Muscle recruitment during lumbar extension exercises

The influence of different modalities, exercise dosage and active stabilization

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1. POSTERIOR EXTENSOR CHAIN: ANATOMY AND FUNCTION

Lumbar extension exercises are widely used to enhance endurance, strength and functionality of extensor muscles located in the thoracic, lumbar and pelvic region (1-7). Together these muscles form the posterior extensor chain. The posterior chain consists of the thoracic and lumbar parts of the longissimus and iliocostalis, the lumbar multifidus, the latissimus dorsi, the gluteus maximus and the biceps femoris, which are functionally coupled via the fascia thoracolumbalis (FTL) (6). Despite the fact that only some of these muscles directly attach on the lumbar vertebrae, a contraction of one of these muscles will influence the lumbar region, although it is not their primary function.

Anatomical, biomechanical and neurophysiological data show the necessity to make a functional differentiation between different parts of the posterior extensor chain (1;6;8;10-15). In the past a number of models have been proposed to demonstrate how the extensor muscles provide mechanical spine stability. The most frequently used model is designed by Bergmark (16) and has been adapted by Comerford et al. (17), who divided the trunk muscles into 3 categories, local stabilizers, global stabilizers and global mobilizers. In our research group, we prefer to subdivide the trunk muscles into two functional categories (15). In this model the muscles are classified according to the muscular systems which are involved in the provision of segmental stability, namely a deep stabilizing system and a large torque producing system, which can provide general stability (15).

The deep stabilizing system comprises small muscles located in the center of the body, immediately adjacent to the spine. These muscles only cross one or two segments and have direct attachments to the vertebrae. Due to their vertebral insertions, the main role of the deep stabilizing muscles is to provide segmental stability and to control motion amongst the vertebrae. These muscles are also characterized by short lever and small moment arms, which makes them more suitable to play a postural holding role (for example maintaining the lumbar lordosis) than to produce spinal movements (17,18).

The torque producing muscles are larger, located more superficial and further from the spine. They cross multiple segments without attaching directly onto the vertebrae, and conjoin the thorax with the pelvis. These long muscles are characterized by large moment arms, which enables them to move the spine and provide general stability. Moreover, they continually modify the load on the lumbar spine and its segments by transferring external loads between the thoracic cage and the pelvis (17-19).
The muscles of the posterior extensor chain are presented in figure 1. The erector spinae (ES) can be divided into a thoracic and a lumbar part. Each of these parts has a different geometry in relation to the lumbar spine and hence a different function in providing dynamic stability (16;17;18). Within this framework the lumbar multifidus and lumbar portions of the erector spinae are considered to be part of the deep stabilizing muscles. The thoracic portions of the erector spinae, the latissimus dorsi, gluteus maximus and biceps femoris are regarded as large torque producers (16).

The lumbar multifidus (LM) is the largest and most medial located muscle (12-14;19;20). It is composed of multiple fascicles and characterized by a segmental arrangement and innervation (21). The superficial fibers originate from the laminae and spinous processes of the lumbar vertebrae and descend in caudal lateral direction to insert onto the mammillary process, laminae and facet-joint capsule of the caudal lumbar vertebrae, or onto the sacrum and/or ilium (19). The deep or laminar fibers have their origin at the vertebral laminae and attach to mammillary process of caudal located vertebrae. The fascicles cross two (deep) to five (superficial) joint segments. Due to their fascicle arrangement, the primary function of the LM is enhancing lumbar stability by generating compressive forces (22). Two thirds of the active stiffness at the 4th and 5th lumbar vertebrae (L4-L5) is attributed to the LM (23). Considering their role as stabilizers type 1 fibers predominate in the LM (24;25).

The lumbar erector spinae (LES) consist of the lumbar parts of the longissimus (LL) and iliocostalis (IL) (12;13;19). The lumbar fascicles of both muscles originate and insert on the lumbar vertebrae. These segmental connections give the muscles the potential to control the segmental motion as well as to extend the lumbar spine (sagittal rotation movement). In addition, the LES has the mechanical advantage to assist in rotation and lateroflexion in the lumbar spine and in accentuating the lumbar lordosis (19). Both parts are characterized by a high portion of type 1 fibers, which may confirm their postural holding role (10).

The LL is medially located and is composed of 5 fascicles each originating from the transverse process and accessory process of the corresponding lumbar vertebrae and inserting on the posterior superior iliac spine. The more laterally located IL originates in 4 fascicles from the lateral parts of the transverse process of L1-L4 and the adjacent thoracolumbar fascia (middle layer). The insertion is situated on the iliac crest lateral from the LL (12;19).

On the left the different parts of the posterior extensor chain are displayed. On the right (adopted from Danneels (15)) the posterior extensor chain muscles divided in the deep stabilizing, i.e. the lumbar multifidus (LM) and the lumbar erector spinae (LES) and large torque producing system, i.e. the latissimus dorsi (LD) and thoracic erector spinae (TES) are presented.
The thoracic erector spinae (TES) is formed by thoracic parts of the longissimus (LT) and iliocostalis (IT) (26). The fascicles of both thoracic parts arise from the thoracic vertebrae or ribs and insert into parts of the sacrum or ilium via the erector spinae aponeurosis, which cross the lumbar spine (26). Via the erector spinae aponeurosis the activation of the TES indirectly affects the lumbar spinal column. Through its long tendons, the TES can increase the lumbar lordosis and can generate a great extension moment in the spine. Compared to the other spine extensors, the TES has the largest movement arm and is the greatest contributor to the extension moment, especially in a lordotic posture (2). At the upper lumbar spine (L1-L3) it has a considerable contribution of 70-90% to the total extensor moment, whereas its contribution to the total extensor moment at the lower lumbar spine (L4-L5) is about 50% (2). Regarding their torque producing role it is suspected that the TES are mainly composed of type 2 fibers, however a balanced distribution of type 1 and 2 fibers has been demonstrated (24).

The latissimus dorsi (LD) is the widest back muscle and covers the back of the thorax, overlaying most of the other posterior trunk muscles (27). It originates in 4 parts at the spinous processes of the lower six thoracic vertebrae, the lumbar vertebrae, the FTL, the iliac crest, the 9th to 12th rib, and the inferior angle of the scapula (27). Mechanically, the LD is a strong adductor and extensor of the shoulder, but when the humerus is fixed the LD can induce a lateroflexion and extension of the trunk. Moreover, through its attachments on the FTL, contraction of the LD can generate an extension torque by increasing the tension of the posterior layer of the FTL (28).

Figure 1 The posterior extensor chain.
The *gluteus maximus (GM)* and *biceps femoris (BF)* are part of the hip extensors and are mainly compound of type 1 and intermediate type 2a fibers. The GM is a large flat muscle, that originates from the back of the ilium, the sacrum and the sacrotuberous ligament and inserts onto the ilio-tibial tract and the gluteal tuberosity (29). The GM is a strong extensor, but also assists in lateral rotation and abduction of the hip (30). During standing, the muscle is inactive and remains inactive during forward bending (29). The BF is one of the three muscles that constitutes the hamstrings. The tendon of the BF splits around the fibular collateral ligament into a long and a short head. The long head of the BF arises from the ischial tuberosity, and the short head from the linea aspera. Both heads insert into the lateral side of the head of the fibula (31). Together with the other parts of the hamstrings, contraction of the BF will induce knee flexion and hip extension. The secondary function of the BF is lateral rotation and adduction of the thigh, and flexion and lateral rotation of the knee (29). The GM and BF can also induce posterior pelvic tilt and are active when raising the trunk after stooping (29). In co-operation with the LD, the GM has been considered to have a stabilizing and lumbar extending effect on the spine through its action on the posterior layer of the FTL (27;28).

The thoracolumbar fascia (FTL) is a dense, thick tendinous membrane consisting of 3 layers. The FTL separates the lumbar and sacral erector spinae muscles from the muscles of the posterior abdominal wall, i.e. the quadratus lumborum and psoas major. Numerous trunk and limb muscles insert onto the connective tissue layers of the TFL (28;32). The posterior layer of the FTL has dominant connections with the aponeuroses of the LD and the serratus posterior inferior which form the superficial lamina. The deep lamina is the central component of the FTL and covers the erector spinae muscles as a retinacular sheat (28;32). The middle layer is a thick collagen band, which divides the paraspinal muscles from the quadratus lumborum. This layer connects laterally to the posterior layer along the lateral raphe. The anterior layer, described as an extension of the transverse fascia, runs anterior to the quadratus lumborum and ends posteriorly between the quadratus lumborum and the psoas. Caudally the GM attaches to the ES aponeurose which is merged with the lamina of the posterior layer of the FTL. In front the deep abdominals (obliquus internus and transversus abdominus) join the middle layer of the TFL. Although the FTL is a non-contractile structure, it provides a mechanism for load transfer between the upper and lower limbs and can act as a lumbar stabilizer. Contraction of the attached muscles increases the tension of the posterior layer, which enhances lumbar stability during static posture and movement (28;32).
2. AIM OF LUMBAR EXTENSION EXERCISES AND THEIR IMPLEMENTATION IN TRAINING PROGRAMS

There is considerable evidence that an optimal condition of the posterior extensor chain muscles and a good balance between the thoracic, lumbar and hip extensors is a perquisite to achieve spinal stabilization and force generation, which are necessary for performing daily and sport activities. Insufficient strength and imbalances in trunk and hip muscles, inhibit appropriate trunk stability and may prevent a good performance of these daily (33) and sport related activities (34-38). Decreased endurance implicates a lower fatigue threshold and loss in precision and control of movement, which affects motor performances (39). Moreover, poor functioning of the trunk muscles is related to the occurrence, recurrence and the persistence of low back pain (LBP) (33;35;40-45). Indeed a large variability of functional muscle changes are presented by LBP patients, entailing impaired motor control, delayed activation, altered activation patterns, higher fatigability, decreased endurance and strength capacity of the trunk muscles. These dysfunctions have been frequently observed in the LM, LES, and TES, and thus seem to affect the extensor muscles to great extent (40-43;46-51). Hence, a good condition of the trunk muscles in general and an optimal balance between these muscles is important in the prevention of LBP. In this light malfunctioning of the trunk extensors seems to play a major role in the pathogenesis of LBP. Therefore, one of the components of LBP prevention and training programs should focus on optimizing and/or maintaining the required levels of endurance, strength and motor control of the lumbar extensors (52-66). As in a general population LBP is the most common medical complaint (lifetime prevalence up to 84%) and even in athletes LBP seems a common source of pain, an adequate prevention program is necessary.

There is a strong theoretical basis that ideally sufficient sensorimotor control is the foundation of muscle rehabilitation and training. Hence, optimal proprioception and coordination of the trunk muscles can be viewed as a prerequisite (substructure) to proceed to strength and endurance training, for which higher loads are recommended (superstructure) (15) (figure 2).

In this light, training programs to optimize the function of the lumbar extensors often start with focusing on improving sensorimotor control of these muscles. Therefore low load stabilization exercises are frequently used (60;67-69). Once sufficient proprioception and a good coordination of the posterior chain extensors are achieved, exercises to increase the strength and endurance of the trunk muscles can be implemented into the training program (15). While daily activities, vary from low to high load, in general they require less muscle endurance and strength than sport activities. So especially people who perform sports at an intensive level such as athletes, require high levels of trunk
Muscle endurance and strength to maintain stability during highly dynamic and highly loaded movements (70). In this light, high load training is essential for athletes in order to achieve their highest abilities.

One of the most popular exercises used by researchers, clinical practitioners and trainers to enhance strength and endurance of the posterior extensor chain, are lumbar extension exercises (58;63;65;71-73). While the posterior extensor chain in its totality can be trained by the lumbar extension exercises, these exercises are considered as the most appropriate to train endurance and strength capacity the lumbar muscles specifically (8;9). As it has been previously shown that to enhance strength or endurance, exercises should be performed at an intensity of more than 40% of the maximal voluntary isometric contraction (MVIC) these exercises are performed against a high training load or resistance. Compared to other back rehabilitation exercises (such as stabilization exercises) it has been shown that these exercises are indeed ‘high load’ as they activate the trunk muscles at a high degree (40-70% MVIC) (1;3;4;8;74-77). Furthermore it has been shown that performing lumbar extension exercises is indeed efficacious for improving the strength and endurance capacity of the lumbar extensors in LBP (52;78-80) and athlete populations (59;80). In addition, lumbar extension exercise programs are beneficial for reducing pain in LBP patients (81).

In conclusion, a large significance of lumbar extension exercises in the treatment and prevention of LBP can be assumed. Lumbar extensions can be considered as high intensity exercises and will, dependent on the degree of lumbar extension, put a high load on the lumbar structures (82;83). In this respect therapists and trainers have to ensure that lumbar extension exercises are conducted in a responsible and safe way. Therefore these kind of

**Figure 2** Sufficient proprioception and coordination, i.e. stabilization (neuromuscular control) establishes the foundation for traditional endurance and strength training. Adopted from Danneels (15).
exercises should only be implemented (often in the later stage of training programs) when an adequate sensorimotor control, necessary to maintain the neutral spine position, is established.

Since lumbar extension exercises are often used in prevention, rehabilitation and training programs, these kind of exercises have been frequently examined by researchers (9,53-56,72,84-91). Numerous studies have assessed the posterior extensor chain performance and tried to get insight in the activation of the different muscles (1,3,4,8,50,74-77,82,92-96) and their fatigability (5,6,71,95,97-100). The outcomes in healthy people (1,3,4,6,8,74-77,82,92-96,98-100) were compared to those suffering from LBP (50,92,99) to identify the presence of muscular dysfunctions. Several studies have used these exercises as evaluation techniques in those with LBP and have demonstrated lower endurance times, altered muscle activity levels and recruitment patterns. Moreover, these tests were shown to be able to discriminate between healthy individuals and patients with LBP (101,102), and even to predict LBP (40,43). As a field test, researchers and clinicians have used these exercises to examine how long subject are able to perform lumbar extension against a certain exercise load and to derive general conclusions regarding the isometric endurance of the posterior extensor chain. Dynamic endurance of the extensor chain muscles can be evaluated by performing these exercises repetitively.

As described later in this thesis many variants of these lumbar extension exercises exist. The main differences among these type of exercise are the position in which the exercises are performed (prone, seated, standing) and the moving body part (trunk or leg extension).

3. EVALUATION OF THE POSTERIOR EXTENSOR CHAIN RECRUITMENT

Clinically the general endurance of the posterior extensor chain can be evaluated using various versions of lumbar extensions exercises. In 1964, Hansen was the first to use this test for evaluating the isometric endurance of trunk extensor muscles (103). The test was performed prone with the lower body fixed to the examining table and the upper body extending beyond the edge of the table. Isometric endurance of trunk extensor muscles was evaluated by registering how long the upper body could be maintained horizontal. Later this test became known as the “Sorensen test” as Biering-Sorensen used this test to show that subjects with reduced endurance are likely to develop LBP complaints within the next year (40). In the meantime, many adaptations of this test have been made (104). However this test does not allow to differentiate between the different muscles which are involved in the performance of the lumbar extension movement. Therefore the “Sorensen
test” is not suitable to get insight in the individual contribution of the different muscles. In order to get information related to specific muscle contribution, the test needs to be combined with physiological evaluation techniques such as ultrasound (US), electromyography (EMG), or muscle functional magnetic resonance imaging (mfMRI).

3.1. Ultrasound (US)

US is a non–invasive method to quantify the amount of muscle activity in relation to the change in muscle thickness (105). The change in thickness between the relaxed and contracted muscles is expressed as a percentage. The use of US has only been found to be valid to evaluate the LM, ES and the abdominals during static contractions and dynamic low load contractions (106;107). For assessment of the spinal region, an important drawback of this technique is the limited field of view as the investigation of several muscles at multiple regions and sides simultaneously is not possible (108).

3.2. Electromyography (EMG)

EMG is a simple and reliable tool to evaluate the electric activity of the back muscles during postures and movements in both a spatial and temporal manner (7;109;110). Widely, it is considered as the gold standard (111). Two types of EMG are in widespread use; namely surface EMG (sEMG) and intramuscular EMG.

In general, measurements are performed by placing an electrode pair on the skin or within the muscle in order to detect the real time myoelectric activity of a contracting muscle. The electric activity consists of action potentials fired by a motor unit (112). Starting from the motor endplates, the action potential spreads along the muscle fiber membrane and inside the muscle fiber, forming a sort of depolarization wave. Accordingly, a potential difference among both electrodes exists, which is dependent on the spatial distance between the electrodes. This potential difference is detected by the electrodes and expressed as the amplitude of the EMG signal (quantified in microvolt) (113;114). The EMG amplitude is influenced by the number of motor units recruited within the measured muscle and the individual firing frequency of these motor units. Few motor units (low force) only elicit small signals. While the demand for force production increases progressively, the motor units are recruited gradually and the signal becomes larger. This means that the EMG signal is composed of superimposed motor units (i.e. all motor units detectable under the electrodes) and can be decomposed for a thorough analysis (113;114). The signals derived from the activated motor units are raw data, which can provide qualitative understandings from the neuromuscular control. However, in order to assess muscle activity quantitatively and increase the validity and reliability of findings, signal processing is required (113). In our studies the raw signals were bandpass-filtered between 10 and 500 Hz to remove noise and motion artefacts. Subsequently, the signal processing consisted of full wave rectification, which means that all signals were converted to positive amplitudes and smoothing. To smooth the signal, a root mean square algorithm
with a 100 ms time constant was used. The RMS is a real time indicator of the amount of electric activity of the investigated muscle.

Intramuscular EMG is less frequently used than sEMG due to its invasive character. Therefore a possible influence of pain related to the insertion of the electrode into the muscle cannot be ruled out when evaluating the muscle function. Moreover, via intramuscular EMG the signals of the motor units recorded are limited to the size of the wire electrode, which makes that intramuscular EMG is not representative for the entire muscle. In contrast the use of surface electrodes enables a better view of the muscle underlying the electrodes (115) (figure 3).

However, a disadvantage of sEMG, which is not applicable for intramuscular EMG is the so called cross talk. Cross talk is the term used to express that adjacent muscles may produce EMG signals that eventually can be detected by the electrodes. Especially, cross talk can occur within muscle groups with a narrow muscle organization, as is the case in the trunk musculature (116). Furthermore, any change in the distance between the origin of the signal and the detection place will modify the signal, which can be a problem during dynamic movements (117).

3.3. Muscle functional MRI (mfMRI)

A reliable mapping of the recruited muscles during exercise can be accomplished using mfMRI (75,118). mfMRI is a recent non-invasive technique that allows to locate activated muscles. The technique is based on acute activity induced changes in the T2 relaxation time of muscle water in the contracting muscles (118-121). As a result of the magnetic field

![Diagram](image.png)

**Figure 3** On the left: The action potential fired by the motor unit spreads along the muscle fiber membrane. On the right: The potential differences can be detected by the surface electrodes.
the protons in tissue water and fat molecules will align with the field to achieve a state of equilibrium (z-axis). Applying a radio frequency pulse causes a rotation of the protons into the transverse plane (xy-plane). Subsequently, protons will emit their absorbed energy because they prefer to be in a low-energy state or equilibrium (118). This event is called ‘relaxation’. One parameter of this process is T2 or the transverse relaxation time, which can be defined as the time required for the transverse signal to reach 37% of its initial value (in ms) (118). Physiological alterations in the working muscles (such as decreased intracellular pH, lactate accumulation, blood flow and osmotic shift of muscle water) will cause a prolongation of the transverse relaxation time (T2-shift) (118;120;121). As T2 is sensitive to metabolic and hemodynamic processes associated with muscle activation, specific muscle patterns can be detected on T2 weighted images (figure 4). On these images the recruited muscles will be brighter, as a result of the increased T2-value, which enhance the signal intensity. A major advantage of mfMRI compared to other techniques is the ability to measure different muscles at varying depths without cross talk. Since mfMRI is a post-exercise assessment method, the main disadvantage is that no temporal details concerning the muscle activity can be rendered. Previous studies have demonstrated a positive linear correlation between the changes in T2 and the exercise intensity, which confirms the validity of mfMRI to quantify the amount of muscle activity (42.60). The inter-tester reliability of T2-shift measurements is shown to be high, with intraclass correlation coefficients ranging from 0.87-0.94 (118).

Figure 4  mfMRI image of the lumbar muscles at level L4 lower endplate (left). T2 weighted images at the same level in rest (center) and after (right) exercise [own images].

As mfMRI and EMG results have been shown to be significantly correlated (75), both methods are comparable and can complement each other in the quantification of the amount of muscle activity. Despite the fact that mfMRI and sEMG are widely used to study the activity of paraspinal and lower limb muscles, studies investigating the recruitment patterns of the thoracic, lumbar and hip muscles simultaneously are scarce. Studies
examining the recruitment of the posterior muscle chain are warranted to detect alterations in muscle function. While mfMRI and sEMG have mostly been used separately it would be interesting if future studies would combine both techniques as this would provide a total view on the electrophysiological and metabolic muscle activity during exercises.

4. MODALITIES AND DOSAGE OF LUMBAR EXTENSION EXERCISES

A large variety of lumbar extension exercises is used for the evaluation of the posterior extensor chain function or to enhance strength and endurance of the extensors during training. The different exercises modalities will be shortly discussed below.

4.1. Trunk or leg extension

Lumbar extension and the activation of the muscles generating this movement can be indirectly induced by extending either the trunk or the legs.

Trunk extension exercises can be performed from seated position (9;44;122-125), standing position (126) or prone lying (1;3;4;6;9;46;53;54;72;100;127;128). Unilateral or bilateral leg extension exercises are performed from prone lying (1;30;95;129;130). The most frequently used modalities, for both evaluation and training purposes, are trunk extension and bilateral leg extension from prone position and trunk extension from seated position.

The movement of the trunk towards extension from a full flexed position can be defined as a coordinated rotation of the hip, pelvis and (lumbar) spine in the sagittal plane through action of the lumbar and hip extensors (131;132). Earlier, Graves et al. (133) described the compound lumbopelvic rhythm during trunk extension, which consisted of a 110° pelvic rotation and a 72° lumbar extension. The initiation of the extension movement in healthy individuals was previously described by Mcclure et al. (134), who concluded that a trunk extension is dominated by hip movement and an increasing contribution of lumbar spine movements in the final stage of the extension movement. In contrast Lee et al. (135) stated that the contributions of the lumbar spine and hip were similar, but characterized by a greater contribution of the spine at the early stage of the movement. During trunk extension the hip extensors will extend the hip and pelvis while the lumbar muscles will stabilize and extend the lumbar spine on the pelvis and the thoracic muscles act as prime movers to lift the trunk.

In training and rehabilitation trunk extensions exercises from seated or standing position are often used to enhance strength. These exercises are mainly performed on back extensor training devices which have a resistance pad that is placed against the back and transfers the exercise load. Back extension devices are often used for training purposes as
they have some advantages. There are devices available on which the range of motion can be limited, hence minimizing the possibility of excessive extension. Some devices provide visual feedback during the training regarding the range of motion, the intensity and the speed of the performed exercises. However, it must be considered that these devices are expensive and therefore not at the disposal of all clinicians. Therefore trainers and physiotherapists rather use trunk extension exercises from prone position. No equipment is required to perform these exercises, and these exercises can easy be implemented in training programs.

