STABILIZATION EXERCISES VERSUS RECONDITIONING
ON DEVICES:
TRUNK MUSCLE RECRUITMENT AND EFFECT
ON CHRONIC LOW BACK PAIN

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Veerle Stevens
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GENERAL INTRODUCTION
INTRODUCTION

Musculoskeletal disorders and complaints comprise an important public health problem due to high impact on physical functioning\(^1\), professional disability\(^2\), and health care costs\(^3\). In 2001, low back pain (LBP) for one or more days during the past six months was reported in 41.8% of a Belgian community sample.\(^4\) In the Netherlands, LBP is the most frequently reported musculoskeletal pain complaint (in a population of 25 to 55-years of age) and the most important cause of professional disability and resulting sick leave.\(^5\) Most pain complaints are continuous or recurrent.\(^1\)

In the aim to decrease pain and disability and to curtail the high socio-economic costs related to chronic LBP (CLBP), several rehabilitation strategies have been proposed. Recent reviews evaluating the effectiveness of exercise therapy in CLBP showed that individually designed strengthening or stabilizing programs appear to be effective for reducing pain and improving function.\(^6,9\) However, contradictory findings exist concerning long-term effects on pain and function.\(^8,9\) More intensive programs and rehabilitation that includes motivational strategies appear to be of greater benefit than less intensive programs.\(^8\) Treatments using exercise alone or as a part of a multidisciplinary treatment reduce sick leave in non-specific CLBP patients.\(^10\) Exercise is also thought to decrease fear-avoidance behaviour and facilitate functional improvements, despite ongoing pain.\(^7\) Consequently, European guidelines recommend supervised exercise therapy as a first-line treatment in the management of CLBP, but no recommendations are given on the specific type of exercise to be undertaken.\(^11\) The optimal intensity, frequency and duration of exercises needs to be further researched.\(^11\)

Today, concerning the active approach of CLBP in Western Europe, the two most popular rehabilitation strategies are specific exercise therapy and device exercise therapy. Specific exercise therapy combined with hands-on treatment is based on the findings of the clinical examination and the daily needs and work complaints of the patient, and intends functional restoration or improvement.\(^12,13\) In this approach, specific stabilization training often is included. Besides the specific hand-on approach, last years device exercise therapy became popular due to the low guidance cost since simultaneous individual training of
different patients is possible supervised by one physiotherapist. However, expensive machines are needed.

In the present dissertation, the muscle activity levels during stabilization exercises and exercises on devices are investigated in order to gain more insight into the working mechanisms of both therapy interventions. In addition, the effectiveness of both active approaches is compared.

**Muscle activity during stabilization exercises**

Joint stability is defined as the effective accommodation of the joints to each specific load demand through an adequately tailored joint compression (as a function of gravity and coordinated muscle and ligament forces) to produce effective joint reaction forces under changing conditions. Stabilization exercises are designed to improve function of the muscles that are believed to govern trunk stability and, when these muscles are functioning optimally, they will protect the spinal joint structures from further repetitive microtrauma, recurrent pain and degenerative change.

Different approaches concerning stabilization exercises have been discussed. It remains unclear whether instruction of stabilization exercises should occur (1) according to the principles of Richardson et al., focusing on the deep local muscles, or (2) whether subjects should be asked to perform an abdominal brace manoeuvre (isometric contraction of all the abdominal muscles) or (3) whether only the neutral spine position should be sustained and no muscle instruction should be given.

The first approach focusing on the deep local muscles is based upon in vivo and in vitro studies, in which the deep local muscles are assumed to provide the ‘fine-tuning’ of intervertebral motion as a component of the complex interdependent activity of the trunk muscles to stabilize the spine. The differentiation between local and global muscles is anatomically based and has been related to specific functions, respectively segmental stabilizing (local) and torque producing and providing general trunk stability (global). There is evidence that in patients with LBP, the deep local muscle system is often very dysfunctional. In addition, consistent differences between local muscle activity of healthy subjects and LBP patients have been found in contrast to inconsistent findings in global trunk muscle activity.
A second assumption concerning stability is that an abdominal brace manoeuvre is beneficial during the performance of stabilization exercises. This idea is based on the concept that muscles act as guy wires to ensure sufficient stability by creating a spring-like stiffness around the joints that they cross.\cite{20,41} A muscle’s line of pull is considered to play a large role in determining the ability of the muscle to stabilize, as does the balanced stiffness and stiffness symmetry around the spine.\cite{41} In this respect, no single muscle can be identified as being the most or least important in stabilizing the spine.\cite{18,19,42} However, co-activation of the superficial muscles, as proposed during an abdominal brace manoeuvre, is assumed to create a loading cost.\cite{43} Moreover, increased stiffness is not the only contributing factor to optimal stability; movement of the spine is required to dissipate forces and minimize energy expenditure.\cite{44} In healthy subjects it was shown that the central nervous system uses movement rather than simple stiffening of the spine to overcome challenges to stability.\cite{45}

The third concept concerns the neutral spine position. Most exercises are performed in a neutral spine position. Some researchers and clinicians suppose that maintaining a neutral spine position during stabilization exercises is the only instruction needed to ensure optimal performance.\cite{21,22} The neutral spine has been advocated as a safe position for exercises\cite{46} due to optimal spine loading\cite{47}. In this position the joints and surrounding passive tissues are in elastic equilibrium and thus at an angle of minimal joint load.\cite{47} Full flexion causes the interspinous ligament complex to strain, imposing an anterior shear force on the superior vertebra. Avoiding full flexion not only ensures a lower shear load but also eliminates ligament damage.\cite{20} A fully flexed spine is significantly compromised in its ability to withstand compressive load.\cite{20} In an extended lumbar spine position, such as during the exercise in which the patient lies prone and extends the legs and outstretched arms, the imposed load on the spine was demonstrated to be up to 6000 N. Consequently, the researchers concluded that this kind of extension exercises are not justifiable for any patient.\cite{20,48} The neutral spine position is assumed to create optimal orientation of all surrounding trunk muscles by which adequate contraction is enhanced during exercises. In this respect, demanding extra preparatory contraction of certain muscles seems redundant.

In conclusion, most recent research demonstrated that all trunk muscles are required for control and stability of the spine\cite{15,18,19,49} and indicated that stability is dependent on the interplay between an array of muscles, both local and global\cite{15,42}. The individual muscular
A contribution to spine stability seems to depend greatly on the demands (i.e., loading magnitude and direction) of the task.\textsuperscript{15,18}

Differences in activation\textsuperscript{20,38}, fatiguability\textsuperscript{26,37}, timing\textsuperscript{32,35}, composition\textsuperscript{30,40} and cross-sectional area\textsuperscript{30,31,36} of trunk muscles have been demonstrated between LBP patients and healthy controls. In order to comprehend the reason for changes in muscle activation related to LBP, knowledge about the muscle characteristics in healthy individuals is needed. Amplitudes of muscle activity in healthy subjects were analyzed during various stabilization exercises.\textsuperscript{21,50,60} However, often, the reported results were incomplete. Concerning the abdominal muscle activity, several studies investigated only the activity of the rectus abdominis (RA) and external oblique (EO)\textsuperscript{21,51,54,55,58,59,60}, both classified as so-called global muscles. Concerning the back muscle activity, the erector spinae muscles were often considered as one muscle group.\textsuperscript{52,56-59} Consequently, a complete overview of relative abdominal and back muscle activity is scarce. Since the interplay between local and global muscle systems is considered important, analysis is needed to detect the relative contribution of the local to global relative muscle activity, presented as ratios.

**Muscle activity during exercises on specific training devices**

During the last years, a few companies have developed devices aimed at creating optimal isolated training of the muscles of the lumbar spine region.

In general, two kinds of training equipment can be observed. The first group of devices comprises specific machines aimed at training strength of the abdominal and back muscles by asking the patients to move with maximal force through a predetermined range of motion (ROM). During this type of exercises frequently no specific performance instruction is given and the execution is usually not controlled.\textsuperscript{61}

The second group of devices aims to create controlled movements in which constant biofeedback on a computer display serves as an automated “coach”, cuing the patient for cadence and effort.\textsuperscript{29} In this way, not only strength, but also muscle coordination is expected to be trained.

In both types of devices, debate exists on the need for pelvic stabilization. Pelvic stabilization was shown to be necessary for restricting pelvic motion\textsuperscript{62}, for isolating and
strengthening the lumbar erector spinae muscles\textsuperscript{63} and to obtain higher activity of the lumbar multifidus (MF)\textsuperscript{64} during extension movements on devices. In contrast, other researchers reported that pelvic stabilization did not influence muscle forces\textsuperscript{62,65,66} and activation of gluteus maximus (GM) and hamstrings\textsuperscript{67}.

Evaluation of muscle activity during dynamic low back training exercises on specifically designed devices is scarce.\textsuperscript{64,67} Today, in most rehabilitation centres, this strategy to train the lower back is popular. The advantage is that several patients can train simultaneously while only accurate instruction and supervision is needed. Although this kind of rehabilitation is very popular, little research was done to improve the insight in the muscle functioning during these exercises. A combination of isometric and dynamic exercises is common in rehabilitation programs. However, most studies analyzing flexion, extension and rotation movements investigated only isometric exertions.\textsuperscript{68-92} Analysis of dynamic exercises is needed since more complex loading on the spine is created in comparison with static exercises\textsuperscript{93} and controlled motions are more related to daily life conditions\textsuperscript{94}. Despite the common use of training devices in clinical practice, most research findings are based on varied positions and complicated settings. Today, the effect of various loads applied to dynamic flexion, extension and rotation movements was not yet reported.

**Effectiveness of specific exercise therapy in CLBP**

Most of the clinical trials describing the effectiveness of specific exercise therapy including stabilization exercises are based on the principles differentiating and integrating the local and global muscle system as described by Richardson et al.\textsuperscript{13,16,17} Ten to 12 sessions of specific stabilization exercises spread over 4 to 10 weeks to rehabilitate specific (spondylolysis-spondylolisthesis) and nonspecific CLBP was shown to reduce significantly pain intensity\textsuperscript{95} and functional disability\textsuperscript{95,96}, even through 30-month follow-up\textsuperscript{95}. Evidence was also provided that the abdominal muscle activation patterns can be altered by these specific exercise interventions.\textsuperscript{97} A combination of manual therapy and specific stabilization exercises\textsuperscript{98}, sometimes combined with education\textsuperscript{99,100} for a period of 4 to 12 weeks (4 to 19 treatment sessions) was reported to improve pain intensity, functional disability\textsuperscript{98,100}, ROM\textsuperscript{99} and the physical
component of quality of life \textsuperscript{98,100}. However, at 12-month follow-up, no consensus was found regarding the effectiveness of this specific exercise therapy in comparison with more general exercise therapy or physician consultation.\textsuperscript{98,100} At 2-year follow-up, except for patient satisfaction, no indications were present to recommend this specific exercise therapy over educational information by a physician.\textsuperscript{101}

When comparing the long-term effects of combined specific stabilization exercises and basic ergonomics to combined manual therapy and basic ergonomics during 6 to 10 weekly sessions, specific stabilization training appeared to be more effective in reducing the need for recurrent treatment periods.\textsuperscript{102} Manual therapy was appropriate as a pain reducing modality in CLBP, but was not advised as an isolated modality because it did not concomitantly reduce disability or improve quality of life.\textsuperscript{103}

Sixteen sessions of specific stabilization exercises combined with abdominal and back muscle strength training at 60-70\% of their maximum activation level appeared to be no more beneficial than trunk strength training as a single therapy.\textsuperscript{104-105} A combination of dynamic back muscle training at similar intensity levels with specific stabilization exercises over 30 therapy sessions showed similar results.\textsuperscript{106-107} However, a combination of specific stabilization exercises with dynamic back muscle training including a 5-second static phase was able to create hypertrophy of the MF muscle.\textsuperscript{107}

Two studies evaluated the effectiveness of a specific exercise program in which maintenance of a neutral spine position was the only instruction during the performance of stabilization exercises. Three months of active rehabilitation with ergonomic advice, which included 4 to 6 outpatient visits and additional self-motivated unsupervised home training, failed to decrease the pain intensity and the functional disability in a small CLBP population.\textsuperscript{21} In contrast, after 12 months (1 guided and 1 unguided session per week) of motor control training and counselling with cognitive-behavioural learning goals, the pain intensity was significantly more decreased compared to the results of a control group.\textsuperscript{22}

Aure et al.\textsuperscript{108} evaluated the effectiveness of 16 treatment sessions (2 sessions per week) of strengthening, stretching, mobilization, coordination and stabilization exercises for the trunk and lower limbs, combined with daily home exercises, brief anatomic and ergonomic information and encouragement for recreational sport at least 3 times per week. No specific instructions concerning muscle activation were given during the coordination and stabilization exercises. Significant improvements in pain, general health, functional
disability and spinal ROM were observed immediately after the intervention period and this improvement was maintained throughout the 1-year follow-up. However, in comparison to the same amount of manual therapy sessions, the exercise group showed significantly smaller improvement. Moreover, at all follow-up moments, significantly more patients in the exercise group were sick-listed when compared to the manual therapy group. 108

In conclusion, although contrasting findings are present concerning both stabilization training with and without specific muscle contraction instruction, this kind of exercise therapy is capable of improving pain intensity and functional disability, and maintaining the improvement throughout 1-year follow-up.

In all but one of the studies the patient population was a heterogeneous group. Only O’Sullivan et al.95,97 included systematically patients with spondylolysis or spondylolisthesis. The cost B13 research group recommended to determine the effectiveness of specific interventions aimed at specific clinical sub-groups of CLBP patients. Although several classification systems have been proposed109-114, well-defined criteria and reliable assessment tools are often lacking. In the present dissertation, we decided to select a well described sub-group of CLBP patients with motor control impairment.115-116 The classification system to determine motor control impairment was recently shown to be highly reliable by experienced clinicians.117

**Effectiveness of exercise programs on specifically designed devices**

Exercises on MedX training devices during 14 to 16 treatment sessions over 8 to 10 weeks were shown to improve pain intensity, physical impairment, trunk extension strength118-119, and general health118. The MedX lumbar extension device of the MedX Corporation (Ocala, US) with a pelvic stabilization system trains the lumbar extensors in a seated position. Eighteen 1-hour sessions over 9 weeks on MedX equipment combined with aerobic exercises, strength training of abdominals, hamstrings and glutei muscles, educational videos, body mechanics education and specific literature showed to improve significantly static and dynamic extensor strength and sagittal ROM in a diverse CLBP population.120 Twenty-four treatment sessions over 12 weeks on David Back Clinic (DBC) (DBC International, Vantaa, Finland) machines combined with stretching and
relaxation, functional muscle and coordination exercises, behavioural support and ergonomic advice was reported to improve pain intensity, physical impairment and spinal ROM, and increase lumbar muscle endurance and trunk flexion and extension strength. Fear-avoidance beliefs and catastrophizing were also reported to decrease after rehabilitation on devices. The DBC equipment with a hip lock system to stabilize the pelvis comprises four different lumbar devices in which seated training in different directions is performed.

In general, positive effects were maintained over the subsequent 12 months. However, some patients were strongly encouraged to follow a continuing individual exercise program after the intervention which may have influenced the long-term outcome. Improvements in lumbar endurance were maintained until 6 months follow-up, but tended to diminish at 1-year follow-up. Mannion et al. compared device therapy with physiotherapy and aerobics. In general, no significant differences were found between the three treatment interventions. The flexion, rotation and lateral flexion strength improved more in the device group, but the estimated improvement in fitness was significantly smaller in the device group in comparison with both other interventions. The lumbar ROM increased significantly more in the device exercise and the aerobics group than in the physiotherapy group.

In a male Dutch military and civilian nonspecific CLBP population following 10 training sessions on a modified lower back test and training machine (Technogym, Italy), spread over 12 weeks, high-intensity (load > 35% of maximal isometric strength) and low-intensity (load ≤ 20% of maximal isometric strength) training created similar improvement in functional disability and general health. The high-intensity training group showed a higher strength gain, but a smaller decline in kinesiophobia compared to the low-intensity training group.

The rather similar 8 to 12 weeks intervention periods utilizing specifically designed devices appear to be capable of positively affecting pain, functional disability, cognitive behaviour and strength. The device rehabilitation adapted in these studies aimed at gradual training of trunk muscle strength. In clinical practice, no standard agreement concerning the velocity of exercise performance on these devices is present. Consequently, the velocity may have differed in the various studies. In contrast, the training devices used in the present dissertation (Tergumed), prescribe controlled ROM and velocity, displayed on a computer
screen in front of the patient in order to train not only trunk muscle strength, but also trunk muscle coordination. More controlled training is supposed to be clinically valuable; consequently, the training effects may differ. However, this was not yet investigated.

**OUTLINE**

The main purpose of rehabilitation programs is to relieve pain and/or improve physical functioning. In that respect, exercise programs have been shown to be effective in CLBP. However, to gain insight into the working mechanisms of this kind of rehabilitation programs, the exercises themselves need to be examined.

In the past, much attention was paid to strength, endurance and muscle timing. However, the amount of muscle activity and the way the different trunk muscles work together needs to be further elucidated.

Consequently, in the **first part** of this dissertation, the muscle activity during often used stabilization exercises is investigated in healthy subjects. Although some stabilization exercises were recently analysed, a clear overview of relative muscle activity levels was lacking concerning bridging exercises and exercises in four-point kneeling.

In *chapter 1*, the relative activity levels (low, moderate, high) of various abdominal, back and hip muscles are investigated during exercises in four-point kneeling in a healthy population. In *chapter 2*, not only the relative activity levels, but also ratios of relative activity provide more insight in the trunk muscle recruitment patterns during bridging exercises in healthy subjects. In those 2 studies, no specific muscle contraction instruction is imposed. These studies intend to gain a better insight in the recruitment patterns in a normal, non instructed way.

Since during the last years much evidence was compiled to promote cocontraction of the local trunk muscles to prevent the onset or recurrence of LBP symptoms, in *chapter 3* the ability to change trunk muscle recruitment patterns in a healthy population using a short intervention period is investigated.

As the costs for health insurances, employers and not at least for the patients themselves concerning loss of quality of life, seem to increase to huge proportions, a call for effective prevention strategies is evident. Secondary prevention programs including specific motor
control training were shown to prevent recurrent pain episodes in LBP patients.\textsuperscript{95,102,137}

Primary prevention strategies are often evaluated by prospective studies based on the number of injuries over a certain period. As muscle activation programs are often used in prevention strategies, it is necessary to evaluate the possibility of changing muscle activation patterns in a pain free population. Structured training programs that emphasize motor control and increase functional stability offer encouraging evidence for the prevention of knee injuries in sports.\textsuperscript{138-140} It was suggested that the decrease in injury incidence in trained female athletes might be due to increased dynamic stability of the knee joint after training.\textsuperscript{141-144} Concerning the lower back, as buckling of the spine at a single level was already witnessed in vivo as a potent spine injury mechanism\textsuperscript{20}, specific stabilization exercises seem useful in the prevention of low back injuries.

In the second part of this dissertation, greater insight into the working mechanisms of exercises on specifically designed devices is aimed. Similar to the studies concerning the stabilization exercises, the relative trunk muscle activity is analysed; since different loads are applied on those machines the effects of increasing resistance levels are investigated. In chapter 4, analysis of seated axial rotation movements occurs and in chapter 5, flexion and extension exercises are evaluated.

Finally, having obtained greater insight in the muscle recruitment patterns, the third part of this dissertation focuses on the effectiveness of specific exercise therapy versus muscle reconditioning on devices.

Extensive outcome measures are considered to determine the treatment effects. On one hand, reliable and validated questionnaires describing pain, functional disability, health and psycho-social characteristics are used.\textsuperscript{145-150} On the other hand functional tests are applied. Recently an extensive review was published of reliable measures of low back function, but only strength, endurance and ROM measures were presented.\textsuperscript{151} Although it was shown that these characteristics are often impaired in LBP patients\textsuperscript{152–161}, reliable evaluation of other variables is needed. Clinical experience demonstrates that muscles are not only important during force exertions, but that an optimal activation is also needed during low-loaded tasks and postures. A functional clinical test battery developed to measure the quality of components of functional stability (muscle functional characteristics, neuromuscular control and postural control)\textsuperscript{162} is used.
In order to obtain reproducible and repeatable functional measurements, a reliability analysis is conducted (*chapter 6*).

*Chapter 7* presents a randomized clinical trial in a CLBP population with a motor control impairment.

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REFERENCES


PART I: MUSCLE ACTIVITY DURING STABILIZATION EXERCISES
CHAPTER 1

ELECTROMYOGRAPHIC ACTIVITY OF TRUNK AND HIP MUSCLES DURING STABILIZATION EXERCISES IN FOUR-POINT KNEELING IN HEALTHY VOLUNTEERS

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ABSTRACT

Stabilization exercises are intended to optimize function of the muscles that are believed to govern trunk stability. Debate exists whether certain muscles are more important than others in optimally performing these exercises. Thirty healthy volunteers were asked to perform three frequently prescribed stabilization exercises in four-point kneeling. The electromyographic activity of different trunk and hip muscles was evaluated. Average amplitudes obtained during the exercises were normalized to the amplitude in maximal voluntary isometric contraction (% MVIC). During all three exercises, the highest relative muscle activity levels (>20% MVIC) were consistently found in the ipsilateral lumbar multifidus and gluteus maximus. During both the single leg extension (exercise 1) and the leg and arm extension exercise (exercise 2) the contralateral internal oblique and ipsilateral external oblique reached high levels (>20% MVIC). During exercise 2 there were also high relative activity levels of the ipsilateral lumbar part and the contralateral thoracic part of the iliocostalis lumborum and the contralateral lumbar multifidus. During the leg and arm extension exercise with contralateral hip flexion (exercise 3) there were high relative muscle activity levels of all back muscles, except for the latissimus dorsi muscle. The lowest relative muscle activity levels (<10% MVIC) were found in the rectus abdominis and the ipsilateral internal oblique during all exercises, and in the contralateral gluteus maximus during exercises 1 and 2. The results of this study show that in exercises in four-point kneeling performed by healthy subjects, hip and trunk muscles seem to work together in a harmonious way. This shows that when relative activity of muscles is measured, both “global and local” muscles function together in order to stabilize the spine.

KEY WORDS

Stabilization exercise – Trunk and hip muscles – Electromyography
INTRODUCTION

Joint stability is defined as the effective accommodation of the joints to each specific load demand through an adequately tailored joint compression (as a function of gravity and coordinated muscle and ligament forces) to produce effective joint reaction forces under changing conditions [43].

To meet this requirement for joint stability, specific training of the local muscles, like the lumbar multifidus (MF) and transversus abdominis (TA) muscles has been advocated [17, 35-38]. In particular, the difference in timing in so-called local and global muscles during specific exercises has been extensively investigated [18, 20, 21, 23]. In contrast, the current study focuses mainly on the evaluation of normal co-operative activity of several muscles by measuring the relative activity of these muscles.

The division into a local and global muscle system refers to the functional classification to discriminate between the muscles responsible for inter-segmental stability (local) and spine motion (global), based on the anatomical division proposed in 1989 by Bergmark [7]. More current research based on relative muscle activity levels and stability analysis has shown that because this classification is not necessarily correct, some rethinking may be required [10, 26, 27, 32].

The division of trunk muscles into local and global ones mainly results from seeing the muscles in isolation and not taking into account their intricate functional relationship with collagenous structures like the fascia. An example could be the action of the gluteus maximus (GM) and latissimus dorsi (LD); within the framework of local and global, these muscles would typically be classified as global [7]. However, Vleeming et al [44] have proposed that tension in the posterior layer of the thoracolumbar fascia (TLF) induced by the latter muscles may contribute to limitation of joint movement by simultaneously stiffening the muscles and fascia of the lumbar spine and sacroiliac joint while enabling transfer of loads between trunk and limbs. Besides the LD and GM the posterior layer of the TLF also has connections to the abdominal internal and external obliques, which was confirmed by Barker et al [4].

Stabilization exercises are designed to improve function of the muscles that are believed to govern trunk stability and, when these muscles are functioning optimally, they will protect the spine from trauma [10]. Stabilization exercises are often used in clinical practice. The
four-point kneeling position provides a relatively low-loaded, non-anti-gravity posture in which good balance can be easily achieved when a neutral spine position is maintained [14, 31].

The single leg extension task in four-point kneeling provides both low joint loading and limited muscular activity, suggesting that this position could be an appropriate choice for persons starting a rehabilitation program for lumbopelvic pain [8]. In four-point kneeling an isolated contraction of the inferior fibres of the internal oblique muscle (IO) can be achieved more often and more consistently compared with a prone position [6, 38]. Haynes [15] suggests that the four-point kneeling exercise involves the whole body and in this way it could prepare the muscular loop and slings for upright bipedal functional tasks.

Although these kinds of stabilization exercises are often used in clinical practice, a clear description of the relative muscle activity during these exercises has only been described in small unisex populations [27, 31], or with a restricted focus on certain muscles [1, 40].

Therefore this study investigated the relative activation level of certain trunk and hip muscles during these exercises in four-point kneeling. In this way a normative database, which is necessary to interpret the results of patients performing these exercises, can be created.

MATERIALS AND METHODS

Study Participants

Thirty healthy volunteers (15 men and 15 women) participated in this study; their mean age was 19.6 (range 19-23) year, mean height was 176.6 (range 157-194) cm, and mean weight was 66.9 (range 42-84) kg. All subjects signed an informed consent. The subjects had no previous experience with stabilization exercises. Subjects were excluded if they reported any past or current low back pain (LBP), current neurologic deficits, and/or pain or disability of the upper or lower limbs. The Ethics Committee of the Ghent University Hospital approved the protocol.
Equipment
The skin was prepared by shaving excess hair and rubbing the skin with alcohol to reduce impedance (typically ≤ 10 kOhm). Disposable Ag/AgCl surface electrodes (Blue Sensor, Medicotest GmbH, Germany) were attached parallel to the muscle fibre orientation, bilaterally over the following abdominal muscles: internal oblique (IO) [13, 24, 41], external oblique (EO) [8, 9, 13, 24, 41, 42] and rectus abdominis (RA) [2, 3, 8, 9, 13, 40]. Marshall et al [30] showed that on the site medial and inferior to the anterior superior iliac spine, the fibers of the TA and IO are blended, so a distinction between the muscle signals cannot be made in this location. The selected back muscles were: lumbar multifidus (MF) [11, 29], the lumbar part of the iliocostalis lumborum (ICLL) (lateral to the vertical line through the posterior superior iliac spine, above the iliac crest) [29] and the thoracic part of the iliocostalis lumborum (ICLT) [11, 13, 29]. Regarding the arm and leg movements, the activity of the latissimus dorsi (LD) [13] and gluteus maximus (GM) [13] were measured. The maximum interelectrode spacing between the recording electrodes was 2.5 cm as recommended by Ng et al [33], and each electrode had an approximately 1.0 cm² pick-up area. The raw surface electromyographic signals were analogue/digital (A/D) converted (12-bit resolution) at 1,000 Hz (MyoSystem 1400 Noraxon). Three-dimensional data of the movements were collected by using an ultrasonic movement analysis system (Zebris CMS 50, Isny, Germany) with local markers. Spatial marker positions were derived by angulation and used to standardize the angular positions of the lumbar spine (L1, L3 and L5) in the sagittal plane.

Data acquisition
Maximum voluntary isometric contractions (MVIC) of the muscles were measured in three trials before the experimental tasks. These exercises were performed to provide a basis for EMG signal amplitude normalization [1-3, 6, 13, 24, 40, 42]. Danneels et al. reported a description of the different isometric exercises [13]. After the registration of the MVICs, the subjects performed three experimental exercises often used in clinical practice to train stability of the lower back. These exercises were performed in the four-point kneeling position with movements of the extremities of both sides (Figs. 1, 2, 3). The exercises were executed in a random sequence. To standardize the position of the subject and the equipment, markers were placed on the floor. At the beginning of each exercise a neutral spine position was assumed by the examiner and the
subject was encouraged to hold this position during the course of the total exercise. The neutral spine position was set about halfway between full extension and a flat position of the spine [11]. The dynamic phases, lifting and lowering of the extremities and movement of the trunk, lasted 2 s. During the static phase, the leg was held for 5 s in an extended position. The pace of 60 beats/min was set by a metronome. Three trials for every exercise were performed. A pause of at least 15 s was allowed between the trials. The starting positions of the lumbar spine were determined in the sagittal plane. The complementary angle between the line connecting the markers on the spinous process of L1 and L3 and the line connecting the markers on the spinous process of L3 and L5 was calculated.

Fig. 1 Exercise 1: Single-leg lift, performed by extending the leg out to the horizontal and returning it to the basic four-point kneeling position

Fig. 2 Exercise 2: The leg extension of exercise 1 coupled with the simultaneous raising of the contralateral arm to the horizontal and then returning to the basic four-point kneeling position

Fig. 3 Exercise 3: The same as exercise 2, but coupled with 30 degrees increased hip flexion
Data analysis

For the EMG amplitude analysis, manually selected, artefact-free, raw EMG sections were used. The stored data were full-wave rectified and smoothed. For each of the muscles the root mean square (RMS) was calculated for the three repetitions of the different exercises. The mean MVICs were used to provide a basis for EMG signal amplitude normalization. The static phases of the exercises were analysed, using an interval of 4,700 ms after the defined starting point of the holding position. The mean (of the three repetitions) normalized EMG values were calculated. Noraxon MyoResearch software 2.10 was used. The ipsilateral and contralateral muscle activity values during the asymmetric bridging exercises were averaged. Ipsilateral involved the same side as the extended leg and contralateral represented the other side. Three general activity levels were created: high, moderate, and low relative muscle activity.

