance of trunk and hip muscles were measured with the "prone bridge" (Figure 7), "side-bridge" (Figure 8) and the Biering-Sørensen (Figure 9) tests [55, 64, 84]. All tests were carried out in one trial and in standardized positions with an emphasis on maintaining a neutral lumbar spine for as long as possible in seconds (s). The Biering-Sørensen and side-bridge tests have been evaluated on healthy subjects and found to be reliable measures [55, 64, 84]. The Biering-Sørensen test has also been shown to be a test with discriminative and predictive validity for LBP. Poor performance in the test has been linked to the development of future LBP [1] and poor performance have also been shown to differentiate between patients with LBP and healthy controls [55, 97].
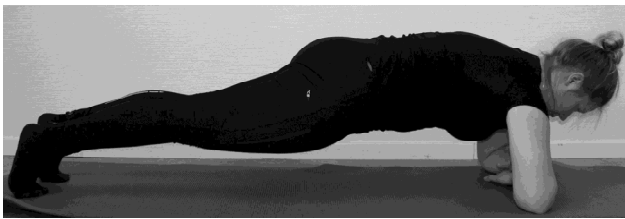
Figure 7. Showing the test position for the prone bridge test.

Figure 8. Showing the test position for the side-bridge test.
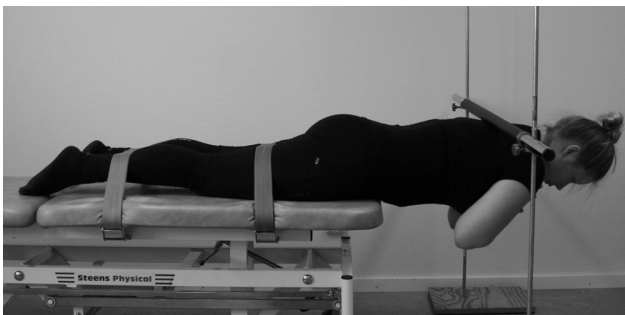
Figure 9. Showing the test position for the Biering-Sørensen test.

Isometric lift strength [5] was assessed with the participant standing on a plate with a strain gauge dynamometer attached to a handle (Figure 10). The participant squatted down and gripped the handle as close to the hips as possible and was instructed to, whilst maintaining a neutral lumbar spine, exert maximum voluntary force in a vertical direction. Participants completed two trials and the highest result was noted.
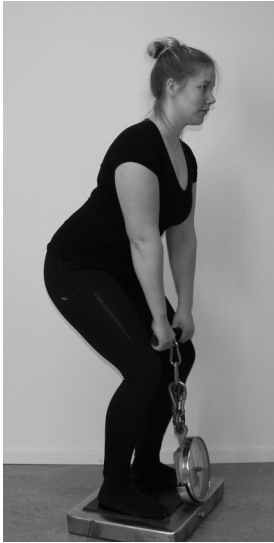

Figure 10. Showing the apparatus and test position for the isometric lift strength test.

Imaging methods

Lumbo-pelvic alignment was assessed with a number of measures, described below, derived from lateral radiographs by one investigator. The images were collected by a nurse specializing in radiology and the participants were booked for the imaging at the same time of day as for the baseline and follow-up data collection. They received no other instructions from the nurse than to stand sideways to the radiograph machine with their arms crossed on their chest to avoid blurring of the imaging of the spine. Regarding the method of deriving the measures of lumbo-pelvic alignment, manual measurement of angles and physical markers of the spine on radiographs are considered reliable [109].

Lumbar lordosis (degrees) was measured with the Cobb method (Figure 11), which is the gold standard for measuring lumbar lordosis on radiographs [109]. The angle of lumbar lordosis is created by drawing two lines, one parallel to the superior endplate of the sacrum and the other parallel to the

superior endplate of the first lumbar vertebrae which form the angle of the lumbar lordosis [7]. The Cobb method is very reliable (inter- and intrarater reliability ICC 0.87-0.98) [109].

The angle between the sacrum and the horizontal plane (Figure 12), also called the sacral angle/sacral slope/sacral inclination is defined as the angle (degrees) between the superior margin of the sacrum and the horizontal plane [26, 49]. Measuring the sacral angle on radiographs is considered very reliable (interrater reliability ICC 0.94 and intrarater reliability ICC 0.89-92) [110]. Furthermore, the sacral angle seems to be closely related to the angle of lumbar lordosis. Increased lumbar lordosis is correlated with a more horizontally inclined sacrum, i.e. more vertical sacral endplate [7].

In addition to the outcome measures of lumbo-pelvic alignment, lumbar lordosis and sacral angle, a third measurement of alignment was included for use in the interpretation of a potential change in the outcome measures in relation to global posture. For example, a change in lumbar lordosis could be an effect of the participant being measured standing inclined further back, thus increasing the lumbar lordosis from a cranial direction. This is as opposed to a change in lumbar lordosis from a caudal direction where instead the pelvis has been anteriorly tilted, thus increasing lumbar lordosis. Therefore, the posterior bend (mm) (Figure 13), defined as the horizontal distance between the posterior-inferior border of the fifth lumbar vertebrae and a vertical line drawn from the posterior-inferior border from the first lumbar vertebrae [49] was included. The posterior bend tells us to what degree the upper body is inclined backwards (as a positive value) or if the trunk is included forward (negative value).
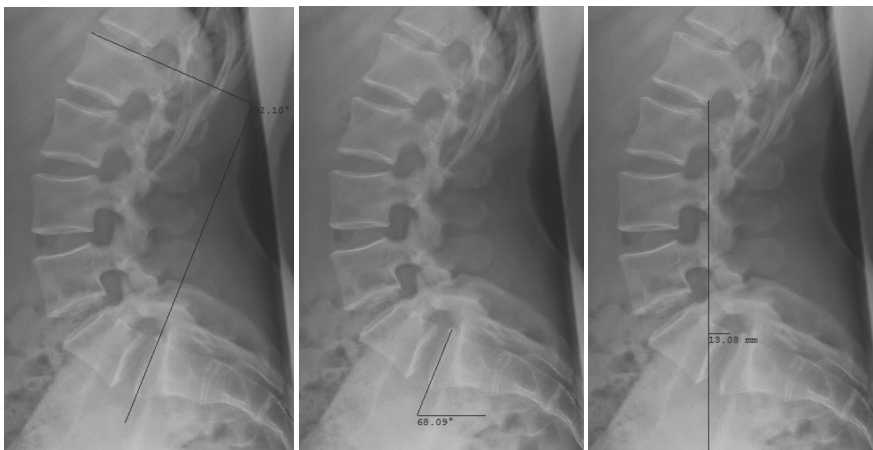

Figure 11-13. Lumbar lordosis (degrees), sacral angle (degrees) and posterior bend (mm) measured on a lateral radiograph.

Thickness of lumbar multifidus muscles was measured with RUSI. Both sides of the spine were measured at the fifth lumbar vertebrae using an Esaote MyLab 25 Gold scanner with a 10–12 mHz linear probe by a physiotherapist with special training in measuring the lumbar multifidus. The lumbar multifidus muscles were imaged in a transverse section which showed fascia, muscle and the bony transverse process/lamina. The measurement of thickness was done from the highest point of the thoracolumbar fascia in a straight line to the transverse process/lamina. To improve the exactness of measurement level and place between the baseline and follow-up measurement, significant landmarks of each participant's low back area were traced on a transparent film which was then used at the follow-up measurement to guide the assessor. The participant being measured was positioned prone, in a relaxed position with both hands under the belly. To ensure measurement of muscle thickness in a relaxed state, the participants were instructed to perform an abdominal bracing manoeuvre, thus contracting the multifidus. Thereafter, measurements were taken in the relaxed state. For the purpose of analysing the lumbar multifidus thickness, the larger and smaller sides (left or right) were determined and coded in the statistical software. RUSI have been tested for validity for measuring multifidus muscle thickness [52]. In the systematic review by Koppenhaver et al. [52], RUSI was found to have good criterion (RUSI compared to magnetic resonance imaging) and construct validity (differentiating between patients with LBP and asymptomatic controls) when analysing muscle thickness and thickness change during activation. Reliability have also been extensively evaluated for measuring thickness and thickness change during contraction of the lumbar multifidus and other trunk muscles [35]. For example, a study by Wallwork et al. [102] how very good intra- and interrater reliability when measuring multifidus thickness at rest and change during activation (ICC 0.84-1.0).

Data analysis and statistical methods

Data was analysed with the statistical package for the social sciences (SPSS) version 21.0 with a significance level set to p≤0.05. The statistical analysis used in each paper is presented in Table 4.

Table 4. Statistical methods applied in Papers I-IV.

Statistical method	Paper I	Paper II	Paper III	Paper IV
Wilcoxon Signed Rank test		x		
Mann-Whitney U-test		x	x	
Spearman's Rank Correlation test		x		
Chi-Square test	x			
Paired Samples T-test	x		x	
Independent Samples T-test	x	x	x	
Linear Regression				x
Linear Mixed Models	x		x	

Sample size and power calculation

Sample size was calculated for one of the primary outcomes in Paper I, namely, Pain intensity during the last 7 days, measured on the 0–100 mm Visual Analogue Scale. To reach an 80 % statistical power (alpha level 0.05) to detect between-group differences of 15 units (SD 21) with the Independent Samples T-test, a sample size of 31 participants per group were needed. In order to ensure sufficient power despite potential drop-outs, 35 participants for each intervention group were enrolled.

Statistical methods

Normality of data was assessed by examining the standard error of skewness for each variable and the value for skewness should be within two times the standard error of skewness for the variable to be considered normally distributed. For normally distributed data parametric tests were performed and for non-normally distributed data, non-parametric tests.

For the descriptive statistics of participant characteristics and baseline values for the outcome measures, mean and standard deviation were used, see Table 2. Baseline differences between the intervention groups and comparisons of attendance to training sessions were evaluated with Independent Samples T-test or the Mann-Whitney U test.

The effects of HLL and LMC regarding pain intensity, activity and tests of physical performance (Paper I) were analysed with linear mixed models with

fixed factors for Time (baseline, two months, twelve months), Group (HLL, LMC) and the interaction term Group by Time.