For evaluation purposes trunk extension exercises on back extensor devices can be used to evaluate the general trunk extensor endurance and strength. However, to evaluate the different muscles of the posterior extensor chain a combination with a physiological technique such as EMG is required. The resistance pad which is placed on the back of the subject does not allow to evaluate the recruitment patterns of all the posterior muscles which contribute to lumbar extension using sEMG. Especially the TES are difficult to evaluate using EMG while performing trunk extension exercises on these devices. Therefore trunk extension exercises from prone position seem more appropriate. Performing trunk extension from prone position allows to evaluate the general trunk extensor endurance based on the performance, or can be used in combination with other techniques such as sEMG to examine the recruitment of individual trunk extensor muscles.

Besides trunk extension, prone bilateral leg extension is a frequently used exercise to evaluate the activation and recruitment patterns of the hip and back extensors (129;130;136). Some studies consider a leg extension exercise as a specific evaluation method appropriate to assess the endurance of the lower spinal extensor muscles (137). A leg extension exercise can be considered as a combined sagittal rotational movement of the legs, hips and pelvis, while the trunk is fixated in a horizontal position (129). The dynamic work (lifting the legs) is performed by the leg extensor muscles (GM and hamstrings) while the thoracic and lumbar back muscles provide more muscle static work. The back muscles need to create a stable platform, by stabilizing the pelvis and spine, to make lifting of the legs possible.

As lumbar extension exercises from prone position are frequently used to evaluate the activation and endurance of the posterior extensor chain, an overview of the different modalities which have been used and described for evaluation purposes is provided in figure 5.

Twenty studies used prone lumbar extension exercises in order to examine the fatigability (5;6;74;95;97-100) or activity levels and recruitment patterns of the posterior extensor chain (1;3;4;8;46;74-77;82;92;94-96), which were evaluated by either sEMG (1;3;6;8;46;74;76;77;82;95-100) or mFMRI (75;92-94). In most of these studies muscle function was assessed through the performance of trunk extension exercises (1;3;4;6;8;46;74-77;82;92;94-96;98), whereas only three studies utilized leg extension exercises (1;45;95).
Figure 5 Various modalities and modification of prone lumbar extension exercises.

The trunk extension exercises were conducted in a static (6;76;96-99), dynamic (3-5,8;94) or dynamic-static way (1;75;77;100). Regarding the static performance subjects maintained trunk position as long as possible (6;76;97;99), during 1 minute (74;99) or during 5 seconds (96). The concentric and eccentric phase during the dynamic modality were each conducted in either 2 seconds (5,8;94) or 5 seconds (3,4). In order to perform the dynamic-static modality, a static phase was performed in between the two dynamic phases. In this condition the duration of the dynamic phases varied from 1 second (1;100) to 2 seconds (75;77), and the static phase has been described to vary from 1 second (1;77;100) to 5 seconds (75).

The movement range of the trunk extension varied widely. In some studies subjects performed the trunk extension exercises starting in 90° (3;4;8;77;102), 75° (94) 45° (1;46;75) or 5° (1) of trunk flexion and extended the trunk to the horizontal position (1;3;46;75,77), 5° of hyperextension (1), or 15° of hyperextension (92;94). The exercises were performed on either the ground, a table, a roman chair or variable angle roman chair without inclination (1;6;8;46;74-77;92;94;96;97;99;100), or with an inclination of 10° (5), 15° (3), 30° (3,4), 45° (3;98), 60° (3) or 75° (3) above the horizontal. During the trunk extension exercises hands were placed along the sides (1;3;46;96), in the neck (92), on the ipsilateral shoulders (4;5;75), on the contralateral shoulders (3;8;76;94;98), on the forehead (6;74), behind the ears (97) or on the back of the head (3;77). In the studies using trunk extension exercises subjects’ their lower limbs were fixated by one or more straps around the ankles (1;3;46;74-77;92;94;98), below the knees (6;74;76;98), the hips (6;74;76;77), or the thighs (97). In two studies the trunk extension exercises were executed without any fixation (1;78).

Prone leg extension exercises were performed on a bench without inclination in either a static (95), dynamic (46) or dynamic-static way (1). During the static performance subjects had to hold their legs in the horizontal position for 1 minute (95). During the dynamic-static exercise each phase was conducted in 1 second (1). The duration of the dynamic exercise performance was not mentioned. Fixation of the trunk was provided by either straps around the thorax (95), or with the hands on the table to stabilize the thorax (1;95). In one study the trunk was not fixated during leg extension (95). Only one study examined dynamic leg extension exercises ranging from 60° flexion until the horizontal position (1). In other studies leg extension exercises were performed in a static way in the horizontal position (95).

Most of the studies using lumbar extension exercises, evaluated the LM (6;73;74;76;91;92) and LES (1;3-6;8;46;75;76;95-100), LL (77), IL (74;77;94), whereas less researchers combined an evaluation of the lumbar muscles with other relevant extensors; namely the TES (95;97-99), LT (6;95), IT (6), LD (6), GM (1;3-6;8;46;76;95;98;100) and BF (1;3-6;8;76;77;95;98;100). The intensity of the prone extension exercises and the method of dosage differed among studies. Most studies did not mentioned the exercise intensity are used the upper or lower
body weight as the exercise load (1;3;4;6;8;46;74-77;92;94;95-100). In contrast, some studies clearly reported the exercise intensity. Dickx et al. evaluated the back muscle function at exercise intensities of 40%, 50%, 70% and 80% of the one repetition maximum (1-RM) (75) and in another study the exercise intensities were set at 40%, 50% and 70% of the peak isometric strength (8). Furthermore, a low load trunk extension at 40% 1-RM (93) or 50% maximal voluntary isometric contraction (MVIC) (5) was performed to examine back muscle activity levels.

It is most likely that these modifications will influence the fatigue, activity and recruitment of the posterior extensor chain at a different extent. Fatigue studies demonstrated that the LD was the least fatigued (6) and the thoracic muscles fatigued at a lower rate than the lumbar muscles during prone trunk and leg extension exercises (6;74;76;95;98;100). The lower fatigue levels of the thoracic muscles could indicate that the lumbar muscles were activated at a higher degree than the thoracic muscles during prone lumbar extension exercises.

Previous studies investigating the activity and recruitment patterns of the posterior extensor chain, proved that during trunk extension exercises all muscles of the chain are activated, though at varying degrees. In general during trunk extension, the highest activity levels were found in the LES or LM (about 60%MVIC) (1;3;4;46;74;76;77;95;96). Regarding the TES, several studies demonstrated significantly lower levels of activity (45%MVIC) compared to the LES (82). The role of the hip extensors during a trunk extension remains ambiguous. Some authors claim a major role of the hip extensors (1;5;6;44;100), while others swear by only a minor role (76;98). However, it should be noted that the hip flexion angle in the study of Clark et al. (5) was 15° and in the study of Champagne et al. (98) 45° at the end position (=horizontal trunk position) and, while in the other studies the hip angle was 0° in the horizontal position. The activity levels of the hip extensors during trunk extension are ranging from 16 to 39% MVIC (1;3-5;8;46;76;95). More specific it has been shown that a number of modifications can alter the degree of trunk extensors activity. At first, it appears that performing a trunk extension exercise dynamically induces a higher recruitment of the LES and LM compared to a static performance (1;46). Secondly, the activity of the trunk extensors depends on the position of the trunk, lumbar region, hip and arms during the exercise performance. Adjusting the starting angle of the variable angle roman chair from upright to a more horizontal position enhances the back extensors (3;98). Also the end position of the trunk strongly influences the recruitment levels of the trunk extensors. Significantly higher levels of lumbar muscle activity are demonstrated during an extension to end range (up to 92%MVIC) compared to a trunk extension to the horizontal (1). Stressing out the maintenance of the lumbar lordosis during trunk extension, internal rotation of the hips, 40° hip flexion and placing the hands further of the axis of rotation during trunk extension increases the quantity of the lumbar extensor activity (3;4;98).
Only few studies presented the degree of muscle activity during leg extension exercises. The highest muscle activity during these exercises was also demonstrated in the LM (>70%MVIC), followed by the LES (53-66%MVIC) and the hip extensors (<30%MVIC) (1;95). To the authors’ knowledge, no data about the LD and TES activity during bilateral leg extension exercises is available. One single study assessed changes in lumbar and hip extensor muscle activity during trunk and leg extension exercises in a healthy population. In this study no differences regarding the activity of LES, Hamstrings and GM between the two different types of extension exercise could be established. This study however did not evaluate the thoracic extensors (1).

In conclusion, previous study findings emphasize the importance of a global view on the contribution of all posterior extensor chain muscles, in particular the LES, LM, TES, hip extensors and LD during the performance of prone extension exercises. The activation levels of the lumbar and the hip extensor musculature have been extensively studied, whereas only few studies documented the TES contribution during prone extension exercise. Moreover, studies investigating the differences in the amount of activity of the posterior extensor chain between a prone trunk and leg extension are scarce. Therefore, this dissertation will investigate and compare the recruitment of the posterior extensor chain in its entirety between a prone trunk and leg extension exercise.

4.2. Contraction modality
The skeletal muscle can contract in different manners, namely in a static or dynamic way, depending on the changes in length of the muscle during activation (138).

A static or isometric contraction refers to a force production of the muscle without the occurrence of any motion. Many muscles contract statically in order to stabilize or protect the joint, while movement occurs in surrounding joints or regions (138;153). A dynamic contraction is described as a force production of the muscle while shortening (concentric phase) or lengthening (eccentric phase). When a concentric contraction takes place the segment is moved in the direction of the muscle contraction. An eccentric contraction takes places when the force is greater than the muscle capacity. In this case the muscle acts to decelerate the joint movement in the opposite direction (138;153).

In the perspective of rehabilitation and training it has been shown that muscles adapt differently to static, dynamic or dynamic-static training programs, as a result of differing underlying physiological mechanisms (139-142). In particular, the blood flow, which affects the oxygen supply and energy metabolism of the activated muscle, varies depending on the type of contraction (140;143). The concentric or static phase of a muscle contraction, induces a compression on the arterial vessels, resulting in a higher blood and intramuscular pressure level. These augmented pressure levels cause a decline in the blood flow of the activated muscle and an accumulation of local metabolites, creating more anaerobic muscle work. In contrast the dynamic phase of a muscle contraction is
characterized by a more effective muscle pump function, in comparison with a sustained contraction (static exercise) (140;144). The enhanced blood flow improves the supply of oxygen and substrates and the elimination of metabolites, which in turn inhibits a decrease of the intracellular pH. These physiological responses are reflected on the T2 weighted images and have the potential to alter neural factors and EMG parameters (140). Motor unit activation and recruitment, motor unit discharge rate, muscle fiber conduction velocity, median frequency, and EMG amplitude seems to be dependent of the contraction type (139;141). Compared to static contractions a smaller decrease in median frequency values is observed during dynamic contractions. Moreover, the motor unit discharge rate, muscle fiber conduction velocity and EMG amplitude is increased during dynamic muscle contractions.

In order to enhance paraspinal muscle hypertrophy or muscle strength, a sufficient metabolic stimulus is considered to be a substantial factor (53;54;145;146). In this respect adding a static component in between the concentric and eccentric phase (dynamic-static exercise) is critical in inducing higher metabolic stress. These findings support the previous observations which indicate that a dynamic-static exercise program was able to cause LM hypertrophy in chronic LBP patients while using solely a dynamic program was not sufficient (53;54). Although, the type of contraction seems to play a crucial role in muscle training, studies concerning the influence of the contraction modality on the recruitment of the posterior muscle chain, are not available at present. Due to a more complex spine loading during dynamic exercises (147) and the benefits of strength training throughout the whole range of motion for daily life and sport activities, this dissertation will focus on analyzing muscle recruitment patterns during the dynamic and dynamic-static exercise performance.

4.3. Exercise intensity

Many training variables (volume, intensity, frequency, duration) and principles (specificity, overload, variance) contribute to specific muscular adaptations upon resistance training and an effective training outcome (151;152). Although all variables need to be considered as essential in maximizing the benefits associated with resistance training, the exercise intensity appears to be a crucial factor. It is assumed that each level of resistance causes different metabolic reactions and influences the intermuscular coordination variously, resulting in different training effects.
In this light a good comprehension of the relation between the level of exercise intensity and the related muscle activation patterns is a prerequisite for composing adequate exercise programs in both healthy individuals as LBP patients. A certain level of exercise load seems to be imperative to overload the posterior chain extensors in order to improve the muscle endurance or strength capacity. For example it has been shown that the exercise intensity should be at least 60% of the MVIC to generate strength increments (152). As progressive overload is considered to be the mother of all training principles, an optimal estimation of the appropriate exercise intensity is important (138).

The exercise intensity level is usually expressed as a percentage of 1-RM, which is an equivalent for one’s maximum strength. The 1-RM is defined as the resistance with which only a single movement can be conducted properly (153). Different methods have been proposed to determine the correct exercise load in both research settings as in clinical practice, making either a direct or indirect estimation of the 1-RM.

The aim of the direct method is to find the maximal weight which can be overcome in as few attempts as possible. The individual has to perform the exercise with an estimated ‘maximal’ weight. If the individual is able to perform more than one repetition, an additional test with a higher weight needs to be executed. Due to the high resistance used, a sufficient recovery period between the attempts is necessary to determine the 1-RM correctly. Kraemer and Fry (153) advised to follow 4 basic steps for the determination of the 1-RM. At first, they proposed a low load warming up of the relevant muscle(group), followed by a 1-min rest (stretch of muscles) and a high load trial. Subsequently, the weight was increased each trial until failure, with a resting period of 3-5 minutes in between each attempt. Finally, the 1-RM value was recorded as the maximum weight successfully moved during the last trial. The 1-RM for trunk extension is usually determined using resistance delivered from rehabilitation devices, mainly conducted in (semi-)seated position (122;133;154-157). Although this trial and error method gives a direct and good rendering of the real 1-RM, it is rarely used in clinical practice due to risk of injury by attempting to move maximal loads, especially for older adults and (back pain) patients (158). Moreover it is a time consuming method. To overcome the possible overloading during the 1-RM test, alternative tests to assess the strength are described. For example, some authors recommended using the 6-RM test in children, others have suggested to estimate the 1-RM indirectly using submaximal test weights (159).

A strong relationship between the maximum number of repetitions performed with a submaximal weight and the percentage of the lifted weight (%1-RM) has been demonstrated (159). Therefore, the 1-RM can be accurately predicted indirectly by a submaximal test. In this regard, various formulas are described to calculate the 1-RM in an indirect way and several charts have been developed which show the relation between the number of repetitions performed and the exercise intensity levels expressed as a percentage of 1-RM (159-163). An example of these diagrams which is often used to
estimate the exercise intensity of prone lumbar extension exercises is the Holten diagram which is displayed in figure 6. The Holten diagram expresses the relation between a submaximal percentage of the 1-RM and the number of repetitions possible to perform with an arbitrary weight (163). Based on this relation one can calculate the exercise load which corresponds with 1-RM.

![Figure 6](image)

**Figure 6** The Holten-diagram as described by Holten (163).

Although this indirect method has been widely used to estimate the exercise load, including the load of a prone lumbar extension exercise (50;51;54;75;93), the exact relation between the number of repetitions to failure and the 1-RM is reckoned as non-consistent. The proposed relation varies on the amount of muscle mass required to complete the exercise and individual variables (such as age, training status, sex) (161;164;165). It has been demonstrated that more repetitions can be completed during multi-joint and large muscle based exercises, such as prone extension, compared to single-joint tasks involving smaller muscle mass (164;165). The author is not aware of any published studies validating the accuracy of this diagram to determine the intensity level of a prone extension exercise.

Only few have investigated the relation between the exercise intensity and the muscle recruitment patterns during prone lumbar extension exercises (8;75;94). Results are conclusive and suggest that the level and recruitment of the posterior extensor chain muscles vary with the resistance level. With regard to the lumbar muscle recruitment both linear (75;94), and non-linear (8) relationships with the exercise intensity have been described. One single study has examined and showed that increasing the load of a dynamic trunk extension exercise is characterized by a relative higher contribution of the hip extensors in relation to the lumbar muscles (8). Based on these results it was suggested that with increasing loads the lumbar musculature becomes less responsible for producing the extension movement, and the more powerful hip extensor muscles are activated in
order to maintain the force output. Moreover, it was hypothesized that because of the high relative percentage of type I muscle fibers, the lumbar muscles are not designed for higher resistance and other muscles will be activated to prevent excessive spinal loads (8).

Taken together, no earlier study examined the accuracy of two widely used dosage methods in predicting the actual intensity level. Moreover, ambiguities exist about the contribution of the different posterior extensor chain muscles during prone lumbar extension exercises at increasing intensity. Therefore, this dissertation will examine the recruitment of the posterior extensor chain during dynamic trunk extension exercises at different intensities. Subsequently, it will investigate to which extent the actual activity of the posterior extensor chain corresponds with the predefined exercise intensity, estimated by a direct or indirect dosage method.

4.4. Stabilization strategies

Although lumbar extension exercises are widely used in training regimes evidence suggests these exercises cause high spinal compressive loads (up to 6000N) due to increased anterior pelvic tilt and hyperlordosis of the lumbar spine (83;95;131;166). It is generally accepted that high spinal loads should be prevented and hyperextension movements should be especially avoided in LBP populations. Therefore, it is advisable to avert this negative effects during the performance of extension exercises. It has been advocated that excessive lumbar extension can be limited actively by lumbopelvic stabilization techniques or passively, using of lumbopelvic fixation pads (44;77;124;156).

As active stabilization strategies are more functional compared to passive strategies, this dissertation will only investigate the active lumbopelvic stabilization techniques. In the past 3 different approaches were suggested to actively stabilize or control the lumbopelvic region. A first approach consists of the abdominal bracing manoeuver (i.e. static contraction of the abdominals) (167-170). A second approach focuses on controlling the neutral spine position during movements, without any other instruction regarding muscle contraction. A last approach focuses on sensorimotor control including the facilitation of the deep stabilizing muscles as an initial step of muscle recruitment to enhance segmental spine stabilization (171-176). This last technique aims at facilitating co-contraction of the deep stabilizing muscles which form the lumbopelvic muscle corset and the ability to integrate this stabilization strategy progressively towards functional activities (66;176-178). A continuous tonic low level activation of the deep stabilizing muscles forms a sort of cylinder around the lumbar spine, which creates functional stability (179-181). There is evidence that this co-activation precedes the contraction of prime movers during movements which jeopardize the trunk stability and provides mechanical stability for spinal loads exceeding 1500N. Furthermore, evidence suggests that this active lumbopelvic stabilization technique influences the thoracic, lumbar and sacral angle during sitting (182) and prone hip extension (129). In particular, when this active lumbopelvic stabilization...
The technique is used during a prone hip extension exercises, these exercises are performed with smaller lumbar lordosis angles and less anterior pelvic tilt, thus less hyperlordosis (129). During sitting, co-contraction of the deep stabilizing muscles will flatten the thoracic and lumbar curvature and increase the sacral angle (182). These findings indicate that this active lumbopelvic stabilization technique can be used to control the neutral pelvic and lumbar position while performing exercises and activities.

In this light, contraction of the lumbopelvic muscle corset during high load exercises, may be advisable to reduce spinal loads. However, to date no study investigated the effectiveness of the application of an active stabilization technique on the lordotic angle and/or the trunk activity patterns during lumbar extensions. Therefore, the current dissertation will examine to which extent the recruitment of the posterior extensor chain muscles is affected by the implementation of a lumbopelvic stabilization strategy during lumbar extension exercises. Moreover, alterations in the hip, lumbar and thoracic angles will be measured.

In conclusion, the use of various modalities results in inconsistent findings regarding muscle function and specific training effects as they complicate the comparison and generalization of findings between various studies and no conclusions can be drawn. As a result, choosing the appropriate evidence based extension exercise in line with the training goal becomes a complex task for trainers and clinicians. In this light, a better understanding of the influence of various modalities on the recruitment of the muscles, which are forming the posterior extensor chain, would be highly valuable to make recommendations regarding the choice of appropriate exercise modalities for the implementation into training programs.

5. OUTLINE AND AIDS

An optimal endurance and strength of the posterior extensor chain is necessary for the performance of daily and sport activities. Furthermore a proper functioning of this chain is crucial in the prevention of LBP. Prone extension exercises are widely used to evaluate the recruitment and fatigability of the trunk extensor muscles, and to enhance the endurance and strength of these muscles when implemented into training programs. Within this context, different modalities of prone lumbar extension exercises have been used and various methods are applied to determine the exercise intensity at which these exercises are performed. Since high spinal loads have been observed during these type of exercises, a safe exercise performance which prevents lumbar hyperextension is essential. Based on the available research, in combination with clinical experience, the implementation of an active lumbopelvic stabilization technique during the performance of these exercises is advised in order to maintain a neutral lumbar lordosis.
However it must be realized that the large variation among the lumbar extension exercises, is likely to have an influence on the recruitment of the posterior chain extensors. Hence, a clear understanding of the posterior extensor chain muscle recruitment during these extension exercises would facilitate making evidence based choices. In order to clarify the ambiguities which were discussed in the introduction, the current dissertation will study the influence of different exercise modalities, exercise dosage and active stabilization on muscle recruitment during lumbar extension exercises. The methodology and results of the different studies have been structured in three parts within this dissertation.

**Part 1: Posterior extensor chain muscle activity during various lumbar extension exercises.**

This part aims at examining how different lumbar extension exercise modalities influence the recruitment of the posterior extensor muscles. To date most studies have focused on examining the activation of these muscles during prone trunk extension. Studies examining the recruitment of the posterior extensor chain during prone leg extension exercises and studies comparing the extensor recruitment between prone trunk and leg extension exercises are scarce. While it has been assumed that the type of contraction will affect the muscle physiology, no studies have examined whether muscle recruitment patterns differ during prone extension exercise performed in a dynamic or a static-dynamic way. Using two observational studies, possible differences in muscle activity and recruitment patterns of the posterior extensor chain during four extension exercise modalities in healthy individuals were examined. The muscle recruitment was investigated using two complementary evaluation methods. Chapter 1 addresses the posterior extensor chain muscle activity, measured by surface EMG (*Posterior muscle chain activity during various extension exercises: an observational study, BMC Musculoskeletal disorders 2013;14:204*). While, chapter 2 uses mfMRI to assess the activity of back extensor muscles (*Muscle functional MRI analysis of trunk muscle recruitment during extension exercises in asymptomatic individuals, Scandinavian Journal of Medicine and Science in Sports; 2015;25(2):196-204*).