Statistical analysis

Statistical analyses were performed using SPSS 11.0 software package (SPSS Inc., Chicago, IL) for Windows. The level for statistical significance was set at $\alpha = 0.05$. A two-way analysis of variance (ANOVA) was used to analyse the effects of the factors muscle and exercise. There was a significant interaction between the two factors ($P < 0.001$). Consequently, least significant difference LSD post-hoc tests were performed on the differences between the muscles in the separate exercises. Given the huge amount of data, only the most relevant differences in relation to the research question are presented in the results section.

RESULTS

Figures 4 and 5 present the relative EMG levels (% MVIC) of the different muscles, and a classification is made into high, moderate and low muscle activity.

The muscles that show high relative activity ($>20\%$ MVIC) during all exercises are the ipsilateral MF and GM; the difference in activity between these two muscles is not significant ($P \leq 0.44$). During exercises 1 and 2 the abdominal obliques, contralateral IO and ipsilateral EO, show a similar high relative muscle activity ($P \leq 0.86$). During exercise 3, both the ICLL and ICLT (on both sides) have high activity levels. In contrast, during
exercise 2, only the relative muscle activity of the ipsilateral ICLL and contralateral ICLT is high. During exercises 2 and 3, the relative muscle activity of the contralateral MF is high. The muscles that demonstrate a moderate relative muscle activity (10 to 20% MVIC) during all exercises are the contralateral EO and the bilateral LD; there is no significant difference between the activity of the contralateral EO and the LD \((P \leq 0.94)\), or between the two LD muscles \((P \leq 0.74)\). The abdominal obliques, contralateral IO and ipsilateral EO (no significant difference: \(P = 0.41\)), and the contralateral GM show a moderate relative muscle activity only during exercise 3. The relative muscle activity of the GM is not significantly different from the activity of the abdominal obliques during this exercise \((P \leq 0.22)\). The contralateral ICLL and the ipsilateral ICLT show similar \((P \leq 0.76)\) moderate activity levels during exercises 1 and 2. In addition, the ipsilateral ICLL and the contralateral ICLT and MF show moderate activity levels only in exercise 1; in this exercise the difference between the ICLL and ICLT muscle activity is not significant \((P = 0.93)\), but the relative muscle activity of the contralateral MF is significantly lower than that of the ipsilateral ICLL \((P = 0.01)\) and the contralateral ICLT \((P = 0.01)\).

A low relative muscle activity (<10% MVIC) is created by the ipsilateral IO, the contralateral GM (except for exercise 3), and the bilateral RA. The bilateral RA shows a significantly lower relative muscle activity compared with all other muscles during all exercises. In exercises 1 and 2 the ipsilateral RA is also significantly lower than the contralateral RA. In exercise 1, the contralateral GM muscle activity is significantly lower than the ipsilateral muscle activity of the IO, but not in exercise 2.

The measurements of the lumbar curve in the sagittal plane at the beginning of the exercises were \(13.06^\circ \pm 5.00^\circ\) (range \(4.17^\circ - 21.87^\circ\)) in exercise 1, \(12.65^\circ \pm 4.77^\circ\) (range \(3.08^\circ - 21.19^\circ\)) in exercise 2, and \(11.72^\circ \pm 3.95^\circ\) (range \(3.47^\circ - 19.58^\circ\)) in exercise 3.
Trunk and hip muscle activity during stabilization exercises in four-point kneeling

**Fig. 4** Abdominal and hip muscles: relative EMG activity and 1 SD. I ipsilateral; C contralateral; IO internal oblique; RA rectus abdominis; EO external oblique; GM gluteus maximus

**Fig. 5** Back muscles: relative EMG activity and 1 SD. I ipsilateral; C contralateral; MF lumbar multifidus; ICL.L. iliocostalis lumborum pars lumborum; ICL.T iliocostalis lumborum pars thoracis; LD latissimus dorsi
DISCUSSION

The present study investigated the relative activation levels of major trunk and hip muscles during exercises in four-point kneeling. A classification into three general activity levels was created, and a possible relationship with the anatomical classification of local and global muscles was studied.

The ipsilateral GM and MF show a high relative muscle activity (>20% MVIC) during all exercises in four-point kneeling. Although this is in accordance with earlier studies [1, 8, 40], the latter results are only available for certain muscles, and only for exercises 1 and 2. In addition, our results seem to indicate that the chosen sequence of the presented exercises challenging the balance and whole body stability, correlates with increased and more varied muscle activity.

The results also show a high activity of the contralateral IO and the ipsilateral EO during exercises 1 and 2. As previous studies showed lower activity levels of these muscles during exercises 1 and 2 [8, 40], these results raise doubts about the statement that this type of exercise mainly activates the paraspinal muscles and not the abdominal muscles [8]. It was suggested that the contralateral IO muscles were activated to maintain a neutral pelvis and spine posture, in effect balancing the internal moments and lateral shear forces [8], but this seems to occur in association with ipsilateral EO activity. In this way, the results of the current study indicate that the abdominal obliques to create a stable unit accomplish an ideal co-operation.

Also dorsally, there seems to be a co-operation between the ipsilateral and contralateral back muscles. Recruitment patterns of the ipsilateral ICLI together with the contralateral ICLT are recognized. This is consistent with the findings of Callaghan et al [8], although that group reported lower activity levels concerning the contralateral MF.

The contralateral EO and the bilateral LD show moderate activity levels (10 to 20% MVIC) during all exercises. In contrast to earlier findings [8], the results of the present study show that extension of the upper extremity does not seem to influence the LD muscle activity. In general, in contrast to its classification as a “global” muscle, symmetrical activity is confirmed during all exercises. A possible reason for such equalized action of the LD could be the tensioning of the TLF in a cranial direction, needed to control the trunk irrespective of the movement or position of the upper limb.
In exercise 3 there are moderate relative activity levels in both the contralateral IO and the ipsilateral EO, and the difference between them is not significant. It seems as if the contralateral IO and the ipsilateral EO can play a role in supporting the stable position to control the neutral spine position. This can not be confirmed by earlier research, as some researchers did not discriminate between ipsilateral and contralateral muscle activity [1, 40] and others did not generalize to those terms because of varied results for the contralateral IO [31]. The hip flexion that is added in exercise 3 in comparison to exercise 2 seems to create a lower abdominal muscle activity ($P \leq 0.005$, except for the ipsilateral IO).

The ICLL and ICLT seem to act together and also reach similar moderate activity levels [8]. By the stretch the hip flexion in exercise 3 causes on the contralateral GM, this muscle exhibits a significant higher muscle activity in exercise 3 in comparison to exercise 2 ($P < 0.001$). It seems that to counteract the more challenging body position by adding the hip flexion, there is a compensation of the ipsilateral GM and ICLT and the contralateral MF.

The low-level symmetric activity of the RA throughout all exercises is confirmed by previous studies [8, 40] and by studies of related exercises [6]. According to Callaghan et al. [8] it indicates that this muscle was not functionally active and did not contribute to stability. However, as the muscle is bilaterally active at a constant level during all exercises, stability analysis (including external loads) is needed to assume that the limited activity is irrelevant. In the current study the contralateral GM also seems to show relative low activity levels during exercises 1 and 2. During all exercises (even on the side opposite to the leg extension) the GM muscle is still active, preventing flexion of the hips and thus preventing destabilization of the spine. The ipsilateral IO also creates a small relative muscle activity.

Although a distinction is made between high, moderate and low relative muscle activity, the electromyographic activity never exceeds 32% of MVIC. It is mentioned that useful stabilization exercises for the clinic with the aim to hold and control the lumbar spine in a neutral position, work the trunk muscles at approximately 30% of their maximum [25].

The results of this study show that in uncomplicated exercises in four-point kneeling performed by healthy subjects, the investigated muscles seem to work together in a harmonious way. These results tend to confirm the recent findings describing that, based
on relative muscle activity, no single muscle appears to be superior in enhancing spine stability, but as loads are applied to the spine there is an integration of the different muscles in order to balance the stability and moment demands [26, 27]. However, the results of this four-point kneeling position cannot be extrapolated to the erect posture, which is the usual posture for the population being investigated.

It seems relevant that in the present study muscles are active in stabilization exercises that are also strongly related to the main thoracolumbar fascia (TLF), such as the IO, EO, GM and LD. Muscles like the ICLL, ICLT and MF have a hydraulic amplifier effect on the different layers of the TLF. The posterior layer of the TLF is ideally positioned to regulate tension via its extensive muscular attachments to both “local” and “global” muscles [5]. When loading the TLF for instance by the IO or EO, deformation and structural integrity of the fascia should be protected by muscles like the LD and GM. The overall effect of these muscles acting together could have a positive cascading effect on the stiffening of both the lumbar spine and sacroiliac joint [44].

Based on the results of differences in cross-sectional area [12, 16] and timing [19, 22], there may be some inhibition of certain muscles and dominance of other muscles [38] to maintain a stable body position in LBP patients. The RA activity during flexion-extension movements [39] and the EO activity during both flexion-extension [39] and left rotation movements [34], as well as the muscle activity of the left thoracic erector spinae during lateral flexion movements [28] were higher in LBP patients than in healthy controls. However, during coordination and left rotation exercises the MF showed lower activity levels in LBP patients than in healthy controls [11, 34]. So-called local muscles might demonstrate lower and so-called global muscles higher activity levels in LBP patients compared to healthy subjects. The present study, describing both local and global muscle activity, provides a normative database which allows comparison with specific pain populations in future research. Apart from the muscle activity levels, further integrated research on muscle strength, muscle timing and movement patterns in specific LBP populations is necessary to effectively distinguish between normal and abnormal spinal function.
CONCLUSION

Based on the harmonious way in which all trunk and hip muscles work together in controlling the neutral spine position during these exercises in four-point kneeling, no single muscle seems to be superior in enhancing spine stability, at least seen from the perspective of muscle activity and not timing. Our study results indicate that both “global and local” muscles function together to stabilize the spine, and this study provides a normative database with which to compare specific pain populations in future research.

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REFERENCES

21. Hodges PW, Richardson CA (1997) Feedforward contraction of transversus abdominis is not influenced by the direction of arm movement. Exper Brain Res 114:362-370
CHAPTER 2

TRUNK MUSCLE ACTIVITY IN HEALTHY SUBJECTS DURING BRIDGING STABILIZATION EXERCISES

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ABSTRACT

Background
Trunk bridging exercises are often used as therapeutic exercises for lumbopelvic stabilization. These exercises focus on the retraining of muscle coordination patterns in which optimal ratios between local segmental stabilizing and global torque producing muscle activity are assumed to be essential. However, a description of such ratios is lacking. The purpose of this study was to investigate both relative (as a percentage of maximal voluntary isometric contraction) muscle activity levels and ratios of local to global muscle activity, during bridging stabilization exercises.

Methods
Thirty healthy university students (15 men, 15 women) with a mean age of 19.6 year volunteered to perform 3 bridging exercises (single bridging, ball bridge and unilateral bridging). The surface electromyographic activity of different trunk muscles was evaluated on both sides.

Results
During all bridging exercises, the ratio of the internal oblique to the rectus abdominis was very high due to minimal relative activity of the rectus abdominis. In general, the ratio of the internal/external abdominal oblique activity was about 1. However, during the unilateral bridging exercise, the ipsilateral internal/external abdominal oblique activity ratio was 2.79 as a consequence of the significant higher relative activity of the internal oblique compared to the external oblique. The relative muscle activity and the ratios of the back muscles demonstrated similar activity levels for all back muscles, resulting in ratios about 1.

Conclusions
Both the minimal relative activity of the rectus abdominis and the high internal oblique to the rectus abdominis activity ratio reported in the present study are in accordance with results of other trunk stabilization exercises. The relative muscle activity and the ratio of the abdominal obliques seem to alter depending on the task and the presumable need for stability. The findings concerning the relative muscle activity and the ratios of the back muscles support the assumption that during these bridging exercises, all back muscles contribute in a similar way to control spine positions and movements in a healthy population.
BACKGROUND

Stability and movement are determined by the coordination of all the muscles that surround the lumbar spine [1-3]. A strategy of trunk stiffening on one hand and creating optimal movement on the other hand is assumed to be essential [1]. Within this context, stabilization exercises are often used in clinical practice today. The main goal of stabilization exercises is to protect spinal joint structures from further repetitive microtrauma, recurrent pain and degenerative change [4]. Long term results of various studies seem to indicate that specific lumbar stabilizing therapy as a single therapy or combined with other treatments can reduce the intensity of the pain and disability in low back pain (LBP) [5-8] and pelvic girdle pain patients [9-10] and prevent recurrent pain episodes [11-13].

Debate exists on the anatomical classification of muscles in local and global muscles related to specific functions, respectively segmental stabilizing (local) and torque producing and providing general trunk stability (global), as proposed by Bergmark [14]. Some mentioned that this classification is incorrect since no single muscle is superior at enhancing stability [2,15,16]. In line with this, assessment of some “stabilization” exercises revealed that no individual muscle could create an unstable situation when artificially reduced in activation [15]. During stabilization training, Marshall & Murphy [17] aimed at minimizing rectus abdominis (RA) activity in comparison with all other muscles of the lumbopelvic region. In contrast, other researchers assumed that, once an optimal local activation has been achieved, the interplay between local and global muscles is thought to be necessary [18,19]. To meet the different opinions, analysis of both so-called local and global muscles was considered necessary. More than evaluation of differences between relative muscle activity levels of local and global muscles, ratios of relative muscle activity were thought to provide insight into the contribution of both muscle systems in relation to each other.

In the past, ratios of local to global muscle activity were only analysed in specific isolated local muscle contraction tasks (abdominal drawing in manoeuvre) [20] and general movement and isometric contraction activities (flexion, extension and lateral flexion from a semiseated position in an apparatus) [21]. Recently, the ratio of the relative internal abdominal oblique (IO) to rectus abdominis (RA) activity was reported in a small
population performing core stability exercises on and off a swiss ball [17]. However, the contribution of both local and global muscles calculated as a ratio was currently not analysed in bridging exercises.

The present study focused on 3 different bridging exercises often used early in a lumbar stabilization training program. The supine posture with the knees and hips bent used during bridging exercises, is to most LBP patients a comfortable, pain-free posture. From this position limited movements, such as lifting the pelvis, can be started. In order to create more functional tasks, limb movements can be added. By combining pelvis and leg movements as used in exercise 3 in the present study, it is hypothesized that more global muscle activity will be required to perform those more demanding tasks [15].

Exercise 2 in the present study was a ball bridge stabilization exercise. To amplify the training effects of a bridging exercise and specifically challenge stability mechanisms, labile surfaces such as gymnastic balls used to be advised [22,23]. However, recent research evaluating bridging [24,25], other stabilization exercises [17,26] and trunk extension exercises [27] could not support that the use of an exercise ball can create a greater challenge for the musculoskeletal system or a training advantage in a healthy population.

The purpose of this study was to investigate the relative (% of maximal voluntary isometric contraction) muscle activity and ratios of local to global muscle activity during single bridging stabilization exercises, ball bridging exercises and bridging exercises with leg movements.

**METHODS**

**Subjects**
Thirty healthy university students (15 men and 15 women) voluntary participated to the study. Subjects had no history of neurological, respiratory or musculoskeletal back or lower limb pathology. All subjects had an ‘average’ activity level, as determined by the Dutch version of the habitual physical activity questionnaire [28]. They had a mean age of 19.6 (range:19-23) year, a mean height of 176.6 (range:157-194) cm and a weight of 66.9
Trunk muscle activity during bridging stabilization exercises

All subjects signed an informed consent. The subjects had no experience with stabilization principles. The protocol was approved by the Ethics Committee of the Ghent University Hospital.

Electromyography (EMG) preparation

Prior to the experimental phase, each subject was prepared for EMG recording as follows. The skin was prepared by shaving excess hair and rubbing the skin with alcohol to reduce impedance (typically ≤ 10 kOhm). Disposable Ag/AgCl surface electrodes (Bleu Sensor, Medicotest GmbH, Germany) were attached parallel to the muscle fibre orientation, bilaterally over the following so-called local trunk muscles: the inferior fibres of the IO (midway between the anterior iliac spine and symphysis pubis, above the inguinal ligament)[29,30], the lumbar multifidus (MF) (lateral to the midline of the body, above and below a line connecting both posterior superior iliac spines)[31,32] and the lumbar part of the iliocostalis lumborum (ICLL) (lateral to the vertical line through the posterior superior iliac spine, above the iliac crest)[32]. The inferior fibres of the IO were considered to represent local muscle activity [4,14] because it was shown that on the site medial and inferior to the anterior superior iliac spine, the fibres of the transversus abdominus and the IO are blended, so a distinction between the muscle signals cannot be made at this location [33]. Concerning the back muscles, the MF and ICLL were so-called local muscles because of their direct attachments to the vertebrae [4,14]. Because the RA, the external abdominal oblique (EO) and the thoracic part of the iliocostalis lumborum (ICLT) transfer the load directly between the thoracic cage and the pelvis, some call them global trunk muscles [4,14]. The electrode placement of those global trunk muscles was as follows: the EO (15 cm lateral to the umbilicus)[22,29,30,34,35], the RA (3 cm lateral to the umbilicus)[30,34,36,37] and the ICLT (above and below the L1 level, midway between the midline and the lateral aspect of the body)[30,32]. The maximum interelectrode spacing between the recording electrodes was 2.5 cm as recommended by Ng et al. [38], and each electrode had an approximately 1.0 cm² pick-up area.

Maximal voluntary isometric contraction (MVIC) assessment

The MVICs of the muscles were measured in three trials before the experimental tasks. These exercises were performed to provide a basis for EMG signal amplitude normalization [30,34,35,39-43]. Normalization of EMG corresponding maximal EMG
amplitude allows interindividual comparison to the individual maximum [44]. Failure to normalize EMG data before quantitative analysis introduces confounding variables not related to muscle function (for example skin impedance, electrode orientation and amount of subcutaneous tissue) [44]. Five different isometric exercises against manual resistance were executed. Verbal encouragement was given to ensure maximal effort. The maximal activation of the abdominal obliques (IO and EO) was obtained by a combined flexion-rotation exertion from a supported, straight-knee sitting position, with the hands placed behind the head and the trunk held in a 45° angle. Manual resistance was applied to the contralateral shoulder [30,39]. From the same sitting position the subject was asked to perform a trunk flexion against bilateral manual resistance applied to both shoulders, for the generation of the maximal isometric activity of the RA [39,43]. Concerning the MVICs of the MF [29,30,34,42,43] and the lumbar and thoracic part of the iliocostalis lumborum (ICLL and ICLT) [29,30,43] manual resistance was applied to the posterior aspect of the scapula while the subject lay in the prone position, with the legs strapped to the table to prevent them from moving. The subject was asked to perform a trunk extension.

**Procedures and instrumentation**

The subjects performed 3 experimental exercises, often used in clinical practice to train the stability of the lower back. These exercises were executed in supine position, knees bent (60° flexion) and feet on the floor. Exercise 1 was a single bridging exercise (figure 1), exercise 2 a ball bridge exercise (figure 2) and exercise 3 a bridging exercise with extension of the left or right leg (unilateral bridging exercise) (figure 3). Exercises 1 and 2 can be called symmetric exercises and exercise 3 is an asymmetric exercise. After a detailed explanation of each exercise, followed by a guided trial, the exercises were recorded. The subjects lifted their pelvis until an angle of zero degrees hip flexion was reached. At the beginning of each exercise a neutral lumbar spine position was determined by the examiner (anterior and posterior iliac spines in line) [3] and the subject was encouraged to hold this position during the course of the total exercise. To standardize the position of the subject and the equipment, markers were placed on the floor. The exercises were executed in a random sequence. The dynamic phases, lifting and lowering of the pelvis and the extremities, lasted two seconds. The bridged positions in exercises 1 and 2 and the leg extension in exercise 3 were hold for five seconds. The pace of 60 beats/min was set by a
metronome. Three trials for every exercise were performed. A pause of at least 15 seconds was allowed between the trials.

The raw surface EMG signals were bandpass-filtered between 10 and 500 Hz and amplified using a differential amplifier (MyoSystem 1400, Noraxon Inc, Scottsdale, AZ). The overall gain was 1000 and the common mode rejection ratio was 115 dB. The signals were analogue/digitally (A/D) (12-bit resolution) converted at 1000 Hz and stored in a personal computer.

Figure 1
Single bridging exercise (exercise 1)

Figure 2
Ball bridge exercise (exercise 2)

Figure 3
Unilateral bridging (exercise 3)
**Data analysis**

The stored data were full-wave rectified and smoothed with a root mean square (RMS) with a window of 150 milliseconds. For each of the muscles and for each testing session, the RMS was calculated for the 3 repetitions of the different exercises. The mean RMS of the three MVIC trials for every muscle was used to provide a basis for EMG signal amplitude normalization of the data of the experimental exercises. The static phases of the exercises were analysed, using an interval of 4700 ms after the defined starting point of the holding position. Noraxon MyoResearch software 2.10 was used.

Not only the relative muscle activity of different trunk muscles, but also ratios of the relative local abdominal muscle activity to the global abdominal muscle activity (IO/RA and IO/EO) were calculated. In a similar way, ratios of the relative back muscle activity (MF/ICLT and ICLL/ICLT) were determined.

**Statistical analysis**

Statistical analysis was performed using SPSS 12.0 software package (SPSS Inc., Chicago, IL) for Windows. The level for statistical significance was set at \( \alpha = 0.05 \). As there was no significant difference between the muscle activity of the left and right muscles during exercise 1 and 2, the mean activity levels were used. There were also no significant differences between the muscle activity at the left side when performing a left leg extension and the muscle activity at the right side when performing a right leg extension (exercise 3). Therefore the mean value was used for further analysis and called ipsilateral muscle activity. In accordance with the same findings on the other side, the new term contralateral muscle activity was introduced. Concerning both the MVICs and the experimental exercises, an analysis of variance for repeated measures was applied to evaluate the effects of the factor muscle during every single exercise, separately for the abdominal and the back muscles. Since the factor abdominal muscle was significant (\( p < 0.001 \)) during all exercises and the factor back muscle was significant (\( p = 0.02 \)) during the ball bridge exercise, post-hoc least significance difference tests (LSD), adjusted by a Bonferroni test to protect against type I errors, were used to analyze the significant differences between the individual muscles in each exercise. Descriptive statistics showed the relative abdominal and back muscle activity ratios.
RESULTS

The mean EMG amplitudes of the different abdominal and back muscles during the 3 bridging exercises are presented in Table 1. Since particularly the contribution of the local muscle activity compared to global muscle activity is concerned, the analysis of the abdominal muscle activity is performed separately from the analysis of the back muscle activity.

Concerning the abdominal muscles, during all exercises, the relative activity of the RA was significantly lower than the relative activity of the obliques (p < 0.001). During the single bridging exercise 1, the muscle activity of the obliques did not differ significantly (p = 1.00). In contrast, during the ball bridge exercise 2, the EO showed significantly higher activity levels than the IO (p = 0.003). During exercise 3, the contralateral EO activity was also significantly higher than the contralateral IO activity (p = 0.007), but the ipsilateral EO activity was significantly lower than the ipsilateral IO activity (p < 0.001).

Regarding the back muscles, except for the ICLL, which showed significant higher activity than the ICLT during the ball bridge exercise 2 (p = 0.01), the activity levels did not differ significantly (p ≥ 0.26).

Table 1: Mean relative muscle activity (% of MVIC) and standard deviation (SD) of the different trunk muscles during bridging exercises.

<table>
<thead>
<tr>
<th></th>
<th>IO Mean (SD)</th>
<th>RA Mean (SD)</th>
<th>EO Mean (SD)</th>
<th>MF Mean (SD)</th>
<th>ICLL Mean (SD)</th>
<th>ICLT Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercise 1</td>
<td>5.58 (5.00)</td>
<td>1.91 (1.27)</td>
<td>5.98 (4.36)</td>
<td>22.64 (7.51)</td>
<td>20.32 (8.56)</td>
<td>20.59 (5.51)</td>
</tr>
<tr>
<td>Exercise 2</td>
<td>6.58 (4.80)</td>
<td>2.76 (2.35)</td>
<td>10.32 (7.99)</td>
<td>23.99 (7.15)</td>
<td>27.17 (10.20)</td>
<td>22.24 (6.96)</td>
</tr>
<tr>
<td>Exercise 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ipsilateral</td>
<td>29.80 (9.97)</td>
<td>4.72 (3.45)</td>
<td>16.34 (12.09)</td>
<td>23.54 (6.33)</td>
<td>28.45 (11.50)</td>
<td>25.84 (7.84)</td>
</tr>
<tr>
<td>Contralateral</td>
<td>10.11 (6.95)</td>
<td>3.55 (2.18)</td>
<td>14.93 (9.34)</td>
<td>24.58 (8.80)</td>
<td>20.44 (9.24)</td>
<td>20.60 (8.22)</td>
</tr>
</tbody>
</table>

IO = internal oblique; MF = lumbar multifidus; ICLL = iliocostalis lumbarum pars lumborum; RA = rectus abdominis; EO = external oblique; ICLT = iliocostalis lumbarum pars thoracis.

To emphasize the relation between so-called local segmental stabilizing muscles and global torque producing muscles, the relative activity was expressed as ratios. The mean ratios are presented in figures 4 and 5.

In general, the ratio of the local to the global muscle activity was about 1.
The IO/RA ratio was much higher than 1 during all exercises (3.00 in exercise 1 and 2.96 in exercise 2). During exercise 3, the ipsilateral IO/RA was 7.95 and the contralateral IO/RA was 3.16. The ipsilateral IO/EO was higher during exercise 3 (2.79).

The MVICs were used to normalize the EMG values obtained during the experimental exercises. The mean EMG amplitudes and standard deviations (SD) are presented in Table 2. The MVICs of the back muscles did not differ significantly (p ≥ 0.60). Except for the significant higher MVIC of the RA in comparison with the MVIC of the IO and EO (p ≤ 0.01), the abdominal muscles did not show significant different amplitudes (p = 1.00).

Figure 4
Mean ratios and SD of relative local muscle activity to relative global trunk muscle activity during the single bridging (exercise 1) and ball bridge exercise (exercise 2). IO = internal oblique; MF = lumbar multifidus; ICLL = iliocostalis lumbarum pars lumborum; RA = rectus abdominis; EO = external oblique; ICLT = iliocostalis lumbarum pars thoracis.
杜克肌活动在bridging稳定化练习中

图5
平均比率和SD的相对局部肌肉活动与相对全局躯干肌肉活动的比率。IO = 内斜肌；MF = 腰多裂肌；ICLL = 竖脊肌；RA = 腹直肌；EO = 外斜肌；ICLT = 竖脊肌胸段。

讨论

研究目的

研究的目的是评估在常用bridging稳定化练习中肌肉活动。这些练习被认为是有利于稳定腰椎区域的。在描述运动治疗时，理解肌肉活动在健康条件下的重要性。在当前研究中，肌肉活动以相对的（作为MVIC百分比）EMG以及相对比率表示。相对比率的描述可以通过计算与使用单独的相对肌肉活动水平[20]。一些研究者和临床医生认为，通过良好的局部肌肉激活，可以创建出较低的背期间接稳定化练习。在这一方面，局部肌肉运动与全球肌肉活动的关系可以被认为是更重要的，而不是相对肌肉
activity levels of the muscles separately. For interpretation purposes, the results of both the relative EMG activity and the ratios of relative activity are integrated.

Table 2: Mean EMG activity (Mean) and standard deviation (SD) of the maximal voluntary isometric contractions.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>(SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IO</td>
<td>184.78</td>
<td>(82.94)</td>
</tr>
<tr>
<td>RA</td>
<td>275.96</td>
<td>(132.06)</td>
</tr>
<tr>
<td>EO</td>
<td>191.50</td>
<td>(136.74)</td>
</tr>
<tr>
<td>MF</td>
<td>264.23</td>
<td>(114.93)</td>
</tr>
<tr>
<td>ICALL</td>
<td>254.17</td>
<td>(147.80)</td>
</tr>
<tr>
<td>ICLT</td>
<td>240.63</td>
<td>(106.78)</td>
</tr>
</tbody>
</table>

IO = internal oblique; MF = lumbar multifidus; ICLL = iliocostalis lumbarum pars lumbarum; RA = rectus abdominis; EO = external oblique; ICLT = iliocostalis lumbarum pars thoracis.

Concerning the abdominal muscles, during all bridging exercises, the relative activity of the RA was significantly lower than the relative muscle activity of the obliques. One of the consequences of this low relative RA activity was that during all exercises, the IO/RA ratio demonstrated the highest values compared to the other abdominal and back muscle activity ratios. However, these findings need to be interpreted with caution, since normalization of the EMG data of the experimental exercises occurred using MVICs and the RA MVIC amplitude was significantly higher in comparison with the MVIC amplitudes of the abdominal obliques. Nevertheless, the consistent low-level activity of the RA was in accordance with the findings of similar research [36,48] and research of related exercises [39]. These studies also used MVIC normalization procedures, but did not report the MVIC values nor analysis performed on these data.