Lumbo-pelvic alignment (Paper II) was analysed between and within the intervention groups (HLL, LMC) and for sub-groups derived from the distribution of the lumbar lordosis and sacral angle. The sub-groups were created for the purpose of analysing the effects of the interventions on participants with extreme variations of lumbo-pelvic alignment. The reason for this was that when examining the data we noted an unexpectedly wide dispersion of the values for lumbar lordosis and sacral angle. The participants were divided into three groups per outcome measure; $LOW_{lu/sa}$, including values up to the 25th percentile, $MID_{lu/sa}$, including values between the 25th and 75th percentile, and $HIGH_{lu/sa}$, including values from the 75th percentile to the highest value. Outcomes were presented descriptively, as mean change from baseline to two-month follow-up and percent change. The analysis between the intervention groups (HLL, LMC) was performed with the Mann-Whitney U-test. For the comparison of the sub-groups ($LOW_{lu/sa}$, $MID_{lu/sa}$, $HIGH_{lu/sa}$), multiple Mann-Whitney U-tests with Bonferroni correction for mass significance were used. The significance level for these tests was calculated to p≤0.017 (0.05/3). For the within-group analyses, the Wilcoxon Signed Rank Test was used. Spearman's correlation was used to analyse the correlation between lumbar lordosis, sacral angle and posterior bend at baseline and the correlation between the changes of respective measure.

Regarding the effects on lumbar multifidus thickness (Paper III) the percentage change of lumbar multifidus thickness from baseline to follow-up [(follow-up–baseline/baseline)*100] was used as outcome measure. A linear mixed model analysis with fixed factors for Group (HLL, LMC), Sex (Men, Women), Asymmetry (Smaller side, Larger side) and the interaction terms Group by Sex and Group by Asymmetry, including covariates of the baseline value for pain intensity and Body Mass Index (BMI), were performed. The factor asymmetry (dichotomous) was used to describe the smaller or larger side at baseline and was included in the analysis in order to differentiate between sides when interpreting a change of lumbar multifidus thickness.

To analyse which patients benefit from the HLL intervention (Paper IV), linear regression was used. Three models were created, one each to predict the two-month follow-up value for pain intensity, activity and disability. For each predictive model, a univariate linear regression was used with the baseline value of the following independent variables; pain intensity, activity, disability, pain related fear of movement, movement control test battery, Biering-Sørensen test, prone bridge, side bridge, age, sex, and BMI.

Significant ($p \leq 0.05$) variables from the univariate analysis were included in a multiple regression model with the independent variable with the highest adjusted R^2 (i.e. explained variance) were first entered in the models. The remaining variables were then entered one by one into the multiple regression model to see whether the models adjusted R^2 value could be increased and form a significant model.

Minimal important change

In this thesis, a minimal important change, i.e. clinically relevant improvement, is regarded as a change of, or above, 30 % from baseline to follow-up. This cut-off has been consolidated in a study by Ostelo et al. [72] where the authors aimed to reach an international consensus regarding the clinical interpretation of change in scores of pain and functional status.

Missing data

In Paper I missing data was not replaced with imputations since the data was analysed with linear mixed models which makes use of all available data. Also, the linear mixed model analysis is said to provide equal or more statistical power when analysing longitudinal data with missing cases compared to ad hoc imputations methods [13].

In Paper II, missing data at follow-up measurement was not imputated ad hoc for the analysis of lumbo-pelvic alignment.

In Paper III, data was manually imputated ad hoc for the dependent variable, lumbar multifidus thickness. Cases with a missing value at follow-up were assigned a zero percent change in lumbar multifidus thickness. Analysis were performed both with and without mentioned imputation.

In Paper IV, the multiple regression models were calculated with the participants which had complete values for the two-month follow-up for pain intensity, activity and disability for the respective model, i.e. data was not imputated.

Results

Attendance, drop-outs and adverse effects

Adherence to the interventions was mixed (minimum 1 session, maximum 12 sessions) and significantly different between intervention groups (p<0.01) HLL mean 11.0, SD 2.6 and LMC mean 6.1, SD 2.0 sessions.

A flow chart showing the participants course through the study is given in Figure 1.

Three participants dropped out during the intervention period. In the HLL group two participants dropped out, one due to adverse effects and the other without explanation. Another participant in the HLL group also reported adverse effects during the intervention but did not drop-out from the study. In the LMC group, one participant dropped out for a reason unrelated to the study (abdominal surgery) and

Baseline comparisons

For most background and outcome variables there were no significant differences between intervention groups at baseline. For BMI (p=0.02), activity (p=0.01), and lumbar lordosis (p=0.03) there were significant differences between the HLL and LMC groups at baseline. The differences in BMI were determined so as not to affect the outcome variables for pain intensity and activity and therefore were not included as a covariate in the analysis of pain intensity or activity. In the analysis of lumbar multifidus thickness, however, BMI was included as a covariate in all analyses based on the assumption that lumbar multifidus thickness is most likely related to body mass. For activity, the differences in baseline values between intervention groups were controlled for by including the baseline values of activity in the statistical analyses as a covariate. To accommodate the analyses regarding the baseline difference in lumbar lordosis, the comparisons between intervention groups were done through the percent change of lumbar lordosis.

Effects of a high-load lifting exercise and individualized low-load motor control exercises (Papers I–III)

The effects of the HLL and LMC interventions have been summarized in Table 5.

Table 5. Overview of the effects of a high-load lifting exercise and individualized low-load motor control exercises between baseline and two months and baseline and twelve months.

Outcome	Baseline to 2 months		Baseline to 12 months	
	Time	Group by Time	Time	Group by Time
VAS	↓		↓	
PSFS	n/a	LMC↑	n/a	LMC↑
MC test battery	n/a	LMC↑	n/a	LMC↑
Prone bridge	n/a	LMC↑	n/a	LMC↑
Side-bridge	↑		⇔	
B-S test	↑		n/a	LMC↑
Lift strength	↑		↑	
Lumbar lordosis	⇔		n/a	n/a
Sacral angle	↓		n/a	n/a
LM thickness	↑		n/a	n/a

Abbreviations: LMC = individualized Low-Load Motor Control exercises, LM = Lumbar Multifidus, MC = Movement Control, B-S = Biering-Sørensen, PSFS = Patient-Specific Functional Scale, VAS = Visual Analogue Scale, n/a = not applicable, ⇔ = no significant change, ↑ = significant increase over time or superior effect, ↓ = significant decrease over time. Note that the above presented effects are derived from different methods of statistical analysis.

Effects on pain intensity and activity (Paper I)

For pain intensity there were no significant between-group effects between HLL and LMC at two- or twelve-month follow-ups (p=0.51, p=0.69). There were statistical significant improvements over time, from baseline to two- and twelve-month follow-up (p<0.001). There was a substantial proportion of participants which achieved a minimal important change (30 % or more) at two- and twelve-month follow-up in both HLL and LMC.

There was a significant between-group effect over time for activity at both two- and twelve-month follow-up in favour of the LMC group (p<0.001). A majority of participants achieved a minimal important change (30 % or more) at two- and twelve-month follow-up in both HLL and LMC.

Effects on physical performance tests (Paper I)

For physical performance, there were significant between-group effects over time in favour of the LMC group in the movement control test battery at two and twelve-months (p<0.001) and prone bridge test at two- (p=0.04) and twelve-months (p=0.01) follow-up. For the Biering-Sørensen test, there was a significant between-group effect over time in favour of the LMC group at the twelve-month follow-up (p=0.04), but not at two-month follow-up (p=0.83).

For the lift-strength and side-bridge tests there were no significant between-group effects at two- or twelve-month follow-up (p>0.05). There were statistical significant improvements over time (p<0.05) for most physical performance tests at both two- and twelve-month follow-up, except for the movement control test battery. In the HLL group, the mean performance of the movement control test battery remained roughly the same, whereas the LMC group increased the number of correctly performed tests significantly (p<0.001) from baseline to two- and twelve-month follow-up.

Effects on lumbo-pelvic alignment and lumbar multifidus thickness (Paper II & III)

Regarding the effects on lumbo-pelvic alignment, i.e. lumbar lordosis and sacral angle, there were no significant differences between HLL and LMC for the percent change of lumbar lordosis, p=0.53 or sacral angle, p=0.84. There were no statistical significant effects from baseline to two-month follow-up within the HLL or LMC group respectively (p>0.05), but a significant change in sacral angle when analyzing the whole sample (p=0.03). However, when investigating the effects for the sub-groups based on the baseline distribution of values for lumbar lordosis or sacral angle, ($LOW_{lu/sa}$, $MID_{lu/sa}$, $HIGH_{lu/sa}$), significant effects over time were observed in some sub-groups. There was a significant difference between baseline and follow-up within the LOW_{lu} group for lumbar lordosis (p=0.02) and in the $HIGH_{sa}$ group for sacral angle (p=0.03). In Figure 14, the within-group differences between baseline and follow-up are presented for each sub-group.

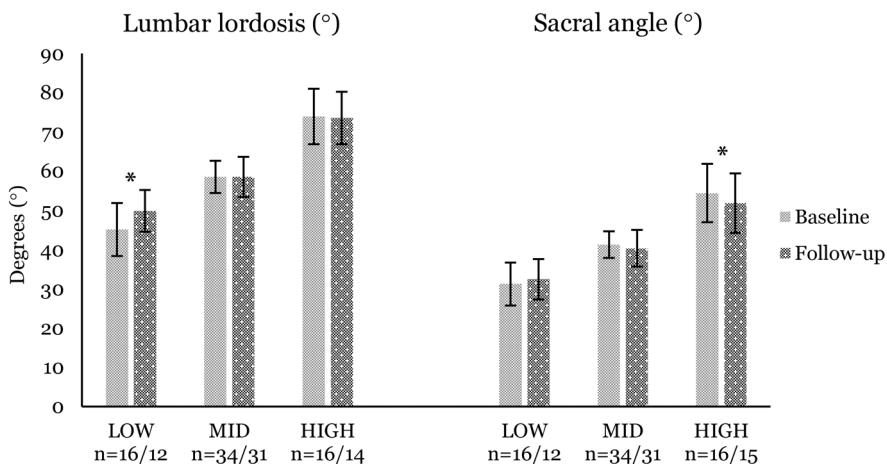
Figure 14. Mean values and standard deviation for lumbar lordosis and sacral angle (degrees) in the three sub-groups LOW, MID, HIGH. The asterisk (*) indicates statistical significance in the Wilcoxon Signed Rank test.