**Part 2: Relation between the predefined and actual activity of the posterior extensor chain muscles during trunk extension exercises.**

Part 2 aimed at studying the correspondence between the estimated and actual activity of the posterior extensor muscles during trunk extension exercises. In addition it was examined how lumbar extension exercises performed at different exercise intensities
influenced the recruitment of the extensor muscles. The effect of both low load as high load exercise intensities was studied. A correct determination of the exercises intensity is a prerequisite for achieving specific training goals and can be estimated using a direct or an indirect method. Although both methods are widely used, no studies have examined whether the estimated exercise intensity corresponds with the actual demand of the posterior extensor muscles during extension exercises. Therefore chapter 3 demonstrates the activity and recruitment patterns of the posterior extensor chain muscles during trunk extension exercises at different intensities (Trunk extension exercises: how is the dosage related to trunk extensor recruitment? Journal of Electromyography and Kinesiology 2015: in press (Epub ahead of print doi: 10.1016/j.jelekin.2015.01.001)). The exercise intensity was estimated using the direct and indirect method, and surface EMG was used to evaluate muscle activation.

Part 3: The effect of an active lumbopelvic stabilization strategy during prone lumbar extension exercises

In this part the effect of an active stabilization strategy during prone extension exercises on the hip, lumbar and thoracic angle was studied. Moreover, the influence of the implementation of this active stabilization strategy on the recruitment patterns of posterior extensor chain muscles was examined. Because lumbar hyperextension is associated with high spinal loads and the development of LBP, excessive extension of the lumbar spine during exercises should be prevented. Several studies have demonstrated alterations in the anterior pelvic tilt and lumbar lordosis using an active strategy which consists of contracting the lumbopelvic muscle corset in order to stabilize the lumbopelvic region. However, no studies have examined if the use of this active stabilization strategy during high load prone extension exercises will influence lumbopelvic kinematics and muscle recruitment patterns. Consequently, the hip, lumbar and thoracic angle as well as recruitment patterns of the posterior extensor chain were examined during prone extension exercises with and without the instruction to actively stabilize the lumbopelvic region using surface EMG. The results of this examination are presented and discussed in chapter 4 (Active stabilization strategy during extension exercises: effect on kinematics and recruitment patterns of the lumbopelvic region. Under revision for the Journal of Electromyography and Kinesiology, 2015).

All studies in this dissertation are performed in healthy individuals, which is necessary in order to comprehend LBP related changes in the muscle activation patterns in future investigations. In the general discussion the findings regarding the influence of exercise modalities, exercise intensity and the use of active stabilization strategies on recruitment patterns during lumbar extension exercises are discussed. Furthermore strengths and
limitations are acknowledged and recommendations for future research are made. Subsequently, a summary of the goal, the methodology and findings described in this dissertation is provided.
6. REFERENCES


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GENERAL INTRODUCTION

Part 1

POSTERIOR EXTENSOR CHAIN MUSCLE ACTIVITY DURING VARIOUS LUMBAR EXTENSION EXERCISES
Chapter 1

Posterior muscle chain activity during various extension exercises: An observational study

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Abstract

Background: Back extension exercises are often used in the rehabilitation of low back pain. However, at present it is not clear how the posterior muscles are recruited during different types of extension exercises. Therefore the present study will evaluate the myoelectric activity of thoracic, lumbar and hip extensor muscles during different extension exercises in healthy persons. Based on these physiological observations we will make recommendations regarding the use of extensions exercises in clinical practice.

Methods: Fourteen healthy subjects performed four standardized extension exercises (dynamic trunk extension, dynamic-static trunk extension, dynamic leg extension, dynamic-static leg extension) in randomized order at an intensity of 60% of 1-RM (one repetition maximum). Surface EMG signals of Latissimus dorsi (LD), Longissimus thoracis pars thoracic (LTT) and lumborum (LTL), Iliocostalis lumborum pars thoracic (ILT) and lumborum (ILL), lumbar Multifidus (LM) and Gluteus Maximus (GM) were measured during the various exercises. Subsequently, EMG root mean square values were calculated and compared between trunk and leg extension exercises, as well as between a dynamic and dynamic-static performance using mixed model analysis. During the dynamic exercises a 2 second concentric contraction was followed by a 2 second eccentric contraction, whereas in the dynamic-static performance, a 5 second isometric interval was added in between the concentric and eccentric contraction phase.

Results: In general, the muscles of the posterior chain were recruited on a higher level during trunk extension (56.6±30.8%MVC) compared to leg extension (mean±SD, 47.4±30.3%MVC) (p ≤ 0.001). No significant differences were found in mean muscle activity between dynamic and dynamic-static performances (p = 0.053). The thoracic muscles (LTT and ILT) were recruited more during trunk extension (64.9±27.1%MVC) than during leg extension (54.2±22.1%MVC) (p = 0.045) without significant differences in activity between both muscles (p = 0.138). There were no significant differences in thoracic muscle usage between the dynamic or dynamic-static performance of the extension exercises (p = 0.574).

Lumbar muscle activity (LTT, ILL, LM) was higher during trunk extension (70.6±22.2%MVC) compared to leg extension (61.7±27.0%MVC) (p = 0.047). No differences in myoelectric activity between the lumbar muscles could be demonstrated during the extension exercises (p = 0.574). During each exercise the LD (19.2±13.9%MVC) and GM (28.2±14.6%MVC) were recruited significantly less than the thoracic and lumbar muscles.

Conclusion: The recruitment of the posterior muscle chain during different types of extension exercises was influenced by the moving body part, but not by the type of contraction. All muscle groups were activated at a higher degree during trunk extension compared to leg extension. Based on the recruitment level of the different muscles, all exercises can be used to improve the endurance capacity of thoracic muscles, however for improvement of lumbar muscle endurance leg extension exercises seem to be more appropriate. To train the endurance capacity of the LD and GM extension exercises are not appropriate.
Introduction

The posterior spine muscle chain consists of the thoracic, lumbar and hip extensor muscles. Optimal condition of this muscle chain includes optimal motor control, strength and endurance, and is a perquisite in the prevention and treatment of low back pain (LBP) in non-athlete and athlete populations [1-3]. Many studies report motor control impairment, decreased muscle strength and endurance in LBP patients [4-12]. With regard to muscle endurance, researchers have found lower endurance times in LBP patients compared to healthy persons [13]. Furthermore Biering-Sorensen reports, that isometric back muscle endurance is a significant predictor of first-time occurrence of LBP among men, and of recurrent LBP [7]. The produced strength of the trunk extensors seems to be less useful for discriminating between healthy people and LBP patients than endurance capacity. Nonetheless, Luoto et al. [6] report that those with poor back muscle strength were 3 times more likely to develop LBP than those with good back muscle strength. Among athletes, sport induced muscles imbalances within the trunk muscles or hip muscles, seem to be related to LBP, due to abnormal spinal loading [14,15]. This implies that a good condition of the posterior muscle chain and a good balance between the lumbar, thoracic and hip extensors is crucial.

Literature provides evidence that endurance and strength training of the trunk extensors is important in the prevention and treatment of LBP [16,17]. Exercise will lead to a decrease in pain and disability, and to a reduction of LBP occurrence among athletes [3,14,15]. Moreover Durall et al. [3] demonstrated that pre-season strength training of the trunk extensors is also beneficial for sport performance in gymnasts. Although several resistance training exercises have been proposed to improve strength and/or endurance of the back muscles, there is little agreement upon which exercises are the most effective [9,17-20]. Extension exercises performed in prone position are frequently described in the literature [18,21-26]. For example prone arch exercises, i.e. combined trunk and leg extension, activate the back muscles at a high level. However, this type of exercise will also cause high spinal compressive loads due to hyperlordosis of the spine [18]. Therefore exercises in which only the subject’s trunk or legs are unsupported, and the neutral lordosis of the low back is sustained, are assumed to be safer [18,27]. This type of exercise will activate the back muscles at 40–70% of their maximal voluntary contraction (MVC) [26,28,29].

Several studies describe that in addition to the thoracic and lumbar muscles, the Latissimus dorsi (LD) and hip extensors contribute during trunk extension performance [28,30-33]. These findings emphasize the importance of a global view on the contribution of various, relevant muscles, when evaluating muscle activity during exercise.

To our knowledge only Plamondon et al. [28] have investigated if differences exist in lumbar muscle activity and the hip extensors during trunk and leg extension exercises in a healthy population. The authors reported that no differences were observed between
the two different types of extension exercise regarding activity of the erector spinae (ES), the multifidus (LM), and the gluteus maximus (GM). This study however did not evaluate the thoracic muscles.

With regard to contraction modalities, back extension exercises can be performed in a static [7,13,21,32-38], dynamic [21,23,28,30,31,38-43], or dynamic-static way [23,28,30,44]. Plamondon et al. [28] described that during the dynamic phase of a trunk extension exercise, the lumbar ES were activated to a higher degree than during the static phase. Furthermore the LM seemed to be less active during isometric trunk extension than during dynamic trunk extension [21]. From the perspective of rehabilitation, a recent study has demonstrated that performing dynamic–static exercises during LBP rehabilitation will result in a better long term outcome compared to dynamic exercises [45,46]. Although the type of contraction seems to play a role in muscle training, at present there are no studies available which have investigated the influence of the contraction modality on the recruitment of the posterior muscle chain.

In order to create specific exercise programs for both elite sportsmen and LBP patients, insights into the relative contribution of the different muscles of the posterior spine muscle chain in healthy persons, during different extension and contraction modalities, are required. This study will be the first to evaluate the recruitment of the hip, lumbar and thoracic trunk muscles during various extension exercises in healthy subjects. Therefore the global posterior spine muscle chain will be evaluated during trunk and leg extensions, and during different contraction modalities (i.e. dynamic and dynamic-static).

Materials and methods

Subjects
Fourteen healthy subjects (6 females, 8 males), with a mean age of 24.7 years and a standard deviation of ±3.2 years volunteered for this study. Subjects had a mean height of 172.9 ±6.4 cm, and mean weight of 64.5 ±12.5 kg, mean Body Mass Index (BMI) of 23.0 ±3.1 kg/m². Subjects were recruited by an advertisement which was spread amongst students and employees from Ghent University and Ghent university Hospital. Exclusion criteria for study participation were a medical consultation for LBP in the past year, current back pain, previous back surgery and spinal deformities. All subjects received a leaflet containing information about the study procedure and were asked to sign the informed consent upon agreement of study participation. The study protocol, information leaflet and informed consent were approved by the local Ethics Committee (Ghent university hospital).
General design
Each subject attended a first testing session, to determine the 1 repetition maximum (1-RM) for each exercise. This was followed by two exercise sessions in which standardized trunk extensions were performed at 60% of 1-RM. The sequence of the four exercises was randomized using lottery, and then distributed among the 2 sessions (two in each session), with at least two days in between the different sessions.

Surface electromyography (sEMG) of the hip, lumbar and thoracic trunk muscles was used to evaluate the muscle activity of the global posterior chain during different modalities of extension exercises. Differentiation between the lumbar and thoracic back muscles was made by detailed electrode placement based on previous work \[45\]. Each exercise session consisted of the electrode placement, measuring the MVC of the different muscles, and the performance of the two different extension exercise modalities.

Electromyography
The sEMG signals of 7 muscles, were bilaterally measured using a 16 channel telemetric surface EMG system (TeleMyo 2400 G2 Telemetry System, Noraxon, USA). To reduce skin impedance and to improve skin contact, the skin was prepared by shaving and rubbing the skin with alcohol. After skin preparation, 7 pairs of surface electrodes (Noraxon dual electrodes) were bilaterally attached, parallel to the muscle fiber orientation over the following muscles \[32,47\]; Gluteus maximus (GM) (midway between the posterosuperior iliac spine and the ischial tuberosity), lumbar Multifidus (LM) (2 cm lateral to the midline of the body, above and below a line connecting both posterior superior iliac spines), Latissimus dorsi (LD) (3 cm lateral and caudal to the angulus inferior of the scapula), Longissimus thoracis pars thoracis (LTT) (at the L1 level, midway between the line through the spinous process and a vertical line through the posterior superior iliac spine), Longissimus thoracis pars lumborum (LTL) (at the L1 level, midway between the lateral palpable border of the erector spinae and a vertical line through the posterosuperior iliac spine), Iliocostalis lumborum pars thoracis (ILT) (at the L1 level, midway between the lateral palpable border of the erector spinae and a vertical line through the posterosuperior iliac spine), and Iliocostalis lumborum pars lumborum (ILL) (at the L4 level, midway between the lateral palpable border of the erector spinae and a vertical line through the posterosuperior iliac spine).

A reference electrode was placed on the angulus inferior of the scapula. The electrodes had a fixed inter-electrode distance of 2 cm and an electric surface contact of 1cm diameter.

The raw signals were bandpass-filtered between 10 and 500 Hz, amplified (common mode rejection ratio >100 dB, overall gain 1000, noise <1 uV Root mean square (RMS)), and analogue-to-digital (16-bit) converted at a sampling rate of 1500 Hz. The signal processing consisted of full wave rectification and smoothing, using a root mean square algorithm with a 100 ms time constant. The RMS is a real time indicator of the amount of electric activity of the investigated muscle.
Muscle activity was measured during all contraction phases of the exercise. As the first repetition was considered as a familiarization repetition, the mean muscle activity level (across all contraction phases) was measured over repetition 2-6 (5 repetitions) and used for further analysis.

**Determination of the exercise intensity (60%RM)**

The exercise intensity for this protocol was set at 60% of 1-RM. The Repetition Maximum represents the maximum number of repetitions performed before fatigue prohibits completion of an additional repetition and generally reflects the intensity of the exercise [46]. The RM was determined for every patient and each exercise during the testing session which took place minimum three days before the first exercise session. To determine the exercise load, all subjects performed a maximal test in which they were asked to execute the maximal amount of repetitions of the dynamic trunk/leg extension with the weight of their upper/lower body as the exercise weight (which is estimated as 70% and 30% of the total body weight respectively). The number of repetitions each subject was able to perform during both types of exercises, using this method, was registered.

The exercise intensity was individually calculated using the following formula [50]:

\[
\text{Exercise load determined on testing day (Holten-diagram)} = \frac{\text{Upper/lower body weight [kg] x Exercise load [60%RM]}}{\text{Exercise load determined on testing day (Holten-diagram)}},
\]

Weight adjustments or assistance during exercises are displayed in **table 1**.

**Exercise protocol**

**Maximal voluntary contraction (MVC)**

In order to compare the muscle activity between muscles, the sEMG data were normalized against their MVC. Before starting the exercises, the MVC’s for the back and hip muscles were measured 3 times during 4 seconds, with 30 seconds of rest between each trial. All tests were performed in prone position. Since the Intraclass Correlation Coefficients (ICC (2,1)) of the MVC’s were found to be high (0.78 - 0.91), the average MVC from each muscle was used for further analysis.

To obtain the MVC of the GM, the knee of the tested side was flexed 90°. The opposite leg was strapped to the table. Maximal resistance against hip extension was given proximal of the knee joint. To measure the MVC of the LD, subjects were lying with their arms in endorotation. Maximal resistance was given proximal of the elbows against retroflexion of the arm [48]. To measure the MVC of the trunk extensors, subjects lay in prone position and had to place the back of their hands on their forehead. The legs were strapped to the table at the middle of the calves. Maximal resistance was given against trunk extension on the angulus inferior of both scapulae [48,49].
Extension exercises
The exercise protocol consisted of four exercises including dynamic trunk extension, dynamic-static trunk extension, dynamic leg extension and dynamic-static leg extension. Between the exercises, a resting period of 40 minutes in lying position, was obligated to prevent muscular fatigue.

In order to perform the trunk extension, subjects were placed in prone position, with the upper body free from the couch, and the superior border of the anterior iliac on the edge of the couch [50]. Their legs were strapped to the couch at the ankles, and hands were placed crossed on the shoulders. The subjects were instructed to raise their upper body from the starting position, i.e. 45° flexion, to horizontal, while looking downward at a visual fixation point. The trunk extension exercise is represented in figure 1.

The leg extension exercise was also performed in prone position on a couch (figure 2). The upper body was strapped to the couch with a belt at the level of the angulus inferior of the scapulae, and hands were positioned under the forehead. The subjects were instructed to lift both legs from the starting position of 45° flexion, to the horizontal.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Adjusted (+) or assistance (-) weight during the different exercises per subject. Accurate to 0.5 kg.</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Dyn Trunk</td>
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<tr>
<td>1</td>
<td>+0</td>
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<td>2</td>
<td>+4</td>
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<td>3</td>
<td>-1</td>
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<td>4</td>
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<td>6</td>
<td>+1</td>
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<td>7</td>
<td>+8.5</td>
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<td>8</td>
<td>+10</td>
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<td>9</td>
<td>-6</td>
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<td>10</td>
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<td>13</td>
<td>+9</td>
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<tr>
<td>14</td>
<td>+5</td>
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<tr>
<td>MEAN</td>
<td>+5</td>
</tr>
</tbody>
</table>

Dyn trunk = dynamic trunk extension; Dyn-stat trunk = dynamic-static trunk extension; Dyn leg = dynamic leg extension; Dyn-stat leg = Dynamic-static leg extension
Both exercises were performed in a dynamic and dynamic-static manner. During the dynamic modality, one repetition consisted of 2 seconds in which the upper body or legs were raised, and 2 seconds during which the upper body or legs were lowered to the start position [42]. During the dynamic-static exercise, the upper body or legs were held in horizontal position during 5 seconds, between the concentric and eccentric phase.

During all exercises, tactile feedback was given by a rope between the two vertical stands to which indicated that the horizontal position had been reached. A metronome (60 beats/min) was used to ensure appropriate timing for the contractions. After each exercise patients assessed the intensity of the exercise by verbally providing a Borg score. The Borg scale measures perceived exertion on a scale from 6-20 (6 = no exertion at all, 20 = maximal exertion).

**Figure 1** Position trunk extension exercises.

**Figure 2** Position leg extension exercises.
Statistical analysis
A mixed model analysis, was conducted with SPSS 19 for Windows (SPSS Inc. Headquarters, Chicago, Illinois), to investigate the influence of 4 independent factors on the posterior chain muscle activity. Following factors were used: factor muscle (7 different muscles), factor side (left and right muscle activity), factor body part (trunk vs leg extension), factor contraction type (dynamic vs static-dynamic extension).

Post hoc comparisons were made with Bonferroni corrections. Because post hoc analysis showed differences between muscles, a second mixed model was performed with the thoracic muscles apart and a third with the lumbar muscles separately. An additional mixed model analysis with factors body part, contraction type and contraction phase (concentric, isometric and eccentric) was conducted for each muscle separately, to investigate the differences in mean muscle activity during the different phases of contraction. Statistical significance for all tests was accepted at the 5% level.

Results
A mixed model analysis showed no significant differences between left and right muscle activity for each exercise, therefore mean muscle activity of both sides for each muscle and exercise was calculated and described in table 2. Mean muscle activity never exceeded 78% of the MVC.

Recruitment of the posterior muscle chain
The model with averaged level of activity among sides showed no significant interaction between the main factors. The factor ‘muscle’ (p ≤ 0.001) and the factor ‘body part’ (p ≤ 0.001) were significant, while the factor ‘contraction type’ (p = 0.053) was not.

Post hoc analysis for ‘muscle’ showed that both the LD and GM were recruited significantly less than the thoracic and lumbar muscles during each exercise. Further analysis of these muscles showed that the mean activity of the LD over all exercises was 19.4±13.9%MVC, while the activity of the GM was slightly higher, namely 28.4±14.6%MVC (p = 0.004) (Figure 3). The type of contraction or the moving body part had no significant influence on the activity of these muscles separately.

Post hoc analyses for ‘body part’ showed that the mean posterior spine muscle usage, was significantly higher during trunk extension (56.6±30.8%MVC) than during leg extension exercises (47.4±30.3%MVC) (figure 3). Thus, independently of the investigated muscle, all muscles were recruited on a higher degree during trunk extension exercises. For all muscles, except for the ILL, the lowest activity was found during dynamic leg extension (9.9-60.0%MVC), however no difference with dynamic – static leg extension (21.9-64.9%MVC) could be established.
Since the post hoc analysis showed that the LD and GM were recruited less than the paraspinal muscles, and given the anatomical and functional differences between the thoracic and lumbar muscles, two more mixed models were conducted without the LD and GM. One model included the thoracic muscles (LTT and ILT), while the other included the lumbar muscles (LM, LTL and ILL).

Recruitment of the thoracic muscles of the posterior muscle chain
For the thoracic muscles, data showed that there was no significant interaction between the main factors. The factor ‘body part’ had a significant influence on the thoracic muscle activity (p = 0.045), while no significant effects could be established for the factors ‘muscle’ (p = 0.574) and ‘contraction type’ (p = 0.138).

This implicates that regarding the performance of the extension exercises, no differences in LTT and ILT activity could be established (Figure 3). Post hoc analysis for ‘body part’ revealed that the thoracic muscle activity was significantly higher during trunk compared to leg extension (mean±SD, 64.9±27.1%MVC vs 54.2±22.1%MVC).

Recruitment of the lumbar muscles of the posterior muscle chain
When the lumbar muscles were examined separately, no significant interaction effects were found between the main factors (p > 0.05), nonetheless the main effect ‘body part’ had a significant effect (p = 0.047) on the lumbar muscle activity. Lumbar muscle usage was higher during trunk extension (70.6±22.2%MVC) compared to leg extension (61.7±27.0%MVC).

No differences between the LM, ILL and LTL could be demonstrated during the extension exercises (p = 0.574). The mean activity level of the LM (62.1%MVC) was slightly, but not significantly lower than the activity of the ILL (68.8%MVC) or LTL (67.8%MVC).

Furthermore, performing the exercises in a dynamic or dynamic-static way did not have an influence on lumbar muscle activity (respectively 68.5%MVC vs 64.8%MVC).

Recruitment of the posterior muscle chain: concentric, isometric and eccentric phase
No main effect for the factor ‘contraction phase’ was found for the LD (p = 0.956) and GM (p = 0.089). No significant differences in mean LD and GM activity could be demonstrated between the concentric, isometric or eccentric phase of contraction, nor during the trunk, nor during the leg extension exercises (Table 2).

For all the paraspinal muscles no interactions between the main factors could be demonstrated, however a significant difference in mean EMG activity between the different contraction phases was noticed for all muscles separately.
Post hoc analysis for ‘contraction phase’ revealed that the LTT and LM activity was significantly higher during the concentric phase of the extension exercises compared to the eccentric contraction phase (respectively, \( p = 0.003 \) and \( p = 0.040 \)). Whereas no significant differences in mean muscle activity between the concentric vs isometric phase and isometric vs eccentric contraction phase existed (\( p > 0.05 \)).

Regarding the ILT, LTL and ILL significantly higher activity levels were found during the concentric contraction phase compared to the eccentric phase of contraction (\( p \leq 0.001 \)). Moreover a significant higher recruitment of these muscles during the isometric contraction compared to the eccentric phase of the dynamic-static extension exercises could be established (resp. \( p = 0.017 \); \( p = 0.002 \); \( p = 0.022 \)).

Mean EMG levels (%MVC) for each contraction phase within the extension exercises are reported in Table 2.
Table 2  Mean muscle activity (±standard deviation) for each muscle during the four extension exercises (%MVIC).