The small relative muscle activity levels reported in the present and the latter studies were not necessarily related to a nonstabilizing capacity of this muscle. Only small activity levels seem to be necessary to ensure sufficient stability in a neutral spine posture in non-weightbearing positions [40]. Generally for most tasks of daily living very modest levels of abdominal wall co-contraction are sufficient [2]. Cholewicki et al. [40] highlighted the
importance of motor control to coordinate muscle recruitment between so-called global and local muscles during functional activities to ensure mechanical stability is maintained. Under such conditions they suggested that intersegmental muscle activity as low as 1 to 3 \% MVC may be sufficient to ensure dynamic stability [40]. Furthermore, biomechanical modelling is needed to draw conclusions about stability contributions as stability is also proportional to the square of the muscle’s moment arm.

The objective for the use of the ratio of IO/RA activity in the present study, was to enhance the understanding of the co-activation of both local and global muscles during this kind of stabilization exercises. Other researchers stated that analysis of the IO/RA ratio is important to verify if the activity of the RA is minimal in comparison with all other muscles of the lumbopelvic region to fulfil the requirement for a good stabilization exercise [17]. In our opinion, respecting adequate activation levels depending on the demands during different tasks is essential, rather than aiming at minimal activity of certain muscles. Ratios assist in providing further insight in the co-operation of the different muscles during various tasks.

During the ball bridge exercise, the EO showed significantly higher relative EMG than the IO. Consequently, the IO/EO ratio was low (<1) during this exercise. In accordance with these results, McGill [1] assumed that the EO may have a greater potential in stabilizing the trunk than the local abdominal muscles. Vera-Garcia et al. [29] found that when performing curl-ups on a gymnastic ball, there was much more co-contraction of the EO muscle with the RA muscle when compared to other tasks because of the greatest possibility of rolling laterally off the ball. In order to enhance this stability, it appears that the motor control system selects to increase EO activity more than the other abdominal muscles. However, recent research evaluating bridging exercises showed no significant differences in relative EO and RA activity between performance on firm or ball surfaces [24,25]. Debate exists on increased [24] or unchanged IO activity [25] during ball bridge exercises. However, the ball bridge exercises described in the latter studies were performed with the feet flat on the ball, in contrast to the calf position on the ball in the present study. Although only the calves were positioned on the ball, the global torque producing EO might be activated more than the local segmental stabilizing IO to prevent the limbs from rolling of the ball and jeopardizing the trunk stability. Analysis of the relative EMG activity levels
showed a greater increase in EO activity compared to IO activity between the single bridging and the ball bridge exercise. This could explain the small ratio of the IO to EO during the ball bridge exercise in the current study.

During the unilateral bridging exercise, the ipsilateral IO showed significantly higher EMG than the ipsilateral EO and the contralateral IO demonstrated significantly lower activity than the contralateral EO. Consequently, the contralateral IO/EO ratio was low (< 1) and the ipsilateral IO/EO ratio was higher than 2 during this exercise. Kavcic et al. [15] reported that during single and unilateral bridging exercises the IO and EO seem to demonstrate consistently a large impact on induced increasing and decreasing stability. Both so-called local and global oblique muscles seem to work together and may have an important role in controlling the neutral spine position during this exercise. When the contralateral leg is raised, a rotational moment about the spine is expected to occur. The ipsilateral IO can cause an ipsilateral rotational moment about the spine and the ipsilateral EO can create a moment in the opposite direction to counter the spine moment. To stop the spine from twisting, appropriate muscle activity may generate stability. The ratio of the IO to EO activity seems to depend on the task and the presumable need for stability.

Regarding the back muscles, in general, the relative muscle activity levels of the local and global muscle system were not significantly different. All ratios of relative back muscle activity were about 1. Van Dieën et al. [21] reported ratios of the lumbar to the thoracic erector spinae (ES) muscles, representing local to global muscle activity, varying from 0.5 to 0.9 in healthy subjects during global exercises in a semi-seated posture. Maximal isometric extension exercises seemed to create a lumbar ES/ thoracic ES ratio of 1.1 [21]. This demonstrates that during different tasks and exercises, all back muscles contribute in a similar way to control spine positions and movements. These findings support the statement that no single muscle seems superior to another and that all muscles act together in the same way to create a stable position of the spine during this kind of exercises [2,15,16].

Only during the ball bridge exercise, the ICLL showed significantly higher activity than the ICLT. In the past, application of unstable surfaces such as a ball was supposed to increase muscle activity [29]. Since the ICLL is located closer to the centre of rotation than the ICLT, the increasing effect might be higher. However, recent research comparing exercise
surfaces in stabilization and trunk extension exercises, demonstrated that the addition of a ball did not influence [17,24-27] or even decreased back muscle activity [27]. In the present study, the ratio ICLI/ICLT remained about 1.

Though the data on the ratios of local to global relative muscle activity were normally distributed, relatively large SDs were noticed concerning the abdominal muscles. These findings represent abdominal ratios spread apart and a relatively flat bell curve, indicating that relatively more subjects showed ratios towards one extreme or the other. Since the mean relative abdominal muscle activity ratios discussed in the present study were supposed to be confined by the spread values, interpretation might be influenced.

LBP patients might demonstrate different recruitment patterns, for instance higher or lower muscle activity due to pain adaptation or spasm caused by pain [49]. Within this context, the current preliminary data may provide a foundation to help determining exercise treatment approaches intended to recruit specific muscle sites.

CONCLUSIONS

To enhance the understanding of the trunk muscle recruitment patterns during stabilization exercises often used in clinical practice, relative EMG activity as well as ratios of muscle activity of both local and global muscles seem important. The present study shows that the abdominal muscle activity ratios IO/RA and IO/EO demonstrate a different pattern. During all exercises, the IO/RA ratio is very high due to minimal RA activity. The relative muscle activity and the ratio of the abdominal obliques seem to alter depending on the task and the presumable need for stability. The findings concerning the relative muscle activity and the ratios of the back muscles support the assumption that during these bridging exercises, all back muscles contribute in a similar way to control spine positions and movements in a healthy population.

Acknowledgements

The authors thank Ms. Evelien De Burck and Ms. Wendy Van Loo for their assistance in collecting the data.
REFERENCES


CHAPTER 3

THE INFLUENCE OF SPECIFIC TRAINING ON TRUNK MUSCLE RECRUITMENT PATTERNS IN HEALTHY SUBJECTS DURING STABILIZATION EXERCISES

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ABSTRACT

Low back pain is a major problem involving high medical costs, therefore effective prevention strategies are essential. Stabilization exercises seem to facilitate the neuromuscular control of the lumbar spine and may be useful in prevention programs. To investigate whether specific lumbar stabilization training has an effect on muscle recruitment patterns in a healthy population, in the present study 30 subjects were recruited to perform two types of testing exercises, i.e. bridging exercises and exercises in four-point kneeling, both before and after training. Surface electromyographic data of different abdominal and back muscles were obtained. After training, analysis of the relative muscle activity levels (percentage of maximal voluntary isometric contraction) showed a higher activity of the local (segmental-stabilizing) abdominal muscles, but not of the local back muscles; minimal changes in global (torque-producing) muscle activity also occurred. Analysis of the local/global relative muscle activity ratios revealed higher ratios during all exercises after training, although not all differences were significant. These results indicate that muscle recruitment patterns can be changed in healthy subjects by means of a training program that focuses on neuromuscular control. Additional studies are needed to evaluate this type of training as a prevention strategy.

KEY WORDS

Stabilization exercise – Prevention – Lumbar stabilization training – Surface electromyography
1. INTRODUCTION

In 1994 52% of Belgian hospital nurses reported musculoskeletal job-related problems that lasted longer than 1 day; low back pain (LBP) was the major cause (53.3%) (Clarijs et al., 1998). Effective primary and secondary prevention strategies are needed to address this problem because the costs for e.g. health insurance, employers and society, as well as the reduced quality-of-life of the patients, are substantial.

Short- and long-term results indicate that specific lumbar stabilizing therapy can decrease the number of recurrent pain episodes (Hides et al., 2001) and recurrent treatment periods (O’Sullivan et al., 1997; Rasmussen-Barr et al., 2003). Specific lumbar-stabilizing therapy involves changing muscle recruitment patterns. Symptomatic chronic LBP patients with clinical evidence of spondylolysis or spondylolisthesis were shown to be able to activate the deep abdominal muscles without significant co-activation of the rectus abdominis muscle (RA) when performing an abdominal drawing-in manoeuvre after a 10-week intervention (O’Sullivan et al., 1998). Lumbar stabilization training that paid no specific attention to the local muscles showed no changes in relative electromyographic (EMG) amplitudes during more complex stabilization exercises after 12 weeks of training (Arokoski et al., 2004).

Apart from these studies on patients, the effect of stabilization training has not yet been investigated in a healthy population in relation to primary prevention.

Local muscles of the trunk, such as the lumbar multifidus (MF), with their vertebrae to vertebrae attachments (as described by Macintosh & Bogduk, 1987), are supposed to control the fine-tuning of the positions of adjacent vertebrae (segmental stabilization) (Bergmark, 1989; Richardson et al., 1999; Hodges and Moseley, 2003). Because of their connection through the thoracolumbar fascia, the transversus abdominis (TA) and the inferior fibres of the internal oblique (IO) also have direct attachment to the lumbar vertebrae and can therefore also be considered as local muscles (Hodges, 1999).

Unlike the local muscles, the global muscles are supposed to be important for torque production and general trunk stability, because they are not directly attached to the spine (Bergmark 1989). The global muscle system includes the RA, the external oblique (EO), the gluteus maximus, the latissimus dorsi and the thoracic part of the iliocostalis lumborum muscles (ICLT) (Richardson et al., 1999).

To train functional stability, once an optimal local activation has been achieved, the interplay between local and global muscles is thought to be necessary (Hodges and
Moseley, 2003; Richardson et al., 2004). Because biomechanical and muscle research has shown no clear distinction between the contribution of the local and global muscles to spine stability, this functional classification based on anatomic findings needs to be considered with some caution (Arokoski et al., 2001; Cholewicki and Van Vliet, 2002; Kavicic et al., 2004a; Stevens et al., 2006). Not only is the local muscle system important, but also the controlled co-operation between the two muscle systems can provide a stable structure. Consequently, the ratio of the local muscle activity to the global muscle activity needs to be further elucidated. According to Edgerton et al. (1996) EMG ratios can be a sensitive discriminator of altered recruitment patterns and muscle dysfunction. In order to highlight differences in the synergistic activity of local versus global muscles (e.g. IO versus RA; lumbar versus thoracic erector spinae muscles), ratios of muscle activity levels during various stabilization exercises have been investigated in healthy subjects (Marshall and Murphy, 2005) and in LBP patients (O’Sullivan et al., 1998; van Dieën et al., 2003).

The purpose of the current study was to evaluate the benefit derived from specific stabilization training for a prevention program by investigating whether this training had an effect on muscle recruitment patterns in healthy subjects. The training was an isolated local muscle contraction (first phase) followed by integrating local co-contraction in different movements starting from various positions. The exercises used for the evaluation were bridging exercises and exercises in four-point kneeling, both of which are often used in clinical practice to train lumbar stability. The specific attention paid to the local muscles during the intervention aimed to increase local muscle activity and consequently change the local/global ratio.

2. METHODS

2.1. Study design
This was a cross-sectional study. The baseline EMG test session was followed by a 3-month intervention period and then a second EMG test session.

2.2. Subjects
Thirty healthy subjects (15 men and women) voluntarily participated in this study. Their mean age was 19.6 (range 19-23) years, mean height was 176.5 (range 157-194) cm and
Influence of specific training on trunk muscle recruitment during stabilization exercises

mean weight was 66.9 (range 42-84) kg. All subjects gave written informed consent. The study was approved by the Ghent University Ethics Committee.

2.3. Procedures

2.3.1. Intervention period

The two EMG test sessions were separated by an intervention period of three months. The subjects were instructed in accordance with the principles often used in training lumbar stability (Richardson and Jull, 1995; Richardson et al., 1999; O’Sullivan, 2000). Instruction in the basic anatomy of the TA, MF and other abdominal and back muscles was aimed at emphasising the difference between the local and global trunk muscles and to help avoid ‘substitution’ strategies of the global muscles. In the first phase of the training, local muscle activity was facilitated without substitution strategies of the global muscles and with focus on the continuation of normal breathing during the exercises. Subsequently, the time for holding the position and the number of repetitions were increased, and different postures (supine, four-point kneeling, prone, sitting and standing) were added (Richardson et al., 1999). Once an accurate and sustained contraction of the local muscles was achieved in different postures (10 contractions with 10-s holds), the exercises progressed to the second phase which involved applying low load to the muscles through controlled movements of the upper and lower extremities (Richardson and Jull, 1995). The aim during the third phase was to integrate the motor skill into normal static tasks and dynamic functional tasks (Richardson et al., 1999). During the 3-month intervention period, eight guided training sessions took place, each lasting 30 min; the subjects were also asked to perform the exercises for about 15 min each day at home as part of the intervention. During the intervention period, no specific attention was paid to the exercises performed in the test sessions.

2.3.2. Test sessions

Before and after the specific stabilization training, the subjects performed two types of testing exercises: bridging exercises and exercises in four-point kneeling. For both, the only instruction given during the testing was to maintain the lumbar neutral spine position. At the moment of the first test session, the subjects had no knowledge or experience of stabilization principles.
2.4. Equipment and measurements

2.4.1. Electromyography

The skin was prepared by shaving excess hair and rubbing the skin with alcohol to reduce impedance (typically ≤ 10 kΩ). Disposable Ag/AgCl surface electrodes (Blue Sensor, Medicotest A/S, Ølstykke, Denmark) were attached parallel to the muscle-fibre orientation, as described previously (Danneels et al., 2001b, 2002), bilaterally over the following so-called local trunk muscles: the inferior fibres of the IO (midway between the anterior iliac spine and symphysis pubis, above the inguinal ligament) and the lumbar MF (lateral to the midline of the body, above and below a line connecting both posterior superior iliac spines). Although the focus of stabilization training was on the TA, it was expected that this would be reflected in the surface EMG of the inferior fibres of the IO. Marshall & Murphy (2003) showed that medially and inferiorly to the anterior superior iliac spine, the fibres of the TA and IO are blended, so that a distinction between the muscle signals cannot be made at this location; also, at this site the direction of the fascicles of both muscles is similar (inferomedial) (Urquhart et al., 2005). Moreover, both the TA and the inferior fibres of the IO play a similar role in compressing the sacroiliac joint and consequently increasing the control of that region (Richardson et al., 2002).

The selected so-called global trunk muscles were the EO (15 cm lateral to the umbilicus), the RA (3 cm lateral to the umbilicus), and the ICLT (above and below the L1 level, midway between the midline and the lateral aspect of the body). The maximal inter-electrode spacing between the recording electrodes was 2.5 cm as recommended by Ng et al. (1998), and each electrode had a pick-up area of approximately 1.0 cm². To reduce the variability due to the electrode position, a personalized template ensured the exact reapplication of the electrodes (Danneels et al., 2001a).

2.4.2. Exercises during the test procedure

Maximal voluntary isometric contractions (MVIC) of the muscles were measured before the experimental tasks. These exercises were performed to provide a basis for EMG signal amplitude normalization. Three different isometric exercises against manual resistance were performed according to the description of Danneels et al. (2001b), and each exercise was registered three times during 3 s.

After the MVICs, the subjects were asked to start the experimental exercises. Six exercises (often used in clinical practice to train lumbar stability) were performed. The first group of
exercises was executed in supine position, knees bent (60° flexion) and feet on the floor. A bridging exercise, either simple or accompanied by leg movements, was performed (exercises 1 - 3 in Table 1). The second group of exercises was performed in four-point kneeling (exercises 4 - 6 in Table 1). At the start of each exercise, the examiner determined the subject’s lumbar neutral spine position and the subjects were asked to hold this position throughout the exercise. In four-point kneeling, the neutral spine position was set about halfway between full extension and a flat spine (Danneels et al., 2002); in supine position the anterior and posterior superior iliac spines were in line (Richardson et al., 2004). The exercises were performed in a random sequence. In order to standardize the position of the subject and the equipment, markers were placed on the floor. The dynamic phases (i.e. lifting and lowering of the pelvis and the extremities) lasted 2 s. The mid-phase (i.e. extended leg/arm and lifted pelvis) was held for 5 s. The rhythm of 60 beats/min was set by a metronome. For each exercise three trials were performed. To prevent muscular fatigue, an interval of at least 15 s was allowed between the exercises; during these periods the exercises were explained.

Before the second test session, an ultrasound (US) evaluation was carried out to assess whether the subjects could produce an isolated contraction of the TA. In a clinical setting the tonic contraction of the MF is easy to palpate, but the difference between contraction of the IO and the TA is not always easy to detect. Therefore, the subjects were placed in a supine position lying crooked, and were then asked to draw in their lower abdomen slowly and gently, without moving the spine. The transducer was placed on the anterolateral aspect of the abdominal wall, at the level of the umbilicus. A Siemens Sonoline SL-1 ultrasound imaging device was used with a linear array probe with a wave frequency of 7.5 MHz. The criterion was a slow and controlled tensioning of the anterior fascial attachment of the TA in a lateral direction. The TA was slightly thickened and the IO and EO remained relatively inactive (Richardson et al., 2004). Because the aim was to evaluate the effect of training local muscle co-contraction on the performance of stabilization exercises, this additional US evaluation was useful to understand the reasons for changes in EMG activity. This US study revealed that 5 subjects were not able to contract the TA in isolation from the global muscle system and were thus excluded.
Table 1

<table>
<thead>
<tr>
<th>Exercises</th>
<th>Group 1</th>
<th>Group 2</th>
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<tbody>
<tr>
<td>Bridging in supine position</td>
<td>Bridging in supine position</td>
<td>Four-point kneeling</td>
</tr>
<tr>
<td>Exercise 1</td>
<td>Bridging in supine position</td>
<td>Exercise 4</td>
</tr>
<tr>
<td>Exercise 2</td>
<td>Ball bridge</td>
<td>Single-leg lift, performed by extending the left/right leg out to the horizontal</td>
</tr>
<tr>
<td>Exercise 3</td>
<td>Unilateral bridging: bridging with extension of the left/right leg</td>
<td>returning it to the starting position</td>
</tr>
<tr>
<td>Exercise 4</td>
<td>The leg extension of exercise 4 coupled with the simultaneous raising of the contralateral arm to the horizontal before returning the extended leg and arm to the original position</td>
<td></td>
</tr>
<tr>
<td>Exercise 5</td>
<td>This exercise is basically the same as exercise 5, but with the addition of moving the trunk/pelvis in a backward direction (i.e. away from the hands), which increases the angle of hip flexion of the loaded leg by 30°</td>
<td></td>
</tr>
<tr>
<td>Exercise 6</td>
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</table>

2.5. Data analysis

The raw surface EMG signals were measured at a bandwidth of 10 - 500 Hz, using a differential amplifier (MyoSystem 1400, Noraxon Inc, Scottsdale, USA). The overall gain was 1000 and the common mode rate rejection ratio was 115 dB. The signals were analogue/digitally (A/D) (12-bit resolution) converted at 1000 Hz and stored in a personal computer. The stored data were full-wave rectified and smoothed with a root mean square (RMS) with a window of 150 millis. For each of the muscles and for each testing session, the RMS was calculated for the 3 repetitions of the different exercises. The mean RMS of the three MVIC trials for every muscle was used to provide a basis for EMG signal amplitude normalization of the data of the exercises. The static phases of the exercises were analysed using an interval of 4700 ms after the defined starting point of the holding position. Noraxon MyoResearch software 2.10 was used for these analyses.

The effect on muscle recruitment patterns was investigated in two ways. First, the changes in muscle activity of each muscle as a result of the training were investigated. Second, the difference in the ratio of local muscle activity to global muscle activity (separately for abdominal and back muscles) before and after training was evaluated. This assessment was based on two ratios of the abdominal muscles (the IO/RA and the IO/EO) and one of the back muscles (the MF/ICLT).

2.6. Statistical analysis

Statistical analysis was performed using the SPSS 11.0 software package (SPSS Inc., Chicago, IL) for Windows. Given the symmetry of the task during the single-bridging and
the ball-bridging exercise \((P \geq 0.1)\), the EMG values of the muscles of the left and the right side were averaged. Because there were no significant differences \((P > 0.05)\) between the ipsilateral and contralateral muscle activity values during the asymmetric bridging exercises, they were also averaged. Ipsilateral referred to the side of the extended leg and contralateral to the other side.

A multivariate analysis of variance (MANOVA) was used to evaluate the changes in muscle activity as a result of specific stabilization training (factors muscle [5 muscles], time [before and after training], and side [only in the asymmetric exercises]). In the event of several significant interactions, least significance difference tests, adjusted by a (although conservative) Bonferroni test to protect against type I errors, were used to analyze the significant differences between the individual muscles in each exercise. Consequently, the level for statistical significance was set at \(\alpha = 0.002\) for exercises 1 to 4 (two-factor interaction) and at \(\alpha = 0.0008\) for exercises 5 and 6 (three-factor interaction).

To analyse the difference in the ratio of local muscle activity to global muscle activity before and after training, paired sample t-tests were used and \(\alpha\) was set at 0.05.

3. RESULTS

3.1. Changes in relative muscle activity

Figures 1 to 3 present the relative pre- and post-training EMG levels (% MVIC) of the different muscles and their respective \(P\)-values.

3.1.1. Local muscle activity

After training, the local IO showed a significantly higher relative muscle activity \((P \leq 0.001)\) during all the bridging exercises. In contrast to the bilateral changes of the local IO during the bridging exercises, after training only the relative muscle activity of the ipsilateral IO increased significantly during the asymmetric four-point kneeling exercise 5 \((P \leq 0.001)\) and exercise 6 \((P = 0.001)\).

3.1.2. Global muscle activity

After training, during the symmetric exercises 1 and 2 the relative muscle activity of the global RA was also significantly higher \((P \leq 0.001)\).
For the global EO and the local and global back muscles, no significant differences between the EMG levels before and after training were found for any of the exercises.

**Fig. 1.** Mean values, SD and $P$-values (between pre- and post-training for each exercise) of the relative EMG activity during the symmetric exercises ($\alpha = 0.002$). Ex, exercise; Pre, before training; Post, after training; MVIC, maximal voluntary isometric contraction; IO, internal oblique; MF, lumbar multifidus; RA, rectus abdominis; EO, external oblique; ICLT, iliocostalis lumbarum pars thoracis.

**Fig. 2.** Mean values, SD and $P$-values (between pre- and post-training for each exercise) of the ipsilateral relative EMG activity during the asymmetric exercises ($\alpha = 0.002$ in exercises 3 and 4; $\alpha = 0.0008$ in exercises 5 and 6). Ex, exercise; Pre, before training; Post, after training; MVIC, maximal voluntary isometric contraction; IO, internal oblique; MF, lumbar multifidus; RA, rectus abdominis; EO, external oblique; ICLT, iliocostalis lumbarum pars thoracis.
3.2. Changes in ratios

Because co-operation between the local and global muscle systems is particularly important in creating a stable structure, changes in the local/global muscle activity ratio after stabilization training were also evaluated. To detect changes in this ratio, paired sample t-tests were used; the level for statistical significance was set at $\alpha = 0.05$.

After training, the ratio of the local to global muscle activity was higher in all exercises (Table 2). However, not in all exercises the increase in the IO/RA and the MF/ICLT ratios was significant. All ratios were significantly higher ($P \leq 0.01$) in the single bridging exercise (exercise 1). In the ball bridge exercise (exercise 2) a significant difference ($P \leq 0.001$) was found for the abdominal muscles (IO/RA ratio and IO/EO ratio), but not for the back muscles (MF/ICLT ratio). In the unilateral bridging exercise (exercise 3), the difference between the ratios before and after training was significant ($P \leq 0.02$), except for the MF/ICLT ratio and the ipsilateral IO/RA ratio. In the exercises in four-point kneeling (exercises 4 - 6), the difference in the ratio local to global muscles before and after training was significant ($P \leq 0.05$) only for the ipsilateral muscles. However, the ratio of the contralateral oblique abdominal muscles also increased significantly ($P = 0.04$) in exercise 5.

**Fig. 3.** Mean values, SD and $P$-values (between pre- and post-training for each exercise) of the contralateral relative EMG activity during the asymmetric exercises ($\alpha = 0.002$ in exercises 3 and 4; $\alpha = 0.0008$ in exercises 5 and 6). Ex, exercise; Pre, before training; Post, after training; MVIC, maximal voluntary isometric contraction; IO, internal oblique; MF, lumbar multifidus; RA, rectus abdominis; EO, external oblique; ICLT, iliocostalis lumborum pars thoracis.
4. DISCUSSION

4.1. Changes in relative muscle activity
Stabilization training involves isolated local muscle contraction and an integration of the local and global muscle systems during particular movement patterns (O'Sullivan, 2000). It was thought that such training with specific attention paid to the TA and MF (Richardson et. al., 1999; O'Sullivan, 2000) would significantly increase the relative muscle activity of the local muscles in healthy subjects.

4.1.1. Local muscle activity
The results of the present study indicate that, since the relative local IO abdominal muscle activity was increased on both sides during bridging exercises and ipsilaterally during four-point kneeling exercises, abdominal muscle activity can be changed after a lumbar stabilization training program in healthy subjects. In contrast, no significant change in relative muscle activity of the local back muscle MF was found after training. One reason for this finding is that it may be more difficult to produce an isolated contraction of the MF during training. This idea is supported by the clinical experience that, in general, subjects find it easier to concentrate on drawing in the lower abdomen than on focusing on the lower back muscle contraction. Also, perhaps it was not possible to train both the deep and the superficial fibres of the MF during the intervention period. Moseley et al. (2002, 2003, 2004) demonstrated a different activation of the deep and superficial fibres of the MF anticipating different loading conditions in standing. Since it has been shown that recording the muscle activity of the deep fibres of the MF by surface electrodes may be difficult (Stokes et al., 2003), this technique may not have been sufficiently accurate to detect any changes in activity of the deep MF fibres. Whatever the reason, the training strategy used in the present study was unable to influence the muscle activation patterns of the local back muscle.

4.1.2. Global muscle activity
Not only did the local (so-called segmental-stabilizing abdominal) muscle activity levels change, but also the relative activity of some global (so-called torque-producing and
general-stabilizing) muscles changed. After training, the activity of the RA was significantly higher during the symmetric bridging exercises.

Co-contraction with other abdominal muscles is often reported when subjects are trying to contract the TA (Richardson et al., 1999). Beith et al. (2001) concluded that while performing an abdominal hollowing manoeuvre, because elimination of activity in the EO muscles may be too difficult or even impossible for some to achieve, it may not always be a feasible goal. Studies on the effect of an isometric contraction of all the abdominal wall muscles (known as an abdominal brace manoeuvre) showed a considerably higher relative muscle activity of the RA in exercises 1, 3, 4 and 5 (Kavcic et al., 2004b). However, the results of the local and global relative muscle activity changes in the present study are limited to only those subjects who have been shown able to isolate TA contraction (investigated using real-time ultrasound).

The absence of co-contraction of the more global abdominal muscles during the exercises in four-point kneeling compared with the bridging exercises, might be explained by the difference in posture and level of difficulty between the two groups of exercises. The four-point kneeling position provides increased awareness of the abdominal wall due to the gravitational stretch on the muscles, and allows complete relaxation of the abdominal wall. This position may increase the sensitivity of the stretch receptors and might enhance the stimulus to contract abdominal muscles separately (Richardson and Jull, 1995; Richardson et al., 1999; Beith et al., 2001). This stretch of the abdominal wall does not exist in the supine position, which might make it harder to recruit the deep abdominals separately in this position.
Table 2
Mean values, standard deviations (SD) and \( P \)-values of the ratio local muscle activity/global muscle activity (mean) during the different exercises

<table>
<thead>
<tr>
<th>Exercise</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Pre Mean</td>
<td>SD</td>
<td>Post Mean</td>
<td>SD</td>
<td>Pre Mean</td>
<td>SD</td>
</tr>
<tr>
<td>IO/RA</td>
<td>3.31 1.76</td>
<td>7.62 6.23</td>
<td>0.01*</td>
<td>3.19 2.19</td>
<td>7.38 5.93</td>
<td>0.001*</td>
</tr>
<tr>
<td>IO/EO</td>
<td>1.19 0.91</td>
<td>2.93 2.18</td>
<td>&lt; 0.001*</td>
<td>0.80 0.54</td>
<td>2.34 1.85</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>MF/ICLT</td>
<td>1.21 0.50</td>
<td>1.81 1.12</td>
<td>0.01*</td>
<td>1.27 0.56</td>
<td>1.59 0.97</td>
<td>0.09</td>
</tr>
<tr>
<td>Ipsilateral</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO/RA</td>
<td>8.26 3.40</td>
<td>9.90 6.28</td>
<td>0.20</td>
<td>4.04 3.03</td>
<td>5.88 4.65</td>
<td>0.04*</td>
</tr>
<tr>
<td>IO/EO</td>
<td>2.70 1.96</td>
<td>3.35 1.95</td>
<td>0.02*</td>
<td>0.43 0.32</td>
<td>0.95 0.61</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>MF/ICLT</td>
<td>1.00 0.36</td>
<td>1.48 0.78</td>
<td>0.15</td>
<td>2.09 1.36</td>
<td>3.21 2.25</td>
<td>0.02*</td>
</tr>
<tr>
<td>Contralateral</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO/RA</td>
<td>3.34 1.86</td>
<td>4.37 2.91</td>
<td>0.01*</td>
<td>10.02 5.07</td>
<td>10.77 9.66</td>
<td>0.72</td>
</tr>
<tr>
<td>IO/EO</td>
<td>0.77 0.38</td>
<td>1.53 1.22</td>
<td>0.01*</td>
<td>1.83 1.50</td>
<td>2.43 1.72</td>
<td>0.11</td>
</tr>
<tr>
<td>MF/ICLT</td>
<td>1.48 0.79</td>
<td>2.48 1.92</td>
<td>0.31</td>
<td>0.86 0.39</td>
<td>1.25 1.99</td>
<td>0.32</td>
</tr>
<tr>
<td>Ipsilateral</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO/RA</td>
<td>3.42 3.35</td>
<td>5.27 3.49</td>
<td>0.02*</td>
<td>3.36 2.84</td>
<td>4.99 3.83</td>
<td>0.05*</td>
</tr>
<tr>
<td>IO/EO</td>
<td>0.30 0.22</td>
<td>0.67 0.50</td>
<td>&lt; 0.001*</td>
<td>0.40 0.25</td>
<td>0.88 0.68</td>
<td>0.001*</td>
</tr>
<tr>
<td>MF/ICLT</td>
<td>1.63 1.05</td>
<td>2.58 1.50</td>
<td>0.004*</td>
<td>1.11 0.37</td>
<td>1.64 1.05</td>
<td>0.01*</td>
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<tr>
<td>Contralateral</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO/RA</td>
<td>10.13 6.47</td>
<td>11.89 9.77</td>
<td>0.44</td>
<td>8.08 5.65</td>
<td>8.23 6.36</td>
<td>0.92</td>
</tr>
<tr>
<td>IO/EO</td>
<td>1.65 1.33</td>
<td>2.43 1.75</td>
<td>0.04*</td>
<td>1.57 1.09</td>
<td>2.17 1.70</td>
<td>0.06</td>
</tr>
<tr>
<td>MF/ICLT</td>
<td>0.89 0.65</td>
<td>0.92 1.38</td>
<td>0.91</td>
<td>1.01 0.28</td>
<td>1.27 1.21</td>
<td>0.31</td>
</tr>
</tbody>
</table>

IO, internal oblique; MF, lumbar multifidus; RA, rectus abdominis; EO, external oblique; ICLT, iliocostalis lumborum pars thoracis.