The analysis of percent change of lumbar multifidus thickness from baseline to two-month follow-up showed no significant between-group effects between HLL and LMC (p=0.52). The thickness of the lumbar multifidus muscles at baseline were significantly different (p<0.001) between the smaller or larger side at baseline (Figure 15). There was a significant effect for asymmetry (p<0.001), indicating a significant increase of the small side, from baseline to follow-up (Figure 15). The large side had remained roughly the same thickness from baseline to follow-up as seen in Figure 15.
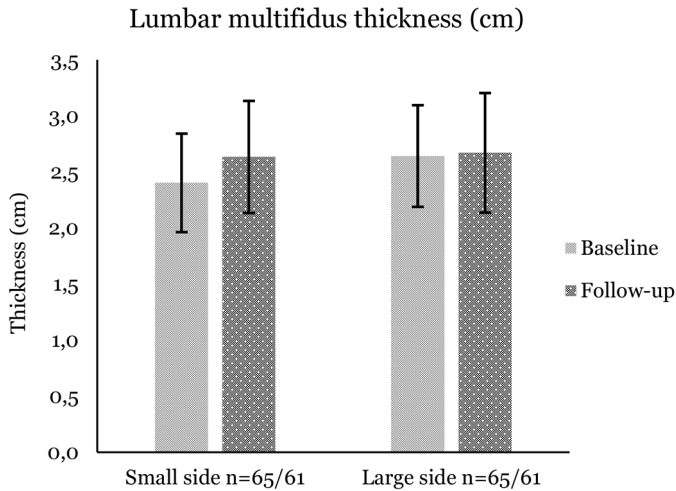
Figure 15. Mean values and standard deviation for lumbar multifidus thickness (cm) on the smaller and larger sides, at baseline and follow-up, in the whole sample.

Which patients benefit from a high-load lifting exercise? (Paper IV)

In the predictive analyses for the two-month follow-up in activity, disability and pain intensity, a few predictors formed the final significant models. The baseline values of the Biering-Sørensen test, pain intensity (VAS) and disability (RMDQ) were significant in the univariate analysis and the best and predictors. A low disability and pain intensity and a high performance on the Biering-Sørensen test predicted a high and low follow-up score, respectively, in activity, disability and pain intensity. The Biering-Sørensen test had an adjusted R^2 value between 0.14 and 0.2, VAS had between 0.14 and 0.18 and RMDQ between 0.1 and 0.22 in the respective univariate analysis. In the final models, the Biering-Sørensen and VAS at baseline formed the predictive models for activity at follow-up (adj. R^2 0.23) and disability at follow-up (adj. R^2 0.17). Regarding the model for pain intensity at follow-up, the RMDQ and the Biering-Sørensen test at baseline formed the final model (adj. R^2 0.28)

Discussion

Main findings

The overall aim of this thesis was to evaluate and compare the effects of a high-load lifting exercise and individualized low-load motor control exercises on patients with nociceptive mechanical LBP. A secondary aim was to evaluate which patients benefit from the HLL intervention. The results showed that the HLL intervention was not more effective when compared to the LMC intervention in any of the outcome measures. Instead, the LMC intervention was more effective than the HLL intervention regarding activity, movement control tests and some tests of endurance of trunk muscles. Furthermore, a majority of participants in both interventions showed a reduced pain intensity and increased activity at both two- and twelve-month follow-up, as they had achieved a minimal important change (≥30 % improvement). Both interventions also seem to have an effect on lumbar multifidus thickness over time and participants with extreme variations in lumbar lordosis or sacral angle had an effect over time on lumbo-pelvic alignment. The results also suggest that the patients who benefit the most from training with the HLL intervention are those with an initial low pain intensity and high performance in the Biering-Sørensen test.

Effects, similarities and differences of interventions

In a recent systematic review by Saragiotto et al. [82], low-load motor control exercises did not appear to be more effective than other exercise interventions regarding pain or activity. The authors therefore concluded that the choice of specific exercise interventions for patients with persistent LBP can be based on the therapists and patients preferences [82]. One reason for the lack of effects in favour of low-load motor control exercises might be the large heterogeneity of patients included the studies.

The results from this thesis confirms the findings regarding effects on pain intensity but diverge regarding the effects on activity. For pain intensity there was no difference in effect between the HLL and LMC interventions. This could be explained by the fact that both interventions included two core components, namely, education and exercises with an emphasis on control of the lumbar neutral position. The education highlighted the relation between movement and muscle recruitment patterns and LBP, which could have affected the participants' thoughts and movement behavior related to their LBP in a positive direction. The exercises in both interventions were also performed with special attention to controlling the magnitude of

movements in the lumbo-pelvic area. This could have been important in order for the participants to minimize the stress on the lumbo-pelvic area and thereby minimizing pain. These two shared components of the interventions might have been more important for the improvements in pain intensity than the components that were different between HLL and LMC. Regarding activity, the LMC intervention was more effective than the HLL intervention at both two- and twelve-month follow-up. The reason for this was most likely the high degree of individualization of exercises, whereas in the HLL intervention all participants performed the same exercise. The exercises in the LMC intervention targeted the participants' individual provocative posture and movement patterns. This is also referred to as the principle of specificity [86], and is often thought to be related to a more positive effect of training.

Furthermore, it is believed that in order to correct impairments in movement control [58] and atrophy of stabilizing muscles [37, 58], associated with LBP, specific low-load exercises are a necessary part of training [79]. Low-load motor control exercises have successfully been used in previous studies to improve lumbo-pelvic movement control [57] and to increase the size of the lumbar multifidus muscles [39]. These findings were confirmed by the results of this thesis in regard to the superior effect of the LMC intervention on the movement control test battery. The tests included in the test battery were thought to reflect the participant's ability to control movements in the lumbo-pelvic area and controlling flexion, extension and/or rotation movements while moving in the hip or knee joint. It is likely that the superior effect seen in the LMC intervention for the movement control test battery is related to the individualization of exercises, directed at the participants specific movement control impairment. In contrast, the participants in the HLL intervention all performed the deadlift exercise which, in regard to movement control, mainly challenges the ability to prevent lumbo-pelvic flexion while movement takes place in the hip, knee and ankle joints.

Regarding the effects on lumbar multifidus thickness and lumbo-pelvic alignment, the results showed that there were no significant differences between HLL and LMC. As mentioned, previous findings and notions about re-training of these impairments advocate the use of low-load exercises to reach optimal effect for patients with persistent LBP [79]. It is, however, my belief that the most important aspect of motor control exercises is that they are carried out with a correct movement pattern, which was emphasized during both interventions. Since this was emphasized, it was not surprising that the thickness of the lumbar multifidus increased over time, i.e. no significant difference between intervention groups. At the same time, it was

surprising that the participants in the HLL intervention did not increase the thickness of their lumbar multifidus muscles more than the participants in the LMC intervention, seeing that the HLL intervention emphasized a progression to trigger hypertrophy and strength of involved muscles.

To progress the HLL intervention, the weight and volume of training were increased as soon as the participants were able to perform the deadlift with an acceptable technique. The progression of the LMC intervention consisted mainly of a transition from simple exercises, moving one joint at a time, to more complex movements where the participants were expected to move multiple joints simultaneously and also control the magnitude of movement in certain joints. Regarding strength, one might have expected that the HLL intervention would have led to superior effects in lift strength compared to LMC since the focus of HLL was progression of load. Since there were improvements in both groups, but no differences between groups, regarding lift strength, it could be speculated that the increase in strength could be explained by the concurrent decrease in pain.

Aside from the individualization and load during training, further differences between the HLL and LMC interventions were the interpretation of pain during exercises, the inclusion of home-based exercises and performing the interventions with single or multiple participants in each session. Regarding pain, the participants in the HLL intervention, were told that pain during exercise was acceptable as long as it did not exceed 50 mm on a 100 mm VAS scale or if they experienced any exacerbation of symptoms after the session. In the LMC intervention the participants were encouraged to use pain when moving as means of intrinsic feedback and a sign that a movement had been performed non-optimally. These different strategies regarding pain cognition were not explicitly evaluated, but there can be advantages to both strategies. On the one hand, pain on movement as a feedback to correct movement patterns could be a good long term strategy to improve movement control; on the other hand, coping with pain could also be seen as a way to emphasize the importance of staying active and not avoiding load on the low back or becoming overly cautious about the sensation to pain. With respect to home-based exercises the participants in the LMC intervention were encouraged to carry out additional home-based exercises, similar to the exercises conducted during the therapist-lead sessions. Moreover, the sessions in the LMC intervention were performed one-on-one with the therapist, while in the HLL intervention there were between three and five participants exercising during the same session, although receiving individualized feedback from the therapist. These differences could have been important mediators of the effects seen over time for the HLL intervention since the sessions also became a group activity

where the participants observed each other while lifting and could discuss lifting technique, difficulties or such. The reason for performing the deadlift training in groups of three to five participants was to avoid down-time for the physiotherapist and participants in the HLL group since they rested several minutes between sets.

All in all, the impact of these differences on the effects on respective outcome is difficult to determine within the frame of this thesis. We are fully aware of these differences and the reason for designing the interventions as we did, was that we wanted to reflect the exercises as they are being used by many physiotherapists in Sweden.

The use of the Deadlift in rehabilitation of patients with low back pain

The studies included in this thesis are the first to investigate the effects of the high-load lifting exercise, the deadlift, in a randomized and controlled fashion. Since the HLL produced similar effects as the LMC in several outcome measures over time and this might lead to more physiotherapists using the deadlift, it was important to provide information to clinicians regarding the application of the HLL intervention for patients with nociceptive mechanical LBP.

For this purpose, the results of Paper IV can be used as a reference for clinicians who wish to implement the deadlift exercise in the rehabilitation of LBP. The results showed that patients with an initial low pain intensity and high performance on the Biering-Sørensen test might benefit more from deadlift training. One explanation why these variables were relevant to the outcome of the HLL intervention could be that they reflect the ability to activate hip and back extensor muscles for a long period of time, which is also necessary to perform the deadlift exercise with proper technique. Therefore, based on the patients and therapists preferences, the deadlift could be considered for those with a low pain intensity and high performance of the Biering-Sørensen test. Notably, we consider it important that the therapist knows about, and can coach, correct performance and movement patterns during the deadlift. Knowledge about proper progression models for resistance training could also be important.

Methodological considerations

There are of course some methodological issues in this thesis that need to be addressed.

Firstly, the participants were recruited through a selected few occupational health care services and were examined by one physiotherapist in the final stages of the eligibility assessment. The purpose of the final assessment was to ensure, through history taking and physical examination, that the participants LBP were of a dominantly nociceptive mechanical character. No verification of this assessment's validity was made prior or during the selection process. It has, however, been shown by Smart et al. [90] that assessment of specific clusters of signs and symptoms can be used with good accuracy to categorize pain in different groups, in this case nociceptive LBP. Moreover, regarding the group of patients included in the work for this thesis, the results should be interpreted in this very important context, i.e. the effects of the interventions on a specific sub-group of LBP. It is likely that the effects of the interventions investigated in this thesis are not generalizable to other sub-groups of LBP where other pain mechanisms dominate the disorder, e.g. central sensitization or peripherally neurogenic pain.

Secondly, there was a significant difference between intervention groups regarding exercise session attendance. The participants in the LMC intervention attended about half (55 %) as many sessions as those in the HLL intervention. The reason for this was that the participants in the LMC group considered themselves satisfactorily rehabilitated and were not motivated to attend further sessions. Of course, this affects the comparability of interventions. However, when strictly comparing the dose of the exercise intervention itself it could be argued that the participants in the LMC group exercised more frequently, because of the unsupervised home-based exercises they were encouraged to perform. In the HLL intervention, the participants were dependent on the scheduled sessions with the physiotherapist at the gym where the necessary equipment to perform the deadlift exercise was situated.