<table>
<thead>
<tr>
<th></th>
<th>LD</th>
<th>LTT</th>
<th>ILT</th>
<th>LTL</th>
<th>ILL</th>
<th>LM</th>
<th>GM</th>
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<tr>
<td><strong>Concentric</strong></td>
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<tr>
<td>Dyn trunk</td>
<td>27.38±6.94</td>
<td>79.03±31.51</td>
<td>64.12±20.72</td>
<td>89.07±19.49</td>
<td>91.47±25.60</td>
<td>78.69±23.88</td>
<td>44.87±30.03</td>
</tr>
<tr>
<td>Dyn-stat trunk</td>
<td>19.43±2.73</td>
<td>69.64±14.57</td>
<td>77.87±23.19</td>
<td>86.90±29.9</td>
<td>75.04±28.92</td>
<td>82.00±30.57</td>
<td>38.18±23.18</td>
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<tr>
<td>Dyn leg</td>
<td>9.72±3.44</td>
<td>67.84±20.68</td>
<td>62.95±10.26</td>
<td>75.24±20.82</td>
<td>88.25±21.64</td>
<td>55.39±8.57</td>
<td>30.33±16.18</td>
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<tr>
<td>Dyn-stat leg</td>
<td>22.64±11.01</td>
<td>81.93±26.91</td>
<td>63.16±31.14</td>
<td>81.36±17.54</td>
<td>79.60±22.21</td>
<td>65.10±36.65</td>
<td>43.25±19.38</td>
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<tr>
<td><strong>Isometric</strong></td>
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<tr>
<td>Dyn-stat trunk</td>
<td>19.30±2.10</td>
<td>69.92±26.48</td>
<td>74.05±21.64</td>
<td>81.54±25.49</td>
<td>70.12±27.10</td>
<td>70.23±29.52</td>
<td>35.49±12.99</td>
</tr>
<tr>
<td>Dyn leg</td>
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<td>N.A.</td>
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<tr>
<td>Dyn-stat leg</td>
<td>20.56±11.63</td>
<td>66.23±31.16</td>
<td>61.15±27.07</td>
<td>77.00±19.56</td>
<td>72.73±21.67</td>
<td>65.77±30.66</td>
<td>35.27±30.29</td>
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<tr>
<td><strong>Eccentric</strong></td>
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<tr>
<td>Dyn-stat trunk</td>
<td>19.06±3.97</td>
<td>60.17±27.79</td>
<td>44.02±15.61</td>
<td>57.56±23.71</td>
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<tr>
<td>Dyn leg</td>
<td>9.84±3.51</td>
<td>46.84±14.60</td>
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</tr>
<tr>
<td>Dyn-stat leg</td>
<td>20.85±7.51</td>
<td>54.76±10.05</td>
<td>51.16±26.47</td>
<td>48.03±11.03</td>
<td>47.71±15.60</td>
<td>58.59±30.25</td>
<td>14.94±9.59</td>
</tr>
</tbody>
</table>

LD = latissimus dorsi, LTT = longissimus thoracis pars thoracic, LTL = longissimus thoracis pars lumborum, ILT = Iliocostalis lumborum pars thoracis, ILL = Iliocostalis Lumborum pars Lumborum, LM = Lumbar Multifidus, GM = Gluteus maximus, N.A. Data Not available.
### Borg score

The mean Borg score was significantly higher during trunk extension (15.5±1.6) than during leg extension (13.8±1.3) \((p = 0.013)\). In addition there was a significant difference regarding the type of contraction. The rate of perceived exertion was higher during dynamic-static exercises (15.7±1.6) than during dynamic exercises (13.7±1.9) \((p \leq 0.001)\).

### Discussion

The present study was designed to investigate whether the amount of activity (％MVC) of the different parts of the posterior spine muscle chain is influenced by different extension exercise modalities. Therefore the mean muscle activity was analyzed during four different extension modalities.

The results of this study show that all muscles of the posterior chain were, given the intensity of 60% of 1RM, active within the expected range during the different trunk and leg extension exercises in healthy individuals. The LD and GM however played a smaller role compared to the paraspinal muscles. The recruitment of the GM and LD during an extension movement of the spine can be clarified by the coupling between these muscles and the paraspinal muscles, which is formed through the fascia thoracolumbalis [51]. The lower activity levels of both GM and LD are in agreement with previous findings [21,26,32,52] and can be explained by the main function of these muscles, which is not back extension but arm and leg extension respectively. In contradiction with our results, other authors suggest a major role of the GM during trunk extension which is dependent upon the intensity of the exercise [40]. These authors suggest that with increasing load and repetitions, the lumbar muscles become less responsible for maintaining the force output, while the GM becomes more powerful and responsible for the force output [40]. In the current study only 5 repetitions were investigated which was probably not sufficient enough to induce similar alterations in the muscle recruitment pattern. These results indicate that for specific strengthening of the LD or the GM other exercises are more appropriate. Nevertheless, we showed that these muscles are contributing to the extension movement.

In literature, a wide variety of muscle activity levels during trunk and leg extension exercises are reported. Different exercise set –ups (starting angle, contraction modality, hand position) and used methods for measuring muscle activity (electrode placement) have been used, making comparisons between results difficult. In the current study mean thoracic and lumbar muscle activity ranged from 45 to 78% of the MVC. These findings are comparable with the findings for the studies of Arokoski et al. [21] and Ng et al. [26,33]. However, the observed activation of the lumbar spinal muscles is slightly higher than reported by Plamondon et al. [52]. The higher muscle activity in the present study could
be explained by the difference in arm position between the studies. In the current study the arms were positioned further away from the center of gravity compared to the arm placement used in the study of Plamondon et al. [52], which resulted in a bigger lever arm and higher muscle recruitment [39].

Although the lumbar and thoracic paraspinal muscles can act synergistically to produce an extension force, several studies suggest that the back muscles are not one homogeneous muscle mass [32,53-55]. The back muscles are composed of different groups of fascicles with different functions. Therefore a distinction, based on anatomical and functional differences, between the thoracic and lumbar muscle groups is necessary.

Both muscle groups cross the lumbar spine, whereas the lumbar muscle parts directly attach on to the lumbar vertebrae, the thoracic parts originate from the thorax and insert in long tendons that form the erector spinae aponeurosis [54]. The thoracic muscles, which are located more superficial, are be more force producing muscles, whereas the deeper lumbar muscles (especially the LM) tend to have a more specific stabilizing function of the spine. Therefore, we decided to investigate the thoracic (LTT and ILT) and lumbar extensor (LTL, ILL, LM) groups separately.

To our knowledge only few researchers have previously investigated the contribution of the LTT and ILT during extension exercises. The amount of thoracic muscle activity (45-64% MVC) in the current study is comparable with findings from previous reports during trunk extension in healthy people, although they did not make a distinction between the LTT or ILT as was done in the present study [18]. The necessity to make a distinction between these thoracic muscles has been demonstrated by Coorevits et al. [32], who showed that the LTT has a higher fatigue rate then the ILT during trunk extension in healthy people. Although the current study did differentiate between the thoracic muscles we did not find any differences between the thoracic muscles during performance of the extension exercise modalities which were previously described. The current study did reveal a higher contribution of the lumbar and thoracic muscles during trunk extension exercises than during leg extension exercise. To our opinion the difference can be attributed to the different kinematics and coupled muscle function between the two exercises. A trunk extension from departing from 45° trunk flexion can be seen as a dynamic pelvic and trunk movement. The leg muscles will extend the pelvis, the lumbar muscles will stabilize and extend the lumbar region on the pelvis, and the thoracic muscles will actually lift the trunk. On the contrary, with a fixed trunk in a horizontal position and the hips in a starting position of 45° flexion, most of the dynamic work is performed by the leg muscles while both back muscles groups deliver more static work. The back muscles need to stabilize the pelvis and spine to make leg lifting possible.

Literature provides evidence that during concentric muscle work higher levels of activity are produced than during static work [30]. No earlier study has made the comparison in thoracic and lumbar muscle recruitment during both trunk and leg extension which emphasizes the relevance of the current study.
A homogeneous recruitment pattern of the lumbar muscles was observed during extension exercises. In agreement with Callaghan [18], we found the LM activity did no differ from ILL and LTL activity. However previous studies showed significant higher recruitment of the LM and the LTL, compared to the more lateral ILL, during trunk extension in healthy subjects [32,56]. In addition, using MRI, a previous study showed higher activity of the LM compared to ILL and LTL during trunk extension in chronic LBP patients [43]. Moreover Ng et al. found higher activity of the LM compared to iliocostalis and Longissimus thoracis during respectively a trunk holding and leg holding test [26,33]. Possible explanations for the contradicting results are differences in exercise and measuring protocol. Coorevits et al. [32] objectified muscle fatigue whereas the present study measures the averaged muscle recruitment. Furthermore Coorevits et al. [32] and Ng et al. [26,33] studied muscle activity during isometric contraction, while in the present study dynamic and dynamic–static contractions were used. A second explanation of the homogeneous lumbar muscle usage found in the present study, could be the relative high intensity of the exercise (60% 1-RM). Since Mayer et al. [57] demonstrated that the contribution of the lumbar parts of the erector spinae compared to the LM was higher with increasing intensity, it is possible that in order to obtain a force output at 60% of the RM all the muscles are recruited at a comparable intensity. Therefore, further investigation regarding lumbar muscle activity in low load conditions is recommended. It is possible that, in agreement with the evidence of functional differences between the lumbar muscles [48,58], these low load conditions are more sensitive for differences in recruitment.

In contrast with a previous investigation [23], this study shows that lumbar muscle activity was higher during trunk than during leg extension. Discrepancies in exercises intensity and starting angle could explain the contradicting results. In the study of Plamondon et al. [23] the weight of the body part was not taken into account, which complicates the comparison with the current results. In the present study, based on the results of the pretest, all exercises were set at an equal intensity (60% of 1-RM) by adding weight or assisting the body part. Moreover, in the study of Plamondon et al. [28] leg extension was performed at 60° and trunk extension at 45° of flexion, while in our study both exercises were performed at 45° flexion. As suggested by Mannion et al. [59] changes in muscle length, induced by differences in starting angle, have a significant effect on force output of these muscles. Based on the Borg score, subjects experienced trunk extension as more intensive than leg extension, although the intensity of both exercises was equal. An explanation could be found in the muscles activity levels. Logically, because thoracic and lumbar muscles were recruited at a higher degree during trunk compared to leg extension, trunk extension was experienced as more fatiguing. The subjective feeling of heaviness, is normally determined by the weakest link. However, we did not inquire the region (upper, lower back or legs) of heaviness, so no judgment can be made about which muscle group is determining the feeling of heaviness. Further research into this aspect is warranted.
Our results also indicate that the modality of contraction (dynamic or dynamic-static) does not affect posterior muscle chain recruitment patterns. To our knowledge a comparison of back muscle activity between dynamic and dynamic-static extension exercises has not been investigated earlier. But in line with these results regarding muscle recruitment, Danneels et al. [22] found no difference in increase of the lumbar spinal muscle cross sectional area between dynamic and dynamic-static extension training.

Inspired by the basic principles of muscle training, when the goal of the exercises is to train muscles in terms of endurance, the intensity must be drawn up to a percentage of 60 [57]. The results of the current study show that when extension exercises are performed at 60% 1-RM, the amount of thoracic muscle activity during all exercises was comparable with the predetermined intensity. Therefore all types of extension exercises are suitable to improve the endurance capacity of the thoracic muscles. The level of lumbar muscle activity during leg extension exercises was also in agreement with this level of the exercise intensity (±60% 1-RM). On the contrary, during trunk extension, the amount of lumbar muscle activity clearly exceeded this level. This means that in clinical practice leg extension can be used to train lumbar muscle endurance, whereas trunk extension exercises at 60% of the 1RM target the lumbar muscles at a higher training level. The recruitment of the GM and LD remained far below 60%MVC, so to enhance the endurance of these muscles other exercises will be more appropriate.

Regarding the recruitment of the posterior muscle chain during the different phases of contraction, the present study showed higher levels of recruitment of all paraspinal muscles during the concentric compared to the eccentric contraction phase of the extension exercises. Higher muscle activation during concentric versus eccentric contraction was already demonstrated by other authors [23,60]. Plamondon et al. found the highest ES activity levels at L5/S1 near the horizontal position of the trunk, so during the concentric phase of the prone back extension exercises, and the lowest levels during the eccentric phase [23]. However, they did not report statistical significant differences. Moreover, Babault et al. reported lower activation levels of the knee-extensors during an eccentric compared to a concentric and isometric contraction of these muscles, which is probably due to a decreased voluntary activation during eccentric contractions [60]. Another explanation could be that during dynamic conditions there is a lower recruitment threshold, so full recruitment in dynamic conditions achieved at lower relative force levels compared to an isometric condition [61]. However, this statement cannot explain the higher activity levels of the ILT, LTL and ILL during isometric compared to eccentric contraction.

In the present study we studied a young healthy population. Since altered muscle activation patterns within specific populations are demonstrated [62], the results of the current study cannot be generalized to LBP patients.
Conclusion

Our results demonstrated that recruitment of the posterior muscle chain during extension exercises at 60% 1-RM was influenced by the body part that was extended, but not by the type of contraction (dynamic or dynamic-static).

The activity of the thoracic extensors varied between 54% and 64%MVC during respectively leg and trunk extension, which is comparable with the premised intensity of 60% 1-RM. This suggests that to improve the endurance capacity of the LTT and ILT all four types of extension exercises could be used.

However, the activity of the lumbar muscle group exceeded the 60%MVC during the trunk extension exercises, whereas during leg extension the lumbar muscles were recruited less. This means that in clinical practice, therapists can use leg extension to ameliorate lumbar muscle endurance, whereas trunk extension exercises can be used to specifically activate the lumbar muscles and enhance their strength and endurance (70% 1-RM).

The LD and GM were activated at a low degree during all exercises, which implicates that to enhance the endurance capacity of these muscles other exercises than extension exercises, are more indicated.

Competing interests
The author(s) declare that they have no competing interests.

Author’s contributions
EMDDR participated in the study design, in collecting the data, the statistical analyses, and drafting of the manuscript. AV, GGV and JOVO participated in the progress and drafting of the manuscript. LAD and JOVO participated in the interpretation of the statistical findings. LAD participated in the study design and in the progress and drafting of the manuscript. All authors read and approved the final manuscript.

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References


Chapter 2

Muscle functional MRI analysis of trunk muscle recruitment during extension exercises in asymptomatic individuals

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Abstract

The present study examined the activity levels of the thoracic and lumbar extensor muscles during different extension exercise modalities in healthy individuals. Therefore 14 subjects performed 4 different types of extension exercises in prone position: dynamic trunk extension, dynamic-static trunk extension, dynamic leg extension, and dynamic-static leg extension. Pre- and post-exercise muscle functional magnetic resonance imaging scans from the Latissimus dorsi, the thoracic and lumbar parts of the Longissimus, Iliocostalis and Multifidus were performed. Differences in water relaxation values (T2-relaxation) before and after exercise were calculated (T2-shift) as a measure of muscle activity and compared between extension modalities. Linear mixed model analysis revealed higher lumbar extensor activity during trunk extension compared to leg extension (T2-shift of 5.01ms and 3.55ms respectively) and during the dynamic-static exercise performance compared to the dynamic exercise performance (T2-shift of 4.77ms and 3.55ms respectively). No significant differences in the thoracic extensor activity between the exercises could be demonstrated. During all extension exercises the Latissimus dorsi was the least activated compared to the paraspinal muscles. While all extension exercises are equivalent effective to train the thoracic muscles, trunk extension exercises performed in a dynamic-static way are the most appropriate to enhance lumbar muscle strength.
Introduction

Up to 40% of the athlete population is affected by low back pain (LBP), which is the most common cause of lost playing time in professional sports (Bono, 2004). Sport induced muscles imbalances within the trunk or hip muscles seem to be related to LBP (Renkawitz et al., 2006 and 2008). Furthermore there is considerable evidence that trunk muscle strength and endurance do not only play a key role in the prevention and treatment of LBP (Holmstrom et al., 1992; Luoto et al., 1995; Moffroid, 1997; Kuukkanen & Malkia, 1996; Mannion et al. 2001a and 2001b; Holm & Dickinson, 2001; Kell & Asmundson, 2009) but are also related to sport performance (Smith et al., 2008; McGill, 2010). As decreased muscle performance implicates a lower fatigue threshold, the precision and control of movements is reduced which results into a poorer sport performance (Durall et al., 2009). This implies that optimal functioning of the trunk extensors is beneficial for sport performance in athletes.

Athlete training and LBP rehabilitation programs exist of different exercise regimes, which are performed to enhance trunk extensor muscle strength, endurance and spinal control, and will lead to decreased levels of pain and disability (Henchoz & So, 2008; Henchoz et al., 2010; Franca et al., 2010; Franca et al., 2012). While spinal control is optimized during stabilization and mobilization exercises, muscles strength and endurance are often enhanced by extension exercises of the trunk and/or the legs. These extension exercise are performed in a dynamic or dynamic-static way and specifically strengthen the thoracic and lumbar extensors. However, at present it is not clear to which extent the contraction modality (dynamic versus dynamic-static and trunk extension versus leg extension) influences the activation of the thoracic and lumbar extensors. This due to the scarce literature regarding this topic and the lacunas in existing studies. The few studies that exist have either compared muscle activation patterns between dynamic and dynamic-static contractions or between trunk and bilateral leg extension exercises and have reported conflicting results. Although these studies have used electromyography (EMG), more recently muscle functional Magnetic Resonance Imaging (mfMRI) has been used to determine the amount of muscle activity during exercise. Its main advantage compared to surface EMG is its superior spatial resolution, imaging deep and superficial muscles simultaneously at multiple levels and both sides of the spine (Adams et al., 1992; Cagnie et al., 2009; Dickx et al., 2010a and 2010b; Mayer et al., 2005). Although fine wire EMG can also be used to investigate the activity of deep muscles, it only provides an idea on electrical activity of a few motor units and is invasive in nature.

Whereas, EMG has been widely used to investigate thoracic and lumbar muscle activation, and lumbar muscle work has frequently been investigated during trunk extension, studies in which both thoracic and lumbar muscle activity during trunk and leg extension exercises is measured with mfMRI are nonexistent. Therefore, this study was the first to
evaluate simultaneously the amount of activity of the thoracic and lumbar muscles during standardized extension exercises with mfMRI in healthy subjects.

The present study examined 1) the influence of different exercise modalities, i.e. trunk or leg extension, on the amount of the thoracic and lumbar extensor muscle activity by evaluating the T2-shift, and 2) whether the findings were influenced by the contraction modality of the exercise, i.e. dynamic or dynamic-static contraction. It was hypothesized that the thoracic extensors, which are conjoining the thorax with the pelvic via long tendons, will be recruited more during trunk extension compared to leg extension. Whereas leg extension may generate more activity of the lumbar extensors, which directly attach onto the lumbar vertebrae. Regarding the contraction modality it was hypothesized that both the thoracic and the lumbar extensors will show bigger T2-shifts during the dynamic-static exercise performance compared to the dynamic exercises.

Materials and methods

Subjects
Fourteen subjects, 8 males and 6 females, participated in this study. Subjects were characterized by a mean age of 24.73 ± 3.19 years, mean height of 172.9 ± 6.4 cm, mean weight of 64.47 ± 12.5 kg and Body Mass Index (BMI) of 22.98 ± 3.1 kg/m², indicating normal weight.

Study design
An observational study to evaluate the recruitment of thoracic and lumbar extensor during different extension exercises was conducted on fourteen healthy individuals. Subjects were recruited through adverts which were spread amongst personal contacts of the researchers, the staff of Ghent University and Ghent University Hospital. If subjects experienced back pain recently, had a medical consultation concerning LBP in the past year, reported previous back surgery or spinal deformities, or when MRI was contradicted they were not eligible for study participation.

Each subject attended 3 sessions. The first session included a consultation of the information leaflet and signing the informed consent followed by anthropometric measurements and determination of the one repetition maximum (1-RM) for each extension exercise. Four different modalities of extensions exercises (i.e. dynamic trunk extension, dynamic-static trunk extension, dynamic leg extension and dynamic-static leg extension) were performed during the 2nd and 3rd session. Two exercise modalities were performed during the 2nd session and 2 during the 3rd session. The exercise sequence was randomized and determined by lottery. MRI scanning was performed before and immediately after performing each exercise modality To prevent the potential influence
of muscle fatigue a rest period of 40 minutes was provided between the two extension exercise modalities. There were at least 7 days between the 2nd and 3rd session. The study protocol, information leaflet and informed consent were approved by the local Ethics committee.

**Extension exercises**

To perform the trunk extension exercises subjects were installed in prone position on a variable angle chair, with their upper body in a 45° of trunk flexion. The superior border of the anterior iliac (SIAS) was positioned on the edge of the table and the ankles were strapped to the table. Hands were placed on the opposite shoulder ([figure 1](#)). The dynamic trunk extension implied that subjects raised their trunk to the horizontal in 2 seconds and returned to the start position in 2 seconds. During the dynamic-static trunk extension the trunk was raised to the horizontal in 2 seconds, the horizontal position was maintained for 5 seconds after which the subject returned to 45° flexion in 2 seconds.

To perform leg extension exercise subjects were installed in prone position with their lower body positioned at 45° flexion. The upper body was strapped at the level of the angulus inferior of the scapulae, hands were positioned under the forehead ([figure 2](#)). The dynamic leg extension consisted of a 2-second raise of the legs till the horizontal, followed by a period of 2 seconds to return to the start position. During the dynamic-static leg extension, the legs were extended horizontally in 2 seconds, held in that position during 5 seconds, and lowered in 2 seconds.

To reach the horizontal position, tactile feedback was given by a rope between the two vertical stands. A metronome (60 beats/min) was used to ensure appropriate timing of the different movements. A set of twenty repetitions of each exercise modality was performed continuously at an exercise intensity of 60% of 1-RM. Thus to complete the dynamic-static exercise 180 seconds (20 repetitions x 9 seconds) were needed, while the dynamic exercise condition was finalized in 80 seconds (20 repetitions x 4 seconds).

**Determination of the exercise intensity (60% 1-RM)**

Minimum 3 days before the 2nd session took place, the individual 1-RM was indirectly determined by registering the maximum number repetitions participants could perform of each exercise modality with the weight of their upper/lower body as the exercise weight. Each 1-RM test was executed in the same position, over the same range of motion, and with an identical timing as during the respective exercise modality.

Afterwards, the exercise load (kg) corresponding to 60% of 1-RM, was estimated using the Holten-diagram. This diagram describes the relation between the performed number of repetitions and the exercise intensity (Danneels et al., 2001b). Calculation of the individual exercises weight occurred identically as described by Dickx et al. (2010a), using following formula: (Upper/lower body weight [kg] x Exercise load [60%RM]) / Exercise load.
determined on testing day [Holten-diagram]. The weight of the upper body is calculated as 70% of the total body weight and of the lower body as 30% of the total body weight. The total body weight was determined on a body scale during the first session. To adjust the exercise weight, the body was assisted via a load-pulley system or extra weights were added (table 1). Extra weight was added to the trunk by holding weight pockets against the chest by crossing their arms. In order to adjust the leg extension, exercise weight cuffs were tied around both thighs.