* \( P \)-value significant at \( \alpha = 0.05 \) level
4.2. Changes in ratios

In general, analysis of the relative muscle activity levels showed significant changes only in the local IO after stabilization training. However, analysis of the local to global muscle activity ratios revealed that all ratios increased after training. This shows that muscle activity patterns can be changed in a healthy population if stabilization training is performed with specific attention paid to the so-called local muscles (Richardson et al., 1999; O'Sullivan, 2000).

The ratio between the local and global muscle activity increased due to a greater increase in local muscle activity compared with global muscle activity. This increase in the local/global ratio was significant in most of the bridging exercises. In the four-point kneeling exercises, the local muscles at the side of the extended leg seemed to be activated to higher intensities than the global muscles. The increase in activity was also apparent at the contralateral side, but the difference between the ratios was not significant.

Similar stabilization training in symptomatic chronic LBP patients with clinical evidence of spondylolysis or spondylolisthesis also resulted in a significant increase in the IO/RA ratio during an abdominal drawing in manoeuvre (O'Sullivan et al., 1998). Simulations based on MVIC contractions in several directions predicted that an increase of the IO/RA ratio would be effective in increasing spinal stability (Van Dieën et al., 2003).

In the present study, the relative muscle activity ratios increased during all exercises independent of the type of exercise or the surface on which the exercise were performed. Marshall and Murphy (2005) also demonstrated no change in the IO/RA ratio between stabilization exercises performed on and off a swiss ball.

A limitation of the present study is that only static phases of stabilization exercises were evaluated. However, during the intervention period, the exercises were progressed to non-neutral positions (Akuthota et al., 2004) and to dynamic functional movements with upper and lower extremity movements (Richardson et al., 2004). In addition to the evaluation of the static phases, further studies could also investigate the more advanced dynamic movements. The results of our relatively young group of participants may not be representative for the whole population. However, the present study was primarily designed to evaluate the effects of a basic stabilization package that could be used in a prevention program.
5. CONCLUSION
In the present study, healthy subjects learned isolated local muscle contractions (controlled by ultrasound) and their integration into basic static stabilization exercises. After training, analysis of the relative muscle activity levels showed a higher activity of the local abdominal muscles, but not of the local back muscles; minimal changes in global muscle activity also occurred. Analysis of the local/global relative muscle activity ratios revealed higher ratios during all exercises after training, although not all differences were significant. This indicates that muscle recruitment patterns can be changed in healthy subjects after a training programme that focuses on neuromuscular control, which could be useful in prevention programs. More studies are needed to substantiate these results.

Acknowledgements
The authors thank Ms. Evelien De Burck and Ms. Wendy Van Loo for their assistance with collection of the data, Prof. van Maele for statistical advice, and Ms. Iris Wojtowicz for linguistic corrections.

REFERENCES
Beith ID, Synnott E, Newman A 2001 Abdominal muscle activity during the abdominal hollowing manoeuvre in the four-point kneeling and prone positions. Man Ther 6(2):82-87.
Influence of specific training on trunk muscle recruitment during stabilization exercises


PART II: MUSCLE ACTIVITY DURING EXERCISES ON SPECIFIC TRAINING DEVICES
CHAPTER 4

THE RELEVANCE OF INCREASING RESISTANCE ON TRUNK MUSCLE ACTIVITY DURING SEATED AXIAL ROTATION

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ABSTRACT

Objectives To investigate the electromyographic (EMG) trunk muscle activity during a low-load instrumented axial rotation exercise (Tergumed) and the relevance of increasing resistance.

Setting Evaluation was done in a training centre in a university hospital.

Participants Thirty healthy subjects without musculoskeletal or neuromuscular complaints.

Main Outcome Measures The normalized (as a percentage of maximal voluntary isometric contractions (MVIC)) EMG activity of 14 abdominal and back muscles were investigated during dynamic trunk rotation exertions at 30, 50 and 70% of maximum mean force (MMF).

Results During the low-load (30% MMF) rotation exercise, the internal abdominal oblique muscle reached activity levels of 30% of MVIC. All the examined back muscles and the external abdominal obliques reached activity levels of 60% of MVIC. Increasing the resistance during seated axial rotation, created significantly higher relative muscle activity levels for all trunk muscles.

Conclusions The results of the present study indicate that increasing resistance to 50% and 70% MMF during seated axial rotation in a Tergumed training device consistently created higher relative activity levels in all trunk muscles. In the vulnerable spine undergoing rehabilitation the results suggest that training at 30% MMF may be sufficient.

KEY WORDS

Electromyography – Rotation – Resistance
1. INTRODUCTION

The majority of our everyday activities such as walking, running and most industrial occupations, require axial rotation of the spine. In most sport activities such as tennis, racquetball, squash, ice hockey, soccer, rugby, cricket, volleyball, badminton, golf, baseball and many others, axial rotation is imperative (Evans, Refshauge, Adams, & Aliprandi, 2005; Kumar, 2004). Rotation of the trunk during tennis serve and groundstroke for example is an essential part of the development of power and transfer of energy up the kinetic chain from the lower to upper extremities (Ellenbecker & Roetert, 2004). General agreement consists on the need to train the athlete in the sport specific movements.

However, trunk rotation has been reported to be significantly associated with low back pain (Kumar, 2004). Disc-related lower back injuries are very common in elite athletes (Gerbino, & d’Hemecourt, 2002; Hickey, Fricker, & McDonald, 1997a & 1997b; Sward, Hellstrom, Jacobsson, Nyman, & Peterson, 1991). To prevent rotational injuries during sports and daily activities, coordination and strength training of the muscles which are important during rotation gains interests. High muscle activity in the erector spinae and abdominal obliques throughout the baseball batting swing suggested the importance of emphasizing abdominal and back exercises in a comprehensive exercise and conditioning program for baseball batters (Shaffer, Jobe, Pink, & Perry, 1993). Activity levels of approximately 30% of maximal voluntary isometric contraction (MVIC) are appropriate for muscle coordination training (Jull, & Richardson, 1994; McGill, 1998; Richardson, Hides, & Hodges, 2004). In contrast, activity levels of at least 60% of MVIC are generally accepted for basic strength training purposes (Andersson, Ma, & Thorstensson, 1998).

Today, it is of major importance to start retraining of the muscles as fast as possible in athletes, without risking too much load and high stress on the spine. However, no clear indication of resistance in rotation exercises has yet been available. Therefore, the main purpose of the present study was to investigate trunk muscle activation during seated rotation at low intensity (30% MMF). The second purpose of this study was to evaluate the clinical relevance of increasing resistance during this exercise.
2. METHODS

2.1. Subjects
Thirty healthy subjects were included in this study. Their mean age was 20.52 (SD 1.74) years, mean height was 172.69 (SD 8.66) cm and mean weight was 64.34 (SD 10.02) kg. Subjects were excluded if they reported any past or current low back pain (LBP). Subjects familiar with coordination or specific trunk training programs were also excluded. All subjects were informed of the experimental protocol and gave written consent. Appropriate ethical approval by the Ghent University Ethics Committee had been granted prior to the commencement of the study.

2.2. Equipment
A rotation device of the Tergumed® Line for the back (Proxomed®, Germany) was used. The Tergumed system is a fixed weight resistance system which measures range of motion (by a cable barrel with greased disc and optical encoder) and force (by a strain gauge) in real time (sample rate of 50 Hz). The interobserver reliability of the equipment was demonstrated to be excellent (ICC 0.95 – 0.96) for the measurement of the maximal isometric strength and good (ICC 0.81 – 0.86) for the measurement of the range of motion (ROM) of the lumbar spine in healthy subjects (Roussel, Nijs, Truijen, Breugelmans, Claes, & Stassijns, 2006). A limitation of our study was that the reliability in taking measures in the present population was not investigated.

The muscle activity was recorded by a 16 channels surface EMG system (MyoSystem 1400, Noraxon USA, Inc., Scotssdale, AZ). The raw surface EMG signals were measured at a bandwidth of 10 - 500 Hz, using a differential amplifier (MyoSystem 2.10, Noraxon Inc, Scottsdale, AZ). The overall gain was 1000 and the common mode rate rejection ratio was 115 dB. The signals were analogue/digitally (A/D) (12-bit resolution) converted at 1000 Hz and stored in a personal computer.

2.3. Electrodes
Disposable Ag/AgCl surface electrodes (Blue Sensor, Medicotest GmbH, Germany) were attached parallel to the muscle-fibre orientation, bilaterally over the following abdominal muscles: the inferior fibres of the internal oblique (IO) (midway between the anterior iliac spine and symphysis pubis, above the inguinal ligament) (Danneels, Vanderstraeten,
Trunk muscle activity during seated axial rotation

Cambier, Witvrouw, Stevens, & De Cuyper, 2001; van Dieën, Cholewicki, & Radebold, 2003; Vera-Garcia, Grenier, & McGill, 2000), the external oblique (EO) (15 cm lateral to the umbilicus) (Danneels et al., 2001; van Dieën et al., 2003; Vera-Garcia et al., 2000) and the rectus abdominis (RA) (3 cm lateral to the umbilicus) (Arokoski, Valta, Kankaanpää, & Airaksinen, 2004; Danneels et al., 2001; van Dieën et al., 2003). The selected back muscles were: the lumbar multifidus (MF) (lateral to the midline of the body, above and below a line connecting both posterior superior iliac spines) (Danneels et al., 2002; Macintosh & Bogduk, 1987), the thoracic part of the iliocostalis lumborum (ICLT) (above and below the L1 level, midway between the midline and the lateral aspect of the body) (Danneels et al., 2001; Danneels et al., 2002; Macintosh & Bogduk, 1987), the thoracic part of the longissimus (LT) (above and below the L1 level, midway between the vertical line through the posterior superior iliac spine and the midline of the body) (Macintosh & Bogduk, 1987), and the latissimus dorsi (LD) (3 cm lateral and inferior to the inferior angle of the scapula) (Danneels et al., 2001). The maximal interelectrode spacing between the recording electrodes was 2.5 cm as recommended by Ng, Kippers, and Richardson (1998), and each electrode had a pick-up area of approximately 1.0 cm². The skin was prepared by shaving excess hair and rubbing the skin with alcohol to reduce impedance (typically ≤ 10 kΩ).

2.4. Experimental procedure

The subject was positioned sitting in the rotation Tergumed device, and all restraining mechanisms and lever arm attachments were adjusted to the subject’s body dimensions, in accordance with the manufacturers’ instructions. The torso was fixed by a chest restraint and a thoracic pad. Lateral and posterior pelvic pads and thigh pads secured the position of the lower limbs and pelvis (Fig. 1).

First, the range of motion was determined. The subject was asked to axially rotate to the end of the range of rotation and return to the neutral position. In a smooth and continuous way, without stopping anywhere in between the movement, this was performed three times. Secondly, three MVICs were performed in the neutral position. The subjects were asked to perform the maximal contraction within the first two seconds and maintain their contraction at that level for another three seconds before terminating the trial (Kumar, Narayan, & Garand, 2002a). Visual feedback, presenting the force signal, and verbal encouragement were given in an attempt to achieve maximal effort. These exercises were
performed three times with a pause of 15 s in between. The range of motion and maximal effort tests were followed by a pause of 15 min (Clark, Manini, Mayer, Ploutz-Snyder, & Graves, 2002; Ng, Parnianpour, Kippers, & Richardson, 2003; Ng, Parnianpour, Richardson, & Kippers, 2001; Ng, Richardson, Parnianpour, & Kippers, 2002).

Thirdly, submaximal dynamic rotations were performed. To determine the resistance, the mean maximal force (MMF) obtained during the maximal isometric rotation contractions was used. Submaximal exercises at 30, 50 and 70% MMF were performed. The exercise cycles at the different percentages of MMF were performed by each subject at random order. The cycles consisted of a movement phase away from the neutral midline position and a phase towards the neutral midline position. Five repetitions of 5 s were performed. Visual feedback presented as a sinusoidal curve on a notebook, indicating time and ROM, supported the controlled performance of the exercises. The subject was only allowed to deviate 5 % of the curve presented. A ROM of 80% of the total ROM was used during these dynamic exercises.

Each subject attended a familiarization and a testing session. The familiarization session was included to allow the subject to gain some knowledge of the equipment and testing procedure (without placement of surface electrodes) (Ng et al., 2002). This session was held at 3 to 7 days before the testing session.

Fig. 1. Left rotation exercise
2.5. Data analysis
Recent research on the Tergumed devices showed that it is more optimal to use the mean of different trials than to use the value of a single trial (Roussel et al., 2006). The mean of the three ROM values was calculated by the software BioMC for Sequential Training Version 1.0.0 (1999-2002 by BfMC GmbH, Leipzig, Denmark). This software also determined the mean force during the three MVIC trials. During these MVIC trials, the time point of maximal effort, as indicated on the Tergumed display, was concurrently marked in the EMG spectrum. The stored EMG data were full-wave rectified and smoothed (window: 150 ms). Root mean square values (RMS) were calculated to quantify the amplitude of the EMG signals. All analyzed EMG periods were 2500 ms. The mean RMS of the three MVIC trials for each muscle was used to provide a basis for EMG signal amplitude normalization of the data of the submaximal exercises. During the submaximal exercises, markers were placed between the two movement phases. The mean RMS values of the 5 movement phases away from the neutral midline position and the 5 movement phases towards the neutral midline position were calculated. Noraxon MyoResearch software 2.10 was used for these analyses.

2.6. Statistical analysis
Statistical analysis was performed using SPSS 11.0 software package (SPSS Inc., Chicago, IL) for Windows. Since no significant differences were present between the right relative muscle activity during trunk rotation to the right and the left relative muscle activity during trunk rotation to the left, the term ipsilateral was introduced. Similarly, the contralateral relative muscle activity was described.
Descriptive statistics were performed of the relative muscle activity levels. An analysis of variance (ANOVA) for repeated measures was used to analyse the main effects of the four factors (resistance level, muscle, side and phase) of the relative muscle activity between the different experimental exercises. The fourfold interaction was not significant. The threefold interactions ‘resistance*muscle*phase’, ‘resistance*muscle*side’ and ‘muscle*side*phase’ were significant. Consequently, Least Significant Difference (LSD) post hoc tests with Bonferroni adjustments were performed. The level for statistical significance was set at 0.05. The observed power was 1.00.
3. RESULTS

The MMF of the left and right trunk rotation was 593.04 N (SD 159.70) and 585.03 N (SD 148.50) respectively. The work attained during the dynamic submaximal exercises is presented in Table 1. The mean range of motion of the left and right rotation was, respectively, 61.29° (SD 5.32) and 62.89° (SD 5.14).

Table 1
Work (Nm) during the different submaximal axial rotation exercises

<table>
<thead>
<tr>
<th></th>
<th>30% MMF</th>
<th>50% MMF</th>
<th>70% MMF</th>
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<tr>
<td>Left rotation</td>
<td>222.76 (89.20)</td>
<td>345.86 (132.68)</td>
<td>401.03 (191.43)</td>
</tr>
<tr>
<td>Right rotation</td>
<td>227.59 (82.31)</td>
<td>324.62 (135.94)</td>
<td>370.00 (171.65)</td>
</tr>
</tbody>
</table>

The normalized EMG activity levels during the dynamic exercises are presented in Figs. 2 and 3.

The results of the rotation at the lowest intensity (30% MMF) demonstrate that the ipsilateral IO, EO and MF and the contralateral LT showed activity levels between 30% and 60% of MVIC during the movement phase away from the neutral midline position of this low-load exercise. During the movement phase towards the neutral midline position, all ipsilateral back muscles (MF, LT, ICLT and LD) and the contralateral MF demonstrated activity levels between 30% and 60% of MVIC. The ipsilateral LT, ICLT and LD and the contralateral EO and MF even reached activity levels of more than 60% of MVIC during the movement phase away from the neutral midline position of this 30% MMF exercise.

Both ipsilateral and contralateral RA and the contralateral IO, ICLT and LD showed activity of less than 30% MVIC during the movement phase away from the neutral midline position at the lowest intensity (30% MMF). During the movement phase towards the neutral midline position of this exercise all abdominal muscles and the contralateral LT, ICLT and LD did not reach activity levels of 30% of MVIC.

The second purpose of this study was to evaluate the clinical relevance of increasing resistance on the normalized EMG activity. These results showed that increasing resistance created systematic higher relative muscle activity levels in all trunk muscles. Only the MF
showed no significant difference between the activity during the 50% and the 70% MMF exercise concerning the movement phase away from the neutral midline position.

**Fig. 2.** Relative muscle activity (% MVIC) levels during the phase away from the neutral midline position. MMF = maximal mean force; I = ipsilateral; C = contralateral; IO = internal oblique; RA = rectus abdominis; EO = external oblique; MF = lumbar multifidus; LT = longissimus thoracis; ICLT = iliocostalis lumborum pars thoracis; LD = latissimus dorsi.

**Fig. 3.** Relative muscle activity (% MVIC) levels during the phase towards the neutral midline position. MMF = maximal mean force; I = ipsilateral; C = contralateral; IO = internal oblique; RA = rectus abdominis; EO = external oblique; MF = lumbar multifidus; LT = longissimus thoracis; ICLT = iliocostalis lumborum pars thoracis; LD = latissimus dorsi.
4. DISCUSSION

The main purpose of the present study was to investigate if low-load seated rotation exercises with a resistance of 30% MMF could create sufficient normalized EMG activity to train the trunk muscles.

Normalized EMG levels of 30% of MVIC have been shown to be appropriate for muscle coordination purposes (Jull, & Richardson, 1994; McGill, 1998; Richardson et al., 2004). When training specific movements, not only strength, but also the adequate co-contraction with the appropriate force and inhibition of different muscles, described as coordination, is essential to carry out the desired activity (Kottke, 1990).

The results of the present study were described according to the movement phase towards and away from the neutral midline position. During the phase away from the neutral midline position, all muscles showed higher activity than during the phase towards the neutral midline position, except for the RA during the 70% MMF exercise. However, because the dynamic rotation movement always consists of both phases in clinical practice, description of the muscle activity levels is clearer when the total movement is considered.

To clarify interpretation of the results of the low-load exercise, a subdivision was made into the muscles that showed activity of less than 30% of MVIC, between 30% to 60% of MVIC and finally, more than 60% of MVIC.

Only the RA showed activity levels smaller than 30% of MVIC. Minimal contribution of the RA to the production of torque in the transverse plane was supposed due to its vertical alignment (Andersson, Grundström, & Thorstensson, 2002; Ng et al., 2001; Pope, Andersson, Broman, Svensson, & Zetterberg, 1986).

The IO reached 30% of MVIC, which is appropriate for muscle coordination training. This activation level could be suggested to be ideal for the IO, because this muscle is often classified as a local, segmental stabilizing muscle (Bergmark, 1989). However, the division of trunk muscles into local and global (torque producing) ones mainly results from seeing the muscles in isolation and not taking into account their intricate functional relationship with collagenous structures like the fascia. The IO, EO and LD are all strongly related to the main thoracolumbar fascia (TLF). Muscles like the MF and ICLT have a hydraulic amplifier effect on the different layers of the TLF (Vleeming, Pool-Goudzwaard, Stoeckart, van Wingerden, & Snijders, 1995). The posterior layer of the TLF is ideally positioned to
regulate tension via its extensive muscular attachments to both “local” and “global” muscles (Barker, & Briggs, 1999).

The EO and all the back muscles even reached basic strength training levels of more than 60% of MVIC at very low resistances of 30% MMF.

Although the rotation movement in this study, in which the subject was seated with a neutral lumbar spine position, lacks some functional relevance in relation to most rotation movements in sports, this seems a safe and useful position which allows early rehabilitation of injured athletes. At 30% MMF this dynamic rotation exercise is expected to create minimal tissue load due to the low resistance and the controlled neutral lumbar spine position (McGill, 2007) in the Tergumed device. Furthermore, disc herniation often related to rotation movements, appears to be more strongly linked to repeated flexion motion rather than load (Calaghan & McGill, 2001). Therefore, this low-load rotation exercise seems safe and creates already strength training of all back muscles and the EO. The athlete can start early with an efficient training preparing him for specific rotation movements essential during his sports activities. Low-load exercises are very important since athletes need to start rehabilitation as fast as possible to maintain their shape and technique.

However, since LBP patients could demonstrate higher relative muscle activity levels during these 30% MMF exercises and the present study only investigated healthy subjects, further research on LBP patients is mandatory.

The second purpose of the current study was to investigate the clinical relevance of increasing resistance on relative activity of different trunk muscles. Since rotation is very important in daily living and sport, many researchers have investigated the trunk EMG activity during rotation movements. However, most studies investigated only isometric exertions (Bankoff, Moraes, Salve, Lopez, & Ferrarezi, 2000; Moraes & Bankoff, 2003; Kumar & Narayan, 1998, 1999a & 2001a; Kumar, Zedka, & Narayan, 1999b; Kumar, Narayan, & Garand, 2001b, 2002a & 2002b; Lavender, Tsuang, & Andersson, 1993; McGill, 1992; Mirka et al., 1997; Ng et al., 2001, 2002, & 2003; Perez & Nussbaum, 2002; Swie & Sakamoto, 2004; Torén & Öberg, 1999; Van Dieën, 1996). Despite the common use of rotation training devices in clinical practice, most research findings are based on varied rotation positions and complicated settings. Today, the effect of various loads applied to dynamic rotation movements on trunk muscle activity was not yet reported. To
our knowledge, the present study is the first study which discusses the activity levels during
dynamic low-loaded seated rotation exercises and the relevance of increasing resistance
during these exercises.

The results of the present study indicated that all trunk muscle activity significantly
increased with increasing resistance. However, in general, the IO and RA did not reach
basic strength training levels, even when increasing the resistance to 70% MMF.
Consequently, with regard to the rehabilitation of these muscles it seems of no benefit to
impose higher loads to the spine. It seems possible that this kind of seated axial rotation
exercises is not optimal to train these specific muscle groups. As the rotation movement is
an essential but not unique part of the prevention or rehabilitation training, other
movements such as flexion might provide optimal recruitment of those muscles.

The EO and all back muscles, which reached strength training levels even at low-load
exercises (30% MMF) showed significantly higher relative activity when increasing the
resistance. However, one can argue about the clinical importance of such high muscle
activity training in rehabilitation. To rehabilitate basic strength with minimal injury risk in
the average active population, there seems no need for an increase in resistance during
these rotation exercises since it could create supplementary stress on the lumbar spine and
might be detrimental in the early rehabilitation. However, maximal strength training at
higher relative muscle activity levels as created in the 50% and 70% MMF exercise could be
justified for jobs demanding intensive rotation movements or sportspecific conditions.

5. CONCLUSION

In conclusion, the results of the present study indicate that increasing resistance to 50%
and 70% MMF during seated axial rotation in a Tergumed training device consistently
created higher relative activity levels in all trunk muscles. In the vulnerable spine
undergoing rehabilitation the results suggest that training at 30% MMF may be sufficient.

Acknowledgements

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REFERENCES


CHAPTER 5

THE EFFECT OF INCREASING RESISTANCE ON TRUNK MUSCLE ACTIVITY DURING EXTENSION AND FLEXION EXERCISES ON TRAINING DEVICES

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ABSTRACT

Although progressive resistance training of trunk muscles on devices is very common, today, the effects of increasing resistance on trunk muscle activity during dynamic extension and flexion movements on training devices have not been reported yet. Thirty healthy subjects participated in maximal isometric and submaximal dynamic (at 30%, 50% and 70% of maximum mean torque (MMT)) extension and flexion exercises on Tergummed lumbar training devices. The normalized (as a percentage of maximal voluntary isometric contractions (MVIC)) electromyographic activity of 16 abdominal and back muscles was investigated. The results of the present study indicated that in general, with increasing resistance from 30% MMT to 50% MMT and 70% MMT, the activity of all back muscles during the extension exercises and the activity of all abdominal muscles during the flexion exercises increased significantly. To train strength (>60% of MVIC), low intensities (30% and 50% MMT) appeared sufficient to affect the back muscles, but for the abdominals higher resistance (70% MMT) was required. In contrast to the other back muscles, the lumbar multifidus demonstrated high activity levels during both the extension and the flexion exercises. As the lumbar multifidus is demonstrated to be an important muscle in segmental stabilization of the lumbar spine, this finding may help in understanding the efficacy of rehabilitation programs using specific training devices.

KEY WORDS

Electromyography – Flexion – Extension – Trunk muscle activity
1. INTRODUCTION

Progressive resistance training of the trunk muscles on devices is a common treatment for low back pain (LBP) (San Juan et al., 2005). Research has shown that muscle reconditioning on specific devices is not only effective in reducing pain and self-experienced disability (Kankaanpää et al., 1999; Risch et al., 1993; Taimela et al., 2000), but it can also modify important psychological factors (Mannion et al., 2001a; Risch et al., 1993; Taimela et al., 2000), diminish the use of health care services (Leggett et al., 1999) and increase isometric strength (Mannion et al., 2001b; Risch et al., 1993; Taimela et al., 2000) and fatigability of the lumbar muscles (Mannion et al., 2001b).

To optimize rehabilitation programs, muscle activation strategies during the performance of exercises on devices need to be understood. The findings of trunk electromyographic (EMG) amplitudes during the flexion and extension movements used daily in standing positions have been reported in a healthy population (Bankoff et al., 2000; Dickey et al., 2003; Gupta, 2001; Kaigle et al., 1998; Kuriyama and Ito, 2005; Larivière et al., 2000; Leinonen et al., 2000; Mathieu and Fortin, 2000; Marras and Mirka, 1992; Mirka et al., 1997; Neblett et al., 2003; Olson et al., 2004; Olson et al., 2006; Paquet et al., 1994; Shirado et al., 1995; Takahashi et al., 2006; Wolf et al., 1979). Extensive research was also performed on muscle fatigability (Kankaanpää et al., 2005; Kankaanpää et al., 1997; Lee et al., 1996; Roy et al., 1989; Sparto et al., 1999; Van Dieën et al., 2003) and muscle activation during different lifting movements (Arjmand and Shirazi-Adl, 2005; Bonato et al., 2003; Cresswell and Thorstensson, 1994; Gagnon et al., 2001; Granata and Marras, 1995; Kingma et al., 2004; Lee and Lee, 2002; Noe et al., 1992; Potvin et al., 1991; Roy et al., 1998; Takahashi et al., 2006). In training exercises, muscle function was analysed in a standing position using loads in the hands (Arjmand and Shirazi-Adl, 2006; Peach et al., 1998) and resistance from a device (Alexiev, 1994; Allison and Henry, 2001; Gallagher, 1997; Granata et al., 2005; Lee et al., 2006; Ross et al., 1993; Sparto and Parnianpour, 1998; Thelen et al., 1994). Today, most training on devices occurs in a seated position, because it is a comfortable posture which limits compensatory movements. Most studies evaluating muscle activity during flexion and extension exercises in a seated position investigated isometric (de Moraes and Bankoff, 2003; Kankaanpää et al., 1998; Parkin et al., 2001; Roy et al., 2003; Tan et al., 1993) and isokinetic (Grabiner and Kasprisin, 1994; Walsworth, 2004) movements. Analysis of dynamic exercises is needed since more complex loading on
the spine is created in comparison with static exercises (Davis and Marras, 2000) and controlled motions are more related to daily life conditions (Marras and Mirka, 1992). Although a few studies investigated muscle activation in healthy subjects during dynamic unresisted (Bankoff et al., 2000) and resisted (Cholewicki et al., 1997; Kankaanpää et al., 1997; San Juan et al., 2005; Udermann et al., 1999) flexion and extension movements performed in sitting, several limitations remain. Cholewicki et al. (Cholewicki et al., 1997) studied the effect of no weight and 32 kg strapped over the shoulders in a semi-seated position. San Juan et al. (San Juan et al., 2005) and Udermann et al. (Udermann et al., 1999) investigated isometric and dynamic movements on a training device (MedX). Though they reported to analyse an extension movement, this was determined as the movement returning from a flexion position to the neutral spine position. In sitting, the neutral lumbar spine position is halfway between full extension and a flat position of the spine (Danneels et al., 2002). In the present study, based on the principles of biomechanics and clinical evaluation (Edwards, 1994; Kendall et al., 1993; Vleeming et al., 1993) and in agreement with different other studies (Kankaanpää et al., 1997; Walsworth, 2004), extending the spine was defined as the backward movement of the trunk starting from the neutral posture. Although currently training devices are very popular in clinical practice, no studies have reported the effect of increasing resistance on trunk muscle activity during dynamic seated flexion and extension movements on training devices. Consequently, different resistance levels were applied in this study. The first purpose of the present study was to analyse the relative activity levels of several trunk muscles during flexion and extension movements. The second purpose was to investigate the effect of increasing resistance during flexion and extension movements on trunk muscle activity in a healthy population.