Thirdly, despite the randomized design and power calculation, there were some baseline differences between the intervention groups. We believe that the fact that the randomization was not performed with stratification by any of the outcome measures may explain the baseline differences. Further, the baseline differences might not have occurred if we had included a higher number of participants (normal distribution). However, the analyses have included the baseline values as covariates or used the percental change from

baseline to follow-up of the outcome measure, in order to take the baseline value into account when comparing the intervention groups.

Fourthly, the sample size for the RCT and data collection, which this thesis is based on, was calculated on pain intensity measured on the VAS which indicated that 31 participants in both intervention groups would be an adequate sample size. At the two-month follow-up there were at least 33 participants in each group (Figure 1), however, at twelve month follow-up there was a substantial reduction in participants (LMC, n=25, HLL n=28). The participants who dropped out did not differ significantly regarding the outcome measures, at baseline, compared to those who continued in the study. Also, the data for the twelve-month follow-up (Paper I) was analysed with the linear mixed model, which handles missing cases in longitudinal studies in a way that improves power compared to other means to account for missing data [13]. Furthermore, for Papers II–IV, sample size was not specifically calculated. However, in Paper IV power was probably not an issue since there were 16 participants per independent variable included in the final multiple linear regression models and it is recommended that there are between 10 and 20 participants per independent variable [30, 96].

Lastly, the RCT design stipulates an emphasis on between-group analyses. Often, when evaluating a new treatment, a placebo intervention or passive control group is used in comparison with the new treatment. In this thesis, the new treatment, i.e. HLL, was compared with a treatment previously proven to be effective compared to placebo/minimal intervention [61, 82]. Because the HLL intervention had not previously been evaluated in an RCT, the effects of the intervention were largely unknown. Therefore, it was also important to show the results of both interventions for the outcomes where there were no between-group effects. However, since a placebo group was not included, the within-group results must be interpreted with caution. Although, as current evidence [82, 85] points to the conclusion that most exercise interventions are more effective than placebo/minimal intervention, it could be argued that both interventions evaluated in this thesis probably would be more effective than placebo. In an RCT by Costa et al. [16], which evaluated motor control exercises versus a placebo group for patients with persistent LBP, the participants in the placebo group had a pain score on the numerical pain rating scale (0-10) which remained roughly the same from baseline (6.6, SD 2.0) to twelve months follow-up (6.3, SD 2.3). In the present RCT, the mean changes in the VAS (0-100) for pain intensity from baseline to twelve-month follow-up were 17.6 mm, (SD 24.6) in the HLL group and 22.1, (SD 23.2) in the LMC group. Notably, a minimal important change in the VAS for pain intensity is considered 15 mm [72], which was achieved for a majority of participants in both intervention groups.

Ultimately, because of economic restrictions, a passive control group was not included in the present RCT. Furthermore, as current guidelines [77] advocates exercise for treating persistent LBP, including a passive placebo group was also considered to be unethical.

Implications for clinicians and future research

The findings summarized in this thesis have implications in respect to both clinical practice and future research. For physiotherapists working in primary health care, LBP is a common problem and knowledge about viable exercises is important for the management of patients. Low-load motor control exercises have been used for some time in clinical practice when treating patients with persistent LBP. The results of this study suggest that the HLL intervention, the deadlift, could also be used to achieve clinically relevant improvements for patients with nociceptive mechanical LBP. There are, of course, disadvantages as well as advantages to both interventions investigated in this thesis. But from a clinical standpoint, it can be argued that the deadlift exercise is advantageous because of the possibility of progressively increasing the load of training in a way that is difficult to achieve with bodyweight exercises alone. Therefore, the deadlift can be a good option for those patients where further strengthening of the low back and hips are needed, for example in patients with more demanding leisure or work activities, who need to continue to exercise to further increase their strength. In this sense, this thesis provides information to clinicians who wish to implement this exercise in their practice, both regarding how to perform the exercise and which patients are likely to benefit most from the training. Furthermore, since the LMC intervention had a greater effect on self-rated activity and lumbo-pelvic movement control, clinicians should reflect upon the patients' goals with their rehabilitation and choose appropriate exercises accordingly. Oftentimes patients' are limited in specific activities and also have specific impairments in movement control, for example, a limitation in activities related to forward bending and an inability to dissociate movements in flexion between the hip joint from the lumbo-pelvic area. The results therefore implies that for patients that need help to address these specific issues, the LMC intervention is preferable.

Regarding implications for future research, the results of this thesis contribute with a few new directions. As stated before, there is still a lack of understanding regarding the evidence how different exercise interventions work to reduce pain and disability for patients with LBP. The results presented in this thesis give some indications for further investigation, for example the importance of improving lumbo-pelvic movement control in relation to improving activity. Also, the results in Paper III showed that the

lumbar multifidus muscles increased in size on the smaller side over time, i.e. there were no between-group effect. As mentioned, re-training of local stabilizing muscles for patients with LBP is usually performed with low-load and it is advised against using more complex high-load exercises in order to stimulate the desired muscle recruitment pattern [79]. Despite the fact that the HLL intervention did not include any isolated training of the lumbar multifidus, there were no differences between HLL and LMC for lumbar multifidus thickness. It should, however, be noted that lumbar multifidus thickness as outcome measure might not reflect muscle function of the multifidus muscles completely. Nevertheless, further investigations of the principles of motor control re-training for patients with LBP are recommended.

Final reflections

During the work with this thesis we, in our research group, have had several discussions related to the terminology used in this field of research. The issue of labeling exercises on the basis of their main goal has been discussed and explored thoroughly in our research group. Despite our efforts, we have not found any reliable source or guide to lean on in this issue.

In this thesis, the exercises used in both interventions were considered to have an emphasis on motor control. According to the definition by Shumway and Cook [86], motor control involves the coordination of muscle activation and movements through organization in the central nervous system, influenced by sensory input, environment and perceptions. With this definition in mind, both the deadlift exercise used in the HLL intervention and the exercises used in the LMC intervention, could be considered motor control exercises, or perhaps movement control exercises.

An exercise such as the deadlift could of course also be considered primarily as a resistance training exercise used for the purpose of increasing strength and muscle size. However, from a motor control perspective, in order to perform the deadlift with ideal technique, there are several important elements required. The physiotherapist in the HLL intervention emphasized control of the lumbar spine by instructing the participants to actively contract their trunk muscles while lifting (i.e. abdominal bracing) and performing the exercise through movement in the ankle, knee and hip joints, without moving the lumbar spine. Thus, the deadlift exercise provided coordinative demands (muscle recruitment pattern, ability to dissociate movements between the hip and low back) for the participants while also emphasizing progression to higher loads in order to stimulate improvements in strength. Furthermore, in a recent systematic review of motor control

exercises for persistent LBP [82], the authors did in fact also, in line with our description, classify both the HLL and LMC interventions as motor control exercises.

Finally, physiotherapists working in the area of musculoskeletal disorders need to discuss the interpretation and use of the words motor control/movement control (in Swedish: motorisk kontroll/rörelsekontroll). For future evaluations of interventions for LBP, it is also recommended that researchers describe their exercises and progression in detail and not simply as e.g. motor control exercises/lumbar stabilizing exercises/resistance training.

Conclusions

The conclusions drawn from the results of this thesis are summarized below. All conclusions outlined are in consideration of patients with a nociceptive mechanical low back pain as their dominating pain pattern.

- Individualized low-load motor control exercises were more effective than a high-load lifting exercise in increasing activity and performance in tests of movement control and in some tests of trunk muscle endurance

- Both interventions reduced pain intensity and increase performance in tests of lift strength and some tests of trunk muscle endurance, over time. Both interventions provided a minimal important change in pain intensity

- Both interventions affected the lumbo-pelvic alignment in patients with extreme variations of lumbo-pelvic alignment towards a normalized "mean" alignment

- Both interventions increased the lumbar multifidus thickness on the side with the smaller thickness at baseline, thus improving symmetry between sides

- Training with a high-load lifting exercise, the deadlift, seems beneficial mainly to patients with an initially lower pain intensity and higher performance in the Biering-Sørensen test of endurance in hip and back extensors

Acknowledgements

Being a PhD student has taught me many things. Among others, when to be bold and when to be humble. My humble thanks to the following persons who have made this thesis possible and my work with the thesis stimulating and enjoyable:

All the patients with low back pain who gave their time to participate in the study.

My main supervisor, Ulrika Aasa, for supervising me both during my master's project and during my doctoral studies. Thank you for your patience, for always having, or making, time to see me and giving quick and thorough feedback on texts. You are an inspiration as a researcher, and this thesis would, of course, not have been possible without you.

My co-supervisor, Peter Michaelson. Thank you for always being thorough in your feedback and challenging my statistical knowledge during the work with this thesis. Together with Ulrika as my principal supervisors you have both been invaluable during our discussions in order to connect the dots between clinical relevance and scientific presentation of the material in this thesis.

My co-supervisors, Lillemor Lundin-Olsson and Ulrica Bergström. Lillemor, thank you for being part of my team of supervisors and contributing with valuable insights about the "bigger picture" of being a researcher. It has been reassuring to have you on my team. Ulrica, for your help during the planning of my PhD studies.

My examiner, Börje Rehn, for being the go-to person for signatures and administration regarding my doctoral studies and, together with Kerstin Waling, introducing me to teaching at the university.

Former and current heads of the Department of Community Medicine and Rehabilitation, Gunnevi Sundelin and Ann Sörlin for introducing me to what it means to be a PhD student and giving valuable advice along the way.

My doctoral colleagues for discussions during seminars and valuable feedback on manuscripts. A special thank you to my roommates Tobias Stenlund and Andre Nyberg, and also Matthias Tegern, for being available for scientific discussions, questions and of course as company at lunch buffets!

Fam. Ögren; Thomas, Ulrika, Oskar, Amanda and Jimmy Falk. Thank you for your hospitality in Jokkmokk, for lovely dinners in Umeå and providing much needed stress-relief in between my work with this thesis. On our next visit to Jokkmokk and Piertinjaure I will leave my computer at home!

Fam. Giunti; Anders, Giulia, Benjamin and Sebastian. Thank you all for your support, hospitality and encouragement throughout these years. Anders, my dear brother, thank you for always providing crystal clear truths about how things are. Giulia, my sister-in-law, for being there and giving much needed cheer and thoughtful advice that only a fellow/former PhD student could do.