**Muscle functional MRI (mfMRI)**

A 3-Tesla Trio Trim scanner (Siemens Erlangen®) was used to assess changes in the relaxation time of muscle water (T2-relaxtion time) as a result of muscle work during the
extension exercises. The amount of muscle activity can be assessed by quantifying shifts in T2-relaxation times and is expressed as the T2-shift. (Meyer & Prior, 2000). To ensure a neutral spine position, subjects were placed symmetrically in supine position, with their head first. Two coils were used to partly cover the thoracic and lumbar spine: ventral, a flexible 6-element body matrix coil centered on the belly button and dorsal a standard phased-array spine coil was positioned. Two transversal slices corresponding the lower endplate of T12 and the lower endplate of L4 (Danneels et al., 2001a) were positioned as horizontal as possible on a sagittal view. A spin-echo multi-contrast sequence (Semc) was used for the acquisition of T2 weighted images. The following parameters were applied: repetition time 1000ms, 256x176mm² matrix, 256 mm field of view (FOV), slice thickness 5mm. Total scan time was 6 minutes 15 seconds. The images were obtained after a period of 15 minutes of prone lying (rest T2), and immediately following the exercises (exercise T2). The time span between the end of the exercise and the beginning of the scan ranged

Table 1 Individual load adjustments of the extension exercises at 60% 1-RM.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Dynamic Trunk Extension</th>
<th>Dynamic-Static Trunk Extension</th>
<th>Dynamic Leg Extension</th>
<th>Dynamic-Static Leg Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Load</td>
<td>Repetitions</td>
<td>Load</td>
<td>Repetitions</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>28</td>
<td>-1,5</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>35</td>
<td>-1</td>
<td>26</td>
</tr>
<tr>
<td>3</td>
<td>-1</td>
<td>26</td>
<td>-17</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>14</td>
<td>49</td>
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<td>25</td>
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<td>5</td>
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<td>20</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>29</td>
<td>-5</td>
<td>20</td>
</tr>
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<td>7</td>
<td>8,5</td>
<td>42</td>
<td>5</td>
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</tr>
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<td>-2,5</td>
<td>24</td>
</tr>
<tr>
<td>11</td>
<td>4</td>
<td>35</td>
<td>0</td>
<td>27</td>
</tr>
<tr>
<td>12</td>
<td>-1,5</td>
<td>25</td>
<td>-6,5</td>
<td>16</td>
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<tr>
<td>13</td>
<td>9</td>
<td>40</td>
<td>1</td>
<td>29</td>
</tr>
<tr>
<td>14</td>
<td>5</td>
<td>34</td>
<td>-3</td>
<td>22</td>
</tr>
<tr>
<td>MEAN (kg)</td>
<td>5</td>
<td>-3</td>
<td>5,5</td>
<td>0</td>
</tr>
</tbody>
</table>
from 1 minute 55 seconds to 2 minutes 30 seconds. Scanning was performed before and immediate after performance of every extension modality. Between two different exercise modalities subjects rested in prone lying over a period of 40 minutes to ensure that the T2-values were able to decrease to baseline values.

The MRI Images were analyzed using Image J (Java-based version of the public domain NIH Image Software, Research Services Branch, National Institutes of Health). Using the ‘MRI analysis calculator plug in’ a T2-value (in milliseconds) per voxel was calculated out of 16 echoes. Subsequently, the region of interest (ROI) was determined on all images by drawing the outlines of all muscles, avoiding visual fat, blood vessels and connective tissue. This method has proven to be reliable in previous work (Danneels et al 2000; Dickx et al., 2010b; D’Hooge et al., 2013).

At T12 the Latissimus dorsi (LD) and the thoracic parts of the Longissimus (LT) and Iliocostalis (IT) were analyzed bilaterally (figure 3). At L4 the MF and the lumbar parts of the Longissimus (LL) and Iliocostalis (IL) were analyzed. Figure 4 represents the MF, LL and IL on a mfMRI image. Finally, the mean T2-value was derived for each ROI and used for further analysis.

**Statistical analysis**

SPSS 19.0 (IMB corporation, Somers, NY, USA) was used to carry out statistical analyses. At first, baseline and post-exercise T2-values of the thoracic and lumbar muscles of the left and the right side were averaged, due to the symmetry of the exercises and the lack of significant side differences in T2-values (p<.05). In addition the symmetry of the exercise was monitored by surface EMG, the results which are published elsewhere confirmed the lack of significant side differences (De Ridder et al., 2013). Subsequently, descriptive statistics (means and SD) were calculated for the anthropometric group characteristics and T2-values.

To investigate the T2-shift values (i.e. the difference in T2-values between post-exercise and baseline) of the back muscles between different exercise modalities, a linear mixed model analysis was conducted. Following main factors were used; **muscle** (LD, IT, IL, LT, LL, MF), **extension modality** (trunk vs leg extension) and **contraction type** (dynamic vs dynamic-static). In case one of the main factors were significant, separate mixed models were conducted. Post-hoc comparisons were made when required and adjusted using a Bonferroni-correction. Statistical significance for all tests was set at p≤.05 (CI 95%).
Results

Recruitment of the trunk muscles

The mixed model analysis which was used to examine the T2-shift in thoracic and lumbar muscles between and within the different extension exercise modalities showed no significant interaction effects between the main factors, whereas the main factors muscle \( (p<0.001) \) and extension modality \( (p=0.045) \) had a significant effect on the T2-shift. No main effect for contraction type \( (p=0.193) \) could be established. A post hoc comparison between the different trunk extensors demonstrated that during all exercise modalities the LD was recruited significantly less compared to all other trunk extensors (fig 5). No differences between the other muscles could be established.

Figure 3 Image at lower endplate level T12

1= Latissimus Dorsi, 2 = Longissimus thoracis pars Thoracic, 3 = Iliocostalis lumborum pars Thoracic

Figure 4 Image at lower endplate level L4

1= Multifidus, 2= Longissimus thoracis pars Lumborum, 3= Iliocostalis lumborum pars Lumborum
### Table 2 Shift of the T2-values of the trunk extensor muscles in response to each extension exercise modality.

<table>
<thead>
<tr>
<th>Muscles</th>
<th>Dynamic Trunk Extension</th>
<th>Dynamic-Static Trunk Extension</th>
<th>Dynamic Leg Extension</th>
<th>Dynamic-Static Leg Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T2 pre</td>
<td>T2 post</td>
<td>T2-Shift</td>
<td>T2 pre</td>
</tr>
<tr>
<td>LD</td>
<td>45.24±4.25</td>
<td>46.60±5.91</td>
<td>1.36±2.70</td>
<td>45.14±3.98</td>
</tr>
<tr>
<td>LT</td>
<td>47.66±7.13</td>
<td>54.45±4.81</td>
<td>6.40±5.40</td>
<td>47.83±4.79</td>
</tr>
<tr>
<td>IT</td>
<td>49.27±5.65</td>
<td>55.35±6.60</td>
<td>6.05±5.67</td>
<td>48.33±3.22</td>
</tr>
<tr>
<td>LL</td>
<td>47.67±3.01</td>
<td>52.15±3.58</td>
<td>4.40±5.11</td>
<td>46.95±2.33</td>
</tr>
<tr>
<td>IL</td>
<td>47.03±4.00</td>
<td>51.63±2.58</td>
<td>4.60±2.72</td>
<td>46.30±2.85</td>
</tr>
<tr>
<td>MF</td>
<td>48.83±4.63</td>
<td>53.75±3.76</td>
<td>4.09±1.67</td>
<td>46.85±2.77</td>
</tr>
</tbody>
</table>

Mean T2-value (in ms) and standard deviation (±SD) at rest (PRE), after performing the exercise (POST), and difference between the two conditions (T2-SHIFT). LD=Latissimus Dorsi, LT=Longissimus thoracis pars Thoracic, IT=Iliocostalis lumborum pars Thoracis, LL=Longissimus thoracis pars Lumborum, IL=Iliocostalis lumborum pars Lumborum, MF=Multifidus.
Moreover, post hoc data revealed that in general the mean T2-shift of all trunk muscles (mean of the sum of all T2-shift values) was significantly higher during trunk extension than during leg extension, regardless of the type of contraction (p=0.045).

Due to the significance of the factor muscle, reflecting possible anatomical and functional differences between the thoracic and lumbar muscles, two new mixed models were conducted using the same factors but one including the thoracic muscles (IT and LT) and one the lumbar muscles (IL, LL and MF).

**Recruitment of the thoracic muscles**

An analysis of only the thoracic muscles was performed and showed no 3-way or 2-way interaction effects between the main factors. Furthermore the T2-shift of the IT was not significantly different from the T2-shift of the LT during the extension exercises (muscle p=0.574). Moreover, nor the extension modality (trunk or leg extension), nor the contraction type (dynamic vs dynamic-static) had a significant effect on the shift in T2-values of the thoracic muscles (p-values of p=0.902 and p=0.591 respectively). The mean T2-values of the thoracic muscles during all exercise modalities are presented in table 2.

**Recruitment of the lumbar muscles**

The analysis which included solely the lumbar muscles, showed no 3-way or 2-way interaction effect between the main factors, however a clear significant main effect of extension modality and contraction type were demonstrated. Lumbar muscles were recruited at a higher degree during the trunk extension exercises (T2-shift of 5.01 ms) compared to the leg extension exercises (p≤0.001) (T2-shift of 3.55 ms). Furthermore the dynamic-static extension exercises demanded more lumbar muscle work than the dynamic extension exercises (p≤0.014) (T2-shift 4.77 vs 3.78 ms). The mean T2-shift of the lumbar muscles during the different exercise modalities are displayed in figure 5.
**Discussion**

The present study examined whether the amount of activity (estimated by the shift in T2-values) of the trunk extensor muscles is influenced by different modalities of extension exercises i.e. which body part is extended (trunk or legs) and in which way the extension exercise is performed (dynamic or static-dynamic).

The difference in mean T2-shift of the thoracic and lumbar extensors, between the various exercise conditions, supports the hypothesis that the activity level of the back extensors is influenced by the manner in which an extension exercise is performed.

These results implicate that, although the exercise load of the different exercises was identical, the T2-shift of the lumbar muscles was higher during trunk extension exercises.
compared to leg extension exercises. The higher shift implies enhanced levels of (metabolic) activity within the lumbar muscles when performing a trunk extension compared to a leg extension exercise, which is the result of more activity of the lumbar muscles. Although previous studies already showed that the thoracic and lumbar extensors are activated during extension exercises (Clark et al., 2002; Mayer et al., 1999 and 2002; Plamondon et al., 1999 and 2002), to our knowledge this is the first study to compare differences in the activity level of thoracic and lumbar extensor muscles and between different trunk and leg extension exercises. In addition this is the first study on this topic using mfMRI. The results confirm our previous findings which were obtained using sEMG and using an identical exercise protocol on the same study population (De Ridder et al., 2013).

The increased lumbar muscle activity during trunk extension in the present study, is inconsistent with the results of Plamondon et al. (2002). Those authors reported greater levels of lumbar extensor spinae muscles (LES) during performance of a dynamic prone leg extension compared to a dynamic prone trunk extension. However we need to considered that Plamondon et al (2002) used a different technique to evaluate lumbar muscle usage. While they used sEMG measures which reflect the real time ‘neural’ muscle changes upon exercises, in the current study mfMRI was used which displays the acute activity-induced prolongation of T2-relaxation times of muscle water. Furthermore inequalities in starting angle exist between the two studies, which could have a significant effect on the muscle force production, due to differences in muscle length (Mannion & Dolan,1996).

The present study was unable to demonstrate differences among the lumbar muscles, which suggest a similar action of these muscles during the extension exercises. This finding is in line with Danneels (2002), who described that the MF and IL have a similar function during trunk movements. However, Ng et al. (1997; 1999) found that the MF was more activated than the IL or LL during respectively isometric trunk and leg holding. The discrepancy between these results could be explained by dissimilarities in exercise modality. Ng et al. (1997; 1999) studied isometric exercises, while the current study examined dynamic and dynamic-static contractions. Since it has been demonstrated that the MF has a more stabilizing function compared to the IL and LL (Wilke et al., 1995), isometric contractions could be more sensitive to little variations in function.

There are few other studies which used MRI to examine differences in lumbar muscle recruitment during trunk extension in a healthy population (Dickx et al.,2010b; Mayer et al., 2005). Mayer et al. (2005) demonstrated higher activity of the MF compared to the LES during dynamic trunk extension, and showed that there was a relationship between lumbar muscle contribution and exercise intensity. This relationship could explain previous
described differences in study findings. More specifically, when a relative high load exercise is performed, as was the case in the present study, the different muscles are recruited in a homogeneous way in order to obtain and maintain a relative high force output. As other studies did not adjust or report the exact exercise intensity, we assume that these low load exercises, are more sensitive to objectify subtle differences in muscle activity. Further investigation in low load conditions is recommended to verify this assumption.

Besides the influence of the extended body part, we also showed clear differences in lumbar muscle usage between a dynamic and dynamic-static performance of the extension exercises.

Although the exercise intensity was identical in both cases, performing the extension exercises in a dynamic-static way caused a higher T2-shift of the lumbar muscles compared to a dynamic contraction. The acute higher metabolic reactions in response to the dynamic-static performance could support the findings of Danneels et al. (2001), who studied the long term effects of two training programs on the cross sectional area (CSA) of the paravertebral muscles. They demonstrated that an increase in the CSA of the paravertebral muscles occurred after dynamic-static muscle training, whereas dynamic training did not affect CSA. On the long term, the higher metabolic cost of dynamic-static exercises may have triggered the volume growing effect within the lumbar muscles, which resulted in a higher CSA.

Since the contraction type (and the duration) of both modalities (dynamic versus static-dynamic) differed, both conditions were tested separately in advance and the load (number of kilograms of resistance) was individually adapted to express 60% of 1-RM. Following this procedure the exercise load which was applied in the static-dynamic condition was systematically lower than the load used in the dynamic version. This ensured that the exercise intensity of both exercises was identical. But although the perceived intensity was identical, it is apparent that the nature of the muscle contraction is different. We can assume that during a static muscle contraction the arterial pressure is higher and the blood flow is lower compared to a dynamic muscle contraction (Masuda et al., 1999; Vanderthommen et al., 2003; Arimoto et al., 2005). In this way, the added static element during the dynamic-static exercise condition, could have resulted in an increased lactic acid accumulation compared to the dynamic condition. However future exercise studies in which mfMRI is combined with lactate determination are necessary to verify these assumptions. The higher lactate accumulation, can support the higher T2-shift in this condition. Moreover, previous studies proved that changes in T2 are depending on the duration of the exercise load (Jenner et al., 1994), resulting in a higher T2-value when the duration of the exercise is increased.
We expected that the work of the thoracic muscles during trunk extension would have been higher compared to leg extension and may be influenced by the contraction type. The lack of difference in thoracic muscle work between the exercise modalities in the present study, did not support this hypothesis.

The present study demonstrated that during all extension exercises the LD was less active compared to the other trunk muscles, which is in agreement with other studies and can be clarified by the main function of the LD, namely arm movement. The lower activity levels of the LD are confirmed by our previous findings using sEMG in a similar protocol (De Ridder et al., 2013), and in line with the findings of Coorevits et al. (2008) who showed that the LD was the least fatigued muscle of the trunk and hip extensor muscles following isometric trunk extension.

This study was limited to a small sample of healthy subjects. Although most MRI studies have a limited number of subjects, it would be useful to investigate a larger and more varied population. Furthermore care should be taken with generalization of the recent study results. The current study did not investigate the trunk muscle activity patterns during a pure static exercise modality or exercises at lower intensities (i.e. stabilization exercises). It is has been recommended that in the initial stage of spine-strengthening programs, subjects should be instructed to become aware of motor patterns and to recruit muscles in isolation at lower exercise intensities (Hibbs et al., 2008), but that an essential requirement is to progress to more functional and dynamic modalities (Akuthota and Nadler, 2004). Especially from an athletic perspective, extension exercises which comprise a dynamic component and a high exercise load are usually preferred for strengthening the trunk muscles (Hibbs et al., 2008). Future studies may reveal which static exercise modality is the most appropriate to target the lumbar extensors during the early stages of LBP rehabilitation. Furthermore, to examine whether LBP or excessive sport participation will cause alterations in the recruitment of the trunk extensor muscles it would be useful for future studies to examine these populations. If impaired recruitment patterns exist, it would be desirable to examine the efficacy of various extension exercise modalities in order to optimize the function of the trunk extensors.

**Conclusion**

Our results demonstrated that during extension exercises the level of activity (shift in T2) of the lumbar extensors is influenced by the modality of the extension exercise, whereas the thoracic extensor activity is not. The highest activity of the lumbar muscles was found during the dynamic-static trunk extension. Therefore, due to the need of a metabolic stimulus to enhance muscle strength, the dynamic-static exercise performance and the trunk extension exercises physiologically seem the most appropriate to train the lumbar
muscles in clinical practice, although this will need to be established by future studies. In order to strengthen the thoracic muscles none of the exercise conditions seems to be superior. During all extension exercises the LD was less active than the other trunk extensor muscles. Thus in case it is desirable to strengthen this muscle in addition to the trunk extensors, the previous described extensions exercises need to be complemented by more appropriate exercises which target this muscle.

**Perspective**
Optimal functioning of the trunk extensors is beneficial for sport performance in athletes and plays a key role in the prevention and treatment of low back pain. In training programs endurance and strength of the lumbar muscles are often enhanced using different extension exercise modalities. The present study examined how activity patterns of trunk muscles differ between several modalities, and which type of modality achieves the highest level of activation of the lumbar extensors.

It was shown that the type of extension exercises did not influence the activity levels of the thoracic extensors, but indeed determined the activity levels of the lumbar muscles. More specifically, it was shown that when trunk and leg extensions exercises comprise a dynamic and static component they will result in higher lumbar muscle activation than when performed pure dynamically. Furthermore, trunk extension exercises will result in higher levels of lumbar muscle activation compared to leg extension exercises. In conclusion, exercise programs which wish to efficiently optimize endurance and strength of the lumbar muscles should give preference to dynamic-static trunk extension exercises.

**Acknowledgements**
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References


Part 2

RELATION BETWEEN THE PREDEFINED AND ACTUAL TRUNK EXTENSOR ACTIVITY DURING TRUNK EXTENSION EXERCISES
Chapter 3

Trunk extension exercises: how is trunk extensor muscle recruitment related to the exercise dosage?

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Abstract

Appropriate exercise dosage is crucial to achieve specific training effects, however literature describing the relation between the estimated intensity during trunk extension exercise and the actual trunk extensors activity is scarce. Furthermore it is unknown whether and how increasing intensity levels during these exercises affect the recruitment patterns.

Fourteen healthy subjects underwent electromyographic evaluation of the trunk extensor muscles while performing trunk extension exercises at increasing training intensities. The exercise load and intensity were predetermined using two different methods, a direct estimation was made by determination of 1-RM for trunk extension on a Tergumed rehabilitation device, and an indirect estimation was made using the Holten-diagram.

The activity of the trunk extensors significantly increased when augmenting the exercise intensity. Moreover, the results indicate that the indirect method is the most accurate to determine the precise exercise dosage for low-load trunk extensions exercises, while the direct intensity determination method is more appropriate for high-load training. When training the trunk extensors on the Tergumed, muscle recruitment patterns are influenced by the exercise intensity, with a differential recruitment between the iliocostalis thoracis and the lumbar extensors at low intensities and a more homogenous recruitment at high intensities. During prone extension exercise training the recruitment patterns of the thoracic and lumbar extensors are not influenced by the exercise intensity and equally contribute to the total muscle work.
Introduction

There is considerable evidence that resistance training of the trunk extensors is beneficial in the prevention and rehabilitation of low back pain (LBP) [Henchoz et al, 2008; Franca et al, 2010; Browder et al, 2007]. To train the endurance and strength of these muscles, trunk extension exercises in different starting positions (standing, semi-seated, seated, prone lying) are frequently prescribed and have been described in scientific literature [Rissanen et al, 1995; Mannion et al, 2001ab; Mayer et al, 2003; da Silva et al, 2009ab; Lariviere, 2011; Steele et al, 2013]. Achievement of the desired training effects is dependent of appropriate exercise dosage.

Different methods have been proposed to determine the correct exercise dosage in both research settings as in clinical practice, making either a direct or indirect estimation of the one repetition maximum (1-RM). The 1-RM is defined as the resistance with which only a single movement can be conducted properly [Kraemer and Fry, 1995]. A well-known approach is to directly determine the 1-RM. According to this method, the 1-RM for trunk extension is usually determined using resistance delivered from rehabilitation devices, mainly conducted in (semi-) seated position. The actual exercise load during training is then expressed as a percentage of 1-RM. Although the direct method seems to give a direct and good rendering of the real 1-RM, it does entail moving maximal loads and thus can lead to overloading and an increased risk for injuries [Shaw et al, 1995]. Hence, alternative submaximal estimation methods to assess strength are preferred as they are safer. This method is especially recommended for older adults, adolescents, cardiac sufferers, and in case of trunk extension exercises for those suffering from LBP [Shaw et al, 1995; Barnard et al, 1999]. The alternative method is based on the relation between the maximum number of repetitions which can be performed against the resistance of an arbitrarily selected submaximal test weight and the percentage of the lifted weight (%1-RM) [Brzycki M, 1993]. One of the methods to determine the exercise dosage for trunk extension exists by indirectly predicting 1-RM using the Holten-diagram and a submaximal test [Grimsby et al, 2008]. More specifically, subjects are asked to execute as many repetitions as possible of dynamic trunk extension from prone lying. These repetitions can be performed with the weight of their own upper body as the resistance or exercise weight. The maximum amount of qualitative repetitions the subject is able to perform is registered and on the Holten-diagram, which describes the relation between the performed number of repetitions and the exercise intensity levels [Dickx et al, 2010], the corresponding percentage of 1-RM is displayed. The desired extension exercise load can then be calculated using a simple formula described by Dickx et al. [2010]. The actual exercise load during training is obtained by increasing the resistance (upper body weight and adding extra weights) or decreasing the resistance (the effort to overcome the weight of the upper body is diminished for instance by the assistance of a load-pulley system).
Although the indirect method is more safe to use in clinical practice and has been widely used to estimate the exercise load for trunk extension exercises, the exact relation between the number of repetitions to failure and the 1-RM has been reckoned as non-consistent. The proposed relation varies on the amount of muscle mass required to complete the exercise and individual variables (such as age, training status, and gender) [Shimano et al, 2006; Grosicki et al, 2014].

Although the use of correct exercise intensities for muscle training is important to obtain proper training effects, research on the validity of the previously described dosing methods is scarce. As a consequence, it is unclear whether the muscles which are targeted with trunk extension exercises actually work at the desired (direct or indirect) predefined exercise intensity levels. It has been demonstrated that in order to enhance trunk extensor muscle endurance, intensity levels of 60% 1-RM [Fleck et al, 2003] are sufficient, while an exercise intensity of approximately 80% 1-RM is required to improve muscle strength [Rhea et al, 1998; Andersson et al, 2003].