2. METHODS

2.1. Subjects
Thirty healthy subjects were included in this study. Their mean age was 20.52 (SD 1.74) years, mean height was 172.69 (SD 8.66) cm and mean weight was 64.34 (SD 10.02) kg. Subjects were excluded if they reported any past or current back pain. Subjects familiar
with coordination or specific trunk training programs were also excluded. All subjects were informed of the experimental protocol and gave written consent. Appropriate ethical approval by the Ghent University Ethics Committee had been granted prior to the commencement of the study.

2.2. Equipment
Flexion and extension devices of the Tergumed® Line for the back (Proxomed®, Germany) were used. The Tergumed system is a fixed weight resistance system which measures range of motion (ROM) (by a cable barrel with greased disc and optical encoder) and force (by a strain gauge) in real time (sample rate of 50 Hz). The interobserver reliability of the equipment was demonstrated to be excellent for the measurement of the maximal isometric strength and good for the measurement of the ROM of the lumbar spine in healthy subjects (Roussel et al., 2006).

The muscle activity was recorded by a 16 channels surface EMG system (MyoSystem 1400, Noraxon USA, Inc., Scotssdale, AZ). The raw surface EMG signals were bandpass-filtered between 10 and 500 Hz and amplified using a differential amplifier (MyoSystem 2.10, Noraxon Inc, Scottsdale, AZ). The overall gain was 1000 and the common mode rate rejection ratio was 115 dB. The signals were analogue/digitally (A/D) (12-bit resolution) converted at 1000 Hz and stored in a personal computer.

2.3. Electrodes
Disposable Ag/AgCl surface electrodes (Blue Sensor, Medicotest GmbH, Germany) were attached parallel to the muscle-fibre orientation, bilaterally over the following abdominal muscles: the inferior fibres of the internal oblique (IO) (midway between the anterior iliac spine and symphysis pubis, above the inguinal ligament) (Cholewicki et al., 1997; Danneels et al., 2001; Van Dieën et al., 2003), the external oblique (EO) (15 cm lateral to the umbilicus) (Cholewicki et al., 1997; Danneels et al., 2001; Peach et al., 1998; Van Dieën et al., 2003) and the rectus abdominis (RA) (3 cm lateral to the umbilicus) (Cholewicki et al., 1997; Danneels et al., 2001; Peach et al., 1998; Thelen et al., 1994; Van Dieën et al., 2003).

The selected back muscles were: the lumbar multifidus (MF) (lateral to the midline of the body, above and below a line connecting both posterior superior iliac spines) (Danneels et al., 2002; Macintosh and Bogduk, 1987), the lumbar part of the iliocostalis lumborum (ICLL) (lateral to the vertical line through the posterior superior iliac spine, above the iliac
crest) (Macintosh and Bogduk, 1987), the thoracic part of the iliocostalis lumborum (ICLT) (above and below the L1 level, midway between the midline and the lateral aspect of the body) (Danneels et al., 2002; Danneels et al., 2001; Macintosh and Bogduk, 1987), the thoracic part of the longissimus (LT) (above and below the L1 level, midway between the vertical line through the posterior superior iliac spine and the midline of the body) (Macintosh and Bogduk, 1987), and the latissimus dorsi (LD) (3 cm lateral and inferior to the inferior angle of the scapula) (Danneels et al., 2001). The maximal interelectrode spacing between the recording electrodes was 2.5 cm as recommended by Ng et al. (Ng et al., 1998), and each electrode had a pick-up area of ≈ 1.0 cm². The skin was prepared by shaving excess hair and rubbing the skin with alcohol to reduce impedance (typically ≤ 10 kΩ).

2.4. Experimental procedure

The subject was seated in an upright position in the lumbar extension and flexion Tergumed devices (Figs. 1 and 2). All restraining mechanisms and lever arm attachments were adjusted to the subject’s body dimensions, in accordance with the manufacturers’ instructions. The knees were flexed at 30° and were positioned so that the thighs were parallel to the seat (San Juan et al., 2005). The feet were placed on a footboard. A posterior pelvic pad, a belt and thigh pads secured the position of the lower limbs and pelvis. For the extension and flexion exercises, force had to be applied to a pad just below the spine of the scapula and to a pad just below the clavicle respectively. The subjects were asked to cross the arms and hold the hands on the opposite shoulders.

To obtain similar positions during the different exercises and for subject’s comfort, first all flexion exercises and secondly all extension exercises were performed or vice versa (at random).

First, the ROM was determined. The subject was asked to extend or flex the trunk to the end of extension or flexion and return to the neutral position. In a smooth and continuous way, without stopping anywhere in between the movement, this was performed three times. Secondly, three maximal voluntary isometric contractions (MVIC) were performed in the neutral upright sitting position. The MVIC of the abdominal muscles was obtained during the isometric flexion exertion and the MVIC of the back muscles during the isometric extension exertion. The subjects were asked to perform the maximal contraction
within the first two seconds and maintain their contraction at that level for another three seconds before terminating the trial (Kumar et al., 2002). Visual feedback, presenting the force signal, and verbal encouragement were given to enable the subject to give maximal effort. These exercises were performed three times with a pause of 15 seconds in between. The ROM and maximal effort tests were followed by a pause of 15 minutes (Clark et al., 2002; Ng et al., 2003; San Juan et al., 2005).

Thirdly, submaximal dynamic flexion and extension movements were performed. To determine the resistance, the mean maximal torque (MMT) obtained during the maximal isometric contractions was used. Dynamic submaximal exercises at 30, 50 and 70% of the MMT, recorded in the upright position, were performed. The exercise cycles at the different percentages of MMT were performed by each subject at random order. The cycles consisted of a movement phase away from the neutral position (extension and flexion) and a phase towards the neutral position (returning to the neutral position). Five repetitions of 5 seconds were performed. Visual feedback presented as a sinusoidal curve on a notebook, indicating time and ROM, supported the controlled performance of the exercises. The subject was only allowed to deviate 5% of the curve presented. A ROM of 80% of the total ROM was used during these dynamic exercises.

Each subject attended a familiarization and a testing session. The familiarization session was included to allow the subject to gain some knowledge of the equipment and testing procedure (without placement of surface electrodes) (Ng et al., 2002). This session was held at 3 to 7 days before the testing session.

Fig. 1. Extension movement.  
Fig. 2. Flexion movement.
2.5. Data analysis

Recent research on the Tergumed devices showed that it is more optimal to use the mean of different trials than to use the value of a single trial (Roussel et al., 2006). The mean of the three ROM values was calculated by the software BioMC for Sequential Training Version 1.0.0 (1999-2002 by BfMC GmbH, Leipzig, Denmark). This software also determined the mean torque during the three MVIC trials.

The stored EMG data were full-wave rectified and smoothed (window: 150 ms). Root mean square values (RMS) were calculated to quantify the amplitude of the EMG signals. All analyzed EMG periods were 2500 ms. The mean RMS of the three MVIC trials for each muscle was used to provide a basis for EMG signal amplitude normalization of the data of the submaximal exercises. During the submaximal exercises, markers were placed between the two movement phases. The mean RMS values of the 5 movement phases away from the neutral position and the 5 movement phases towards the neutral position were calculated. Noraxon MyoResearch software 2.10 was used for these analyzes.

2.6. Statistical analysis

Statistical analysis was performed using SPSS 12.0 software package (SPSS Inc., Chicago, IL) for Windows. The level for statistical significance was set at 0.05.

Descriptive statistics were performed of the relative muscle activity levels.

The dependent variable was EMG. To assess the effects of the four independent variables (resistance level, muscle, side and phase) on the dependent variable EMG, an analysis of variance (ANOVA) for repeated measures was performed, separately for flexion and extension.

Analysis of the extension movement showed a significant 4-way interaction resistance level x muscle x side x phase \( (p = 0.01) \). Consequently, Least Significant Difference (LSD) post hoc tests with Bonferroni adjustments were performed.

Analysis of the flexion movement demonstrated that the 4-way interaction was not significant \( (p = 0.41) \). The 3-way interactions resistance level x muscle x side \( (p = 0.52) \), resistance level x phase x side \( (p = 0.84) \) and phase x muscle x side \( (p = 0.48) \) were not significant. The interaction resistance level x muscle x phase showed a significant p-value \( (p < 0.001) \). The 2-way interaction muscle x side was also significant \( (p = 0.001) \). Consequently, Least Significant Difference (LSD) post hoc tests with Bonferroni adjustments were performed.
3. RESULTS

The MMT during extension and flexion was 342.16 Nm (SD 141.96) and 169.96 Nm (SD 63.72) respectively. The mean ROM of the extension and flexion was 25.42 (SD 3.57) and 29.57 (SD 3.76) cm respectively. The normalized EMG activity levels during the dynamic exercises are presented in Table 1.

The results of the extension movement demonstrated relative MF and LT activity levels of higher than 60% of MVIC and relative ICLI and ICLT activity levels between 30% and 60% of MVIC during extension at the lowest intensity (30% MMT). Even when returning to the neutral position during this exercise, all these back muscles showed activity levels of about 30% of MVIC. The left LD approximated the level of 30% of MVIC during the 70% MMT exercises. The abdominal muscles presented low relative activity levels during all extension exercises (5.44 to 18.78 % of MVIC).

Post-hoc tests (the 4-way interaction resistance level x muscle x side x phase was significant) analysing the effect of the resistance level showed the following results. Increasing resistance during extension created significant higher relative activity levels in all back muscles during both movement phases (Figs. 3 and 4). There was no significant difference between the resistance levels for the activity of the MF during the returning movement to the neutral position. Concerning the relative abdominal muscle activity, increasing the resistance during extension did not create significant differences in relative muscle activity of the IO and RA, but in general, significant increases in relative EO activity were reported.

Post-hoc tests investigating the effect of the movement phase demonstrated that the relative activity of all back muscles and the EO was significantly higher during the movement phase away from the neutral position compared with the phase towards the neutral position. The relative muscle activity of the IO and RA was not significantly different between both phases during the 30% MMT and the 50% MMT exercises.

Post-hoc tests analysing the effect of the factor side showed no significant differences in relative activity between both sides, except for the RA, EO and LD. During all extension exercises and phases the relative activity of the EO and LD was significantly higher at the left side compared with the right side and the relative activity of the RA was significantly higher at the right side compared with the left side. During the movement phase towards
the neutral position, the left MF also showed significantly higher relative activity than the right MF.

The results of the *flexion movement* demonstrated that no single muscle exceeded the 25% of MVIC activity level during the low-intensity exercise (30% MMT). The abdominal muscles reached activity levels of about 30% of MVIC and 60% of MVIC during flexion at 50% MMT and 70% MMT respectively. In contrast to the other back muscles that showed low activity levels during all flexion movements (5.68 to 16.85 % of MVIC), the MF showed relative activity of more than 30% of MVIC during flexion at the 70% level.

Post-hoc tests (the 3-way interaction resistance level x muscle x phase was significant) analysing the effect of the resistance level showed the following results. Increasing resistance during the flexion movements created significant higher relative activity levels in all abdominal muscles (Figs. 5 and 6). In general, back muscle activity was not significantly different between 30% and 50% MMT (except for the ICLL and ICLT during flexion), but increasing resistance to 70% MMT caused significantly higher back muscle activity.

Post-hoc tests investigating the effect of the movement phase demonstrated that the relative activity of all muscles was significantly higher in the movement phase away from the neutral position compared to the movement phase towards the neutral position. Only the MF during the 30% MMT exercise and the LT during the 50% MMT exercise showed no significant differences between both movement phases.

The 2-way interaction muscle x side was significant (*p* = 0.001) and post-hoc analysis showed significant higher relative activity for the RA, ICLL, LT and ICLT at the right side compared with the left side.
<table>
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<td>Data on relative EMG activity (% of MVIC) during the extension and flexion exercises (means and standard deviations; SD).</td>
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<tr>
<th></th>
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<th>ILIOLATERAL LUMB</th>
<th>LONGIS THOR</th>
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<td>24.29</td>
<td>42.37</td>
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</table>
Fig. 3. Effect of increasing resistance on the relative muscle activity levels during the extension movement – phase away from the neutral position (extension).

Fig. 4. Effect of increasing resistance on the relative muscle activity levels during the extension movement – phase towards the neutral position.
Fig. 5. Effect of increasing resistance on the relative muscle activity levels during the flexion movement – phase away from the neutral position (flexion).

Fig. 6. Effect of increasing resistance on the relative muscle activity levels during the flexion movement – phase towards the neutral position.
4. DISCUSSION

The purposes of the present study were to investigate the activity levels and the effect of increasing resistance during seated extension and flexion exercises on relative muscle activity of the trunk.

In general, during the extension exercises, the relative back muscle activity was high and the abdominal muscles showed low relative activity levels. The relative activity of all back muscles increased significantly with increasing resistance from 30% MMT to 50% MMT and 70% MMT.

Particularly during the movement phase away from the neutral position, the back muscles reached high activity levels. At 30% MMT resistance, the MF and LT demonstrated activity levels of about 60% of MVIC. Activity levels of at least 60% of MVIC are generally accepted for basic strength training purposes (Andersson et al., 1998). In the 70% MMT exercise, these relative activity levels were almost doubled. The uncomplicated pelvic stabilization as commonly used on the Tergumed devices may have contributed to these high activity levels of the MF (San Juan et al., 2005). Pelvic stabilization was shown to be necessary for restricting pelvic motion (Petersen et al., 1987), for isolating and strengthen the lumbar erector spinae muscles (Graves et al., 1994) and to obtain higher activity of the MF (San Juan et al., 2005) during extension movements on devices. However, debate exists on the need for pelvic stabilization. Other researchers reported that pelvic stabilization did not influence muscle forces (Petersen et al., 1987) and activation of gluteus maximus (GM) and hamstrings (Udermann et al., 1999). Pelvic stabilization was considered not so important (Walsworth, 2004) or even not needed to strengthen the lumbar erector spinae muscles (Mayer et al., 2002).

The thoracic and lumbar part of the iliocostalis lumborum reached activity levels between 30 and 60% of MVIC during the low resistance 30% MMT exercise. Relative EMG levels of 30% of MVIC have been shown to be appropriate for muscle coordination purposes (Jull and Richardson, 1994; McGill, 1998; Richardson et al., 2004). When training specific movements, not only strength, but also the adequate co-contraction with the appropriate force and inhibition of different muscles, described as coordination, is essential to carry out the desired activity (Kottke, 1990). To train this coordination function and to create controlled dynamic movements, the Tergumed device in the present study displayed both
ROM and pacing of the movements. Biofeedback devices were described to serve as an automated “coach”, cuing the athlete or patient for cadence and effort (Cassisi et al., 1993). Cholewicki and Van Vliet (Cholewicki and Van Vliet, 2002) reported that the lumbar back muscles showed the largest contribution to spine stability during isometric extension exertions, but not during flexion trials.

At 50% MMT resistance, both the thoracic and lumbar part of the iliocostalis lumborum reached strength training activity levels (60% of MVIC).

During the 70% MMT exercise, the activity levels obtained during the lowest resistance exercise (30% MMT) were almost doubled. Consequently, the MF, ICLL and ICLT reached relative activity levels of more than 100% of MVIC during the movement phase away from the neutral position in the 70% MMT extension exercise. Relative activity levels exceeding 100% of MVIC suggest inadequate maximal exertions. To ensure that maximum EMG was obtained, subjects were asked to return the next week to perform manually resisted maximal exertions (Danneels et al., 2001). In general, no significant differences were found between the manual resisted and the device resisted maximal EMG. The MVIC of the RA and ICLL were higher when performed on the devices. Though isometric exercises are often used to normalize dynamic movements (Cholewicki et al., 1997; Gallagher, 1997; Udermann et al., 1999; Walsworth, 2004), length-force properties may have caused high relative activity levels. Analysis of EMG signals over the full ROM may ignore the differences in EMG-force relationships and this could be regarded as a limitation of the present study. However, other procedures often fail to maintain the dynamic character of the exercises.

The results of the present study were described according to the movement phase towards and away from the neutral position. In general, all muscles showed higher relative activity during the phase away from the neutral position than during the phase towards the neutral position. Concerning a flexion movement in standing, Nouwen et al. (Nouwen et al., 1987) reported similar findings for the abdominal muscles, but opposite results for the paraspinal muscles. A change in neural drive to the muscles (Gabriel et al., 2006), possibly caused by the subjects’ thoughts that it is harder to push against a resistance and move away from the neutral upright sitting position than preventing the resistance from dropping down and moving towards the neutral position, might have created the higher EMG activity during the phase away from the neutral position of both flexion and extension exercises. Nevertheless, because the dynamic flexion and extension movements always consist of
both phases in clinical practice, description of the muscle activity levels is clearer when the total movement is considered.

Considering the global exercises including both phases, the extension movements in the present study created an adequate training of the back muscles. In accordance with the results of isometric seated extension exercises (Tan et al., 1993), greater activation of the more medially located back muscles (MF and LT) was demonstrated compared with the more lateral located thoracic and lumbar part of the iliocostalis lumborum.

The relative activity levels of the LD were much lower (< 30% of MVIC, even during the 70% MMT exercise). During extension exercises in standing, the LD also appeared to be not susceptible to trunk angle changes (Gallagher, 1997). Due to the anatomical attachments to the humerus, this muscle also has an important role at the shoulder joint. This shoulder joint was not involved in this movement since the subjects were asked to cross the arms and hold the hands on the opposite shoulders. The lower activity levels might also be adequate to stabilize the trunk. The LD in association with the GM can induce tension in the posterior layer of the thoracolumbar fascia and may contribute to limitation of joint movement by simultaneously stiffening the muscles and fascia of the lumbar spine and sacroiliac joint while enabling transfer of loads between trunk and limbs (Vleeming et al., 1995). In the present study, because the subjects were seated, the activity of the GM could not be measured accurately.

Although the relative activity levels of the EO also increased significantly with increasing resistance, the EO never exceeded 11% of MVIC. Both EO and LD showed higher relative activity levels at the left side compared with the right side. Minimal movement to left lateral flexion of the upper torso during the extension exercises could have contributed to the asymmetric activity of these muscles. The location of all weights and the basis of the device at the left side of the subject may have caused less symmetric activity.

During the extension exercises, in general, the relative activity of the IO and RA did not differ significantly between the exercises at different resistance levels. Since the activity levels of those muscles were similar during all resistance levels and during both phases, a stabilizing function of the IO and RA during the extension movement might be expected. In accordance with the present findings, external resistance induced no significant activity of the RA during flexion movements (Takahashi et al., 2006) and movements starting from various flexion positions to neutral (Ross et al., 1993) in standing. Research on rotation
Trunk muscle activity during extension and flexion exercises on devices

Exercises demonstrated a global stabilizing role of the lumbar spine for the RA (Ng et al., 2001). In contrast, during various isometric flexion and extension exertions the RA was reported to have a negligible effect on spine stability (Cholewicki and Van Vliet, 2002). In the present study, RA showed significant higher relative activity at the right side in comparison with the left side. These contradictory findings concerning RA activity might be attributed to the different neuromuscular requirements for controlling dynamic versus isometric activities (Ross et al., 1993). The IO, investigated at a location where the direction of the muscle fibres is similar to those of the transversus abdominis (Marshall and Murphy, 2003; Urquhart et al., 2005), showed no significant differences between both sides and might demonstrate the commonly accepted segmental stabilizing role of the latter muscle. Since in vitro experiments with a lumbar spine model demonstrated that activity levels of at least 1 to 3% MVIC of the MF, ICLI and LT were sufficient to ensure segmental stability of the lumbar spine (Cholewicki and McGill, 1996), the low activity levels of the IO and RA are assumed to be adequate. However, this has not yet been evaluated in abdominal muscles.

In general, during the flexion exercises, the relative abdominal muscle activity was about 30% of MVIC during the 50% MMT exercise. Except for the MF, the relative back muscle activity was low during flexion movements. The relative activity of all abdominal muscles increased significantly with increasing resistance from 30% MMT to 50% MMT and 70% MMT.

Fifty percent MMT resistance appeared necessary to obtain relative abdominal activity levels of 30% of MVIC, deemed important for coordination training purposes (Jull and Richardson, 1994; McGill, 1998; Richardson et al., 2004). Strength training levels of 60% of MVIC were demonstrated during the 70% MMT exercise. However, the relative abdominal muscle activity levels during the flexion exercises were lower than the activity levels obtained by the back muscles during the extension exercises. Antagonistic muscle activity can indicate co-activity of the trunk musculature system (Davis and Marras, 2000; Lee et al., 2006) and might be affected more by dynamics than agonistic muscle activity (Davis and Marras, 2000). It is speculated that muscle co-activity may contribute to trunk stability (Davis and Marras, 2000; Granata and Marras, 1995; Granata and Marras, 2000).
The RA, the ICLI, LT and ICLT showed higher relative activity at the right side in comparison with the left side. Since handedness has been shown to influence EMG (De Luca et al., 1986; Merletti et al., 1994) and all but three subjects were right handed, this could be involved in the higher relative activity at the right side. In chronic back pain patients (Larivière et al., 2000; Nouwen et al., 1987) and in healthy subjects (Nouwen et al., 1987), during flexion and extension exercises from a standing posture, paraspinal EMG was also demonstrated to be higher on the right side than on the left.

As expected, in general, the relative back muscle activity was low during the flexion exercises (not higher than 23% of MVIC). According to Tan et al. (Tan et al., 1993), the erector spinae muscles seem to have a mechanical advantage in trunk flexion which increases torque production with less EMG output. In contrast to the other back muscles, the MF demonstrated relative activity levels between 20% and 42% of MVIC during the flexion exercises and showed no significant differences between the left and right relative EMG activity. The MF is described as the muscle important for controlling and stabilizing the lumbar spine and seemed to be recruited symmetrically and at moderate to high levels during almost all of these flexion and extension exercises. Inhibition and selected atrophy of MF has been shown by changes in activation (Cassisi et al., 1993), fatiguability (Biedermann et al., 1991; Roy et al., 1998), composition (Yoshihara et al., 2001; Zhao et al., 2000), size and consistency (Danneels et al., 2000; Hides et al., 1994) in LBP patients compared to healthy controls. Although the present study only investigated young healthy subjects and further investigation in LBP populations is indispensable, the current findings concerning the activation of the MF during these flexion and extension exercises are encouraging.

5. CONCLUSION

The results of the present study indicated that in general, with increasing resistance from 30% MMT to 50% MMT and 70% MMT, the activity of all back muscles during the extension exercises and the activity of all abdominal muscles during the flexion exercises increased significantly. The exercises in the present study created adequate coordination and strength training activity levels of the back and abdominal muscles during extension
and flexion respectively. Though the flexion and extension movements were symmetric, several muscles demonstrated asymmetric activity. To train strength, for the MF and LT low resistance of 30% MMT and for the ICLL and ICLT 50% MMT extension exercises were sufficient, but for the abdominals higher resistance (70% MMT) was required. In contrast to the other back muscles, the lumbar multifidus demonstrated high activity levels during both the extension and flexion exercises. As the MF is demonstrated to be an important muscle in segmental stabilization of the lumbar spine, this finding might help in understanding the efficacy of rehabilitation programs using specific training devices.

Acknowledgements
The authors thank Ms. Sofie Haelterman, Ms. Greet Aelbrecht and Mr. Ruben Van Assche for their assistance with the collection of the data.

REFERENCES


Trunk muscle activity during extension and flexion exercises on devices


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PART III: EFFECTIVENESS OF SPECIFIC
EXERCISE THERAPY VERSUS EXERCISE
THERAPY ON DEVICES
CHAPTER 6

RELIABILITY OF A FUNCTIONAL CLINICAL TEST BATTERY EVALUATING POSTURAL CONTROL, PROPRIOCEPTION AND TRUNK MUSCLE ACTIVITY

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ABSTRACT

Objective
The purpose of this study was to examine the repeatability and reproducibility of the different tests of a clinical test battery evaluating the components of functional spinal stability: i.e. postural control (sway velocity data), proprioception (repositioning error) and muscle activation (electromyographic data).

Design
A total of 28 healthy volunteers participated in this study: 14 in the repeatability study and 14 in the reproducibility study. Each subject was tested three times with an interval of 1 week between the test sessions. The intraclass correlation coefficients and the standard error of the measurements as a percentage of the grand mean were calculated.

Results
The intraclass correlation coefficients for both the repeatability and the reproducibility evaluation showed good to excellent reliability for all variables (ICC 0.60–0.98). The standard error of the measurements as a percentage of the grand mean ranged from 0.004 to 19.94.

Conclusions
The functional clinical test battery investigated in this study proved to be a reliable tool in the assessment of healthy subjects. The evaluation of postural control, proprioception and muscle activity (coordination, stabilization, maximal voluntary isometric contraction, endurance and flexion-relaxation) showed good to excellent repeatability and reproducibility. Further analysis of the reliability of these parameters in a clinical setting, particularly in patients with low back pain, seems appropriate.

KEY WORDS
Lumbar back disorders are very common. A British group recently reported that the prevalence of low back pain (LBP) is higher than 40 years ago.¹ To curtail this high prevalence and the related socio-economic implications, reliable assessment tools are needed in clinical practice. In contrast to the one-sided evaluation methods used in the past, combining multiple tests allows to obtain a global assessment of each individual. In the present study, different clinical tests were chosen based on the components of functional stability of the lumbar spine, as determined by: (1) passive structures of the spine, (2) muscle functional characteristics, (3) neuromuscular control, and (4) postural control.² To evaluate the ability to relax the back muscles, a full trunk flexion exercise was added to the functional clinical test battery.

The purpose of the present study was to examine the repeatability and reproducibility of the different tests of a clinical test battery evaluating postural control (sway velocity data), proprioception (repositioning error), and muscle activation (electromyographic [EMG] data).

**METHODS**

**Subjects**
Two groups of healthy, active subjects were included in this study. Oral/written requests were made to colleagues, family and friends to serve as test subjects. Excluded were subjects with a history of musculoskeletal/neuromuscular complaints or earlier visits to a physician for back problems, and subjects who had already experienced back pain that affected their daily activities. A total of 14 subjects (seven men and seven women) volunteered for the repeatability study; their mean age was 38.71 (SD 11.75) yrs, mean height was 171.07 (SD 11.27) cm, and mean weight was 63.29 (SD 9.17) kg. Fourteen other subjects (eight men and six women) volunteered to participate in the reproducibility study; their mean age was 39.50 (SD 11.20) yrs, mean height was 170.36 (SD 10.96) cm, and mean weight was 66.43 (SD 10.29) kg. All subjects were informed of the experimental protocol and gave written consent. The study was approved by the Ethics Committee of Ghent University.
Testers
The four testers were physical therapists in the final year of a 2-yr postgraduate course on manual therapy. Because none of them were familiar with the tests or the equipment before the start of the present study, all testers practised together. They agreed on a standard protocol that was used during all test sessions to ensure a strictly standardized performance of the tests, and to guarantee that each subject was given exactly the same information.

Experimental procedure and equipment
In the repeatability study, the same tester evaluated all 14 subjects three times, with a 1-week interval between each test session. In the reproducibility study, all 14 subjects were tested by three different testers on three different occasions, again with a 1-week interval between the test sessions. All tests were performed at the same time each day. For the reproducibility study, the order in which a subject was tested by one of the testers (i.e. first by tester 1, or 2 or by tester 3) was randomly determined using numbered cards. For practical reasons and for the subjects’ comfort, the sequence of the exercises was fixed. The subjects were allowed to rest between the different exercises to minimize the effects of fatigue. The endurance tests of the abdominal and back muscles were performed at the end of each session.
In both studies, the subjects were asked to perform 26 exercises, subdivided into three categories: postural control, proprioception, and muscle activity. The total time needed to complete the test protocol was about 1.5 hrs.