My parents, Bernt and Lehna Berglund, for your unconditional love and support and for always believing in me in whatever I have set out to do.

My beloved life-companion, Johanna Ögren, for your love, support, encouragement, coaching and promptly reminding me to "go to sleep", "close my computer" and the importance of disconnecting from work once in a while.

****

References

1. Alaranta, H., et al., Static back endurance and the risk of low-back pain. *Clin Biomech (Bristol, Avon)*, 1995. 10(6): p. 323-324.

2. Bagraith, K.S., J. Hayes, and J. Strong, Mapping patient goals to the International Classification of Functioning, Disability and Health (ICF): examining the content validity of the low back pain core sets. *J Rehabil Med*, 2013. 45(5): p. 481-7.

3. Balague, F., et al., Non-specific low back pain. *Lancet*, 2012. 379(9814): p. 482-91.

4. Bank, P.J., et al., Motor consequences of experimentally induced limb pain: a systematic review. *Eur J Pain*, 2013. 17(2): p. 145-57.

5. Barnekow-Bergkvist, M., et al., Development of muscular endurance and strength from adolescence to adulthood and level of physical capacity in men and women at the age of 34 years. *Scand J Med Sci Sports*, 1996. 6(3): p. 145-55.

6. Bautz-Holter, E., et al., Does the International Classification of Functioning, Disability and Health (ICF) core set for low back pain cover the patients' problems? A cross-sectional content-validity study with a Norwegian population. *Eur J Phys Rehabil Med*, 2008. 44(4): p. 387-97.

7. Been, E. and L. Kalichman, Lumbar lordosis. *Spine J*, 2014. 14(1): p. 87-97.

8. Beneciuk, J.M., et al., The STarT back screening tool and individual psychological measures: evaluation of prognostic capabilities for low back pain clinical outcomes in outpatient physical therapy settings. *Phys Ther*, 2013. 93(3): p. 321-33.

9. Beneck, G.J. and K. Kulig, Multifidus atrophy is localized and bilateral in active persons with chronic unilateral low back pain. *Arch Phys Med Rehabil*, 2012. 93(2): p. 300-6.

10. Bergmark, A., Stability of the lumbar spine. A study in mechanical engineering. *Acta Orthop Scand Suppl*, 1989. 230: p. 1-54.

11. Bjorck-van Dijken, C., A. Fjellman-Wiklund, and C. Hildingsson, Low back pain, lifestyle factors and physical activity: a population based-study. *J Rehabil Med*, 2008. 40(10): p. 864-9.

12. Burton, A.K., et al., Chapter 2. European guidelines for prevention in low back pain : November 2004. *Eur Spine J*, 2006. 15 Suppl 2: p. S136-68.

13. Chakraborty, H., Gu, H., A Mixed Model Approach for Intent-to-Treat Analysis in Longitudinal Clinical Trials With Missing Values. *Research Triangle Park, NC: RTI International*, March 2009.

14. Cholewicki, J., S.M. McGill, and R.W. Norman, Lumbar spine loads during the lifting of extremely heavy weights. *Med Sci Sports Exerc*, 1991. 23(10): p. 1179-86.

15. Comerford, M.J. and S.L. Mottram, Functional stability re-training: principles and strategies for managing mechanical dysfunction. *Man Ther*, 2001. 6(1): p. 3-14.

16. Costa, L.O., et al., Motor control exercise for chronic low back pain: a randomized placebo-controlled trial. *Phys Ther*, 2009. 89(12): p. 1275-86.

17. Cott, C., et al., The movement continuum theory of physical therapy. *Phys Can*, 1995. 47(2).

18. Dagenais, S., J. Caro, and S. Haldeman, A systematic review of low back pain cost of illness studies in the United States and internationally. *Spine J*, 2008. 8(1): p. 8-20.

19. Dankaerts, W., et al., Altered patterns of superficial trunk muscle activation during sitting in nonspecific chronic low back pain patients: importance of subclassification. *Spine*, 2006. 31(17): p. 2017-23.

20. Dankaerts, W., et al., Differences in sitting postures are associated with nonspecific chronic low back pain disorders when patients are subclassified. *Spine*, 2006. 31(6): p. 698-704.

21. Duehring, M.D., C.R. Feldmann, and W.P. Ebben, Strength and conditioning practices of United States high school strength and conditioning coaches. *J Strength Cond Res*, 2009. 23(8): p. 2188-203.

22. Dworkin, R.H., et al., Core outcome measures for chronic pain clinical trials: IMMPACT recommendations. *Pain*, 2005. 113(1-2): p. 9-19.

23. Ekman, M., O. Johnell, and L. Lidgren, The economic cost of low back pain in Sweden in 2001. *Acta Orthop*, 2005. 76(2): p. 275-84.

24. Engel, G.L., The need for a new medical model: a challenge for biomedicine. *Science*, 1977. 196(4286): p. 129-36.

25. Fairbank, J., et al., The Role of Classification of Chronic Low Back Pain. *Spine*, 2011. 36(21): p. S19-S42.

26. Ferguson, A., The clinical and roentgenographic interpretation of lumbosacral anomalies. *Radiology*, 1934. 22: p. 548–58.

27. Ferreira, M.L., et al., Comparison of general exercise, motor control exercise and spinal manipulative therapy for chronic low back pain: A randomized trial. *Pain*, 2007. 131(1-2): p. 31-7.

28. Fersum, K.V., et al., Integration of subclassification strategies in randomised controlled clinical trials evaluating manual therapy treatment and exercise therapy for non-specific chronic low back pain: a systematic review. *Br J Sports Med*, 2010. 44(14): p. 1054-62.

29. Fersum, K.V., et al., Integration of subclassification strategies in randomised controlled clinical trials evaluating manual therapy treatment and exercise therapy for non-specific chronic low back pain: a systematic review. *Br J Sports Med*.

30. Field, A., Discovering Statistics Using IBM SPSS Statistics. 2013, London: *SAGE Publications Ltd*.

31. Fritz, J.M., et al., Primary care referral of patients with low back pain to physical therapy: impact on future health care utilization and costs. *Spine (Phila Pa 1976)*, 2012. 37(25): p. 2114-21.

32. Grenier, S.G. and S.M. McGill, Quantification of lumbar stability by using 2 different abdominal activation strategies. *Arch Phys Med Rehabil*, 2007. 88(1): p. 54-62.

33. Hackett, D.A. and C.M. Chow, The Valsalva maneuver: its effect on intra-abdominal pressure and safety issues during resistance exercise. *J Strength Cond Res*, 2013. 27(8): p. 2338-45.

34. Hamlyn, N., D.G. Behm, and W.B. Young, Trunk muscle activation during dynamic weight-training exercises and isometric instability activities. *J Strength Cond Res*, 2007. 21(4): p. 1108-12.

35. Hebert, J.J., et al., A systematic review of the reliability of rehabilitative ultrasound imaging for the quantitative assessment of the abdominal and lumbar trunk muscles. *Spine (Phila Pa 1976)*, 2009. 34(23): p. E848-56.

36. Helmhout, P.H., et al., Exercise therapy and low back pain: insights and proposals to improve the design, conduct, and reporting of clinical trials. *Spine (Phila Pa 1976)*, 2008. 33(16): p. 1782-8.

37. Hides, J., et al., Multifidus size and symmetry among chronic LBP and healthy asymptomatic subjects. *Man Ther*, 2008. 13(1): p. 43-9.

38. Hides, J.A., G.A. Jull, and C.A. Richardson, Long-term effects of specific stabilizing exercises for first-episode low back pain. *Spine (Phila Pa 1976)*, 2001. 26(11): p. E243-8.

39. Hides, J.A., et al., Effect of stabilization training on multifidus muscle cross-sectional area among young elite cricketers with low back pain. *J Orthop Sports Phys Ther*, 2008. 38(3): p. 101-8.

40. Hides, J.A., et al., Retraining motor control of abdominal muscles among elite cricketers with low back pain. *Scand J Med Sci Sports*, 2010. 20(6): p. 834-42.

41. Hides, J.A., et al., Evidence of lumbar multifidus muscle wasting ipsilateral to symptoms in patients with acute/subacute low back pain. *Spine*, 1994. 19(2): p. 165-72.

42. Hodges, P.W., J. Cholewicki, and J. Van Dieen., Spinal Control: The Rehabilitation of Back Pain, 1st Edition. State of the art and science. 2013: *Churchill Livingstone*. 344.

43. Hodges, P.W., et al., New insight into motor adaptation to pain revealed by a combination of modelling and empirical approaches. *Eur J Pain*, 2013. 17(8): p. 1138-46.

44. Holmberg, D., H. Crantz, and P. Michaelson, Treating persistent low back pain with deadlift training : a single subject experimental design with a 15-month follow-up *Adv Physiother*, 2012. 14(2): p. 61-70.

45. Hoy, D., et al., The Epidemiology of low back pain. *Best Pract Res Clin Rheumatol*, 2010. 24(6): p. 769-81.

46. IASP. International Association for the Study of Pain. Taxonomy.; Available from: http://www.iasp-pain.org/Taxonomy, Accessed 2016-03-09.

47. IPF. International Powerlifting Federation. Disciplines of powerlifting. Available from: http://www.powerlifting-ipf.com/about-ipf/disciplines.html, Accessed 2016-04-15.

48. Johansson, E. and P. Lindberg, Subacute and chronic low back pain. Reliability and validity of a Swedish version of the Roland and Morris Disability Questionnaire. *Scand J Rehabil Med*, 1998. 30(3): p. 139-43.

49. Kapandji, I.A., The Physiology of the Joints, volume III 2008, Edinburgh: *Churchill-Livingstone*.

50. Karayannis, N.V., G.A. Jull, and P.W. Hodges, Physiotherapy movement based classification approaches to low back pain: comparison of subgroups through review and developer/expert survey. *BMC Musculoskelet Disord*, 2012. 13: p. 24.

51. Koes, B.W., et al., An updated overview of clinical guidelines for the management of non-specific low back pain in primary care. *Eur Spine J*, 2010. 19(12): p. 2075-94.

52. Koppenhaver, S.L., et al., Rehabilitative ultrasound imaging is a valid measure of trunk muscle size and activation during most isometric sub-maximal contractions: a systematic review. *Aust J Physiother*, 2009. 55(3): p. 153-69.

53. Kristensen, J. and A. Franklyn-Miller, Resistance training in musculoskeletal rehabilitation: a systematic review. *Br J Sports Med*, 2012. 46(10): p. 719-26.

54. Lambeek, L.C., et al., The trend in total cost of back pain in The Netherlands in the period 2002 to 2007. *Spine (Phila Pa 1976)*, 2011. 36(13): p. 1050-8.