Therefore, the present study measured the EMG activity of different trunk muscles during trunk extension exercises at different intensities (40, 60, 80, 100%), and investigated whether increasing intensity levels affected the recruitment patterns among the different trunk extensors. The exercise loads were calculated using both the indirect method and the direct method, and for both approaches it was examined whether the actual activity of the thoracic and lumbar extensors corresponds with the predefined intensity.

Materials and Methods

Subjects
Fourteen healthy individuals (11 men, 3 women) were recruited from the student population at our university. Subjects under 18 years and subjects who had consulted a physician regarding LBP in the past year, reported current LBP, a history of back surgery or established spinal deformities, were not eligible for study participation. All subjects were asked to read the information leaflet in which the study was explained, and to provide written consent upon agreement to study participation. The information leaflet, informed consent, and study protocol were approved by the local Ethics Committee. The study population was characterized by a mean age of 21±2.1 years old, weight of 73.6±6.5 kilograms and height of 1.79±0.07 meters.

Procedure
All subjects were examined on three different days, and between different days there was an interval of minimum 3 days.
During the first day, anthropometric characteristics were recorded. Furthermore, the 1-RM was determined according to each dosage method separately. The determination of the 1-RM for both approaches was necessary to set up the exercise protocol. Following the first day of testing, the sequence of the exercise protocol as well as the order of the performed exercise intensities was randomly determined by lottery. The exercise protocol comprised of two days of testing: one day performing semi-seated trunk extension exercises at increasing intensities predetermined using the direct method, on the other day the trunk extension exercises in prone lying were performed at increasing intensities predetermined using the indirect method.

During the different trunk extension exercises the EMG activity of trunk and hip extensor muscles was measured.

**Determination of the exercise intensity**

**Direct determination of 1-RM**

The exercise intensity, expressed as a percentage of 1-RM, was determined by the maximum extension strength on a Tergumed® extension device (Proxomed®, Germany). Subjects were placed in semi-seated position on the device, with the movement axis set at the superior border of the anterior iliac crest, hip flexed at 40°, knees at 30° and their feet supported on a platform. The pelvic pad was removed and the thighs were fixed parallel to the seat by the thigh pads. The back resistance pad was placed at the angulus inferior of the scapula and subjects placed their hands on the contralateral shoulder (Figure 1). Subjects were instructed to generate a maximum isometric force towards extension against the device for 7 seconds. This protocol was repeated 3 times, with a resting period of 1 minute between each attempt. The average value of these three trials was considered as the maximum extension force. Based on the maximum extension force the different intensity levels for the exercise protocol were calculated using following formula: 

\[
\text{(maximum extension force (kg) * intensity level) / 100 = adjusted weight.}
\]

**Indirect determination of 1-RM**

The exercise intensity, expressed as a percentage of 1-RM, was estimated using the Holten-diagram [Grimsby et al, 2008]. The diagram indicates the number of repetitions theoretically possible at a range of submaximal percentages of 1-RM. This means that concretely all subjects were asked to perform prone dynamic trunk extension exercises, with the weight of their upper body as the exercise weight (which is estimated as 70% of the total body weight), until fatigue prohibited (a correct) performance of the exercise. The extension exercises were performed using a standardized procedure. Subjects were placed in prone position on a variable angle chair (40° flexion), with their upper body unsupported and the superior border of the anterior iliac crest on the edge of the couch. Subject’s legs were fixed by a strap around the ankles and their hands were placed on the opposite shoulders [De Ridder et al, 2013] (Figure 2). One repetition consisted of lifting
the trunk to 20° of extension in 2 seconds (concentric phase) and returning to starting position (40° of flexion) in 2 seconds (eccentric phase). To reach the end position, tactile feedback was given by a plumb attached to a rope between two vertical stands. A metronome (60 beats/min) was used to ensure appropriate timing. The maximal amount of repetitions each subject was able to perform, was recorded and subsequently used to calculate the different exercise intensities for the exercise protocol using a formula described earlier [Dickx et al, 2010]: (arbitral test weight * predefined exercise intensity) / intensity level according the Holten-diagram.

**Figure 1** Position during trunk extension exercises on the Tergumed® extension device.

**Exercise protocol**

The exercise protocol consisted of two separated exercise sessions each performed on a separate day. During one test session prone dynamic trunk extension exercises were performed as described above. In this session the exercise intensity was determined by the indirect dosage method. During the other test session the dynamic trunk extension exercises were performed on the Tergumed extension device, in the same position as described above. In this case the exercises were dosed by the direct dosage method. During each exercise session the dynamic trunk extension exercises were performed at 4 different intensity levels, i.e. 40, 60, 80, and 100% of 1-RM. Each intensity level was repeated 3 times. The sequence of the different intensity levels was randomized by lottery, and there was a 5-minute recovery period between each intensity level.

The extension exercises were performed in 2.1, and visual and auditive feedback assured appropriate timing of the trunk extension exercises on the Tergumed® device, while tactile and auditive feedback ensured appropriate timing of the prone trunk extension exercises. The total ROM and speed rate of the trunk extension exercises was equal for both methods, i.e. 60° ROM (40° of flexion to 20° extension) at a speed of 30°/s.
Electromyography
The EMG signals of 6 muscles were bilaterally measured using a 16 channel telemetric surface EMG system (TeleMyo 2400 G2 Telemetry System, Noraxon, USA). Prior to the electrode placement, the skin was prepared to reduce impedance and improve skin contact. Sequentially, the skin was shaved and rubbed with alcohol.

Figure 2 Position during trunk extension exercises on a variable angle chair with weight assistance using a pulley system.

Figure 3 Electrode placement of the trunk muscles.

CHAPTER 3

Afterwards, Noraxon surface dual electrodes were bilaterally attached, parallel to the muscle fiber orientation over the Latissimus Dorsi (LD), Longissimus thoracis pars Thoracic (LT), Longissimus thoracis pars Lumbarum (LL), Iliocostalis lumbarum pars Thoracis (IT), Iliocostalis lumbarum pars Lumbarum (IL) and the Lumbar Multifidus (LM) in analogy with earlier studies [Danneels et al, 2002; Coorevits et al, 2008; Dickx et al, 2010; De Ridder et al, 2013] (Figure 3). The electrodes had a fixed inter-electrode distance of 2 cm and an electric surface contact of 1cm diameter. The reference electrode was placed on the angulus inferior of the right scapula.

Before starting the exercise protocol, EMG reference data were obtained by performing 3 maximal voluntary isometric contractions (MVICs). Each contraction was obtained during 4 seconds, and with 30 seconds of rest were left between each trial. Regarding the direct method, the MVIC was obtained during the maximal extension exertion on the Tergumed extension device in the same position as used during the exercise protocol. Afterwards the average RMS of each trial was computed. Regarding the indirect method, the MVIC was performed in prone position against manual resistance, in analogy to earlier investigations [Danneels et al, 2001; Stevens et al, 2006].

Raw signals were bandpass-filtered between 10-500Hz, amplified (common mode rejection ratio >100dB, overall gain 1000, noise <1uV Root mean square (RMS)), and analogue-to-digital (16-bit) converted at a sampling rate of 1500Hz. The signal processing consisted of full wave rectification and smoothing, using a RMS algorithm with a 100ms time constant. For further analysis the average of the EMG signals of each muscle (3 repetitions) was normalized against the mean MVIC (mean of 3 repetitions) of the specific muscle.

Statistical analysis
Statistical analysis was performed using the SPSS 21.0 software package (IBM corporation, Somers, NY, USA). At first descriptive statistics were computed for the anthropometric characteristics, the used exercise load, and the relative muscle activity during the different exercise conditions. Secondly, possible differences between the left and right muscle(group) were analyzed using a linear Mixed model analysis with factors: intensity level, muscle and side. Because of the symmetry of trunk extension exercise and the lack of a significant side effect (p>.05), the relative EMG values of both muscle sides were averaged and used for further analysis.

Subsequently, for each dosage method separately, a linear Mixed model analysis with two factors i.e. intensity level (40, 60, 80, 100% 1-RM), and muscle (LD, IT, IL, LT, LL, LM) was conducted to analyze if the produced EMG activity of the posterior spine muscle chain during extension exercise corresponds with the pre-determined exercise intensity and to assess the effect of the increasing exercise intensity on the trunk muscle recruitment. If
required, a new mixed model analysis was conducted and post-hoc comparisons were made and adjusted using Bonferroni-correction. The first statistical analysis showed that the LD does not play a key role during trunk movement in the sagittal plane. Since this was in line with earlier findings [Coorevits et al, 2008; De Ridder et al, 2013], it was decided to exclude the LD from further analysis. The significance level was set at 0.05

**Results**

**Trunk extension exercises dosed using the direct method**

*Relative muscle activity (%MVIC) versus the predefined exercise intensity*

The mean total trunk extensor muscle activity (%MVIC) increased significantly with increasing intensity (p≤0.001). While an exercise intensity of 40%, 60%, 80% or 100% of their maximal capacity was assumed, the EMG results showed that the actual activation presented 28.3%, 50.0%, 72.7% and 102.1% of the MVIC respectively (Figure 4). These percentages demonstrate that the assumed trunk extensor levels are more in line with the real trunk extensor activity during the high load conditions (60 and 100% 1-RM) than during the low load extension exercises (40 and 60% 1-RM).

*Relative muscle activity (%MVIC) of the different trunk extensors during increasing intensities*

A significant 2-way interaction between the factors intensity level and muscle (p≤0.001), as well as a significant main effect of both factors (p≤0.001), was established. This interaction effect implies that increasing the intensity of a dynamic trunk extension exercise on the Tergumed device influences the muscle recruitment patterns. Thus, a new mixed model analysis for each intensity level was conducted to examine how the muscles were precisely recruited at each intensity level. The mean loads applied during the performance of the dynamic trunk extensions at different intensities are represented in table 1. It was demonstrated that the exercise weights increased significantly with increasing intensity level (p≤0.001).
The additional analysis demonstrated that throughout all intensity levels there were no significant differences in EMG activity within the IT and LT (p>0.05) or within the lumbar extensors (p>0.05). However, it was demonstrated that when trunk extensions exercise were performed at an intensity of 40% the IT, which is a thoracic extensor, was significantly activated to a lesser extent than the lumbar extensors IL, LL and LM (respectively -10.31%; p≤0.001, -7.87%; p=0.007 and -10.01%; p≤0.001). At an exercise intensity of 60% the IT was 10.2% less activated than the LL (p=0.009) and 13.0% less than the LM (p≤0.001), whereas the difference between the IT and IL activity no longer existed (p=0.167) (Table 2). At the

![Table 1](image)

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Direct method Mean (kg)</th>
<th>Indirect method Mean (kg)</th>
<th>Direct method SD</th>
<th>Indirect method SD</th>
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</thead>
<tbody>
<tr>
<td>40%</td>
<td>39.7</td>
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<td>10.9</td>
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<td>59.3</td>
<td>55.2</td>
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<td>73.6</td>
<td>21.3</td>
<td>12.3</td>
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<tr>
<td>100%</td>
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<td>93.9</td>
<td>27.2</td>
<td>14.0</td>
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</table>

![Table 2](image)

<table>
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<tr>
<th>Muscle</th>
<th>Direct method 40% 1-RM Mean</th>
<th>Direct method 60% 1-RM Mean</th>
<th>Direct method 80% 1-RM Mean</th>
<th>Direct method 100% 1-RM Mean</th>
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<tr>
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<td>47.88</td>
<td>75.19</td>
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<td>IT</td>
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<td>40.34</td>
<td>67.59</td>
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<tr>
<td>LL</td>
<td>31.67</td>
<td>50.49</td>
<td>71.87</td>
<td>103.26</td>
</tr>
<tr>
<td>IL</td>
<td>29.23</td>
<td>47.43</td>
<td>69.99</td>
<td>100.49</td>
</tr>
<tr>
<td>LM</td>
<td>31.37</td>
<td>53.33</td>
<td>78.18</td>
<td>101.98</td>
</tr>
</tbody>
</table>

LT= Longissimus thoracis pars Thoracic, IT= Iliocostalis lumborum pars Thoracic, LL= Longissimus thoracis pars Lumborum, IL= Iliocostalis lumborum pars Lumbarorum, LM= Lumbar Multifidus, SD= Standard Deviation, 1-RM= one repetition maximum

* is significant (p≤0.05)
80%-level only a significant difference between the IT and LM activity (67.59% versus 78.18% respectively; p=0.036) remained. At the maximal exercise intensity of 100% all muscles were activated equally as no significant differences in EMG activity between any of the trunk extensor muscles were found (p=0.879). The mean EMG activity of each muscle at each exercise intensity is represented in table 2.

Trunk extension exercises dosed using the indirect method

*Relative muscle activity (%MVIC) versus the predefined exercise intensity*

The mixed model analysis demonstrated a significant main effect of the factor intensity level (p≤0.001), without any muscle (p=0.306) or interaction effect (p=0.989). Meaning that the mean total trunk extensor muscle activity (%MVIC) rose significantly in line with the increasing exercise intensity (Table 3). Per ascending intensity level the total amount of trunk extensor muscle activity increased with respectively 12.8%, 17.9% and 11.7% MVIC.

The degree of the total trunk extensor muscle activity (%MVIC) corresponded well with the predetermined exercise intensity levels at the low load conditions, but less at the high load conditions. More precisely, when the expected exercise intensity was set at 40%, 60%, 80% or 100% of the 1-RM, the EMG results showed that the actual muscle work of the trunk extensor represented respectively 35.5%, 51.2%, 70.9% and 83.9% of the MVIC respectively (Figure 4). The mean loads applied during the performance of the dynamic trunk extensions at different intensities are represented in table 1. It was demonstrated that the exercise weights increased significantly with increasing intensity level (p≤0.001).

### Table 3

Mean muscle activity (% MVIC) and standard deviation (SD) with increasing intensity level using the indirect dosage method.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>40% 1-RM</th>
<th>60% 1-RM</th>
<th>80% 1-RM</th>
<th>100% 1-RM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>LT</td>
<td>34.64</td>
<td>14.14</td>
<td>46.27</td>
<td>16.40</td>
</tr>
<tr>
<td>IT</td>
<td>28.15</td>
<td>12.83</td>
<td>46.84</td>
<td>22.21</td>
</tr>
<tr>
<td>LL</td>
<td>36.96</td>
<td>16.88</td>
<td>55.31</td>
<td>22.68</td>
</tr>
<tr>
<td>IL</td>
<td>38.11</td>
<td>13.16</td>
<td>54.49</td>
<td>23.35</td>
</tr>
<tr>
<td>LM</td>
<td>40.87</td>
<td>15.95</td>
<td>52.44</td>
<td>17.61</td>
</tr>
</tbody>
</table>

LT=Longissimus thoracis pars Thoracic, IT= Iliocostalis lumborum pars Thoracic, LL= Longissimus thoracis pars Lumborum, IL= Iliocostalis lumborum pars Lumborum, LM= Lumbar Multifidus, SD= Standard Deviation, 1-RM= one repetition maximum

* is significant (p≤0.05)
Relative muscle activity (%MVIC) of the different trunk extensors during increasing intensities

The fact that the factor muscle (p=0.306) did not influence or interact (p=0.989) with the exercise intensity implies that increasing the resistance of a trunk extension exercise using the indirect method did not affect the intermuscular coordination between the trunk extensor muscles. For all intensity levels, no significant difference between the EMG signals among the thoracic (LT and IT) and lumbar paraspinal muscles (LL, IL and LM) could be determined (table 3). The lack of a difference to which extent the lumbar and thoracic muscles are recruited suggests that the trunk extensor muscles are working homogeneously to perform a prone dynamic trunk extension exercise at different exercise intensities.

![Figure 4](image)

Figure 4 Corresponding mean EMG activity (%MVIC) and standard deviation (SD) of the thoracic and lumbar paraspinal muscles with varying intensity levels for each dosage method.

1-RM = one repetition maximum

Discussion

Appropriate exercise dosage is important to achieve the desired training effects. In clinical practice direct and indirect methods are used to determine 1-RM and the corresponding exercise intensity for trunk extension exercises. The main research question was to get insight in the actual activity of the thoracic and lumbar extensors at various predefined intensity levels of trunk extension exercises. The present study showed that when the trunk extension exercises were performed from prone position on a variable angle chair and the exercise intensity was estimated using the Holten-diagram, the difference
between the actual muscle work and the aimed exercise intensity increased in line with the exercises intensity. At an exercise intensity of 40% the difference was -4.5%, at 60% -8.8%, at 80% -9.1% and at 100% -16.1%. From the increase in differences it is clear that the indirect method of dosage is accurate for extension exercises performed at lower exercise intensities or low load conditions, as at higher levels the theoretical exercise intensity overestimates the actual muscle work. When the exercise intensity was estimated by directly determining 1-RM and was performed on the Tergumed device, the difference between the actual muscle work and the aimed exercise intensity decreased with the increase of the exercises intensity. At an exercise intensity of 40% the mean difference was -11.7%, at 60% -10%, at 80% -7.3% and at 100% +2.2%. These observations suggest that determining the dosage of low-load trunk extension exercises using the indirect method will most closely reflect the actual muscle work of the trunk extensors during the performance of these exercises, while for high-load trunk extension exercises the direct method is preferred from that perspective.

With regard to the second research question, which aimed to answer whether increasing intensity levels affect the recruitment patterns among the different trunk extensors, different phenomena were observed depending on the performance of the exercise. When trunk extension exercises are performed from prone position on a variable angle chair and the exercise intensity is estimated using the Holten-diagram, the thoracic and lumbar trunk extensors will contribute equally to perform the trunk extension exercises at different exercise intensities. However, when trunk extension exercises are performed on the Tergumed device which is also used to directly determine the exercise intensity, the trunk extensor muscle recruitment patterns are dependent of the exercise intensity levels. More specifically, low load exercise intensities primarily activated the lumbar trunk extensors, and by increasing the exercise intensity the thoracic and lumbar trunk extensors were recruited in a homogenous way.

These findings suggest that an optimal exercise intensity and training method should be chosen in the light of the training goal. Imbalances in strength within the trunk muscles have been related to LBP, emphasizing the importance of a good balance between the lumbar and thoracic extensors [Renkawitz et al, 2006; Cho et al, 2014]. Especially the lumbar muscles are sensitive for deconditioning. When the goal is to target these muscles, extension exercises on the Tergumed at relatively low intensity levels (≤60% 1-RM) seem to be more appropriate since they primarily activate the lumbar trunk extensors. When the lumbar extensors are relatively weak compared to the thoracic muscles, trunk extension exercises from prone position on the variable angle chair seem less appropriate. As our results indicate that the trunk extensors are recruited homogenously in healthy subjects, it is realistic that in case of a muscle imbalance, the dominant muscles group is overruling the weakened part of the chain. This could result in an enhancement of the preexisting imbalance between the thoracic and lumbar extensors. When there is a good balance between the lumbar and thoracic extensors the prone extension are accurate,
even in low load conditions. High load extension exercises can be performed on either the Tergumed device or in prone position.

As expected increasing the exercise intensity during a dynamic trunk extension influences the activity level of the trunk extensor muscles, therefore training and rehabilitation programs should implement a progression in exercise intensity in order to optimize strength and endurance of the trunk extensors. The present study showed that the EMG signals of each investigated trunk extensor muscle augmented significantly when increasing the resistance of the extension exercise from 40 to 100% 1-RM. This observation was made for both methods and is in line with previous study findings, showing a positive correlation between the exercise intensity and the EMG activity of the trunk extensor muscles [Dickx et al, 2010] and hip extensor muscles [Callaghan et al, 1998] during prone and seated [Stevens et al, 2008] trunk extension exercises.

The present study showed that, when the goal is to enhance trunk extensor muscle endurance, which corresponds with an intensity of 60% 1-RM [Fleck et al, 2003], prone trunk extension exercises dosed by the indirect method are slightly more appropriate than the semi-seated trunk extension exercises, dosed by the direct method.

On the contrary, the current results suggest that to improve muscle strength, which corresponds with an exercise intensity of approximately 80% 1-RM [Rhea et al, 2003; Andersson et al, 1998], determining the exercise load using the direct method and performing the semi-seated trunk extension exercises will be more sufficient. When one wishes to train the trunk extensor muscles at their maximal capacity of 100% MVIC, an instrumented trunk extension dosed by the direct method is highly accurate while prone trunk extensions dosed by the indirect method clearly activates the trunk extensor muscles insufficiently.

Although the present study was not designed to compare both dosing methods, it was demonstrated that the recruitment of the trunk extensor muscles is dependent on the used method. With regard to the direct dosing method, a shift from a differentiated to a more homogeneous trunk extensor muscle work was demonstrated with increasing load. During a low load trunk extension the IT was less active than all lumbar extensor muscles. As the exercise intensity increased, the differences in activity between the IT and the lumbar extensor muscles decreased, so that at the highest intensity level (100%) the difference no longer existed.

Alterations in the trunk muscle recruitment patterns during extension exercises at increasing intensities have not been reported before. However, our study results are in line with other observations from the literature. The homogeneous trunk extensor muscle work demonstrated at maximal intensities is in line with Clark et al. [2002] who described, that during a high resisted trunk extension other muscles than the lumbar extensors will create the extra force to complete the exercise. Furthermore the differentiated trunk extensor muscle work demonstrated from low to submaximal intensities are supported
by the mfMRI findings of Mayer et al. [2005] who showed that during a prone trunk extension at different intensities (40-50-70% extension strength) the LM was activated at greater extent that the LT and IT at each intensity level. This is consistent with the trend to a higher LM activity compared to the other back muscles up to an exercise intensity of 80% in the present study.

With regard to the indirect dosing method, homogeneous activation of the thoracic and lumbar trunk extensor muscles was demonstrated, regardless of the level of exercise intensity.

This phenomenon could be caused by the fact that the trunk, as one large lever arm, has to be lifted till the horizontal at all intensities. In prone position both thoracic and lumbar extensors have to work synergistically to extent the whole trunk en bloc. These results are in line with our previous study, in which recruitment patterns of different trunk extension exercises at 60%1-RM were examined [De Ridder et al, 2013].

Present findings are very relevant for clinical practice. Current results show that to create progressive resistance training for the trunk extensors both approaches are appropriate to dose the intensity. However, regarding the differences between the actual trunk muscle activity and the intended percentage of muscle activity, disparities between both methods exist.

When the differentiation between the lumbar and thoracic extensors is relevant within the context of training, this study shows that during prone trunk extension dosed by the indirect method all trunk extensors are activated at all intensities without any difference, whereas at lower intensities an instrumented trunk extension from a semi-seated position mainly target the lumbar muscles.