Postural control
Postural control was evaluated by a unilateral stance test on a force plate. The bare feet were placed in a standardized position, and the subject was asked to hold the hands on the iliac crest. The subject had to perform a unilateral hip flexion, lifting the foot to a height of 10.5 cm while keeping the lower leg in a vertical position. Standing on the left and on the right foot, and with the eyes open and closed, the subject had to maintain this position for 10 secs (exercises 1 - 4). Each exercise was performed three times, and for every condition one extra trial was allowed.
A Balance Master dual forceplate (version 8.0, NeuroCom International, Inc., Clackamas, OR) was used to measure unilateral stance in the balance point position. The forceplate consisted of two 23 × 152 cm footplates connected by a pin joint. Each footplate rested on
two force transducers with sensitive axes oriented vertically. The data from the force plate were stored on a computer until analysis.

**Proprioception**

Proprioception was determined by measuring the position-reposition accuracy of the lumbar spine. To define both position and reposition, the coordinates of the spinous processes of the lumbar spine were obtained using a three-dimensional analysis system. A pointer held by the tester touched the marked spinous processes. The subject was seated on a stool with 95 degrees of knee flexion, feet placed at hip width, and arms hanging freely alongside the trunk (exercise 5). First, the tester placed the subject in a neutral lumbar spine position. In sitting, the neutral spine position was halfway between full extension and a flat position of the spine. Data on this position were stored. After performing three pelvic rotations (anterior and posterior pelvic rotation), the subject was asked to reassume the reference position as accurately as possible. This position-reposition cycle was repeated three times. The same procedure was repeated in a standing position, with the feet placed at hip width, and the arms hanging freely alongside the trunk (exercise 6). The neutral spine position in standing was determined by a horizontal alignment between the anterior superior iliac spine and the posterior superior iliac spine.

To evaluate the proprioception of the lumbar region, an ultrasound movement analysis system (Zebris CMS70P, Isny, Germany) was used. The three-dimensional data of the spinous processes of the lumbar spine were calculated by measuring the travel time of the ultrasonic pulses by markers on a pointer to three built-in microphones on a tripod. The data were collected at a sampling rate of 10 Hz.

**Muscle activity**

Trunk muscle activity was investigated during six categories of exercises: maximal voluntary isometric contractions (MVICs), coordination, stabilization with limb movements, stabilization with trunk movements, flexion-relaxation (of the back muscles), and endurance. Each exercise was explained and demonstrated by the tester, and the subject was then allowed to practice until proper pacing was achieved. A pace of 60 beats/min was set by a metronome. Each exercise was performed three times. Because of the many different muscles, Bergmark suggested a classification of trunk muscles into two groups. Based on anatomical characteristics, Bergmark made a
distinction between trunk muscles important for segmental stabilization of the vertebrae (deep local muscles), and muscles used for global stabilization and torque production (global superficial muscles). Muscles such as the transversus abdominis, the inferior fibres of the internal oblique and the lumbar multifidus were classified as local muscles. The global muscle group consisted of many muscles, including the external oblique and the thoracic part of the iliocostalis lumborum. Therefore, in the current test battery, muscles from both these groups were selected.

Parallel to the muscle fiber orientation, surface electrodes were attached bilaterally over the following local trunk muscles: the inferior fibres of the internal oblique and the lumbar multifidus. The selected global trunk muscles were the external oblique and the thoracic part of the iliocostalis lumborum. The maximal interelectrode spacing between the recording electrodes was 2.5 cm. The skin was prepared by shaving excess hair and rubbing the skin with alcohol to reduce impedance (typically ≤ 10 kOhm).

In the repeatability study, use of a personalised template ensured exact replacement of the electrodes to reduce variability caused by electrode positioning.

Maximal voluntary isometric contractions
There were three different isometric exercises, which were described previously by Danneels et al. Figure 1 presents photographs of exercises 8 and 9. During all exercises the tester verbally encouraged the subject to give maximal effort.

Coordination
During the coordination exercises, the trunk muscle activity generated by the subject to maintain the neutral spine position during a posture was measured. In sitting (exercise 10) and standing (exercise 11), the tester determined the neutral lumbar spine position, and the subject was asked to maintain this position for 3 secs before relaxing. The subject was seated on a stool with 95 degrees of knee flexion, feet at hip width, and arms hanging freely alongside the trunk. In standing, the feet were at hip width and the arms were relaxed.

Stabilization exercises with limb movements (Type 1)
During the stabilization exercises (types 1 and 2), the trunk muscle activity generated by the subject to maintain the neutral spine position during limb and trunk movements was measured. In sitting (exercises 12 - 16) and standing (exercises 17 - 21) movements of arms
and legs were added. Figure 2 illustrates exercises 12, 14 and 21. The tester determined the neutral lumbar spine position. The subject was asked to lift the limb in a standardized and controlled manner during 3 secs at a uniform speed, hold this position for 3 secs (static phase) and then return to the original position during 3 secs. The subject was asked to hold the neutral spine position throughout the exercise. The movement of the arm consisted of a 90-degree flexion movement of the shoulder with the elbow extended and a dumbbell of 1.5 kg held in the hand. In both sitting and standing, the left, right, and both shoulders were flexed. The leg movement was a hip flexion with a vertical position of the lower leg until the foot was at a height of 10.5 cm in a sitting position and a height of 25.5 cm when standing. This position was standardized by the placement of a rope above the knee.

**Stabilization exercises with trunk movements (Type 2)**

During the stabilization exercises with trunk movements, the subject was asked to perform a 45-degree controlled and paced trunk flexion while maintaining the neutral spine position that was determined by the tester. This was performed in a sitting (Fig. 2) and in a standing position (exercises 22 and 23).

**Flexion-relaxation**

The flexion-relaxation exercise was designed to evaluate the ability of the back muscles to relax in a full trunk flexion position. The subject was standing with the feet at hip width and was asked to bend forward as far as possible (while relaxing the arms and head, but keeping the knees straight). At the moment the subjects stated they were in a full trunk flexion position, they were asked to relax all muscles and EMG data were collected for 3 secs (exercise 24).

**Endurance**

The isometric endurance exercise for the abdominal muscles consisted of an unsupported, straight-knee sitting position, with the trunk held at a 45-degree angle (exercise 25). To prevent extreme thoracic flexion, the hands were placed on the shoulders and the arms were flexed alongside the trunk. Once this position was optimal, a tape was placed at the fifth thoracic vertebra level, connecting both scapulae, to detect compensation maneuvers.
The back muscle isometric endurance test was the modified Biering-Sørensen test (exercise 26). The subjects were placed in a prone position on a bench with the anterior superior iliac spine at the rotation point of the bench. The legs were strapped to the table with two belts to prevent them from moving. With the hands under the forehead, the elbows pointing outwards and a neutral head position, the subject was asked to hold this antigravity position for as long as possible. Verbal encouragement was given by the tester during both endurance tests to ensure that the maximal effort was produced by the subject.

Figure 1 presents photographs of these exercises.

The muscle activity was recorded by a surface EMG system with eighth channels (MyoSystem 1400, Noraxon Inc, Scotsdale, AZ, USA). Disposable Ag/AgCl surface electrodes (Blue Sensor, Medicotest A/S, Ølstykke, Denmark) were used. The raw surface EMG signals were preamplified (overall gain 1000, common mode rate rejection ratio 115 dB; filtered to produce a bandwidth of 10 - 500 Hz) and analog-to-digital conversion (12-bit resolution) was at 1000 Hz.

**FIGURE 1** Photographs illustrating exercises 8, 9, 25 and 26 (maximal voluntary isometric contractions and endurance exercises)
Data analysis

Postural control

The vertical ground reaction forces were used to calculate the position of the center of pressure and the equivalent center of gravity sway angles. The center of pressure excursion (sway velocity in degree per second) was used for further analysis.

Proprioception

The three-dimensional data were processed with the BioAnalyse software program (version 2.0, BioMatt) to calculate the lumbar lordosis. The lumbar lordosis angle was determined as the angle between the lines connecting the spinous process of L1 and L3 and the line connecting the spinous process of L3 and L5.

The repositioning error (in degrees) was evaluated by calculating the difference between the angle of the lumbar lordosis position set by the tester and the angle of the lumbar lordosis position assumed by the subjects themselves.
**Muscle activity**
The stored surface EMG data were full-wave rectified and smoothed. The static phases of the exercises were analysed using an interval of 2500 msecs after the defined starting point of the holding position. The mean averaged root mean square value (in microvolts) of the three repetitions was used for further analysis.

In the analysis of the endurance data, the EMG recordings were divided into 5-sec epochs, and a fast Fourier transform was applied to each epoch to obtain a frequency amplitude spectrum. The relative decrease (slope) in median frequency, defined as the frequency that divided the spectrum into two equal areas, was calculated. The endurance time was also measured. The Noraxon MyoResearch 2.10 software package was used.

**Statistical analysis**
Statistical analysis was performed using the SPSS 11.0 software package (SPSS, Chicago, IL) for Windows. The intraclass correlation coefficient (ICC) model 2,3 was used. According to Bartko, ICC values in the range 80-100% indicate “excellent repeatability”, those from 60-80% “good repeatability”, and those < 60% “poor repeatability”.

To objectively identify reliability, it is suggested to combine ICC calculations (which represent a relative measure of reliability) with the standard error of the measurement (SEM) (which quantifies the precision of individual scores on a test and is referred to as the typical error). To enhance interpretation of the SEM values, the SEM as a percentage of the grand mean (%SEM) was calculated.

**RESULTS**

**Repeatability**
The sway velocity data, representing the postural control, showed good repeatability (ICC 0.68-0.90; %SEM 4.04-9.50), and proprioception values in sitting (ICC 0.67; %SEM 9.71) and standing (ICC 0.61; %SEM 9.38) were also reliable.

Table 1 presents the ICC values and the %SEM calculations for the EMG amplitudes during exercises 7 - 24 and for the frequency and time parameters during the endurance exercises 25 and 26. Good to excellent repeatability was demonstrated (ICC 0.60-0.98; %SEM 0.004-19.94).
Reproducibility

The reproducibility study resulted in ICC and %SEM values similar to those of the repeatability study. Data on postural control showed good, reliable results (ICC 0.67-0.85; %SEM 3.44-9.24). The reproducibility of the repositioning error, representing proprioception, was also good (ICC 0.60-0.68; %SEM 9.98-13.56). The EMG data and time data in the reproducibility study showed good to excellent reproducibility (ICC 0.61-0.95; %SEM 0.004-17.73). Table 2 presents the data on reproducibility.
TABLE 1  Repeatability (intraclass correlation coefficient [ICC] and standard error of the measurement as a percentage of the grand mean [%SEM] values) for the mean electromyographic amplitude measure (root mean square values) of the abdominal and back muscles in exercises 7-26.

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L, left; R, right; IO, internal oblique; EO, external oblique; MF, lumbar multifidus; ICLT, thoracic part of the iliocostalis lumborum; MVIC, maximal voluntary isometric contraction.
TABLE 2 Reproducibility (intraclass correlation coefficient [ICC] and standard error of the measurement as a percentage of the grand mean [%SEM] values) for the mean electromyographic amplitude measure (root mean square values) of the abdominal and back muscles in exercises 7–26.

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L, left; R, right; IO, internal oblique; EO, external oblique; MF, lumbar multifidus; ICLT, thoracic part of the iliocostalis lumborum; MVIC, maximal voluntary isometric contraction.
DISCUSSION

To assess the interacting components of functional stability, a functional test battery requires reliable and consistent responses. The present study investigated the repeatability and reproducibility of postural control, proprioception, and muscle activity measurements. All components demonstrated good to excellent repeatability and reproducibility.

Postural control
Although a test duration of 10 secs was reported to be the least reliable\textsuperscript{10}, evaluation of postural control by means of a 10-sec unilateral stance test on a force platform as performed in the present study is repeatable and reproducible.

Proprioception
The repeatability and reproducibility of the repositioning error in the present study confirm the results of Brumagne et al.,\textsuperscript{11} who used a similar test protocol with pelvic movements and lumbar spine repositioning. However, in contrast to the ultrasound movement analysis system used in the present study, they worked with a piezoelectric accelerometer.

Muscle activity
The repeatability and reproducibility of the averaged EMG data were generally good to excellent (considering both ICC and %SEM indices) during all exercises of this clinical test battery.

The generally high correlation scores of the maximal voluntary isometric contractions were in accordance with the finding that the level of contraction force influences the repeatability and reproducibility. It has been shown that the higher the force, the better the reliability.\textsuperscript{12}

In general, the muscle activity reliability values of the coordination exercises were slightly lower than those of the maximal voluntary isometric contractions. This could be attributed to the relatively low activity in the sitting and standing posture. This low activity could also easily be influenced by small changes in posture and subsequent stability demands on the trunk muscles.\textsuperscript{13} Nevertheless, excellent repeatability for the back muscle EMG signals during quiet stance\textsuperscript{13} and excellent repeatability and reproducibility during standing with a neutral lumbar spine position\textsuperscript{3} have been demonstrated in similar studies.
In stabilization exercises with arm movements (in sitting as well as in standing) the local trunk muscles showed better repeatability and reproducibility than the global trunk muscles.

In both the repeatability and the reproducibility study, the %SEMs of the unilateral arm movements in the sitting position were exceptionally low (0.004-0.24), representing better test stability than was indicated by the ICCs. Based on these results, this exercise can be considered to be the best repeatable and reproducible exercise of all the clinical tests analysed in this particular test battery.

In general, the repeatability and reproducibility of the trunk EMG data during stabilization exercises with leg movements were good, but not as good as during stabilization exercises with arm movements.

During the stabilization exercises with trunk movements the back muscles showed better ICC values and lower %SEM values compared to the abdominal muscles. This could be due to the higher activity levels of the back muscles compared with the abdominal muscles during the static phase with the forward leaning trunk position.

Testing the ability to relax the back muscles is important because the flexion-relaxation phenomenon is often used to discriminate patients from healthy controls. Similar to the results of Watson et al.,\textsuperscript{14} in our study the repeatability of the flexion-relaxation phenomenon was excellent. Neblett et al.\textsuperscript{15} also reported high repeatability and reproducibility correlations in healthy subjects.

Similar to the repeatability study of Dedering et al.,\textsuperscript{16} describing a static back endurance modified Biering-Sørensen test, in the present study ICC values of the total median frequency slope ranged from 0.77 to 0.87 and the %SEM values ranged from 7.26 to 11.48. In accordance with our reproducibility results, Larivière et al.\textsuperscript{17} demonstrated that the results of the more lateral muscles (thoracic part of the iliocostalis lumborum in the present study) were generally less reliable than the corresponding EMG indices obtained with more medially located muscles (lumbar multifidus in the present study). The lumbar multifidus, as a local muscle, was characterized by optimal endurance qualities and seemed to be preferentially selected during extension tasks. In contrast, the lateral muscles seemed to be active in the frontal and transverse planes during extension tasks,\textsuperscript{18} and as global muscles, they were better qualified to create powerful movements for a shorter period of time.
In both the repeatability and reproducibility study, the %SEM values of the time variable are smaller than those of the slope median frequency parameters of the abdominal and the back muscle endurance test. This supports the use of these tests in a clinical test condition requiring only an appropriate bench and a stopwatch.

**Limitations of the study**
In the present study, as in most other reliability studies, subjects without any pain in the lower back were studied. Consequently, the repeatability and reproducibility results are only applicable to healthy subjects. The reliability of the results from chronic LBP patients could be lower because they may not perform the tests maximally due to fear of (re)injury and pain. Use of the current clinical test battery in patients with chronic LBP would probably require additional questionnaires in order to understand the pain, thoughts and behavior of these patients and thus better interpret the test results.

**CONCLUSION**
In the present study, the clinical test battery, based on the different components of functional spinal stability, was shown to be a reliable tool in the evaluation of healthy subjects. The evaluation of postural control, proprioception and muscle activity (coordination, stabilization, MVIC, endurance and flexion-relaxation) showed good to excellent repeatability and reproducibility. Further analysis of all these parameters in a clinical setting, particularly in patients with low back pain, therefore seems appropriate.

**Acknowledgements**
The authors thank Ms. Daisy De Proft, Ms. Carla Franco, Ms. Mieke Haeck and Ms. Isabelle Heylbroeck for their assistance with the collection of the data. They also thank Mr. Pascal Coorevits for the statistical advice and Ms. Iris Wojtowicz for the linguistic corrections.
REFERENCES


CHAPTER 7

THE EFFECTIVENESS OF SPECIFIC EXERCISE THERAPY VERSUS DEVICE EXERCISE THERAPY IN THE TREATMENT OF CHRONIC LOW BACK PAIN PATIENTS

Veerle K. Stevens¹, Geert Crombez², Thierry G. Parlevliet³, Filip A. Descheemaeker¹, Katie G. Bouche¹³, Guy G. Vanderstraeten¹³, Lieven A. Danneels¹

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ABSTRACT

Two popular rehabilitation programs for chronic low back pain are specific exercise therapy and device exercise therapy. However, adequate comparison of both active approaches is lacking. Chronic nonspecific low back pain patients with a motor control impairment were included in this clinical trial. Randomization referred 39 patients to 18 sessions of specific exercise therapy (specific lumbar stabilization therapy + minimal manual therapy and education) and 39 patients to device exercise therapy (specific lumbar training devices). A clinical functional test battery, an isokinetic trunk strength test and several functional disability, pain, health and psychosocial questionnaires were completed at baseline and after the intervention period. The clinical test battery evaluated postural control, proprioception and electromyographical trunk muscle activity during different low- and high intensity exercises. One-year follow-up was obtained by telephone questionnaire. The results of this clinical trial demonstrated that relative lumbar multifidus activity was increased in both active therapy groups, but more in the specific exercise group than in the device exercise group. The endurance capacity of the abdominal muscles increased in both groups, as well as the flexion and extension peak torque. Overall, pain, disability, and quality of life improved in both groups. Physical and social functioning significantly improved in the specific training group, but less or no change was reported in the device exercise group. In both groups, functional disability further decreased even at 1-year follow-up. The decreased levels of pain intensity immediately after treatment were maintained at 1-year follow-up in both groups.

In conclusion, 18 treatment sessions of specific exercise therapy or device exercise therapy improved trunk strength torque, relative lumbar multifidus activity, abdominal endurance capacity and psycho-social status and health of chronic low back pain patients with a motor control impairment. Limited evidence was found to recommend specific exercise therapy over device exercise therapy.

KEY WORDS

Low back pain – Rehabilitation – Exercise – Motor Control – Devices
INTRODUCTION

European guidelines recommend exercise therapy as a first-line treatment in the management of chronic low back pain (CLBP) [3]. Specific exercise therapy and device exercise therapy are often used active rehabilitation methods. Specific exercise therapy focuses on the findings of the clinical examination and the daily needs and work complaints of the patient. In the present study, specific exercise therapy consists of motor control stabilization therapy. Various studies show that specific lumbar stabilizing therapy as a single therapy or combined with other treatments reduces pain intensity and disability in low back pain [7,14,24,28,38,40,41,44,48,52,66] and in pelvic girdle pain patients [63,64], and prevents recurrent pain episodes [18,44,48].

Device exercise therapy allows the patients to train on their own, once the clinical examination is done and the individual training is programmed. This training as a single therapy [16,23,27,33-36,53] or combined with functional muscle and coordination exercises, behavioural support and ergonomic advice [22,67,68] or combined with education and aerobic and strength training of other muscles [39] improves pain intensity and physical impairment [22,33-35,53,67] and increases lumbar muscle endurance [22,36] and trunk flexion [27,36,67] and extension [16,27,36,39,53,67] strength.

There is no adequate comparison of both interventions at this moment. Due to the common clinical application, this is however important. The European guidelines recommend research to determine the effectiveness for specific target groups [3]. The main aim of the present study was to investigate the effect of 2 active 18-session treatment programs on chronic non-specific low back pain patients with motor control impairment.

MATERIALS AND METHODS

Participants
Eighteen to 65-year-old study participants were recruited at the department of physical medicine and orthopaedic surgery of the University Hospital of Ghent. Aspecific low back pain patients with a history of more than three pain episodes during the past year or pain persisting for at least three months were invited to participate in the study. The physician performed a clinical examination and when needed, additional investigations were asked for
to assure that no identifiable specific anatomical or neurophysiological causative factors were present. A musculoskeletal therapist performed a clinical investigation to determine whether motor control impairment was present [42]. Motor control impairment is associated with impairment or deficits in the control of the symptomatic spinal segment in the primary direction of pain. Pain in these disorders is associated with a loss of functional control around the neutral zone of the spinal motion segment due to specific motor control deficits (and muscle guarding in some situations) of the spinal muscles. These disorders frequently present in a directional manner (flexion, extension (passive or active) and lateral shift control impairment), as well as in combinations of these directions (multi-directional control impairment) [42,43].

Exclusion criteria were: specific LBP, such as tumors, fractures, infections, spinal stenosis, spinal malformations; radicular symptoms (radiating pain below the buttock, loss of sensation, muscle dysfunction or loss of reflexes); organic lesions; neurologic or systemic conditions; spinal surgery; pregnancy. Also highly distressed patients were excluded because research has shown less favourable outcomes for this subgroup [21]. We used the cutt-off criteria of the Distress Risk Assessment Method (DRAM). The DRAM includes the Modified Zung Questionnaire (MZQ) and the Modified Somatic Perception Questionnaire (MSPQ). Patients with a score of more than 33 on the MZQ, defined as distressed depressive or a MZQ score between 17 and 33 and a MSPQ score higher than 12, defined as distressed somatic patients [30] were excluded.

A flow diagram summarizing the study design is presented in Figure 1. All patients signed informed consent in ignorance of the group assignment. Ethical approval had been obtained from the Ethics Committee of the Ghent University Hospital.
Figure 1. Flow chart summarizing the study design

Interventions
Prior to the commencement of the study, it was determined that in chronological order of acceptance into the study, each patient would be assigned a number. Patients with an odd number were directed to specific exercise therapy and patients with an even number followed device exercise therapy. Administrative staff without knowledge of the study protocol electronically arranged the patient’s appointments to ensure the objectiveness.

The rehabilitation program included 18 individual sessions during 12 weeks (2 times per week during the first 6 weeks and 1 time per week during the next 6 weeks). Due to the Belgian insurance system of contribution to physiotherapy costs, 18 treatment sessions are most common in Belgium. All patients were given therapy sessions of approximately 45 minutes. Musculoskeletal therapists guided the sessions.
Specific exercise therapy

The specific exercise therapy consisted of 90% motor control stabilization exercises [31,49,50,51,56] and 10% manual therapy (mobilization and soft tissue techniques) and education. Manual therapy and education aimed to enhance the effects of the specific exercise intervention [49].

This motor control approach aimed to train the integration of the so-called local and global muscle systems, and to progress through a program of functional exercises in varying environments and contexts that were tailored to the needs of the patients. There were also functional exercises directed to the patients’ needs. These exercises were practiced in different environments and contexts to maximize transfer to daily situations [20]. The classification into a local and global muscle system is based on anatomical and functional diversity [5]. The deeper local muscles such as transversus abdominis (TA), lumbar multifidus (MF) and the pelvic floor muscles seem responsible for the control of the buckling forces and the overall orientation of the spine and pelvis on the one hand, and for the control of intervertebral translation and rotation during trunk movement on the other hand [20]. The global muscle system is thought to be responsible for global stability and producing torque. The treating musculoskeletal therapist (8 years of experience in treating motor control problems) was free to choose the type of exercises and the progression he felt most suitable for the individual patient. The patients were observed and guided closely by the therapist during each session.

The treatment process contained a clear line of progression achieved by changing parameters such as postural load, reduction of attention demands, reduction of speed, or additional strategies to augment performance [20] with the final goal to obtain functional improvement. Daily home exercises were encouraged. Compliance with the home program was not assessed [38].

Device exercise therapy

Four lumbar back training units (flexion, extension, lateral flexion and rotation) were used to rehabilitate trunk muscle function and coordination (Tergumèd® Line for the back, Proxomed®, Alzenau, Germany). Restraining mechanisms and lever arm attachments were adjusted to the subject’s body dimensions, in accordance with the manufacturers’ instructions. A posterior pelvic pad, a belt and thigh pads secured the position of the lower limbs and pelvis.
Specific exercise therapy versus exercise therapy on devices

The exercise program was based on the patient’s results of isometric strength and mobility measured on the devices during the first and the 10th treatment session. The increase in torque in the 10th session compared with the first session was 23.76% (SD 50.28), 4.05% (SD 17.87), 38.47% (SD 42.95), 31.97% (SD 30.43), 27.48% (SD 45.09) and 42.90% (SD 46.75) for extension, flexion, left and right lateral flexion and left and right rotation, respectively. Maximal isometric strength was determined in a neutral upright sitting position.

The treatment program started with a minimum of 4 isometric training sessions. Visual feedback presented as a sinusoidal curve on a notebook, indicating required time and force (30 to 40% of maximal), supported the controlled performance of the isometric exercises. The patient performed 3 sets of 6 repetitions with a pause of 45 seconds in between. Test and detailed training results of each patient were saved on a notebook connected to each device.

After the isometric training sessions, the patient performed dynamic movements with a gradual increase in weight resistance from about 12% to 70% of maximal force concerning the flexion and extension movements and from about 12% to 55% of maximal force concerning the rotation and lateral flexion movements. Visual feedback was presented as a sinusoidal curve on a notebook, indicating required time and range of motion (ROM) (80% of maximal ROM) and supported the controlled performance of the dynamic exercises. Three sets of 6 to 12 repetitions were performed with a pause of 45 to 60 seconds in between.

Prior to each training session, 10 minutes warming-up on an exercise bicycle were performed and at the end of each session 4 different stretching exercises (a rotational stretching in crook-lying by turning over both legs, a standing stretching exercise for the latissimus dorsi and 2 stretching exercises for the lumbar extensors in supine and four-point kneeling) were repeated 3 times for 30 seconds. The therapists were instructed not to give any additional information to the patients.

**Outcome Measurements**

Patients performed physical functioning tests and filled in several questionnaires at baseline and at the end of the treatment. At follow-up there was a short telephone survey.
**Functional clinical test battery**

The functional clinical test battery evaluated postural control on a force plate, position-reposition accuracy of the lumbar spine using an ultrasound movement analysis system and trunk muscle activity through surface electromyography.

Trunk muscle activity was investigated during six categories of exercises: maximal voluntary isometric contractions (MVIC), coordination exercises, stabilization exercises with upper and lower limb movements, stabilization exercises with trunk movements, abdominal and back muscle endurance tests and a full trunk flexion exercise to analyze the flexion-relaxation capacity of the back muscles. The complete description of all exercises, equipment and data analysis are reported in a manuscript reporting the reliability of this test battery [60]. Because debate exists on the use of MVIC exercises for EMG signal amplitude normalization purposes in low back pain patients [9], the mean amplitudes during standardized submaximal exercises (first 2500 ms of the static endurance tests) were used. To facilitate the interpretation of the EMG data of the different tests, data concerning similar exercises in the same position were averaged. Averaging measures increase the reliability of the EMG indices [26].

In addition, the trunk flexion and extension peak torque were measured using an isokinetic dynamometer (Biodex System 3, New York, US). The test was conducted in a seated position at 60°/s. The pelvis and distal thighs were stabilized by Velcro straps. The leverarm axis was aligned with the L4-L5 intervertebral space. Anterior belts along both shoulders and in front of the chest and a pad distal to the scapular spines were used as force pads. Testing was performed along a ROM of 40°, from -10° (extension) to 30° (flexion) [12].

**Questionnaires**

*Functional disability*

The Quebec Back Pain Disability Scale (QBPDS) is a 20-item instrument and assesses functional disability. Each item is scored on a scale from 0 to 5. The maximum score of 100 represents maximum disability. The Dutch language version of the QBPDS was shown to be a reliable and valid instrument for assessing functional status in patients with LBP [57]. This scale was used at baseline, immediately after the intervention and at 1-year follow-up.
Pain

At baseline, after the intervention and at 1-year follow-up, the patients were asked to indicate the average pain intensity over the past week (0-10).

The Multidimensional Pain Inventory – Part One (MPI-I) measured several domains of pain: pain severity (3 items), interference with the daily life due to pain (11 items), perceived life control (4 items), affective distress (3 items) and social support (3 items). Each item obtained a score between 0 and 6. Good scores involved high scores on perceived life control and social support and low scores on pain severity, interference with the daily life due to pain and affective distress. The Dutch version was proven reliable and valid [29].

Psycho-social status

The Pain Catastrophizing Scale (PCS) is a 13-item instrument which assesses the tendency to focus excessively on pain sensations (rumination), to magnify the threat value of pain sensations (magnification), and to perceive oneself as unable to control the intensity of pain (helplessness) [65]. Scores between 0 and 52 can be obtained. A score of ≥ 24 seems predictive for CLBP [46]. The original factor structure of the PCS with the subscales rumination, magnification and helplessness is supported in CLBP Dutch-speaking samples [70].

Fear of movement/injury or reinjury was measured using the 17-item Tampa Scale of Kinesiophobia (TSK), a scale determining the level of a person’s fear to perform physical movement and activities resulting from a feeling of vulnerability to painful injury or reinjury. Minimal and maximal scores are 17 and 68. If the score on the TSK is larger than the median of 40, it appears worth inquiring about the essential stimuli of the fear [8]. In a CLBP sample construct validity and predictive validity of the Dutch language version of the TSK subscales were supported [55]. Reverse items (item numbers 4, 8, 12 and 16) were omitted [15].

The Hospital Anxiety and Depression Scale (HADS) is a 14-item scale designed to detect anxiety and depression, independent of somatic symptoms. Scores range from 0 to 42 (maximum 21 for each subscale). A score of ≥ 11 on each of the subscales (anxiety and depression) seems to indicate the probable presence (‘caseness’) of the mood disorder [58].
Validity was reported to be good in different populations [6]. Homogenity and test-retest reliability of the Dutch language version of the HADS was demonstrated to be good [59].