55. Latimer, J., et al., The reliability and validity of the Biering-Sorensen test in asymptomatic subjects and subjects reporting current or previous nonspecific low back pain. *Spine*, 1999. 24(20): p. 2085-2089.

56. Lundberg, M., J. Styf, and S. Carlsson, A psychometric evaluation of the Tampa Scale for Kinesiophobia - from a physiotherapeutic perspective. *Physiother Theory Pract*, 2004. 20(2): p. 121-133.

57. Luomajoki, H., et al., Improvement in low back movement control, decreased pain and disability, resulting from specific exercise intervention. *Sports Med Arthrosc Rehabil Ther Technol*. 2: p. 11.

58. Luomajoki, H., et al., Movement control tests of the low back; evaluation of the difference between patients with low back pain and healthy controls. *BMC Musculoskelet Disord*, 2008. 9: p. 170.

59. Luomajoki, H., et al., Reliability of movement control tests in the lumbar spine. *BMC Musculoskelet Disord*, 2007. 8: p. 90.

60. Macedo, L.G., et al., Effect of motor control exercises versus graded activity in patients with chronic nonspecific low back pain: a randomized controlled trial. *Phys Ther*, 2012. 92(3): p. 363-77.

61. Macedo, L.G., et al., Motor control exercise for persistent, nonspecific low back pain: a systematic review. *Phys Ther*, 2009. 89(1): p. 9-25.

62. Manchikanti, L., et al., Epidemiology of low back pain in adults. *Neuromodulation*, 2014. 17 Suppl 2: p. 3-10.

63. Matthijs, O.C., et al., Co-contractive activation of the superficial multifidus during volitional preemptive abdominal contraction. *PM R*, 2014. 6(1): p. 13-21.

64. McGill, S.M., A. Childs, and C. Liebenson, Endurance times for low back stabilization exercises: clinical targets for testing and training from a normal database. *Arch Phys Med Rehabil*, 1999. 80(8): p. 941-4.

65. McNeill, T., et al., Trunk strengths in attempted flexion, extension, and lateral bending in healthy subjects and patients with low-back disorders. *Spine (Phila Pa 1976)*, 1980. 5(6): p. 529-38.

66. Moseley, G.L., Evidence for a direct relationship between cognitive and physical change during an education intervention in people with chronic low back pain. *Eur J Pain*, 2004. 8(1): p. 39-45.

67. Naugle, K.M., R.B. Fillingim, and J.L. Riley, 3rd, A meta-analytic review of the hypoalgesic effects of exercise. *J Pain*, 2012. 13(12): p. 1139-50.

68. NSCA. National Strength and Conditioning Association. Exercise technique: Deadlift. Available from: https://www.nsca.com/Videos/Exercise_Technique/Exercise_Technique__Deadlift/, Accessed 2016-04-15.

69. Nuzzo, J.L., et al., Trunk muscle activity during stability ball and free weight exercises. *J Strength Cond Res*, 2008. 22(1): p. 95-102.

70. O'Connor, S.R., et al., Walking exercise for chronic musculoskeletal pain: systematic review and meta-analysis. *Arch Phys Med Rehabil*, 2015. 96(4): p. 724-734 e3.

71. O'Sullivan, P., Diagnosis and classification of chronic low back pain disorders: maladaptive movement and motor control impairments as underlying mechanism. *Man Ther*, 2005. 10(4): p. 242-55.

72. Ostelo, R.W., et al., Interpreting change scores for pain and functional status in low back pain: towards international consensus regarding minimal important change. *Spine (Phila Pa 1976)*, 2008. 33(1): p. 90-4.

73. Panjabi, M.M., Clinical spinal instability and low back pain. *J Electromyogr Kinesiol*, 2003. 13(4): p. 371-9.

74. Patti, A., et al., Effects of Pilates exercise programs in people with chronic low back pain: a systematic review. *Medicine (Baltimore)*, 2015. 94(4): p. e383.

75. Petersen, T., et al., Diagnostic classification of non-specific low back pain. A new system integrating patho-anatomic and clinical categories. *Physiotherapy Theory & Practice*, 2003. 19(4): p. 213-237 25p.

76. Petty, N., Neuromusculoskeletal Examination and Assessment, 4th ed. 2011, London: *Churchill-Livingstone Elsevier*. 468.

77. Pillastrini, P., et al., An updated overview of clinical guidelines for chronic low back pain management in primary care. *Joint Bone Spine*, 2012. 79(2): p. 176-85.

78. Porter, J.L. and A. Wilkinson, Lumbar-hip flexion motion. A comparative study between asymptomatic and chronic low back pain in 18- to 36-year-old men. *Spine (Phila Pa 1976)*, 1997. 22(13): p. 1508-13; discussion 1513-4.

79. Richardson, C., et al., Therapeutic exercise for lumbopelvic stabilization : a motor control approach for the treatment and prevention of low back pain. 2nd ed. 2004, Edinburgh ; New York: *Churchill Livingstone*. x, 271 p.

80. Roussel, N.A., et al., Altered lumbopelvic movement control but not generalized joint hypermobility is associated with increased injury in dancers. A prospective study. *Man Ther*, 2009.

81. Sahrmann, S.A., Diagnosis and treatment of movement impairment syndromes. 1:st edition ed. 2002, St. Louis: *Mosby*.

82. Saragiotto, B.T., et al., Motor control exercise for chronic non-specific low-back pain. *Cochrane Database Syst Rev*, 2016. 1: p. CD012004.

83. Saragiotto, B.T., T.P. Yamato, and C. Maher, Yoga for low back pain: PEDro systematic review update. *Br J Sports Med*, 2015. 49(20): p. 1351.

84. Schellenberg, K.L., et al., A clinical tool for office assessment of lumbar spine stabilization endurance: prone and supine bridge maneuvers. *Am J Phys Med Rehabil*, 2007. 86(5): p. 380-6.

85. Searle, A., et al., Exercise interventions for the treatment of chronic low back pain: a systematic review and meta-analysis of randomised controlled trials. *Clin Rehabil*, 2015. 29(12): p. 1155-67.

86. Shumway-Cook, A., Woollacott, MH., Motor Control: Translating Research Into Clinical Practice. 3rd ed. 2007, Philadelphia, PA: *Lippincott Williams & Wilkins*.

87. Smart, K.M., et al., Self-reported pain severity, quality of life, disability, anxiety and depression in patients classified with 'nociceptive', 'peripheral neuropathic' and 'central sensitisation' pain. The discriminant validity of mechanisms-based classifications of low back (+/-leg) pain. *Man Ther*, 2012. 17(2): p. 119-25.

88. Smart, K.M., et al., Mechanisms-based classifications of musculoskeletal pain: part 1 of 3: symptoms and signs of central sensitisation in patients with low back (+/- leg) pain. *Man Ther*, 2012. 17(4): p. 336-44.

89. Smart, K.M., et al., Mechanisms-based classifications of musculoskeletal pain: part 2 of 3: symptoms and signs of peripheral neuropathic pain in patients with low back (+/- leg) pain. *Man Ther*, 2012. 17(4): p. 345-51.

90. Smart, K.M., et al., Mechanisms-based classifications of musculoskeletal pain: part 3 of 3: symptoms and signs of nociceptive pain in patients with low back (+/- leg) pain. *Man Ther*, 2012. 17(4): p. 352-7.

91. Steele, J., S. Bruce-Low, and D. Smith, A reappraisal of the deconditioning hypothesis in low back pain: review of evidence from a triumvirate of research methods on specific lumbar extensor deconditioning. *Curr Med Res Opin*, 2014. 30(5): p. 865-911.

92. Steele, J., S. Bruce-Low, and D. Smith, A review of the clinical value of isolated lumbar extension resistance training for chronic low back pain. *PM R*, 2015. 7(2): p. 169-87.

93. Steele, J., et al., A randomized controlled trial of limited range of motion lumbar extension exercise in chronic low back pain. *Spine (Phila Pa 1976)*, 2013. 38(15): p. 1245-52.

94. Steele, J., et al., Can specific loading through exercise impart healing or regeneration of the intervertebral disc? *Spine J*, 2015. 15(10): p. 2117-21.

95. Stradford, P., M. Westway, and J. Binkely, Assessing disability and change on individual patients: A report of a patient specific measure. *Physiother Can*, 1995. 47(4): p. 258-263.

96. Tabachnick, B., Fidell, LS. , Using Multivariate Statistics, 6th ed. 2013, Boston: *Pearson*.

97. Tekin, Y., et al., Biering-Sorensen test scores in coal miners. *Joint Bone Spine*, 2009. 76(3): p. 281-5.

98. Tsao, H. and P.W. Hodges, Immediate changes in feedforward postural adjustments following voluntary motor training. *Exp Brain Res*, 2007. 181(4): p. 537-46.

99. Tsao, H. and P.W. Hodges, Persistence of improvements in postural strategies following motor control training in people with recurrent low back pain. *J Electromyogr Kinesiol*, 2008. 18(4): p. 559-67.

100. Waddell, G., The back pain revolution. 2nd ed. 2004, Edinburgh ; New York: *Churchill Livingstone*. xiii, 475 p.

101. Wadell, G., The Back Pain Revolution. 2004, Edinburgh: *Churchill Livingstone*.

102. Wallwork, T.L., J.A. Hides, and W.R. Stanton, Intrarater and interrater reliability of assessment of lumbar multifidus muscle thickness using rehabilitative ultrasound imaging. *J Orthop Sports Phys Ther*, 2007. 37(10): p. 608-12.

103. Van Dillen, L.R., K.S. Maluf, and S.A. Sahrmann, Further examination of modifying patient-preferred movement and alignment strategies in patients with low back pain during symptomatic tests. *Man Ther*, 2009. 14(1): p. 52-60.

104. Van Dillen, L.R., et al., The effect of modifying patient-preferred spinal movement and alignment during symptom testing in patients with low back pain: A preliminary report. *Archives of Physical Medicine and Rehabilitation*, 2003. 84(3): p. 313-322.

105. Van Dillen, L.R., et al., Movement system impairment-based categories for low back pain: Stage 1 validation. *Journal of Orthopaedic & Sports Physical Therapy*, 2003. 33(3): p. 126-142.

106. van Middelkoop, M., et al., Exercise therapy for chronic nonspecific low-back pain. *Best Pract Res Clin Rheumatol*, 2010. 24(2): p. 193-204.

107. WCPT. World Confederation for Physical Therapy. Policy statement: Description of physical therapy. Available from: http://www.wcpt.org/policy/ps-descriptionPT, Accessed 2016-04-11.

108. WHO. World Health Organization. ICF: International Classification of Functioning, Disability and Health. Geneva: World Health Organization. 2001; Available from: http://www.who.int/classifications/icf/en/, Accessed 2016-04-01.