At first some caution should be taking into account when interpreting the results as some studies demonstrated that the relationship between the EMG activity and the amount of muscle force is not strictly linear [Hof, 1997]. Secondly, the relative small number of participants as well as their young age is considered to be a limitation of this study. Furthermore, the present study only investigated healthy individuals, with no recent history of LBP. Due to the evidence that dysfunctions of the trunk muscles as well as altered trunk muscle recruitment can be related to LBP [Renkawitz et al., 2006; Cho et al.,2014], the current results cannot be generalized to a patient population. Therefore, further research in different populations (older, LBP) is warranted.
Conclusion

In conclusion, this study showed that increasing the load of a trunk extension exercise, using both the direct or indirect method, influences the activity of the trunk extensor muscles as well as the activation patterns significantly. Regarding the use of the dosage methods we can conclude that to activate the trunk extensor muscles at submaximal intensities, the indirect method approaches better the assumed intensity, whereas the direct method is more suitable to determine the load when higher trunk extensor activity is required. Moreover when there is an imbalance or when the differentiation between the lumbar and thoracic extensors is relevant within the context of training, this study shows that at lower intensities an instrumented trunk extension from a semi-seated position mainly target the lumbar muscles.

Acknowledgements

We would like to thank Jan Vanderjeugt in assisting in the data collection and statistical analysis. Jessica Van Oosterwijck is a postdoctoral research fellow funded by the Special Research Fund of Ghent University.
References

Part 3

ACTIVE LUMBOPELVIC STABILIZATION DURING PRONE EXTENSION EXERCISES
Chapter 4

Active stabilization strategy during extension exercises: effect on kinematics and recruitment patterns of the lumbopelvic region

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Abstract

Background context Active lumbopelvic stabilization (co-contracting the deep stabilizing muscles) is used to prevent hyperlordosis and excessive lumbar spinal load during extension exercises. However, it is unknown if this affects the recruitment of trunk/hip extensor muscles during these exercises and is effective in decreasing lumbar lordosis.

Purpose To study whether this active stabilization strategy affects lumbopelvic kinematics (hip angle, spinal curvature) and recruitment of different trunk and hip muscles during trunk and leg extension exercises and whether findings are influenced by the exercise modality.

Study Design/Setting An observational electromyographic study conducted in a research laboratory at the University hospital.

Patient sample Thirteen healthy adults.

Outcome measures The amount of electrical trunk extensor activity as well as the thoracic, lumbar and hip angles in the sagittal plane.

Methods Electromyography of the latissimus dorsi, the thoracic and lumbar parts of longissimus and iliocostalis, gluteus maximus and biceps femoris, and video-analysis of lumbopelvic kinematics during dynamic trunk and leg extension exercises with and without active lumbopelvic stabilization. An optimal active stabilization strategy was acquired during training prior to the actual investigation.

Results Implementation of the active stabilization strategy decreased the lordotic angle during trunk and leg extension exercises (resp. p=.045; -3.17°, p=.019; -9.95°), whereas the hip angle was solely affected during trunk extension (p<.001; +9.20°). Higher activity of latissimus dorsi (p≤.001; +9.57%), gluteus maximus (p=.038; +8.56%) and biceps femoris (p<.001; +20.20%) during trunk extension exercises was seen when these exercises were performed with active lumbopelvic stabilization. When the stabilization strategy was implemented into the leg extension exercises, this actual resulted in less activity of longissimus thoracic (p=.015; -10.21%) and latissimus dorsi (p=.010; -4.41%), and increased use of gluteus maximus (p≤.001; +16.84%).

Conclusions Performing an active lumbopelvic stabilization strategy during extension exercises in healthy people, decreases the degree of lumbar lordosis and influences the recruitment patterns of trunk and hip extensors. Probably, the hip and trunk muscles have a more stable base to work on when the stabilization strategy is used, which changes the lever arm of the extensor muscles.
Introduction

Performing extension exercises for the lower back has been shown to be beneficial in the rehabilitation of low back pain (LBP) patients. Not only does resistance training of the back muscles induce ameliorations in strength, endurance and functionality, it also results in reduced levels of pain and disability. Therefore different modalities of these extension exercises are widely used in rehabilitation programs, with especially trunk and leg extensions exercises being popular modalities used in clinical practice. However, scientific studies have mainly evaluated lumbar muscle activation and kinematics in healthy people during trunk extension exercises from prone lying, whereas seated trunk extensions exercises and bilateral leg extension exercises are less investigated.

Even though extension exercises are well integrated in therapy, they cause high spinal loads due to excessive lumbar extension. It is hypothesized that this can be limited by stabilizing the lumbopelvic region. Several extension devices used in practice allow to stabilize the lumbopelvic region passively, by using external lumbopelvic fixation pads. As this approach does not facilitate functional integration, learning the patient to actively stabilize the lumbopelvic region seems more appropriate. More specifically, it is assumed that contraction of the lumbopelvic muscle corset, which entails co-contraction of the lumbar multifidus (LM), the transversus abdominus (TA), and the pelvic floor muscles, contributes to spinal and pelvic stability. However, no studies have examined how this active stabilization strategy affects the lumbar or thoracic curve during extension exercises, and thus if it is indeed able to prevent excessive lumbar lordosis.

Currently, little is known on how active involvement of this lumbopelvic muscle corset during extension exercises influences the recruitment of trunk and hip muscles and the lumbopelvic kinematics in healthy people. A few studies have shown that using such a stabilization strategy does indeed lead to altered recruitment patterns of the back extensor muscles. On the one hand it has been demonstrated that an abdominal drawing-in maneuver, used to facilitate activation of the TA, during prone unilateral leg extension reduces the lumbar erector spinae (LES) activity but increases the activity of the hip extensors. On the other hand, it has been shown that contraction of the lumbopelvic muscle corset during active sitting enhances the activity of the LES and LM. As these studies have used different extension modalities and have not examined the activity of the thoracic extensors it is difficult to compare findings and to conclude how muscle recruitment is exactly influenced when an active stabilization strategy is implemented to the exercises. In the same context, it is also relevant to note, that most studies investigating muscle recruitment patterns during extension exercises have overlooked the contribution of the hip extensors. A trunk extension consists of a combined extension movement of the thoracic and lumbar spine as well as anterior rotation of the pelvis and hips.
whereas a leg extension is composed of a rotation of the hips, pelvis and a lumbar spine extension movement. From this biomechanical perspective it is clear that extension exercises do not only require activation of the back extensor muscles but also of the hip extensor muscles.

In order to evaluate if extension exercises and active stabilization strategies can be effectively used in the rehabilitation of those with LBP, it is of great importance that we first understand and compare lumbopelvic muscle recruitment and kinematics during different extension exercise modalities in healthy people. To resolve existing ambiguities and shortcomings, this study will evaluate the muscle recruitment of the thoracic, lumbar and hip extensors and the thoracic and lumbar spinal curvature and hip angle during prone trunk extension exercises and prone bilateral leg extension exercises performed by healthy people. Furthermore, this study will be the first to examine if and how precisely an active lumbopelvic stabilization strategy during these exercises influences the muscle recruitment patterns and weather this stabilization strategy is able to prevent excessive lumbar lordosis.

**Materials and methods**

**Subjects and procedure**

Thirteen healthy males and females, between 18 and 30 years were recruited from the student population of our university and acquaintances of the researchers by advertisement or email. The volunteers were excluded from participation if they reported previous back surgery or established spinal deformities, had consulted a physician regarding LBP in the past year, or currently experienced LBP. Participants with a history of severe neurologic, respiratory, cardiovascular, or orthopedic disorders were also excluded. Furthermore, elite athletes as well as participants with neck or hip pain were not included in the study. All subjects received an information leaflet in which the study was explained, and provided written consent. The study was approved by the local Ethics Committee. All subjects attended three training sessions and two separate test sessions. Video-analysis was used to evaluate the lumbopelvic kinematics and muscle activity was measured with surface electromyography (EMG).

**Training sessions**

All subjects participated in three individual training sessions (40 minutes 1x/week) to acquire an optimal active stabilization strategy of the lumbopelvic region. During the first training session subjects were informed about the basic anatomy and function of the muscles which form the lumbopelvic muscle corset, learned to control their lumbar spine in neutral position in different postures (sitting, standing, and 4-point kneeling), and
learned to contract their lumbopelvic muscle corset without substitution of superficial muscles. Once subjects were able to contract the lumbopelvic muscle corset whilst maintaining a normal breathing pattern and without substitution of superficial muscles, the duration of the contractions and the repetitions were increased so that subjects were able to sustain each contraction for 10 seconds and repeat this 10 times. The second and third session were aimed at integrating the active stabilization strategy within more dynamic and functional activities. During the second session controlled leg movements were added in supine and 4-point kneeling position. During the last training session, subjects were instructed to sustain the co-contraction during more complicated exercises as presented in figure 1. All exercises were performed in 3 sets of 15 repetitions. During the training sessions the researchers gave tactile and verbal feedback about the co-contraction. In addition subjects received a leaflet describing the exercises and were asked to perform them daily at home.

At the end of the training program, the ability to contract the lumbopelvic muscle corset without compensatory strategies was evaluated by two out of the four researchers (EDR, MDS, JD, or BVW). Therefore subjects were asked to perform an isolated contraction of the lumbopelvic muscle corset in 4-point kneeling stance. The contraction of the LM and the

**Figure 1** Dynamic and functional positions and movements during which active contraction of the lumbopelvic corset is trained.
TA were assessed through palpation lateral from the spinous process at L3-L5, and 2 cm inferior and medial of the anterior superior iliac spine respectively. In agreement with all researchers, subjects who were unable to contract their lumbopelvic muscle corset in a proper way were excluded from the study.

**Test sessions**

The first test session consisted of the indirect determination of the 1-RM. During the second and third session all subjects performed lumbar extension exercises conformed 4 different modalities.

**Indirect determination of the 1-RM**

At least three days before the first exercise session, the exercise load, expressed as a percentage of the one repetition maximum (1-RM), was estimated using the Holten-diagram. This diagram describes the relation between the performed number of repetitions and the exercise intensity. To determine the exercise load, all subjects were asked to execute the maximal amount of repetitions of dynamic prone trunk/leg extension with the weight of their upper/lower body as the exercise weight (which is estimated as 70% and 30% of the total body weight respectively). The number of repetitions each subject was able to perform during both types of exercises using this method was registered. The exercise intensity was individually adjusted at 60% 1-RM, which was calculated using the formula described by Dickx et al.

**Extension exercises**

During the test sessions 4 different lumbar extensions exercise modalities were performed i.e. dynamic trunk extension, dynamic bilateral leg extension, dynamic trunk extension with implementation of the lumbopelvic stabilization strategy, and dynamic bilateral leg extension in combination with the lumbopelvic stabilization strategy. During each exercise session 2 modalities were performed. The order of the exercise modalities was randomized by lottery.

All lumbar extension exercises were performed in prone position on a variable angle chair with the trunk or legs positioned at 45° of flexion and the superior border of the anterior iliac (SIAS) was positioned on the edge of the variable angle chair as described by De Ridder et al. For the trunk extension exercises the legs were strapped to the table at the ankles, and subjects their hands were placed on the opposite shoulder. To perform the leg extension exercises the upper body was strapped to the table at the level of the angulus inferior of the scapulae, and subjects their hands were placed under their forehead. The exercise positions are presented in figure 2.
One repetition consisted of lifting the trunk/legs to the horizontal in 2 seconds and returning to starting position in 2 seconds. To reach the horizontal position, tactile feedback was given by a rope between two vertical stands. A metronome (60 beats/min) was used to ensure appropriate timing of the contractions. Subjects performed one set of 10 dynamic repetitions. Before starting the exercises which included active stabilization following instructions were given; ‘Keep your lumbal region in neutral position and maintain a lumbopelvic muscle co-contraction during the whole exercise’.

To prevent muscular fatigue, only two different exercise modalities were performed during one test session and an interval of 30 minutes was obligated between these two exercise modalities.

**Measures**

**Kinematics**

To measure the lordotic angle markers were placed on L1, the deepest point of the lordosis, and the spina iliaca posterior superior. To determine the kyphotic angle markers were placed on C7, the highest point of the kyphosis, and L1. The hip extension angle was measured via markers on the malleolus lateralis, the trochanter maior, and spina iliac anterior superior.

Video recordings were made throughout the entire exercise, using a camera placed in a standardized position. Using the video footage, the 3 angles mentioned above were calculated at the moment the subject reached the horizontal position during the exercise using the Kinovea software package (version 0.8.15, www.kinovea.org). The mean angle was calculated from the measured angles during repetitions 1, 3 and 5.

**Figure 2** Position of the lumbar extension exercises.
Electromyography

The EMG signals of 8 muscles, were bilaterally measured using a 16 channel telemetric surface EMG system (TeleMyo 2400 G2 Telemetry System, Noraxon, USA).

First the skin was shaved and rubbed with alcohol, to reduce the impedance and improve skin contact. Subsequently, Noraxon surface dual electrodes were bilaterally attached, parallel to the muscle fiber orientation, in analogy to Coorevits et al. (2008) and Danneels et al. 17,36 over the Gluteus Maximus (GM) (midway between the posterosuperior iliac spine and the ischial tuberosity), Biceps Femoris (BF) (midway between the ischial tuberosity and the lateral femoral epicondyl), Lumbar Multifidus (LM) (2 cm lateral to the midline of the body, above and below a line connecting both posterior superior iliac spines), Latissimus Dorsi (LD) (3 cm lateral and caudal to the angulus inferior of the scapula), Longissimus thoracis pars Thoracis (LT) (at the L1 level, midway between the line through the spinous process and a vertical line through the posterior superior iliac spine), Longissimus thoracis pars Lumborum (LL) (lateral at the intersection of a horizontal line through the spinous process of L5 and a line between the interspinous space of L1–L2 and the posterosuperior iliac spine), and Iliocostalis lumborum pars Thoracis (IT) (at the L1 level, midway between the lateral palpable border of the erector spinae and a vertical line through the posterosuperior iliac spine), and Iliocostalis lumborum pars Lumborum (IL) (at the L4 level, midway between the lateral palpable border of the erector spinae and a vertical line through the posterosuperior iliac spine). The electrodes had a fixed inter-electrode distance of 2 cm and an electric surface contact of 1cm diameter. A single reference electrode was placed on the angulus inferior of the right scapula.

Before starting the exercise protocol, EMG reference data were obtained by performing 3 maximal voluntary isometric contractions (MVIC’s) of 4 seconds against manual resistance for each muscle or muscle group separately. All tests were performed in prone position analogue to earlier investigations and each MVC was followed by 30 seconds of rest 35,37,38.

Raw signals were bandpass-filtered between 10-500 Hz, amplified (common mode rejection ratio >100 dB, overall gain 1000, noise <1uV Root mean square (RMS)), and analogue-to-digital (16-bit) converted at a sampling rate of 1500 Hz. The signal processing consisted of full wave rectification and smoothing, using a RMS algorithm with a 100ms time constant. Muscle activity was measured during the whole exercise. The mean activity level for each muscle was calculated over 5 separate repetitions (repetitions 2-6) and used for further analysis. Because the muscle activity during the exercises was measured on two separate days, which could result in differences in skin resistance, the EMG signals of the muscles were normalized against their MVIC’s.
Statistical analysis
Statistical analysis was performed using the SPSS 19.0 software package (IBM corporation, Somers, NY, USA). Due to the symmetry of the exercises and the lack of a side effect (left vs right), the EMG values of the muscles of both sides were averaged. The Kolmogorov-Smirnov was used to test the normality of all variables and descriptive statistics were computed for the anthropometric characteristics and muscle activity. The recruitment pattern of the posterior muscle chain (%MVIC) during the extension exercises was analyzed using a linear mixed model analysis, with following factors: stabilization (exercise with vs without lumbopelvic stabilization strategy), muscle (LD, IT, IL, LT, LL, LM, GM, and BF) and extension modality (trunk extensions vs leg extension). Secondary, because the influence of pelvic stabilization depends on the moving body part (stabilization x body part), trunk and leg extension exercise were analyzed separately. Therefore two new mixed models were conducted. When required, post-hoc comparisons were made and adjusted using a Bonferroni-correction. Paired sample T-tests were used to determine the alterations in kinematics between the extension exercise with and without active stabilization. Statistical significance for all tests was set at p≤.05.

Results

Subjects
Thirteen healthy subjects (9 females, 4 males) volunteered for this study. The mean age±standard deviation of the subjects was 22.6±2.1 years, mean height and weight were 172±7.3 cm and 61.3±9.5 kg. After training all subjects were able to perform a contraction of lumbopelvic muscle corset without compensation strategies, therefore all subjects performed the exercise sessions and their results were included into the analysis.

Kinematics
The use of an active lumbopelvic stabilization strategy during dynamic bilateral leg extension and dynamic trunk extension resulted in significant less lumbar lordosis (resp. -9.95°, t(3)=4.65, p=.019, 95% CI [0.95, 6.23]; -3.17°, t(5)=2.65, p=.045, 95% CI [4.32, 21.15]) compared to the same exercises during which this strategy was not used. The thoracic angle showed no significant differences between the extension exercises performed with or without stabilization strategy (p between .059 and .082).

The hip extension angle during stabilized trunk extension was significantly larger compared to the non-stabilized modality (+9.20°, t(4)=−15.78, p<.001, 95% CI [7.58, 10.81]). No significant differences in hip angle could be found between the leg extension exercises with and without stabilization (p=.061).
Mean angles and standard deviations are presented in Table 1.

**General effect of active lumbopelvic stabilization during extension exercises**

No significant 3-way interactions (stabilization x body part x muscle) was found ($F=1.997$, $p=.053$). The trunk and leg extension exercises were analyzed separately (stabilization x muscle), showing a significant 2-way interaction for the leg extension exercises ($F=3.73$, $p=.001$). Regarding the trunk extension exercises no 2-way interaction effect was found, but a significant effect of the main factors was observed (stabilization $F=27.17$, $p=.026$, stabilization and muscle $F=39.14$, $p<.001$).

**The effect of active lumbopelvic stabilization during trunk extension**

When an active lumbopelvic stabilization strategy was implemented in the dynamic trunk extension exercise this resulted in a significant ($F=27.18$, $p=.026$, 95% CI [5.62, 12.42]) higher recruitment level (+9.02%) of the posterior muscle chain (i.e. mean of the relative activity of all muscles (%MVIC)).

Post hoc analysis revealed alterations in the recruitment patterns of the trunk and hip extensor muscles. More specifically the relative activity of the thoracic (LT and IT) and lumbar muscles (LL, IL, LM) did not significantly ($p>.05$) differ when lumbopelvic stabilization was used. On the other hand, the mean activity of the LD, GM and BF increased significantly when active lumbopelvic stabilization was performed during the trunk extension exercises ($F=11.98$, $p<.001$; $F=4.5$, $p=.038$; $F=15.73$, $p<.001$ respectively). When the lumbopelvic stabilization strategy was implemented in the exercise the recruitment of the LD increased 9.57%MVIC (95% CI [4.41, 14.93]), the activity of the GM increased with 8.56%MVIC (95% CI [5.84, 10.15]), and the BF activity increased with 20.20%MVIC (95% CI [14.96, 29.61]). The mean activity of the different trunk muscles during

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Mean kyphotic, lordotic and hip angle and standard deviation (SD) during prone extension exercise modalities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Trunk Extension</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Without stabilization</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Mean (SD)</strong></td>
</tr>
<tr>
<td>Angles</td>
<td></td>
</tr>
<tr>
<td>Kyphotic</td>
<td>145.00° (3.61°)</td>
</tr>
<tr>
<td>Lordotic</td>
<td>37.17° (6.46°)</td>
</tr>
<tr>
<td>Hip</td>
<td>145.60° (2.07°)</td>
</tr>
</tbody>
</table>

* * significant difference at $p<.05$ between the exercise modality without and with stabilization.
the performance of the trunk extension exercises with and without lumbopelvic stabilization is displayed in Table 2 and Figure 3.

**Table 2** Mean muscle activity (%MVIC) and standard deviation (SD) during prone extension exercise modalities

<table>
<thead>
<tr>
<th>Muscles</th>
<th>Trunk Extension Without stabilization</th>
<th>Trunk Extension With stabilization</th>
<th>Leg Extension Without stabilization</th>
<th>Leg Extension With stabilization</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>LD</td>
<td>20.94 (8.84) *</td>
<td>30.51 (14.37)</td>
<td>12.02 (8.64) *</td>
<td>7.60 (3.30)</td>
</tr>
<tr>
<td>LT</td>
<td>52.80 (20.67)</td>
<td>59.80 (23.56)</td>
<td>61.48 (19.55) *</td>
<td>51.27 (11.78)</td>
</tr>
<tr>
<td>IT</td>
<td>51.12 (20.17)</td>
<td>54.89 (17.60)</td>
<td>48.55 (22.73)</td>
<td>51.04 (14.68)</td>
</tr>
<tr>
<td>LL</td>
<td>57.70 (22.62)</td>
<td>65.43 (18.37)</td>
<td>62.24 (22.76)</td>
<td>53.55 (16.67)</td>
</tr>
<tr>
<td>IL</td>
<td>58.38 (21.03)</td>
<td>67.47 (19.21)</td>
<td>56.77 (19.62)</td>
<td>51.26 (20.63)</td>
</tr>
<tr>
<td>LM</td>
<td>57.21 (20.40)</td>
<td>63.50 (20.99)</td>
<td>64.21 (27.47)</td>
<td>57.07 (18.10)</td>
</tr>
<tr>
<td>GM</td>
<td>23.83 (10.10) *</td>
<td>32.39 (21.57)</td>
<td>21.99 (7.70) *</td>
<td>38.83 (24.11)</td>
</tr>
<tr>
<td>BF</td>
<td>44.24 (20.28) *</td>
<td>64.44 (20.78)</td>
<td>39.87 (22.52)</td>
<td>42.31 (18.08)</td>
</tr>
</tbody>
</table>

LD = Latissimus Dorsi, LT = Longissimus thoracis pars Thoracic, IT= Iliocostalis lumborum pars Thoracis, LL= Longissimus thoracis pars Lumborum, IL= Iliocostalis lumborum pars Lumborum, LM= Lumbar Multifidus, GM= Gluteus Maximus, BF= Biceps Femoris

* significant difference at p≤.05 between the exercise modality without and with stabilization

**The effect of lumbopelvic stabilization during leg extension**

The mean relative activity of the trunk and hip extensor muscles did not significantly differ between leg extension exercises performed with lumbopelvic stabilization (44.11%MVIC) and those without lumbopelvic stabilization (45.89%MVIC). However, a significant interaction effect between leg extension with or without active lumbopelvic stabilization and muscle activity was noticeable, suggesting that the influence of active lumbopelvic stabilization during leg extension depends on the analyzed muscle.

The LD and LT showed significant lower levels of mean muscle activity during stabilized leg extensions (respectively -4.41%MVIC, F=7.03, p=.010, 95% CI [-5.95, -2.61]; -10.21%MVIC, F=6.24, p=.015, 95% CI [-17.88, -2.77]). The recruitment of the IT, LL, IL, MF and BF did not significantly (p>.05) change when the stabilization strategy was added, whereas the GM was clearly activated at a higher degree (+16.84%MVIC, F=14.57, p<.001, 95% CI [9.36, -21.50]) when lumbopelvic stabilization was performed during the exercise.