**General health status**
The value of the SF-36 is that the patient’s changing health perception can be tracked over time to determine the success of rehabilitation and intervention [27]. For each dimension, item scores are coded, signed, and transformed into a score from 0 (worst health) to 100 (best health) (manual SF-36). The Dutch language version of the SF-36 has proven to be a practical, reliable, and valid instrument for use in studies of chronic disease populations [2].

**Therapy Satisfaction**
In addition to the above mentioned questionnaires, the patients were asked to indicate their overall satisfaction with the program on a visual analogue scale of 10 cm (0 = not satisfied at all; 10 = completely satisfied with the therapy).

**One-year Follow-up Outcome Measurements**
One year after the end of the intervention, patients were telephoned and asked for their current work situation, drug use, work absenteeism due to LBP, other received therapies, exercise compliance, pain intensity and functional disability (QBPDS).

**Statistical Analysis**
Statistical analysis was performed using the SPSS 12.0 software package (SPSS Inc., Chicago, IL) for Windows. The level for statistical significance was set at \( \alpha = 0.05 \).
Changes in variables in the two groups pre and post therapy were assessed using a two-factor analysis of variance (ANOVA) with repeated measures (group x time of assessment). When the interaction was significant, least significance difference tests, adjusted by a Bonferroni test to protect against type I errors, were used.
Based on the primary outcome measure QBPDS, the current study achieved 73% power to detect between group and time differences.

**RESULTS**
Table 1 details the demographic data for the 2 groups after randomization.
Table 1. Baseline characteristics of patient population.

<table>
<thead>
<tr>
<th></th>
<th>Specific therapy group</th>
<th>Device therapy group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N = 33</td>
<td>N = 32</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>32.77 (11.97)</td>
<td>39.87 (12.30)</td>
</tr>
<tr>
<td><strong>Body Mass Index</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>23.14 (3.57)</td>
<td>22.84 (3.45)</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* male</td>
<td>39.39%</td>
<td>25%</td>
</tr>
<tr>
<td>* female</td>
<td>60.61%</td>
<td>75%</td>
</tr>
<tr>
<td><strong>Duration CLBP in months</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>45.91 (79.74)</td>
<td>44.04 (49.70)</td>
</tr>
<tr>
<td><strong>Marital status</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* maried</td>
<td>39.39%</td>
<td>40.62%</td>
</tr>
<tr>
<td>* living together</td>
<td>9.09%</td>
<td>9.37%</td>
</tr>
<tr>
<td>* boy/girlfriend</td>
<td>3.03%</td>
<td>3.12%</td>
</tr>
<tr>
<td>* divorced</td>
<td>6.06%</td>
<td>9.37%</td>
</tr>
<tr>
<td>* widow(er)</td>
<td>3.03%</td>
<td>0%</td>
</tr>
<tr>
<td>* living alone</td>
<td>39.39%</td>
<td>37.50%</td>
</tr>
<tr>
<td><strong>Education level</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* primary school</td>
<td>3.03%</td>
<td>3.12%</td>
</tr>
<tr>
<td>* comprehensive school</td>
<td>12.12%</td>
<td>9.37%</td>
</tr>
<tr>
<td>* secondary school</td>
<td>33.33%</td>
<td>31.25%</td>
</tr>
<tr>
<td>* higher education</td>
<td>51.51%</td>
<td>56.25%</td>
</tr>
<tr>
<td><strong>Current status</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* working outside</td>
<td>60.61%</td>
<td>81.25%</td>
</tr>
<tr>
<td>* housewife/houseman</td>
<td>3.03%</td>
<td>3.12%</td>
</tr>
<tr>
<td>* student</td>
<td>24.24%</td>
<td>9.37%</td>
</tr>
<tr>
<td>* unemployed</td>
<td>16.06%</td>
<td>3.12%</td>
</tr>
<tr>
<td>* insurance compensation</td>
<td>6.06%</td>
<td>3.12%</td>
</tr>
<tr>
<td><strong>Hours working/week</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>37.55 (4.37)</td>
<td>34.77 (10.22)</td>
</tr>
<tr>
<td><strong>Smoking</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12.12%</td>
<td>18.75%</td>
</tr>
<tr>
<td><strong>Sport recreational</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>57.57%</td>
<td>50%</td>
</tr>
<tr>
<td>Mean (SD) hours sport/week</td>
<td>2.21 (1.68)</td>
<td>2.12 (1.5)</td>
</tr>
</tbody>
</table>
**Functional clinical test battery**

Tables 2 and 3 present the data concerning the functional clinical test battery.

The data concerning the *proprioception* and the *postural control* after therapy did not differ significantly from the data before therapy.

The *EMG* data showed significant higher relative activity after therapy in both groups for the external abdominal oblique (EO) and the thoracic part of the ilio-costalis lumborum (ICLT) during the MVIC exercises and for the internal oblique (IO) during the stabilization exercises with upper limb movements in standing. The MF demonstrated significant higher relative activity in both groups during the MVIC, the stabilization exercises with lower limb movements in sitting and the stabilization exercises with trunk movements in standing. A tendency to significant increased relative MF activity ($p = 0.06$) was found in seated stabilization exercises with trunk movements. After specific exercise therapy, but not after device exercise therapy, the MF showed higher relative activity during the stabilization exercises with lower extremity movements in standing and during stabilization exercises with upper limb movements in both sitting and standing.

Concerning the endurance tests, in both groups the slope of the median frequency of the IO and the duration of the abdominal endurance test were significantly improved after the intervention period.

Flexion and extension peak torque increased significantly after both specific and device exercise therapy.
Table 2. Outcome data concerning postural control, proprioception, peak torque and endurance time for both active therapy groups.

<table>
<thead>
<tr>
<th></th>
<th>Specific therapy</th>
<th>Device therapy</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Postural control (° /s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* unilateral left - eyes open</td>
<td>0.99</td>
<td>0.90</td>
<td>1.04</td>
</tr>
<tr>
<td>* unilateral left - eyes closed</td>
<td>3.74</td>
<td>1.88</td>
<td>3.56</td>
</tr>
<tr>
<td>* unilateral right - eyes open</td>
<td>0.80</td>
<td>0.19</td>
<td>0.83</td>
</tr>
<tr>
<td>* unilateral right - eyes closed</td>
<td>3.19</td>
<td>1.75</td>
<td>3.00</td>
</tr>
<tr>
<td>Proprioception ()</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* in sitting</td>
<td>9.35</td>
<td>6.62</td>
<td>11.71</td>
</tr>
<tr>
<td>* in standing</td>
<td>16.93</td>
<td>12.36</td>
<td>15.38</td>
</tr>
<tr>
<td>Peak torque (Nm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* extension</td>
<td>142.31</td>
<td>54.80</td>
<td>178.02</td>
</tr>
<tr>
<td>* flexion</td>
<td>114.48</td>
<td>46.73</td>
<td>136.22</td>
</tr>
<tr>
<td>Endurance time (ms)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* abdominal</td>
<td>88532.81</td>
<td>62336.76</td>
<td>117956.31</td>
</tr>
<tr>
<td>* back</td>
<td>99137.73</td>
<td>36697.32</td>
<td>111010.64</td>
</tr>
</tbody>
</table>
Table 3. Relative EMG activity (µV) during maximal voluntary isometric contractions (MVIC), coordination, stabilization, flexion-relaxation and endurance exercises for both active therapy groups.

<table>
<thead>
<tr>
<th></th>
<th>Specific therapy</th>
<th>Device therapy</th>
<th>Specific therapy</th>
<th>Device therapy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre SD</td>
<td>Post SD</td>
<td>P</td>
<td>Pre SD</td>
</tr>
<tr>
<td>MVIC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coordination exercises</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* sitting</td>
<td>36.64</td>
<td>24.48</td>
<td>0.069</td>
<td>38.80</td>
</tr>
<tr>
<td>* standing</td>
<td>40.19</td>
<td>32.36</td>
<td>0.230</td>
<td>43.44</td>
</tr>
<tr>
<td>Stabilization exercises with upper limb movements</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* sitting</td>
<td>32.20</td>
<td>22.75</td>
<td>0.120</td>
<td>35.95</td>
</tr>
<tr>
<td>* standing</td>
<td>43.00</td>
<td>33.35</td>
<td>0.030</td>
<td>44.76</td>
</tr>
<tr>
<td>Stabilization exercises with lower limb movements</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* sitting</td>
<td>68.54</td>
<td>28.25</td>
<td>0.510</td>
<td>74.03</td>
</tr>
<tr>
<td>* standing</td>
<td>74.96</td>
<td>34.70</td>
<td>0.490</td>
<td>74.47</td>
</tr>
<tr>
<td>Stabilization exercises with trunk movements</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* sitting</td>
<td>27.08</td>
<td>23.88</td>
<td>0.390</td>
<td>25.80</td>
</tr>
<tr>
<td>* standing</td>
<td>31.80</td>
<td>28.34</td>
<td>0.430</td>
<td>30.56</td>
</tr>
<tr>
<td>Flexion-relaxation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endurance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* Slope Median Frequency (Hz/s)</td>
<td>-0.14</td>
<td>0.13</td>
<td>-0.06</td>
<td>0.22</td>
</tr>
<tr>
<td>Endurance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* Slope Median Frequency (Hz/s)</td>
<td>-0.33</td>
<td>0.60</td>
<td>-0.26</td>
<td>0.22</td>
</tr>
</tbody>
</table>

IO = internal abdominal oblique; EO = external abdominal oblique; MF = lumbar multifidus; ICLT = thoracic part of the iliocostals lumborum
Questionnaires

Table 4 shows the data of the several questionnaires.

Functional disability
The QBPDS demonstrated significant lower functional disability after therapy in both groups. However, after therapy the QBPDS score was significantly lower in the specific exercise therapy group compared with the device exercise therapy group.

Pain
The average pain over the past week decreased significantly after therapy in both groups. The scores of all subscales of the MPI-I, the ‘social support’ subscale excepted, improved significantly after both active interventions.

Psycho-social status
The total scores of the PCS, TSK and HADS decreased significantly after therapy in both groups.

General Health status
The SF-36 demonstrated in both groups a significant higher score after therapy concerning the ‘general health’, ‘vitality’, ‘lack of bodily pain’ and ‘role limitations due to physical functioning’ subscales. The scores on the subscales ‘physical functioning’, ‘social functioning’ and ‘health transition’ were significantly better after specific exercise therapy, but not after device exercise therapy. No significant changes were reported concerning the ‘mental health’ and the ‘role limitations due to emotional problems’ subscales between before and after therapy.

Satisfaction with therapy
The patients of the specific and the device exercises group showed therapy satisfaction of 7.20 (SD 2.24) and 6.03 (SD 2.79), respectively. There were no differences between groups.
Table 4. Outcome measures concerning the questionnaires for both active therapy groups.

<table>
<thead>
<tr>
<th></th>
<th>Specific therapy</th>
<th>Device therapy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Quebec Back Pain Disability Scale</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td></td>
<td>30.39</td>
<td>14.75</td>
</tr>
<tr>
<td>Multidimensional Pain Inventory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* pain severity</td>
<td>7.64</td>
<td>3.94</td>
</tr>
<tr>
<td>* interference with the daily life due to pain</td>
<td>26.97</td>
<td>19.95</td>
</tr>
<tr>
<td>* perceived life control</td>
<td>15.76</td>
<td>4.02</td>
</tr>
<tr>
<td>* affective distress</td>
<td>5.79</td>
<td>3.38</td>
</tr>
<tr>
<td>* social support</td>
<td>11.11</td>
<td>5.69</td>
</tr>
<tr>
<td>Pain Catastrophizing Scale</td>
<td>18.39</td>
<td>10.64</td>
</tr>
<tr>
<td>Hospital Anxiety and Distress Scale</td>
<td>9.59</td>
<td>5.76</td>
</tr>
<tr>
<td>Tampa Scale for Kinesiophobia</td>
<td>37.12</td>
<td>8.05</td>
</tr>
<tr>
<td>SF-36 Health Inventory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* physical functioning</td>
<td>67.58</td>
<td>20.51</td>
</tr>
<tr>
<td>* role physical</td>
<td>50.00</td>
<td>36.44</td>
</tr>
<tr>
<td>* role emotional</td>
<td>78.79</td>
<td>38.02</td>
</tr>
<tr>
<td>* lack of bodily pain</td>
<td>49.18</td>
<td>16.69</td>
</tr>
<tr>
<td>* social functioning</td>
<td>75.00</td>
<td>19.51</td>
</tr>
<tr>
<td>* general health</td>
<td>63.56</td>
<td>19.81</td>
</tr>
<tr>
<td>* vitality</td>
<td>63.33</td>
<td>14.67</td>
</tr>
<tr>
<td>* mental health</td>
<td>71.15</td>
<td>15.83</td>
</tr>
<tr>
<td>* health transition</td>
<td>35.15</td>
<td>8.70</td>
</tr>
</tbody>
</table>
One-year follow-up

The general information concerning the 1-year follow-up is demonstrated in Table 5. In both groups, the pain intensity score at 1-year follow-up did not differ significantly from the pain intensity score after the intervention, but was still significantly lower (p = 0.02) than the pain intensity score before therapy (Table 6).

In both groups, the QBPDS further significantly decreased at 1-year follow-up (Table 6), but no significant difference between the groups was demonstrated.

Table 5. Information obtained by telephone questionnaire at 1-year follow-up.

<table>
<thead>
<tr>
<th></th>
<th>Specific exercise group</th>
<th>Device exercise group</th>
</tr>
</thead>
<tbody>
<tr>
<td>N = 29</td>
<td>N = 30</td>
<td></td>
</tr>
<tr>
<td>Patients with changed job</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Sick leave</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Mean (SD) duration sick leave (days)</td>
<td>20 (14.14)</td>
<td>8.5 (8.18)</td>
</tr>
<tr>
<td>Other therapy for LBP</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>* infiltration</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>* osteopathy</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>* massage + electrotherapy</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>* massage + manipulation</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>* exercises + manual therapy</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>* acupuncture + whole body vibration</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>* medication</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Continued doing exercises</td>
<td>19</td>
<td>12</td>
</tr>
<tr>
<td>Mean (SD) frequency exercises (days/week)</td>
<td>2.39 (2.20)</td>
<td>3.73 (2.69)</td>
</tr>
</tbody>
</table>

Table 6. Outcome pain intensity and functional disability (QBPDS) at 1-year follow-up for both active therapy groups.

<table>
<thead>
<tr>
<th></th>
<th>Pre</th>
<th></th>
<th>Post</th>
<th></th>
<th>1-year</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>P</td>
<td>Mean</td>
<td>SD</td>
<td>P</td>
</tr>
<tr>
<td>Pain Specific exercise group</td>
<td>4.02</td>
<td>2.41</td>
<td>2.41</td>
<td>2.72</td>
<td>0.008</td>
<td>3.32</td>
<td>2.69</td>
<td>1.00</td>
</tr>
<tr>
<td>Device exercise group</td>
<td>4.37</td>
<td>2.16</td>
<td>3.74</td>
<td>2.61</td>
<td>0.008</td>
<td>2.97</td>
<td>2.12</td>
<td>1.00</td>
</tr>
<tr>
<td>QBPDS Specific exercise group</td>
<td>32.39</td>
<td>14.10</td>
<td>22.93</td>
<td>13.65</td>
<td>&lt; 0.001</td>
<td>13.14</td>
<td>11.33</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Device exercise group</td>
<td>33.33</td>
<td>14.03</td>
<td>26.23</td>
<td>11.83</td>
<td>&lt; 0.001</td>
<td>15.37</td>
<td>10.46</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>
DISCUSSION

The purpose of this study was to evaluate the effect of two forms of popular exercise therapy on CLBP patients with motor control impairments.

Both exercise programs created decreased pain intensity and improved physical functioning, general health, psychosocial status and several functional parameters.

Functional clinical test battery

The functional clinical test battery used in the present study included exercises of the different components of functional stability: postural control, proprioception and muscle activity during coordination and stabilization exercises, as well as during MVIC and endurance exercises [60]. The flexion-relaxation capacity of the back muscles was also evaluated. The EMG activity of the IO and MF was analysed to represent the so-called local muscle system and the activity of the EO and the ICLT was representative for the so-called global muscle system [5]. The IO was expected to represent also the TA activity since it was shown that medially and inferiorly to the anterior superior iliac spine, the fibres of the transversus abdominis (TA) and IO are blended, so that a distinction between the muscle signals cannot be made at this location [37]; also, at this site the direction of the fascicles of both muscles is similar (inferomedial) [69].

The findings of the present study showed significantly increased relative MF activity during all stabilization exercises after the intervention (concerning seated stabilization exercises with trunk movements tendency to significant increase (p = 0.06)). However, the relative MF activity during the seated stabilization exercises with lower limb movements and during the stabilization exercises with upper limb movements, both in sitting and standing only increased significantly in the specific exercise therapy group, but not in the device exercise therapy group. Since the specific stabilizing therapy paid attention to the MF, TA and the pelvic floor muscles, the results of this study show that 18 treatment sessions were adequate to demonstrate significant increases in relative MF activity, but not in relative IO activity. Only during stabilization exercises with upper limb movements in standing, the relative IO activity increased significantly after both therapy interventions. O'Sullivan et al. [45] investigated IO and rectus abdominis activity during an abdominal drawing in manoeuvre before and after 10 weeks specific lumbar stabilization therapy. Nonnormalized data showed a significant increase in IO activity, but in accordance to the findings of the present study, data normalized to a submaximal exercise, showed no significant differences
in IO activity. Although debate exists concerning the use of maximal or submaximal exercises to normalize patient data, nonnormalized data are supposed inappropriate to compare different patients and different test occasions [1]. Failure to normalize EMG data before quantitative analysis was reported to introduce confounding variables not related to muscle function (for example skin impedance, electrode orientation and amount of subcutaneous tissue) [1,4].

During the stabilization exercises with trunk movements and during the stabilization exercises with lower limb movements in standing the relative activity of the MF not only increased in the specific exercise group, but also in the device exercise group. This finding may be related to the fact that the device exercise therapy consisted of controlled movements in different directions at predetermined velocities. In addition, recent research in healthy subjects showed high relative MF activity when performing rotation, flexion and extension exercises on these devices, even at low intensity levels [61,62]. Mannion et al. [35] considered positive results in various active therapy groups to be attributable to generalized increased activity rather than any specific changes in core stability. However, since only the MF and in one case the IO showed significant differences during low-load exercises after the interventions and not the so-called global muscles, specific localised training rather than a general reconditioning seemed to have occurred. It should be noted that at baseline, the subjects who dropped out of the device exercise therapy displayed significant higher relative MF activity and significant lower EO and ICLT activity during some stabilization exercises in comparison with the subjects who completed the device program.

In the early 90ties, strength and endurance were the main outcome measures in most active treatment programs [32,47,54]. Recent studies reporting on the effect of specific stabilization exercises often neglected these muscle properties, since strength increases caused by low level exercises might not be expected to occur [7,14,18,19,28,38,40,41,44,45]. However, Koumantakis et al. [25] demonstrated significant muscle strength improvements after stabilization training. In the present study, not only the MF activity, but also the activity of the EO and ICLT increased significantly after both specific and device exercise therapy. A qualitative indication of a relationship between the EMG and force is provided by the observation that the EMG signal amplitude generally increases with higher force and/or contraction velocity of the muscle [11]. The relation between EMG measurements
of MVIC and force was supported in the present study since significant increases in flexion and extension torque were reported in both groups. In accordance to these results, device exercise therapy was reported to improve strength, but all researchers used the same devices to test and to train [27,36,39,53,67]. However, in such case the cause of potential between-group differences cannot be determined accurately due to familiarization with the equipment for the patients attending device training. For that reason, isokinetic torque was determined on another device that was only used for testing.

In the present study, the abdominal muscle endurance increased in both groups. Although in general the relative IO activity was not changed during the low level testing exercises, the endurance of this muscle seemed to be improved. No significant changes were present concerning the endurance of the back muscles. In contrast to the results of the present study, Sung [66] demonstrated significant changes in a modified Biering-Sørensen test after a 4-week spinal stabilization exercise program. However, Sung’s test involved hyperextension of the lumbar spine. Evaluation of the effect of 12 weeks specific device training, using an identical Biering-Sørensen test as the test used in the present study, demonstrated increased endurance time, but no significant changes in the slope of the median frequency [36].

In accordance to the present findings, Mannion et al. [36] demonstrated no significant differences in flexion-relaxation capacity of the back muscles between baseline measurements and data after 12 weeks of device training.

**Questionnaires**

In both groups, functional disability (QBPDS) decreased after the intervention period and further decreased at 1-year follow-up. Immediately after therapy, there was a statistically significant between-group difference in favour of the specific exercise therapy, but at 1-year follow-up this difference was no longer present. Some consideration should be showed to the fact that more patients of the device exercise group (28.57%) followed other therapies during the year following the intervention in comparison with the patients in the specific exercise group (14.81%). This could have eliminated the between-group difference after 1 year. Lewis et al. [28] reported a mean decrease of 15.4 in QBPDS from patients receiving 8 sessions of a similar treatment to the present specific exercise therapy, but to which an
information booklet (The Back Book) was added. In the present study, the mean decrease between baseline and 1-year follow-up was 19.44 (SD 16.74) and 18.07 (SD 13.84) for the specific exercise group and the device exercise group, respectively. This was in agreement with the criterion that a change of at least 15 points in the QBPDS score was necessary to be 90% confident that real change had occurred [10,13].

In accordance with the results of the present study, functional disability measured by the Oswestry Disability Inventory (ODI) [14,40,41,44,52,66] or the Roland-Morris Disability Questionnaire (RMDQ) [7,19,38] was shown to be significantly reduced after specific stabilization exercise therapy. Device training showed similar results based on the RMDQ [33-35]. In the present study, the QBPDS was preferred due to some limitations of the ODI and the RMDQ. The ODI did not specifically score disability because a pain intensity and a social life question were included in the questionnaire. The RMDQ was reported to show poor reliability possibly due to the instructions which urge the patient to indicate the disability on that specific day; this could lead to uncompleted forms if patients have not attempted certain activity that day [10].

The time period (current pain, pain over past week/6 weeks/month/…) in measuring pain intensity appears to differ substantially. The time period used in the present study, namely the average pain intensity over the past week, was shown to demonstrate best reliability (ICC=0.88, SEM=6.59) [24]. In both groups, this pain intensity decreased significantly after treatment, but there was no significant difference between the scores immediately after treatment and the scores at 1-year follow-up. Similar results were reported in lumbar stabilization training programs with 5-month [24] and 1-year follow-up [40] as well as in device exercise training with 1 year follow-up [34]. In contrast, Kankaanpää et al. [22] reported even a further significant decrease between post-treatment and 1-year follow-up pain intensity after device training.

In accordance with the initial pain intensity findings, the MPI-I demonstrated significantly decreased pain severity, but also significantly improved pain interference with daily life, perceived life control and affective distress. The affective descriptors of the Short-Form McGill Pain Questionnaire showed similar results after specific stabilization training [24]. The baseline scores of both the MPI and the average pain intensity over the past week were significantly different in the subjects who dropped out and the subjects who completed the device therapy. Since both therapy interventions did not pay attention to social functioning,
the score of the ‘social support’ subscale remained unchanged after both therapy interventions.

Psychosocial questionnaires revealed a significant reduction in fear-avoidance (TSK) after both active interventions. Koumantakis et al. [24] described very similar TSK baseline and post-stabilization treatment scores to the scores obtained in the present study. The tendency to focus excessively on pain sensations and to perceive oneself as unable to control the intensity of pain, as measured by the PCS, was significantly decreased in both groups. Pain catastrophizing was only described in the study of Mannion et al. [35] and appeared not to change significantly after 12 weeks of device training. However, only a score of 0 to 2 was used to indicate the catastrophizing strategies. To interpretate treatment changes appropriately, it is considered indispensable to use validated and reliable questionnaires [70]. Since the TSK and PCS scores were higher in the patients who dropped out than the patients who completed the device training, our study results may be affected.

Though the DRAM has been used to determine changes in depression and distress in stabilization programs [7] and device exercise training [35], the present study opted to exclude patients with clear distress or depression symptoms. However, to be able to evaluate these properties over time in the remaining population, the HADS was applied. The HADS was shown to be capable of detecting minor changes in depression and anxiety [17]. The HADS findings report significant decreased scores in the anxiety and depression subscales as well as in the total scale. No differences were reported between both groups. Though the present population was a specific selected population and no multidisciplinary treatment was offered, the active treatments applied in the present study appeared to have a positive effect on these psychological properties. In contrast, Risch et al. [53] demonstrated no significant improvements in anxiety and depression, measured by the Mental Health Inventory (MHI), after 10 weeks of device exercise training. Pre-treatment MHI scores were reported high in contrast to the ‘mild disturbance’ HADS scores in the present study [71]. These mild scores were not unexpected due to the DRAM exclusion criterion.

The SF-36 questionnaire evaluated several health-related components. The findings of the present study showed improvements in physical functioning, social functioning and health
transition in the specific exercise group, but not in the device exercise group. The findings of the physical functioning concur with the results of the QBPDS and confirm that the patients of the specific exercise group obtained more improved physical functioning in daily life in comparison with the device exercise group. It appears that when active therapy is directed to the daily needs and work complaints of the CLBP patient as applied in the present specific therapy, the physical functioning can change effectively. The reason the social functioning only improved in the specific exercise group, may be related to the therapy location. Though both groups came to the same building in the university hospital, the patients of the specific exercise therapy group were in a room with only themselves and the musculoskeletal therapist in contrast to the patients of the device exercise therapy group who trained in a larger room where also other patients were training on other devices. Having seen other patients train may also have influenced the fact that they did report smaller improvements in health transition (‘compared to one year ago, how would you rate your health in general now’).

In accordance to the results of the pain inventories, the SF-36 subscale reporting ‘lack of bodily pain’ showed similar improvements in both groups. General health, vitality and role limitations due to physical problems also improved quite equally in both groups. However, baseline data concerning general health, vitality, lack of bodily pain and mental health were significantly lower in the patients who dropped out of the device exercise training than in those who completed the program. Earlier research confirmed improvement of the physical component of the SF-36 after specific stabilization training [7] and of all SF-36 subscores after device exercise training [27].

CONCLUSION
The findings of this study indicate that in a CLBP population with motor control impairment 18 sessions of specific exercise therapy or device exercise therapy are effective to improve pain, functional disability, psychosocial status and general health. Functional tests indicated also increased flexion and extension strength, abdominal muscle endurance and relative MF activity during stabilization exercises with trunk movements and seated stabilization exercises with lower limb movements. Between-group differences were in favour of the specific exercise therapy. More improved physical and social functioning, less beliefs that pain was a signal for damage and increased
relative MF activity during stabilization exercises with upper limb movements and standing stabilization exercises with lower limb movements in the specific exercise group versus the device exercise group indicate that specific therapy focusing on the patients’ daily needs and work complaints is more beneficial than general muscle reconditioning.

In conclusion, both active therapy interventions are effective. Limited evidence was found to recommend specific exercise therapy over device exercise therapy.

Acknowledgements

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REFERENCES


GENERAL DISCUSSION
SUMMARY AND CLINICAL IMPLICATIONS

Trunk muscle recruitment patterns during stabilization exercises in a healthy population

Analysis of stabilization exercises in four-point kneeling (Chapter 1) and bridging stabilization exercises (Chapter 2) showed that the relative muscle activity did not exceed 32% of maximal voluntary isometric contraction (MVIC). From a clinical point of view, appropriate stabilization exercises, with the aim to hold and control the lumbar spine in a neutral position, were assumed to work the trunk muscles at approximately 30% of their maximum. The studies presented in this dissertation demonstrated that exercises in four-point kneeling and bridging exercises with control of the neutral spine position are adequate stabilization exercises.

However, not all trunk muscles demonstrated activity levels of 30% of MVIC. In accordance to related studies, relative abdominal muscle activity of RA was low during all bridging exercises and exercises in four-point kneeling. Considering the distal caudal directed fibre orientation, the RA is effective in creating posterior rotation of the pelvis, trunk flexion and producing force to counteract the hip flexor force vectors. Since this were not the main directions in the present stabilization exercises, low level activity was evident. If, in function of real reconditioning, higher relative activity levels of the RA are needed, curl-ups can be recommended which produce relatively low activity of the oblique abdominals. During exercises with bilateral leg movements in supine position, the RA was also shown to respond with a large increase in activity. However, in clinical practice it often occurs that the RA shows adequate coordination and strength, with only the oblique abdominal activity that need to be adjusted. The relative oblique abdominal muscle activity was in general somewhat lower during the bridging exercises in comparison with the four-point kneeling exercises.

Though symmetric activity of the inferior fibres of the internal oblique (IO), in accordance to its suggested segmental stabilizing function, was shown during asymmetric lifting movements, the IO showed asymmetric activity during the asymmetric stabilization exercises investigated in the present studies. During asymmetric exercises in four-point kneeling, the contralateral IO demonstrated higher relative activity levels in comparison
with the ipsilateral IO, but during asymmetric bridging exercises, the ipsilateral IO showed higher relative activity levels than the contralateral IO. During both types of stabilization exercises, a hip and knee extension was present in the ipsilateral leg, but during the four-point kneeling exercises the contralateral hip was flexed in contrast to an extended contralateral hip joint during the bridging exercises. The different influence of gravity in both postures may also have contributed to the contrasting IO activation during the asymmetric exercises. In general, during these stabilization exercises, the IO seems to cooperate with the EO in order to create a stable unit.