109. Vrtovec, T., F. Pernus, and B. Likar, A review of methods for quantitative evaluation of spinal curvature. *Eur Spine J*, 2009. 18(5): p. 593-607.

110. Wu, W., et al., Reliability and reproducibility analysis of the Cobb angle and assessing sagittal plane by computer-assisted and manual measurement tools. *BMC Musculoskelet Disord*, 2014. 15: p. 33.

111. Yamato, T.P., et al., Pilates for low back pain. *Cochrane Database Syst Rev*, 2015. 7: p. CD010265.

Dissertations written by physiotherapists, Umeå University 1989–2016

1. Birgitta Bergman. Being a physiotherapist - Professional role, utilization of time and vocational strategies. Umeå University Medical Dissertations, New Series no 251, 1989 (Department of Physical Medicine and Rehabilitation)

2. Inger Wadell. Influences from peripheral sense organs on primary and secondary spindle afferents via gamma-motoneurones - A feedback mechanism for motor control and regulation of muscle stiffness. Umeå University Medical Dissertations, New Series no 307, 1991 (Department of Physiology)

3. Jessica Elert. The pattern of activation and relaxation during fatiguing isocinetic contractions in subjects with and without muscle pain. Arbete och hälsa 1991:47. Diss. 1992 (sammanfattning). (Departments of Clinical Physiology, National Institute of Occupational Health and Physical Medicine and Rehabilitation)

4. Gunnevi Sundelin. Electromyography of shoulder muscles - The effects of pauses, drafts and repetitive work cycles. Arbete och Hälsa, 1992:16. Diss. (sammanfattning). (Departments of Anatomy, National Institute of Occupational Health, Division of Work and Environmental Physiology, Divisions of Occupational Medicine and Applied Work Physiology and Occupational Medicine)

5. Birgit Rösblad. Visual and proprioceptive control of arm movement - Studies of development and dysfunction. Diss. (sammanfattning) 1994 (Department of Paediatrics)

6. Charlotte Häger-Ross. To grip and not to slip - Sensorimotor mechanisms during reactive control of grasp stability. Umeå University Medical Dissertations, New Series no 429, 1995 (Department of Physiology)

7. Lars Nyberg. Falls in the frail elderly – Incidence, characteristics and prediction with special reference to patients with stroke and hip fractures. Umeå Medical Dissertations, New Series no 483, 1996 (Department of Geriatric Medicine)

8. Margareta Barnekow-Bergkvist. Physical capacity, physical activity and health -A population based fitness study of adolescents with an 18-year follow-up. Umeå University Medical Dissertations, New Series no 494, 1997 (Departments of Physiology and Technology, National Institute for Working Life and Epidemiology and Public Health)

9. Britta Lindström. Knee muscle function in healthy persons and patients with upper motor neurone syndrome. Umeå University Medical Dissertations, New Series no 505, 1997 (Departments of Physical Medicine and Rehabilitation and Clinical Neuroscience)

10. Monica Mattsson. Body Awareness - applications in physiotherapy. Umeå University Medical Dissertations, New Series no 543, 1998 (Departments of Psychiatry and Family Medicine)

11. Hildur Kalman. The structure of knowing. Existential trust as an epistemological category. Umeå studies in the humanities. 145, 1999 (Department of Philosophy and Linguistics)

12. Hamayun Zafar. Integrated jaw and neck function in man: studies of mandibular and head-neck movements during jaw opening-closing tasks. Umeå University Medical Dissertations, New series no 74, 2000 (Departments of Odontology, Clinical Oral Physiology and Centre for Musculoskeletal Research, National Institute for Working Life, Umeå)

13. Lillemor Lundin-Olsson. Prediction and prevention of falls among elderly people in residential care. Umeå University Medical Dissertations, New Series no 671, 2000 (Department of Community Medicine and Rehabilitation, Physiotherapy and Geriatric Medicine)

14. Christina Ahlgren. Aspects of rehabilitation – with focus on women with trapezius myalgia. Umeå University Medical Dissertations, New Series no 715, 2001 (Department of Public Health and Clinical Medicine, Occupational Medicine)

15. Ann Öhman. Profession on the move - changing conditions and gendered development in physiotherapy. Umeå University Medical Dissertations, New series No 730, 2001 (Departments of Community Medicine and Rehabilitation, Physiotherapy and Public Health and Clinical Medicine, Epidemiology)

16. Kerstin Söderman. The female soccer player – Injury pattern, risk factors and intervention. Umeå University Medical Dissertations, New series no 735, 2001 (Departments of Surgical and Perioperative Sciences, Sports Medicine, and Community Medicine and Rehabilitation, Physiotherapy)

17. Lena Grönblom-Lundström. Rehabilitation in light of different theories of health. Outcome for patients with low-back complaints – a theoretical discussion. Umeå University Medical Dissertations, New series no 760, 2001 (Departments of Public Health and Clinical Medicine, Epidemiology, and Community Medicine and Rehabilitation, Social Medicine)

18. Kerstin Waling. Pain in women with work-related trapezius myalgia. Intervention effects and variability. Umeå University Medical Dissertations, New series no 762, 2001 (Departments of Public Health and Clinical Medicine, Occupational Medicine, and Community Medicine and Rehabilitation, Physiotherapy)

19. Eva-Britt Malmgren-Olsson. Health problems and treatment effects in patients with non-specific musculoskeletal disorders. A comparitson between Body Awareness Therapy, Feldenkrais and Individual Physiotherapy. Umeå University Medical Dissertations, New series no 774, 2002 (Department of Community Medicine and Rehabilitation, Physiotherapy and Department of Psychology)

20. Jane Jensen. Fall and injury prevention in older people living in residential care facilities. Umeå University Medical Dissertations, New series no 812, 2003 (Department of Community Medicine and Rehabilitation, Physiotherapy and Geriatric Medicine)

21, Anncristine Fjellman-Wiklund. Musicianship and teaching. Aspects of musculoskeletal disorders, physical and psychosocial work factors in musicians with focus on music teachers. Umeå University Medical Dissertations, New series no 825, 2003 (Department of Community Medicine and Rehabilitation, Physiotherapy)

22. Börje Rehn. Musculoskeletal disorders and whole-body vibration exposure among professional drivers of all-terrain vehicles. Umeå University Medical Dissertations, New series no 852, 2004 (Department of Public Health and Clinical Medicine, Occupational Medicine)

23. Martin Björklund. Effects of repetitive work on proprioception and of stretching on sensory mechanisms. Implications for work-related neuromuscular disorders. Umeå University Medical Dissertations, New series no 877, 2004 (Department of Surgical and Perioperative Sciences, Sports Medicine Unit, Umeå University, The Center for Musculoskeletal Reseach, University of Gävle, Umeå, and Alfta Forskningsstiftelse, Alfta)

24. Karin Wadell. Physical training in patients with chronic obstructive pulmonary disease – COPD. Umeå University Medical Dissertations, New series no 917, 2004 (Departments of Community Medicine and Rehabilitation, Physiotherapy; Public Health and Clinical Medicine, Respiratory Medicine and Allergy, Surgical and Perioperative Sciences, Sports Medicine)

25. Peter Michaelson. Sensorimotor characteristics in chronic neck pain. Possible pathophysiological mechanisms and implications for rehabilitation. Umeå University Medical Dissertations, New series no 924, 2004 (Departments of Surgical and Perioperative Sciences, Sports Medicine Unit, University of Umeå, Southern Lappland Research Department, Vilhelmina, Centre for Musculoskeletal Research, University of Gävle, Umeå)

26. Ulrika Aasa. Ambulance work. Relationships between occupational demands, individual characteristics and health related outcomes. Umeå University Medical Dissertations, New series no 943, 2005 (Department of Surgical and Perioperative Sciences, Sports Medicine and Surgery, University of Umeå and Centre for Musculoskeletal Research, University of Gävle)

27. Ann-Katrin Stensdotter. Motor Control of the knee. Kinematic and EMG studies of healthy individuals and people with patellofemoral pain. Umeå University Medical Dissertations, New series no 987, 2005 (Department of Community Medicine and Rehabilitation, Physiotherapy)

28. Tania Janaudis Ferreira. Aspects of muscle function and training with oxygen in patients with chronic obstructive pulmonary disease – COPD. Umeå University Licentiate Thesis, 2005 (Department of Community Medicine and Rehabilitation, Physiotherapy)

29. Erik Rosendahl. Fall prediction and a high-intensity functional exercise programme to improve physical functions and to prevent falls among older people living in residential care facilities. Umeå University Medical Dissertations, New Series no 1024, 2006 (Department of Community Medicine and Rehabilitation, Geriatric Medicine and Physiotherapy)

30. Michael Stenvall. Hip fractures among old people. Their prevalence, consequences and complications and the evaluation of a multi-factorial intervention program designed to prevent falls and injuries and enhance performance of activities of daily living. Umeå University Medical Dissertations, New Series no 1040, 2006 (Department of Community Medicine and Rehabilitation, Geriatric Medicine and Physiotherapy)

31. Petra von Heideken Wågert. Health, physical ability, falls and morale in very old people: the Umeå 85+ Study. Umeå University Medical Dissertations, New Series no 1038, 2006 (Department of Community Medicine and Rehabilitation, Geriatric Medicine and Physiotherapy)

32. Karl Gisslén. The patellar tendon in junior elite volleyball players and an Olympic elite weightlifter. Umeå University Medical Dissertations, New Series no 1073, 2006 (Department of Surgical and Perioperative Sciences, Sports Medicine Unit)

33. Gerd Flodgren. Effect of low–load repetitive work and mental load on sensitising substances and metabolism in the trapezius muscle. Umeå University Medical Dissertations, New series no 1130, 2007 (Department of Surgical and Perioperative Sciences, Sports Medicine Unit, Centre of Musculoskeletal Research, University of Gävle, Umeå, and the Department of Community Medicine and Rehabilitation, Rehabilitation Medicine)

34. Staffan Eriksson. Falls in people with dementia. Umeå University Medical Dissertations, New series no 1135, 2007 (Department of Community Medicine and Rehabilitation, Physiotheraphy and Geriatric Medicine)

35. Jonas Sandlund. Position-matching and goal-directed reaching acuity of the upper limb in chronic neck pain: Associations to self-rated characteristics. Umeå University Medical Dissertations, New series no 1182, 2008 (Department of Surgical and Perioperative Sciences, Sports Medicine Unit, Umeå University, Centre of Musculoskeletal Research, University of Gävle, Umeå)

36. Gunilla Larsson. Motor function over time in Rett syndrome-loss, difficulties and possibilities. Umeå University Licentiate Thesis, 2008 (Department of Community Medicine and Rehabilitation, Physiotherapy)

37. Charlotte Åström. Effects of vibration on muscles in the neck and upper limbs. With focus on occupational terrain vehicle drivers. Umeå University Medical Dissertations, New series no 1135, 2008 (Department of Community Medicine and Rehabilitation, Physiotherapy)

38. Ellinor Nordin. Assessment of balance control in relation to fall risk among older people. Umeå University Medical Dissertations, New series no 1198, 2008 (Department of Community Medicine and Rehabilitation, Physiotherapy)

39. Bertil Jonsson. Interaction between humans and car seat. Studies of occupant seat adjustment, posture, position and real world neck injuries in rear-end impacts. Umeå University Medical Dissertations, New Series no 1163, 2008 (Department of Surgical and Perioperative Sciences, Sports Medicine Unit)

40. Jenny Röding. Stroke in the younger. Self- reported impact on work situation, cognitive function, physical function and life satisfaction. A national survey. Umeå University Medical Dissertations, New series no 1241, 2009 (Department of Community Medicine and Rehabilitation, Physiotherapy)

41. Therese Stenlund. Rehabilitation for patients with burn out. Umeå University Medical Dissertations, New series no 1237, 2009 (Department of Public Health and Clinical Medicine, Occupational and Enviromental Medicine)

42. Elisabeth Svensson. Hand function in children and persons with neurological disorders. Aspects of movement control and evaluation of measurements. Umeå University Medical Dissertations, New series no 1261, 2009 (Department of Community Medicine and Rehabilitation, Physiotherapy)

43. Helena Nordvall. Factors in secondary prevention subsequent to distal radius fracture. Focus on physical function, co-morbidity, bone mineral density and health-related quality of life. Umeå University Medical Dissertations, New series no 1252, 2009 (Department of Community Medicine and Rehabilitation Physiotherapy and Department of Surgical and Perioperative Sciences, Orthopaedics)

44. Ingela Marklund. Intensivträning av nedre extremitet för personer med stroke– effekter och upplevelser. Umeå University Licentiate Thesis, 2009 (Department of Community Medicine and Rehabilitation, Physiotherapy)

45. Ulrik Röijezon. Sensorimotor function in chronic neck pain. Objective assessments and a novel method for neck coordination exercise. Umeå University Medical Dissertations, New series no 1273, 2009 (Department of Community Medicine and Rehabilitation, Physiotherapy, Centre of Musculoskeletal Research, University of Gävle, Umeå)

46. Birgit Enberg. Work experiences among healthcare professionals in the beginning of their professional careers. A gender perspective. Umeå University Medical Dissertations, New series no 1276, 2009 (Department of Community Medicine and Rehabilitation, Physiotherapy and Department of Public Health and Clinical Medicine, Epidemiology and Public Health Sciences)

47. Per Jonsson. Eccentric training in the treatment of tendinopathy. Umeå University Medical Dissertations, New series no 1279, 2009 (Department of Surgical and Perioperative Sciences, Sports Medicine Unit)

48. Taru Tervo. Physical activity, bone gain and sustainment of peak bone mass. Umeå University Medical Dissertations, New series no 1282, 2009 (Department of Surgical and Perioperative Sciences, Sports Medicine, Department of Community Medicine and Rehabilitation, Geriatric Medicine, Department of Community Medicine and Rehabilitation, Rehabilitation Medicine)

49. Kajsa Gilenstam. Gender and physiology in ice hockey: a multidimensional study. Umeå University Medical Dissertations, New series no 1309, 2010 (Department of Surgical and Perioperative Sciences, Sports Medicine Unit)

50. Margareta Eriksson. A 3-year lifestyle intervention in primary health care. Effects on physical activity, cardiovascular risk factors, quality of life and costeffectiveness. Umeå University Medical Dissertations, New series no 1333, 2010 (Department of Community Medicine and Rehabilitation, Physiotherapy and Department of Public Health and Clinical Medicine, Epidemiology and Public Health Sciences)

51. Eva Holmgren. Getting up when falling down. Reducing fall risk factors after stroke through an exercise program. Umeå University Medical Dissertations, New series no 1357, 2010 (Department of Community Medicine and Rehabilitation, Physiotherapy and Department of Public Health and Clinical Medicine, Medicine)

52. Tania Janaudis Ferreira. Strategies for exercise assessment and training in patients with chronic obstructive pulmonary disease. Umeå University Medical Dissertations, New series no 1360, 2010 (Department of Community Medicine and Rehabilitation, Physiotherapy)

53. Sólveig Ása Árnadóttir. Physical activity, participation and self-rated health among older community-dwelling Icelanders. A population-based study. Umeå University Medical Dissertations, New series no 1361, 2010 (Department of Community Medicine and Rehabilitation, Physiotherapy)

54. Maria Wiklund. Close to the edge. Discursive, embodied and gendered stress in modern youth. Umeå University Medical Dissertations, New series no 1377, 2010 (Department of Public Health and Clinical Medicine, Epidemiology and Global Health and Department of Community Medicine and Rehabilitation, Physiotherapy)

55. Catharina Bäcklund. Promoting physical activity among overweight and obese children: Effects of a family-based lifestyle intervention on physical activity and metabolic markers. Umeå University 2010 (Department of Food and Nutrition)

56. Helene Johansson. En mer hälsofrämjande hälso- och sjukvård: hinder och möjligheter utifrån professionernas perspektiv. Umeå University Medical Dissertations, New series no 1388, 2010 (Department of Public Health and Clinical Medicine, Epidemiology and Global Health)

57. Håkan Littbrand. Physical exercise for older people: focusing on people living in residential care facilities and people with dementia. Umeå University Medical Dissertations, New series no 1396, 2011 (Department of Community Medicine and Rehabilitation, Geriatric Medicine and Physiotherapy)

58. Marlene Sandlund, Motion interactive games for children with motor disorders. Umeå University Medical Dissertations, New series no 1419, 2011 (Department of Community Medicine and Rehabilitation, Physiotherapy)

59. Ann Sörlin, Health and the Elusive Gender Equality. Can the impact of gender equality on health be measured? Umeå University Medical Dissertations, New series no 1420, 2011 (Department of Public Health and Clinical Medicine, Epidemiology and Global Health)

60. Björn Sundström, On diet in ankylosing spondylitis. Umeå University Medical Dissertations, New series no 1440, 2011 (Department of Public Health and Clinical Medicine, Reumatology)

61. Gunilla Stenberg, Genusperspektiv på rehabilitering för patienter med rygg- och nackbesvär i primärvård. Umeå University Medical Dissertations, New series no 1482, 2012 (Department of Community Medicine and Rehabilitation, Physiotherapy and Umeå centre for Gender Studies.

62. Mattias Hedlund, Biomechanical and Neural Aspects of Eccentric and Concentric Muscle Performance in Stroke Subjects. Implications for resistance training. Umeå University Medical Dissertations, New series no 1510, 2012 (Department of Community Medicine and Rehabilitation, Physiotherapy)

63. Joakim Bagge, TNF-alfa och neurotrophins in achilles tendinosis. Umeå University Medical Dissertations, New series no 1538, 2013 (Department of Integrative Medical Biology, Anatomy and Department of Surgical and Perioperative Sciences, Sports Medicine)

64. Gunilla Larsson, Motor development, mobility and orthostatic reactions in Rett syndrome. Loss of function, difficulties and possibilities. Umeå University Medical Dissertations, New series no 1566, 2013 (Department of Community Medicine and Rehabilitation, Physiotherapy)

65. Ludvig J Backman, Neuropeptide and catecholamine effects on tenocytes in tendinosis development. Studies on two model systems with focus on proliferation and apoptosis. Umeå University Medical Dissertations, New series no 1572, 2013 (Department of Integrative Medical Biology, Anatomy and Department of Surgical and Perioperative Sciences, Sports Medicine)

66. Sven Blomqvist, Postural balance, physical activity and capacity among young people with intellectual disability. Umeå University Medical Dissertations, New series no 1579, 2013 (Department of Community Medicine and Rehabilitation, Physiotherapy)

67. Eva Tengman, Long-term consequences of anterior cruciate ligament injury. Knee function, physical activity level, physical capacity and movement pattern. Umeå University Medical Dissertations, New series no 1631, 2014 (Department of Community Medicine and Rehabilitation, Physiotherapy)

68. Andre Nyberg, Single limb exercises in patients with chronic obstructive pulmonary disease. Feasibility, methodology, effects and evidence. Umeå University Medical Dissertations, New series no 1645, 2014 (Department of Community Medicine and Rehabilitation, Physiotherapy)

69. Maria Strömbäck, Skapa rum. Ung femininitet, kroppslighet och psykisk ohälsa – genusmedveten och hälsofrämjande intervention. Umeå University Medical Dissertations, New series no 1655, 2014 (Department of Community Medicine and Rehabilitation, Physiotherapy, Clinical Science, Psychiatry and Umeå Centre for Gender Studies, National Research School for Gender Studies)

70. Joakim Bjerke, Gait and postural control after total knee arthroplasty. Umeå University Medical Dissertations, New series no 1664, 2014 (Department of Community Medicine and Rehabilitation, Physiotherapy)

71. Elisabet Sonntag-Öström, Forest for rest. Recovery from exhaustion disorder. Umeå University Medical Dissertations, New series no 1667, 2014 (Department of Public Health and Clinical Medicine, Occupational and Environmental Medicine)

72. Maria Sehlin, Resistance breathing with PEP and CPAP. Effects on respiratory parameters. Umeå University Medical Dissertations, New series no 1674, 2014 (Department of Surgical and Perioperative Sciences, Anaesthesiology and Intensive Care Medicine, Department of Community Medicine and Rehabilitation, Physiotherapy, Department of Radiation Sciences, Biomedical Engineering)

73. Petra Pohl, Falls in older community-dwelling women and men: risk factors and safety strategies. Fall risk awareness, fear of falling, and preferred exercise properties from a gender perspective. Umeå University Medical Dissertations, New series No 1692, 2015 (Department of Community Medicine and Rehabilitation, Physiotherapy)

74. Gudrun Johansson, Clinical and kinematic assessments of upper limb function in persons with post-stroke symptoms. Umeå University Medical Dissertations, New series No 1722, 2015 (Department of Community Medicine and Rehabilitation, Physiotherapy)

75. Camilla Sandberg, Physical performance, physical activity, body composition and exercise training in adults with congenital heart disease. Umeå University Medical Dissertations, New series No 1758, 2016 (Department of Public Health and Clinical Medicine, Medicine, Department of Community Medicine and Rehabilitation, Physiotherapy)

76. Tobias Stenlund, Seated postural reactions to mechanical shocks. Laboratory studies with relevance for risk assessment and prevention of musculoskeletal disorders among drivers. Umeå University Medical Dissertations, New series No 1780, 2016 (Department of Community Medicine and Rehabilitation, Physiotherapy)