Analysis of the relative contribution of local to global abdominal muscles during bridging exercises showed a very high IO/RA ratio and a variable IO/EO ratio. The IO/RA ratio was very high due to minimal RA activity. Since during the asymmetric bridging exercise the relative EO activity was quite symmetric and the IO showed important differences between the ipsilateral and contralateral side as mentioned above, the ipsilateral ratio was significantly higher than the contralateral ratio and the ratios during the symmetric bridging exercises. The relative muscle activity and the ratio of the abdominal obliques seem to alter depending on the task and the presumable need for stability.

The relative back muscle activity levels were similar in four-point kneeling and bridging exercises. However, during the bridging exercises, rather symmetric back muscle activity was found in contrast to the results of the four-point kneeling exercises.

When the hip was extended from a four-point kneeling position, a rotational moment about the spine was expected to occur. The ipsilateral MF can cause an ipsilateral rotational moment about the spine and the contralateral ICLT may create a moment in the opposite direction to counter the spine moment. Appropriate co-contraction of the ipsilateral MF and the contralateral thoracic part of the iliocostalis lumborum (ICLT) may generate stability. This finding is contrasting to the symmetric MF activation demonstrated during asymmetric lifting exercises. However, during the asymmetric lifting exercises the pelvis was more stabilized since both feet remained on the ground, in contrast to only a single floor contact during the bridging stabilization exercises and the stabilization exercises in four-point kneeling.

The findings concerning the relative muscle activity and the ratios of the back muscles support the assumption that during these stabilization exercises, all back muscles contribute in a similar way to control spine positions and movements in a healthy population.
A rehabilitation program addressing the back muscles could include both bridging and four-point kneeling stabilization exercises. If higher activity levels of the abdominal muscles are required, the four-point kneeling exercises seem more appropriate than the bridging exercises.

Analysis of relative muscle activity levels and ratios of relative muscle activity during four-point kneeling and bridging stabilization exercises in healthy subjects indicates a harmonious co-operation of all trunk muscles, both local and global muscles. The investigation of ratios during the four-point kneeling exercises could have created even more comparisons between both types of stabilization exercises. Since this analysis was not performed, it may be considered a limitation of the first study.

Today, specific stabilization therapy is often used in primary and secondary prevention programs of LBP. In order to assess the usefulness of specific stabilization training adapted in primary prevention programs, evaluation of the capability to change muscle recruitment patterns was a first step (Chapter 3). Analysis in healthy subjects demonstrated a significant increase in local abdominal muscle activity, but the increase of local back muscle activity was not significant after motor control training. During the symmetric bridging exercises, the relative global RA activity significantly increased after the intervention. The global ICLT back muscle showed not significantly decreased relative activity during all exercises. The significantly higher relative local abdominal muscle activity and the combination of small unsignificant increased local and decreased global relative back muscle activity after training was responsible for the result that all post-training local/global relative muscle activity ratios were higher (not all significantly higher) than the pre-training ratios. The increased local/global relative muscle activity ratios during all exercises in four-point kneeling and bridging stabilization exercises indicated that muscle recruitment patterns can be changed in a healthy population.

Since deficient motor control was shown to be associated with low back problems, improvement of this motor control may be expected to intervene in the natural process and perhaps prevent the onset or recurrence of LBP. However, not all participants of primary prevention programs may benefit from this training. It seems obvious that healthy controls and patients with appropriate motor control will not need this training and
perhaps need other, maybe more intensive, preventive exercises. A key issue within this context is detecting patients with a motor control impairment.

Selecting patients with motor control deficits has been shown difficult. Several tests have been proposed. To determine whether the local muscle system functions adequately, assessment of the motor control of the transversus abdominis (TA) and the MF has been described by Hodges.\textsuperscript{14,22} The assessment of motor control of TA involves evaluation of the ability of a person to cognitively perform the skill of contraction of TA independently from the global muscles. The parameter that is measured is the precision of the task. Contraction of TA involves narrowing the waist and a slow and gentle inward movement of the lower abdomen. The performance of the task is assessed in two ways: (1) identification of signs that TA is active and (2) identification of evidence that there is no activity of the other muscles. At the completion of the assessment, the clinical outcome is judged from the precision of the independent activation of TA. The test of MF evaluates the ability to cognitively perform the skill of contraction of MF, particularly the deep fibres, independently of the superficial fibres. It is also supposed to be useful to palpate the relaxed muscle, because changes in muscle consistency may be present. From a prone position, the test of MF activation involves an isometric “swelling” contraction of the muscle. The outcome of the assessment of the local muscles is judged on the interpretation of the observation, palpation and if possible, EMG findings. Ultrasound may also provide a more accurate indication of activation of TA and MF.\textsuperscript{14,23}

It may be assumed that when healthy people are not able to perform adequately these motor control tasks, specific stabilization training might be advised in prevention programs. However, other clinicians have suggested a broader evaluation method including different physical tests to determine motor control impairment.\textsuperscript{21}

**Trunk muscle recruitment patterns in a healthy population during exercises on specifically designed lumbar training devices**

In chapters 4 and 5, it was demonstrated that during low-load exercises on training devices (at 30\% of mean maximal torque), activity levels of more than 60\% of MVIC were obtained by the MF and the longissimus thoracis (LT) and by the MF, LT, ICLT, latissimus dorsi (LD) and EO during extension and rotation, respectively. Activity levels of at least
60% of MVIC are generally accepted for basic strength training purposes. The ICLL and ICLT during low-load extension exercises and the MF, ICLT, LD and abdominal obliques during low-load rotation exercises showed relative activity levels between 30 and 60% of MVIC. All muscles during the flexion exercises, the abdominal muscles during the extension exercises and the RA during the rotation exercises showed relative activity levels of less than 25% of MVIC.

Mindful of these findings, the movement direction trained during low-load exercises can be selected based on the preferred muscles to be trained at certain intensities as well as on the functional need of the subject in daily life conditions.

Dynamic exercises on training devices at 30% of maximal mean torque (MMT) appeared to reach higher relative activity levels than stabilization exercises. Caution should however be taken in comparing both exercise types. The analyzed time periods during the stabilization exercises were static, in contrast to dynamic movements during the exercises on devices. Analysis of EMG signals during dynamic movements may ignore the differences in length-force relationships and consequently may create higher activity levels. In a dynamic contraction, various mechanical, physiological, anatomical, and electrical modifications occur throughout the contraction that affect, in substantial ways, the relationship between signal amplitude and muscle force.

The effect of increasing resistance during exercises on specifically designed lumbar training devices, evaluated in a healthy population

In general, increasing resistance from 30% MMT to 50% MMT and 70% MMT created significantly increased relative activity of all back muscles during the extension exercises and of all abdominal exercises during the flexion exercises. During rotation exercises, increased resistance from 50% to 70% MMT created consistently higher relative activity levels in all trunk muscles. However, the relevance of increasing resistance on specifically designed training devices should be questioned. Since in general high relative activity levels were obtained even during low-load 30% MMT exercises, increasing the resistance on this kind of training devices may be questioned and may not always be beneficial. Applying high resistance levels may be appropriate for sport training situations, but may not always be
needed in rehabilitation context. Furthermore, especially during the first period of rehabilitation, high resistance may be detrimental since higher resistance levels may be associated with high loads on the spine. It seems appropriate to advice clinicians to evaluate the needs of each specific subject in order to try to accurately match the training and the subject rather than completely relying on the system to progress the training scheme.

The effectiveness of specific exercise therapy versus trunk muscle reconditioning on devices in a chronic LBP population

The main purpose in the rehabilitation of CLBP patients is functional improvement or restoration and if possible, pain relief to increase the general well-being. The results of the randomised clinical trial demonstrated improvement of all three components after both exercise interventions. In comparison to the device exercise therapy group, functional disability and physical and social functioning improved more in the specific exercise therapy group. The patients of the specific therapy also reported higher self-rated health change compared to one year ago.

The Quebec Back Pain Disability Scale (QBPDS), measuring functional disability, as well as the subscale physical functioning of the SF-36 showed greater improvement in the specific exercise group in comparison with the device exercise group. Through 1-year follow-up, the QBPDS score further significantly decreased, but the between-group difference disappeared. Due to the results at 1-year follow-up and since in both therapy groups clinical significant 15-points increases were found concerning the QBPDS, caution is warranted in extolling the effect of the specific exercise therapy. The QBPDS can be completed in 5 minutes by the patient and is scored in 1 minute by the therapist. Consequently, application in clinical practice is easy and useful.

The pain intensity scale and a subscale of the first part of the Multidimensional Pain Inventory demonstrated decreased pain intensity in both groups. Similar outcome obtained by different questionnaires as reported concerning pain and physical functioning, confirms the validity of the scores. Nor immediately after the intervention nor at 1-year follow-up a
between-group difference was present. Pain intensity at 1-year follow-up was not significantly different from the scores immediately after treatment, but remained smaller than before the intervention.

General health was only determined before and immediately after exercise therapy. Improvement was shown in both groups without a between-group difference. General well-being encloses both physical and emotional components and consequently the whole patient.

Though positively affecting physical functioning, pain and general well-being are the most important issues for patients, the effect on functional outcome measures and psycho-social characteristics is assumed to be important to avoid dependence on the health care system at long-term.

Several psycho-social patient characteristics were improved after both therapy interventions, but no differences were observed between both groups. Though patients with severe distress or depression were excluded from the study, it appeared still possible to affect psycho-social outcome. As often described, pain and certainly chronic and recurrent pain is not only a matter of physical “dysfunction”, but the whole person is involved. Without specific cognitive or psychological therapy, exercises appeared to be capable of improving the psycho-social functioning of the population investigated in the present randomized clinical trial. The present population showed mild to moderate kinesiophobia, anxiety, distress and catastrophizing baseline scores. The patients excluded from the present study, as well as patients consulting other departments than the physical medicine and orthopaedic surgery department of the hospital, for example the chronic pain clinic may need more intensive multidisciplinary rehabilitation.

Concerning the functional measurements, it was shown that 18 treatment sessions of specific exercise therapy or device exercise therapy are capable of improving trunk strength torque, relative MF activity, abdominal endurance capacity of chronic and recurrent LBP patients with a motor control impairment.
The functional clinical test battery evaluated muscle activity during coordination, stabilization, flexion-relaxation, endurance and strength exercises, as well as proprioception and postural control.

Although proprioception and postural control were shown to be dysfunctional in CLBP patients, only one study evaluated the effect of LBP rehabilitation on postural control and no LBP population studies were reported on proprioception. Kuukkanen et al. concluded that in subacute LBP patients specific exercise programs may be required in order to enhance balance performance. Their three-month home training program increased sway velocity in standing.

The results of the present randomized clinical trial demonstrated no significant changes in proprioception and postural control due to any intervention. It may be difficult to influence these parameters which could be a reason why these characteristics were scarcely investigated in the past. The measurement methods, although similar to the ones used to demonstrate differences between healthy subjects and LBP patients, may not be appropriate and sensitive enough to detect smaller changes caused by therapy. Repeatability and reproducibility of these measurements appeared to be good in a healthy population (Chapter 6), but was not yet evaluated in a LBP population.

Analysis of relative muscle activity showed a significant increase of the relative MF activity during all stabilization exercises (with upper and lower limb and trunk movements in sitting and standing) and significant increased relative IO activity during stabilization exercises with upper limb movements in standing. However, during the seated stabilization exercises with lower limb movements and during the stabilization exercises with upper limb movements, both in sitting and standing, the relative MF activity only increased in the specific exercise group and not in the device exercise group. Since in the specific exercise therapy attention was paid to local muscle co-contraction in various postures and during several exercises, benefit for the specific exercise outcome could be expected. This benefit was however limited, since in several exercises the relative MF activity of the device exercise group also increased. Muscle activity analysis in healthy subjects during bridging stabilization exercises and stabilization exercises in four-point kneeling, as well as during rotation, extension and flexion exercises on devices, presented in chapters 1 to 5, showed high relative activity levels for MF during all exercises. The MF could be suggested a muscle that is susceptible for various kinds of exercise therapy. If MF would be very
susceptible to any kind of exercise, automatic recovery after resolution of acute, first-episode LBP may be expected. However, this was contradicted by Hides et al.\textsuperscript{42} A possible reason for the overall high relative MF activity may be related to the spine posture. Despite the different nature of the exercises, the similarity between all tasks was that the criterion to start the exercises was a neutral spine position, determined by the therapist. This emphasizes the idea that the spine position is crucial and that it may be more important to control the neutral spine position than to give specific muscle contraction instruction. Since trunk muscle evaluation in chapters 1 to 5 occurred in healthy subjects, future research in patients is needed to confirm this finding.

Concerning the high relative MF activity during the device exercises, it needs to be remarked that the Tergumed devices use controlled movements via constant biofeedback on a computer display in front of the patient. In this way, not only strength, but also muscle coordination is expected to be trained. Other devices without specific performance instructions or biofeedback may generate different muscle training and different general rehabilitation effects.

Only minimal effect was created on the relative activity of the local abdominal muscle IO.

In contrast to the results of the randomized clinical trial in a specific chronic and recurrent LBP population, evaluation of a short training program in healthy subjects (chapter 3) showed a clear effect on the relative local abdominal activity and no significant differences concerning the local back muscle. The difference in results of both studies may be related to the different population. However, other differences between both interventions were also present. In contrast to a rather strict stepwise program applied in the healthy population, a more global program including minimal manual therapy was used to rehabilitate the chronic and recurrent LBP patients. The intervention period was also of more extensive duration in the pain population than in the healthy subjects. In addition, the exercises to test muscle recruitment that were applied during the pre and post intervention test sessions were different in both populations. In the healthy population, stabilization test exercises in four-point kneeling and bridging stabilization test exercises were used. In contrast, in the chronic and recurrent LBP population, easier stabilization test exercises in sitting and standing were adapted. Consequently, adequate comparison between both studies is not possible. Additional research in healthy subjects may facilitate comparison and clarify potential differences.
The endurance capacity of the abdominal muscles increased in both patient exercise groups, as well as the flexion and extension peak torque. Although the specific exercise training not aimed at strength training, but rather at functional restoration, the therapy appeared to increase both abdominal and back muscle strength and abdominal muscle endurance. Lower intensity exercises, encouraged to execute daily, seem capable of increasing basic muscle characteristics which may have a positive influence on long-term outcome. Functional disability further decreased throughout 1-year follow-up, but since strength and endurance were not re-evaluated after 1 year, it is not possible to determine the impact of strength and endurance on the long-term functional improvement. Though optimal strength training was recommended to be performed three times a week and the frequency of the device exercise training was only twice a week during the first 6 weeks and once a week during the following 6 weeks, significant post-intervention improvements of abdominal and back muscle strength were present. Literature describes that many chronic low back pain patients have been advised to continuously decrease their activity level and to let pain guide their activity level. Such patients become conditioned to avoid pain, which may cause general deconditioning. This kind of population may demonstrate strength adaptations more easily.

The back muscles demonstrated increased strength and the MF showed increased relative activity during stabilization exercises, but the back muscle endurance capacity was not influenced. Such variety in results should motivate clinicians as well as researchers to apply different aspects in clinical evaluation. Consequently, the need for extensive functional evaluation including different muscle characteristics is emphasized in order to comprehend the working mechanisms of rehabilitation programs.

Both active therapy interventions affected the abdominal and back muscles in a different way. In contrast to the coordination and strength changes of the back muscles, the abdominal muscles demonstrated improved endurance and strength.

The results of the randomized clinical trial in chronic and recurrent LBP patients with motor control impairment showed that 18 exercise treatment sessions are capable of improving almost all subjective and some objective outcome measures. Though the few between-group differences concerning relative MF activity during stabilization exercises,
functional disability and physical and social functioning are all in favour of specific exercise therapy, it seems overstated to claim that this intervention is more effective than device exercise therapy in this population.

**FUTURE DIRECTIONS**

In the first and second part of the present dissertation, the muscle activity during stabilization exercises and exercises on training devices was investigated in healthy subjects. In order to obtain more insight in the performance of patients during this kind of exercises, future research may direct at different specific chronic and recurrent LBP populations. Application of the same test protocols would allow appropriate comparison between patients and healthy controls.

The functional clinical test battery discussed in the third part of the present dissertation was rather extensive. To limit time expenses, reconsideration of the obtained results could allow omitting certain tests. Based on the findings of the randomized clinical trial, the coordination exercises may be left out. Since the stabilization exercises displayed rather similar results in sitting and standing, but seemed somewhat more discriminative in standing, the seated stabilization exercises could be removed. Though no changes were present in the postural control and proprioception parameters, currently we suggest preserving these tests in order to maintain all components of functional stability.

From a clinical point of view, analysis of correlations between tests of a standard clinical examination and tests of the clinical test battery seems very useful. Evaluation using the clinical functional test battery on the field is possible, but requires much equipment and trained investigators. Future research identifying clinical useful, easily applicable, relevant, reliable and valid tests will be very challenging. In the present dissertation, we were able to demonstrate that evaluation of the modified Biering-Sørensen test to determine the back muscle endurance capacity displays good reproducible and repeatable measurements using a stopwatch to obtain the test duration. Earlier research reported that this test can discriminate between subjects with and without nonspecific LBP.45
In the randomized clinical trial in the present dissertation, patients were randomly allocated to a therapy intervention, irrespective of the results of the functional clinical test battery. Currently, a normative database is available for the functional clinical test battery. Comparison of the test results of each patient with the normative database demonstrates the exercises during which the patient performs worse than the average healthy population. Consequently, on the one hand directing the patient to motor control training and specific hands-on therapy may be indicated when low scores are obtained during coordination, stabilization and proprioception exercises. On the other hand, when mainly strength and endurance appear deficient, general trunk muscle reconditioning may be advised. Evaluation of the effectiveness of therapy assignment based on the results of the functional clinical test battery in the rehabilitation of a subgroup of chronic and recurrent LBP patients could be addressed in future research.

GENERAL CONCLUSIONS

The aims in the present dissertation were to analyse muscle recruitment patterns during exercises which are frequently used in clinical practice and to compare the effects of the two most popular rehabilitation strategies in CLBP today: specific exercise therapy and exercise therapy on specifically designed devices.

In stabilization exercises in four-point kneeling and in bridging stabilization exercises, hip and trunk muscles, of the so-called local as well as the global muscle system, seem to work together in a harmonious way.

Muscle recruitment patterns can be changed in healthy subjects by means of a training program that focuses on motor control.

Increasing resistance from 30% to 50% and 70% MMT during seated axial rotation in a Tergummed training device consistently create higher relative activity levels in all trunk muscles. During seated extension and flexion exercises, the relative activity of all back muscles during the extension exercises and the relative activity of all abdominal muscles during the flexion exercises increase significantly.
To train strength (>60% of MVIC), low device intensities (30% and 50% MMT) appear sufficient to affect the back muscles, but for the abdominal obliques higher resistance (70% MMT) seem required. In the vulnerable spine undergoing rehabilitation, training at 30% MMT may be sufficient.

In a chronic and recurrent LBP population with motor control impairment 18 sessions of specific exercise therapy or device exercise therapy are effective to improve pain, functional disability, psychosocial status and general health. Functional tests indicate also increased flexion and extension strength, abdominal muscle endurance and relative MF activity during stabilization exercises with trunk movements and seated stabilization exercises with lower limb movements. Limited evidence is found to recommend specific exercise therapy over device exercise therapy.

The main purpose of the present dissertation was to make a valuable contribution to the clinical practice of physiotherapy. The presentation of the muscle activity levels during frequently used stabilization and device exercises and the results of the randomized clinical trial in chronic and recurrent LBP patients will hopefully assist the clinicians in selecting adequate rehabilitation programs in patients.

REFERENCES


NEDERLANDSTALIGE SAMENVATTING
In 2001 bleek uit een enquête dat 41,8% van de Belgen tijdens de afgelopen 6 maanden geconfronteerd werd met lage rugpijn gedurende één of meerdere dagen. Lage rugklachten blijken een grote impact te hebben op het fysiek functioneren, het professionele leven en op de gezondheidszorg. Om de pijn en functionele beperkingen en eveneens de hoge socio-economische kosten aan banden te leggen, worden verscheidene revalidatiestrategieën voorgesteld. Recentere reviews die de effectiviteit van oefentherapie in chronische lage rug patiënten evalueren, toonden aan dat individueel gerichte spierversterkende en stabiliserende oefentherapie de pijn kan verminderen en het functioneren van de patiënt kan verbeteren. Er is echter nog onvoldoende duidelijkheid betreffende de effecten op lange termijn.

Binnen de actieve aanpak zijn momenteel in België, maar ook internationaal, twee grote tendensen waar te nemen. Enerzijds wordt getracht om na grondig klinisch onderzoek zo specifiek mogelijk in te spelen op de klachten van de patiënt door hands-on en sterk individueel begeleide oefentherapie gericht op de dagelijkse activiteiten en werksituatie van de patiënt. Binnen deze individueel begeleide aanpak wordt vaak specifieke stabilisatietraining toegepast. Anderzijds wordt geïnvesteerd in dure machines zodat patiënten zelfstandig kunnen trainen volgens individueel geprogrammeerde oefenschema’s op specifiek ontworpen lumbale trainingstoestellen.

Om de werking van deze revalidatieprogramma’s goed te kunnen begrijpen en interpreteren, leek het in eerste instantie noodzakelijk om een idee te hebben van de spierwerking die optreedt tijdens de uitvoering van stabilisatietraining enerzijds (deel 1 van deze thesis) en oefeningen op specifiek ontworpen toestellen anderzijds (deel 2 van deze thesis).

De geselecteerde stabilisatietrainingen waren oefeningen in handen- en knieënstand met arm- en beenbewegingen (hoofdstuk 1) en oefeningen in ruglig waarbij het bekken opgetild werd (hoofdstuk 2). De resultaten van deze onderzoeken toonden aan dat de romspieren een activiteitsniveau leverden van circa 30% van de maximale vrijwillige isometrische contractie (MVIC). Dit activiteitsniveau wordt verondersteld optimaal te zijn voor coördinatie en stabilisatie doeleinden. Alle romp- en heupspieren blijken harmonisch samen te werken om
de controle over de neutrale lage rugpositie te behouden tijdens deze stabilisatieoefeningen. Tijdens de oefeningen waarbij het bekken getild werd vanuit ruglig vertoonden de rugspieren een hogere activiteit ten opzichte van de buikspieren. Tijdens beide types oefeningen was de activiteit van de rechte buikspieren minimaal.

In hoofdstuk 3 was het de bedoeling om na te gaan of specifieke stabilisatietraining zinvol zou kunnen zijn in primaire preventieprogramma’s. Een interventieperiode van 3 maanden bestaande uit 8 trainingssessies toonde aan dat het mogelijk is om rompspierrecruiteringspatronen te wijzigen bij een gezonde populatie. Bijgevolg lijkt specifieke stabilisatietraining nuttig te kunnen zijn in primaire preventie, indien klinisch onderzoek aangeeft dat de spiercontrole niet optimaal is. Verder prospectief onderzoek is echter nodig om deze veronderstelling te bevestigen.

De oefeningen op de specifieke lumbale trainingstoestellen (Tergumed) werden uitgevoerd in zit. Bij dynamische oefeningen aan een lage weerstand (30% van het gemiddelde maximale krachtmoment (GMK)), bleek bij gezonde proefpersonen tijdens verschillende oefeningen reeds een behoorlijk hoge spieractiviteit aanwezig te zijn (hoofdstuk 4 en 5). Sommige rugspieren (lumbale m. multifidus en m. longissimus thoracis) vertoonden tijdens rotatie- en extensiebewegingen aan deze lage weerstand reeds een relatieve spieractiviteit van ongeveer 60% van MVIC. Dit niveau van spieractiviteit wordt algemeen beschouwd als het niveau nodig voor spierkrachtttraining. De buikspieren vertoonden globaal een lagere activiteit tijdens de flexie- en extensieoefeningen aan lage weerstand, maar tijdens de rotatiebewegingen aan lage weerstand (30% GMK) vertoonde enerzijds de m. obliquus internus abdominis een relatieve activiteit tussen de 30 en 60% van MVIC en anderzijds de m. obliquus externus abdominis een activiteit van 60% van MVIC.

Aangezien reeds verscheidene rompspieren een relatief hoge activiteit blijken te vertonen tijdens een oefening tegen een weerstand van 30% GMK, kan men zich afvragen of het noodzakelijk en opportuun is om te trainen aan hogere intensiteiten. Hogere intensiteiten lijken bij patiënten, zeker in de initiële trainingsfase, niet meteen noodzakelijk. Directe extrapolatie van deze onderzoeksrезультатen bij een gezonde populatie naar een patiëntengroep is misschien echter niet geoorloofd. Verder onderzoek bij specifieke subgroepen van chronische lage rugpatiënten zou een beter inzicht kunnen verschaffen.
In het derde deel van deze thesis werd een klinisch gerandomiseerd onderzoek uitgevoerd waarbij de effectiviteit van de beide actieve therapievormen werd geëvalueerd. Bij 78 patiënten met aspecifieke chronische lage rugpijn met een motor controle disfunctie werd de effectiviteit van specifieke oefentherapie versus rompspierreconditionering op lumbale trainingstoestellen onderzocht (hoofdstuk 7). De therapie omvatte 12 weken met een frequentie van 2 oefensessies per week gedurende de eerste 6 weken en 1 per week gedurende de volgende 6 weken.

De specifieke oefentherapie bestond voor 90% uit motor controle stabilisatietraining en voor 10% uit manuele therapie (mobilisatie en weke delen technieken) en educatie. Het behandelproces bevatte een graduede progressie door verandering van onder andere posturale belasting, vermindering van aandacht en van snelheid met het uiteindelijk doel om functionele verbetering te bekomen bij de patiënt. Dagelijkse thuisoefeningen werden aangemoedigd.

Voor de globale rompspierreconditionering werd beroep gedaan op 4 lumbale Tergumeb trainingstoestellen. Het oefenprogramma was gebaseerd op de individuele resultaten van de patiënt van isometrische kracht en mobiliteit zoals gemeten tijdens de eerste en tiende behandelsessie. Het oefenprogramma startte met minimaal 4 isometrische trainingsessenties gevolgd door dynamische oefensessenties. Tijdens de uitvoering van de oefeningen ontving de patiënt continu feedback via een te volgen sinusoidale curve op een beeldscherm. Elke sessie werd voorafgegaan door 10 minuten opwarming op een hometrainer en beëindigd door de uitvoering van 4 verschillende stretchingsoefeningen. Ter evaluatie van de effectiviteit van de therapie werden verschillende vragenlijsten gehanteerd en werd een functionele testbatterij doorlopen. De functionele testbatterij evalueerde verschillende componenten van functionele stabiliteit, namelijk proprioceptie, posturale controle en spierwerking. Wat de spierwerking betrof, werden diverse oefeningen uitgevoerd (coördinatie-, stabilisatie-, kracht- en uithoudingsoefeningen, evenals een volledige rompflexieoefening om het relaxatievermogen van de rugspieren te beoordelen). Deze testbatterij bleek een betrouwbare meetinstrument (hoofdstuk 6).

De resultaten van dit effectiviteitsonderzoek toonden aan dat zowel pijn, functionele beperking, algemene gezondheid, psychosociale aspecten als functionele parameters positief beïnvloed werden. Een licht voordeel van de specifieke therapie ten opzichte van de oefentherapie op toestellen werd vastgesteld. Aangezien dit voordeel betreffende de functionele beperking echter verdwenen was bij de 1-jaar follow-up en de andere metingen
niet herhaald werden na 1 jaar, dient dit voordeel met de nodige voorzichtigheid geïnterpreteerd worden.

De resultaten zijn tevens enkel geldig voor de specifieke subpopulatie van chronische lage rugpatiënten die geselecteerd werd, namelijk patiënten met specifieke klachten zonder radiculaire symptomen en zonder eerdere rugchirurgie waarbij een motor controle disfunctie werd vastgesteld.

Niettegenstaande de onderzoeken naar de spierwerking plaatsvonden bij een gezonde populatie blijken de resultaten gecorreleerd te kunnen worden aan de resultaten van de patiëntenstudie. Tijdens de onderzochte stabilisatieoefeningen, evenals de geanalyseerde oefeningen op de toestellen bleek steeds een vrij hoge relatieve activiteit van de lumbale m. multifidus aanwezig te zijn. Deze spier bleek tijdens de patiëntenstudie als enige een significante activiteitstoename tijdens de stabilisatieoefeningen na therapie te vertonen.

Wat betreft de oefeningen op de lumbale trainingstoestellen, dient het specifieke karakter van de toestellen vermeld te worden. Doordat de Tergumed toestellen een biofeedback systeem hanteren waarbij de snelheid van de bewegingen, evenals de ROM continu gecontroleerd worden, is het misschien niet geoorloofd de resultaten van deze therapie te extrapoleren naar trainingsprogramma’s op andere toestellen waarbij minder of geen controle aanwezig is.

Met deze thesis werd getracht een waardevolle bijdrage te leveren aan de klinische kinesitherapeutische praktijk door een beter inzicht in vaak gebruikte oefeningen te verschaffen, evenals door de effectiviteit van actieve therapievormen te vergelijken in een specifieke chronische lage rugpopulatie.
Things should be made as simple as possible, but not any simpler.

(Albert Einstein)