The influence of lumbopelvic stabilization on the mean muscle activity during leg extension is presented in Table 2 and Figure 3.
CHAPTER 4

Discussion

This study is the first to demonstrate that an active stabilization strategy of the lumbopelvic region during high load dynamic prone extension exercises affects the lumbar lordosis, the hip angle and alters the recruitment patterns of the posterior muscle chain. The finding that active stabilization is able to limit the increase in lumbar lordosis during extension suggests that by implementing this strategy spinal loads can be controlled. This is an important element to consider in clinical practice when creating exercise programs.

The EMG data of this study indicate that the posterior muscles are more active when trunk extension is performed with active stabilization of the lumbopelvic region. The increase in the total muscle work during a stabilized trunk extension can be explained by a more detailed analysis of the moving body parts during the exercise. Earlier studies consider a trunk extension as a compound movement of the thoracic and lumbar spine, combined with a rotation of the pelvis and extension of the hips. In the present study it was demonstrated that the use of an active lumbopelvic stabilization strategy effectively prevents excessive lumbar lordosis during trunk extension, resulting in an augmentation of hip extension. Co-contracting the deep stabilizing muscles of the lumbopelvic corset provides a higher lumbar stability and reduces lumbar displacement, which explains the decrease in lumbar extension. Due to the decreased lumbar extension, the trunk extension needs to be performed with more hip extension in order to reach the horizontal.

Figure 3 Differences in activity of the trunk muscles between the extension exercises performed with and without the use of active lumbopelvic stabilization.

LD = Latissimus Dorsi, LT = Longissimus thoracis pars Thoracic, IT= Iliocostalis lumborum pars Thoracis, LL= Longissimus thoracis pars Lumborum, IL= Iliocostalis lumborum pars Lumborum, LM= Lumbar Multifidus, GM= Gluteus Maximus, BF= Biceps Femoris
As a result of the changed biomechanics, the lever arm to lift the trunk will be greater, therefore more effort of the muscles, and in particular the hip extensors, is necessary. In line with the altered lever arm, the muscles conjoining the thorax with the pelvis, have a more stable basis to lift the trunk and the muscles will be able to pull the trunk as a solid mass upwards which could explain their increased recruitment.

Although active stabilization requires a substantial increase of the contribution of the lumbar muscles, no significant differences in MF, LL or IL activity during trunk extension could be demonstrated. Possibly, during the stabilized modality, the hip extensors are capable to contribute more to the trunk extension which could compensate for the initial increased activity of the lumbar muscles. Therefore, it is possible that the net contribution of the lumbar muscles is not significantly different between the two exercise modalities. Furthermore, it could be expected that the greater thoracic lever arm requires a higher contribution of the LT and IT during a stabilized trunk extension. However, in the current study no difference in LT and IT activity could be established between the two exercise conditions. In contrast the activity level of the LD clearly increased during a trunk extension with active lumbopelvic stabilization. It seems that the LD assists the thoracic extensors in lifting the trunk during a stabilized trunk extension which could explain the minimal increment in the EMG signals of the LT and IT.

To the authors’ knowledge only the effect of altering the lumbar posture during dynamic trunk extension was already examined by Mayer et al. 43. They proved that maintaining the lumbar lordosis during a prone extension exercise, did not influence the recruitment level of the gluteals or hamstrings. However, they found a 25% increase in the EMG activity of the lumbar extensors in healthy subjects. The dissimilarities with our results could be explained by differences in stabilization strategies used. Whereas in the current study subjects were learned to effectively co-contract the deep stabilizing muscles of the lumbopelvic region during different training sessions and instructed to integrate this strategy during the extension exercises, the study of Mayer et al. 43 only instructed to maintain the lumbar lordosis, without focusing on the deeper muscles. To date, both strategies, without consensus about which strategy is the most beneficial, are used in clinical rehabilitation and exercise programs.

This is the first study to investigate the effect of an active lumbar stabilization strategy during bilateral leg extension exercises. It was shown that although the use of this strategy did not influence the overall amount of posterior muscle activity, excessive lumbar lordosis was prevented and that the distribution of the activity between the muscles altered.

During dynamic bilateral leg extension, the thoracic extensor muscles (LD and LT) contract and as a consequence the lumbar lordosis increases. However, when the lumbopelvic region is actively stabilized their lordotic action is counteracted possibly resulting in diminished activity. Furthermore leg extension consists of a compound lumbar, pelvic and hip movement. However when this movement is accompanied by active stabilization of the lumbopelvic region, it primarily exists of hip extension as
extension of the lumbar spine is limited. This resulted in an increase of 17% of GM activity. The present observation is confirmed by the study of Oh et al. 19 who established a decreased anterior pelvic tilt, higher GM activity and a decrement in LES activity when performing prone unilateral leg extension during which the lumbar region was actively stabilized. Although in the present study the lower lumbar extensor activity levels also decreased, differences were not statistically significant.

The present study has several limitations that need to be taken into account. The study was executed on a small population of young healthy individuals. As altered muscle patterns occur in case of LBP, and LBP is related to poor muscle function, future research in patients with LBP would be appropriate. Furthermore, surface EMG was used to measure muscle activity, and crosstalk from surrounding muscles cannot be excluded.

**Conclusion**

The present study showed that an active stabilization strategy, existing of co-contraction of the deep lumbopelvic muscles, is able to prevent excessive lumbar lordosis during high load dynamic trunk extension exercises and bilateral leg extension exercises performed by healthy people. However, the use of this lumbopelvic stabilization strategy effects the muscle recruitment patterns of the posterior muscle chain during these exercises. More specifically, during trunk extension the diminished lordosis is accompanied by an increase in hip angle, resulting in an increase in posterior muscle chain activity, especially the LD and hip extensors. During bilateral leg extension the total muscle activation of the posterior muscles remains unchanged but a shift in activation patterns from LD and LT towards GM occur.

The observation that an active lumbopelvic stabilization strategy, as used in this study can diminish the degree of lumbar lordosis during prone extension exercises, is highly valuable for clinical practice. When integrating these exercises in prevention or rehabilitation programs, it is advisable to use active stabilization to reduce the spinal load. As this is an observational study, implementation of this strategy in clinical populations and in interventional studies have to evaluate its clinical relevance.
References

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GENERAL DISCUSSION
1. SUMMARY OF THE RESULTS

This dissertation aimed at unraveling a part of the puzzle regarding lumbar extension exercises. More specifically the influence of different exercise modalities, exercise dosage and an active stabilization strategy on muscle recruitment during lumbar extension exercises was studied. The findings of these research questions were structured in three parts. In part 1 it was examined whether and how different lumbar extension exercise modalities influence the recruitment of the posterior extensor chain. A proper exercise intensity is a perquisite to achieve specific training adaptations and to judge and interpret test results adequately. Therefore, the accuracy of two different dosage methods, a direct and an indirect method, to estimate the actual activity of the trunk extensors during trunk extension exercises was examined in part 2. Furthermore it was examined to which extent the performance of lumbar extension exercises at different exercise intensities influenced the recruitment of the posterior extensor chain. Finally, in part 3 it was examined whether the implementation of an active lumbopelvic stabilization strategy during high load prone lumbar extension exercises would affect the lumbopelvic kinematics (hip angle, spinal curvature) and recruitment patterns of the posterior extensor chain. In order to reach our research goals four types of prone extensions exercises were investigated, namely prone trunk extension and prone leg extension, performed in a dynamic and dynamic-static way. The dynamic modalities were performed with and without the instruction to actively stabilize the lumbopelvic region. Moreover, a dynamic trunk extension exercise was performed at different intensities.

The results of these three parts will first be considered separately and the observations will be clarified following the current scientific knowledge regarding muscle recruitment and kinematics. Findings will be summarized and translated into clinical considerations and recommendations regarding the selection of prone exercise modalities. Strengths and limitations of the study protocols will be acknowledged and discussed. Finally directions for further research will be proposed.

Part 1: Posterior extensor chain activity during various lumbar extension exercises.

In the first part of this dissertation it was examined whether the modality of a high load lumbar extension exercise affects the recruitment of the posterior extensor chain. The amount of activity of the different posterior extensor chain muscles was quantitatively assessed through the measurement of the myoelectric activity levels (chapter 1) and the shift in T2 (chapter 2) during the dynamic and dynamic-static performance of prone trunk and leg extension exercises. First it will be shortly described how the muscles of the
posterior extensor chain are recruited during lumbar extension exercises, and subsequently it is described how these recruitment patterns are affected by the chosen exercise modality.

The studies of this dissertation demonstrated that regardless of inducing the lumbar extension by lifting the trunk or the legs, the lumbar and thoracic muscles were more active than the LD and hip extensors (GM and BF) during these prone extension exercises. The moderate activity levels of the LD and hip extensors are in line with earlier investigations (1-6) and are not surprising given the main function of these muscles (7;8). A previous study stated that, although the main function of the LD and GM was not related to the spinal region, they contribute to the extension moment through their connection with the FTL (9). However, in our studies the relative activity of the LD (chapters 1, 2 and 4) indicates only a minor role of the muscle during prone lumbar extension exercises, whereas a higher contribution of the GM (chapters 1 and 4) during lumbar extension exercises was noticed. The results from chapter 1 and 2 show that the degree to which the muscles of the posterior extensor chain are activated and contribute to the extension moment is dependent on the chosen exercise modality and contraction modality. Below the specific influence of two different exercise modalities which can be used to induce lumbar extension will be further discussed, namely a trunk extension exercise versus a bilateral leg extension exercise. Furthermore the influence of two different contraction modalities of these lumbar extension exercises is discussed: a dynamic and a dynamic-static contraction.

Trunk versus leg extension

As described in the introduction it is assumed that the required function of the muscles of the posterior extensor chain varies during a prone trunk versus a prone leg extension exercise, due to different biomechanics. The findings of chapter 1 support this assumption, as it was shown that the recruitment of the posterior extensor chain is influenced by the type of prone extension exercise which is performed. Our results regarding the activity level of the posterior extensor chain in total, indicate that the muscle of the extensor chain are recruited at a higher degree during prone trunk extension exercises than during prone leg extension exercises (chapters 1 and 2). These findings are supported by the self-reported rate of perceived exertion, which is higher following trunk extension exercises then following leg extension exercises.

Besides examining the posterior extensor chain in its totality, the studies from this dissertation tried to provide more detailed information by studying the recruitment of the different muscles of the posterior extensor chain separately. Hence relative activation of the LD, the TES (LT and IT), the LES (LL and IL), LM and the hip extensors (GM and BF) was examined during trunk and leg extension exercises using sEMG and mfMRI. The detailed analysis showed that not all extensors were activated at the same degree. A general overview of these detailed findings are presented in table 1.
Regarding the lumbar muscles (LES and LM), both the sEMG (chapter 1) and mfMRI results (chapter 2) indicate that these muscles were activated to a higher degree during prone trunk extension than during prone leg extension exercises. This difference can be explained by the different function which the lumbar muscles have to fulfill during both exercise modalities. In order to perform a prone trunk extension the lumbar muscles need to work dynamically to lift and lower the lumbar spine while providing dynamic lumbar spine stability. Whereas during prone leg extension, the lumbar muscles need to deliver more static work to stabilize the spine and pelvis, allowing the hip muscles to lift the legs. In this regard the lumbar muscles contribute only partially to the extension moment during the leg extension exercises. Our results concerning the recruitment of the lumbar muscles, are in contrast with the findings of Plamondon et al. (1), who showed slightly higher LES activity during a prone leg extension compared to a prone trunk extension. Causative factors for the dissimilarities may be related to discrepancies in starting angle and arm position between the investigations. Moreover, differences in the intensity of the exercises were also present between the study of Plamondon et al. (1) and our study. While in our study the extension exercises were performed with an exercise intensity of 60% 1-RM, the study of Plamondon et al. failed to the take the difference in weight of both body parts into account (1). Consequently, a proper comparison between both studies is not possible.

An analysis of the lumbar muscles separately, revealed that the lumbar muscles are working rather homogeneous during the performance of prone extension exercises. This indicates that all lumbar muscles have a similar function when conducting a prone trunk or leg extension, which is in line with the findings of Danneels et al. (10). Other studies have reported more differentiated patterns among the lumbar muscles during trunk extension exercises (11-14). The uniformity of the lumbar muscle function, demonstrated in this dissertation, may be caused by the relative high exercise intensity. Higher resistance levels have been shown to result in an increased contribution of the LES in relation to the LM to maintain the force output (11). In this regard, low load exercises could be more appropriate to illustrate the functional differences among the lumbar muscles. However our results (chapter 3) could not support this assumption with regard to trunk extension at lower intensities. This might indicate that regardless of the exercise intensity, the extensor muscles of the lumbar region contribute equally to the extension moment from prone position.

When the recruitment of the TES was investigated, it was demonstrated that in order to extend the trunk or legs from prone lying the TES are less activated than the LES and LM (chapter 1). These findings confirm that compared to the lumbar muscles, the TES is mechanically in favor to produce an extension moment. Through its long tendons crossing the lumbar region the TES can highly contribute to the extension torque and can
be reckoned as the most efficient trunk extensor (15;16). Furthermore, in chapter 1 it was observed that the activity of the TES was significantly higher during the trunk extension exercises than during the leg extension exercises which points to a significant influence of the extension modality on the TES activity. The higher myoelectric activity of the TES during trunk extension compared to leg extension can be explained by the altered muscle demands between the extension exercises. In order to perform a trunk extension the length of thoracic muscles shortens (concentric activity). Since, the thorax is fixated on the table, only minimal alterations in the length of the thoracic muscles will occur while extending the legs. As a result, the TES will work in a more isometric way during leg extension. As more motor units are activated during a concentric contraction compared to an isometric muscle contraction, larger electrical muscle activity will be generated during the trunk extension exercises (21;23).

However, the observations made using sEMG could not be substantiated by the mfMRI data (chapter 2) as no differences in the exercise induced T2-shift of the TES between prone trunk and leg extension exercises could be demonstrated. An explanation of these contrasting data can be found in the fact that both evaluation techniques are measuring different elements of muscle activity. Whereas sEMG measures real time myoelectrical activity, mfMRI is a post-exercise evaluating method measuring physiological adaptations upon exercise (17;18). As a result of the different biomechanics, it is hypothesized that during prone leg extension the TES has to work in an isometric way, while during prone trunk extension a dynamic contraction (concentric and eccentric contraction) of the TES is required. The difference in the type of TES contraction between the extension exercises is associated with different physiological responses (the blood flow and metabolic cost). However, based on the results of chapter 2 it seems that these differences in metabolic cost and blood flow between both exercise modalities will compensate each other. Normally, the blood flow increases in the relaxation phase following contraction (19). However, during a sustained contraction the blood flow is limited by a high intramuscular pressure, creating a more anaerobic working state for the muscles. The accumulation of metabolic side products during this anaerobic muscle work, is expected to alter the osmolality of the exercised muscle, which affects the signal intensity on the T2 weighted images. In contrast the metabolic cost during the dynamic (concentric and eccentric) work of the TES, as occurred during trunk extension exercises, will be higher than during isometric muscle work. The higher metabolic demands will also increase the signal intensity on the T2 weighted images (18;20). Our results indicate that although the TES works in a different way during both exercises, no alterations in T2-shift between the extension exercises could be observed. This reflects similar exercise induced physiological adaptations following both exercises modalities. More specifically, this indicates that during a sustained contraction the metabolic cost is low but the accumulation of side products is high due to an occluded blood flow. In contrast the energetic demands of a
Table 1  General overview of the findings of chapters 1, 2 and 4 regarding the differences in activity of the posterior extensor chain muscles during various prone lumbar extension exercises.

<table>
<thead>
<tr>
<th>PRONE LUMBAR EXTENSION</th>
<th>TRUNK VS LEG EXTENSION (CHAPTER 1+2)</th>
<th>DYNAMIC VS DYNAMIC-STATIC CONTRACTION (CHAPTER 1+2)</th>
<th>LUMBOPELVIC STABILIZATION (CHAPTER 4)</th>
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<td>Trunk</td>
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<td>Electric activity</td>
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<td></td>
<td>LD</td>
<td>Trunk = leg</td>
<td>Dynamic = Dynamic-static</td>
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<tr>
<td></td>
<td>TES (IT &amp; LT)</td>
<td>Trunk &gt; leg</td>
<td>Dynamic = Dynamic-static</td>
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<td>LES (IL &amp; LL)</td>
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<td>LM</td>
<td>Trunk &gt; leg</td>
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<tr>
<td></td>
<td>GM</td>
<td>Trunk = leg</td>
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<td>BF</td>
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<td>Metabolic activity</td>
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<td>data analysis in progress</td>
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<td>TES (IT &amp; LT)</td>
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LD = Latissimus Dorsi, TES = Thoracic Erector Spinae, LT = Longissimus thoracis pars Thoracis, IT = Iliocostalis lumborum pars Thoracis, LES = Lumbar Erector Spinae, LL = Longissimus thoracis pars Lumborum, IL = Iliocostalis lumborum pars Lumborum, LM = Lumbar Multifidus, GM = Gluteus Maximus, BF = Biceps Femoris.

* only significant for IT.
Dynamic contraction are higher, but the accumulation of side products will be smaller due to a better muscle perfusion.

Regarding the hip extensors, no differences in the recruitment level of the GM between both exercise modalities could be observed. Biomechanically both exercises are characterized by an extension moment in the hip joint, which is achieved by contraction of the GM and hamstrings muscles. However, the muscle length and the required contraction differ with regard to the extension modality. The length of the GM is only affected to a limited extent in both exercises, whereas the length of the hamstrings varies to a greater extent during the leg extension exercise. In this respect, the hamstrings muscle could participate at a higher degree compared to the GM and therefore compensate the total work of the hip extensors during leg extension. Since, the activation of the hamstrings was not evaluated in this study, this assumption can not be validated. Moreover, because we were not able to investigate the GM activity in combination with the other posterior chain extensors by means of mfMRI, possible variations in the physiological responses of the GM upon a trunk or leg extension cannot be discussed.

In conclusion, while the existing literature has focused solely on the extensor muscles of the lumbopelvic region, in this dissertation the role of all posterior extensor muscles was concurrently assessed during two prone lumbar extension exercise modalities. The examination of the posterior extensor chain in its entirety seemed necessary as the recruitment level of some extensor muscles is dependent on the exercise modality. Both types of lumbar extension exercises mainly target the lumbar muscles and subsequently the thoracic muscles. In contrast the latissimus dorsi and hip extensors are recruited at a lesser extent compared to the thoracic and lumbar muscles. Although the two lumbar extension exercise modalities were performed at an identical exercise intensity, the lumbar and thoracic muscles were recruited at a higher degree during trunk extension exercises than during leg extension exercises. While the higher recruitment of the lumbar muscles during trunk extension exercises was established using both sEMG and mfMRI, the higher thoracic extensor activity was shown using sEMG and could not be supported by a higher shift in \textit{T2}. These findings regarding the different recruitment of the posterior extensor chain can be explained in the light of diverged biomechanics and differences in the required muscle work during both extension exercises.

**Dynamic versus dynamic-static contractions**

In the general introduction of this dissertation a close relation between the contraction modality of an exercise and the amount of muscle activity has been documented. There was a lacuna in the literature, as the influence of different contraction modalities of lumbar extension exercises on the posterior extensor chain activity had never been investigated before. Therefore differences in the activity of the posterior chain extensors, related to a dynamic or dynamic-static exercise modality were examined in healthy individuals (chapters 1 and 2).
It was hypothesized that the electrical and physiological muscle responses induced by combined dynamic-static contractions will be more apparent than during dynamic contractions. This expectation is based on the observed differences in the amount of motor units recruited and the energetic demands between the two contraction modalities (21;22;24;25). It has been demonstrated that with prolonged exercise duration additional motor units are recruited in order to maintain the force output necessary to maintain a constant level of performance (26). Furthermore it has been shown that when the required muscle force enhances, as a result of increased exercise load, more motor units will be progressively activated (22;26). This higher fiber muscle recruitment can be detected by surface electrodes and is reflected by the EMG signals (27). Furthermore, not only the motor unit recruitment but also the energetic demands vary among the different types of contractions. The energetic cost of a dynamic contraction is assumed to be the twofold of that of a static contraction (28). Moreover, in order to respond to the required energy expenditure the muscle blood flow is larger when contracting dynamically. These exercise induced changes can be considered as a measure of the degree of muscle activity and are visualized on the T2 weighted images by a lighter color of the exercised muscles. Like the myoelectric activity, the alteration in T2 is dependent upon the exercise duration and intensity (11;14;18;25;29). Based on the differences in exercise duration between the dynamic and dynamic-static exercise modality used in this dissertation, higher muscle work could be expected during the dynamic-static exercise condition. However, the results of part 1 showed that the recruitment of the posterior extensor was not influenced by the contraction modality of the lumbar extension exercises.

In chapter 1, the myoelectrical activity of the posterior extensor chain in its totality was assessed using sEMG during both prone trunk extension and prone leg extensions exercises. Whether the exercises were performed in a dynamic-static or a dynamic way did not influence the total amount of muscle work produced during these exercises. This can be explained by the fact that in this dissertation a pretest was conducted in order to individually adjust the exercise load in accordance with the predefined exercise intensity (60% 1-RM). As a consequence of this pretest the exercise weight necessary to complete the dynamic-static exercises was lower than the required exercise weight during the dynamic exercise performances. These adjustments led to lower levels of muscle activity during the concentric and eccentric phase of the dynamic-static exercises in comparison to the pure dynamic exercise condition in our study. Since the total amount of muscle work depends on the duration and the amount of muscle action, the lower external loading during the dynamic-static exercises probably compensates for the longer duration of this exercise. This explains why the recruitment of the posterior extensor chain was equal during prone extension exercises performed dynamic-statically and dynamically performed exercises.
Besides examining the posterior extensor chain in its totality, the different muscles of the posterior extensor chain were also examined separately. Based on the sEMG results (chapter 1) it was demonstrated that the myoelectric activity levels of the lumbar, thoracic and the hip extensor muscles were not influenced by the contraction modality. In contrast when mfMRI was used to evaluate the muscle activity, a higher activation of the lumbar muscles was observed during the dynamic-static compared to the dynamic exercises (chapter 2). The higher lumbar muscle recruitment during the dynamic-static contraction modality can be explained by the fact that the lumbar muscles are the most targeted muscles of all posterior chain extensors during prone extension exercises as previously discussed. Hereby it is conceivable that the modifying effect of the different rates of energy metabolism and oxygen supply between both contraction types is only significantly presented in the lumbar muscles. It has previously been demonstrated that the increased shift in T2 is dependent on the duration (29) and the (an)aerobic state of the exercise (30). In this regard the role of the static component cannot be ignored. Adding a static phase in between the concentric and eccentric phase prolonged both the duration of the exercise and increased the accumulation of osmotic metabolites due to the restricted blood flow, which is detected by the mfMRI measurements. However, nor the blood flow nor the metabolic side products were measured in this dissertation. Hence, further research is necessary in order to corroborate our findings. Another explanation for the contrasting findings with regard to the lumbar muscles could be the difference in the used muscle evaluation technique between the two studies. Whereas in chapter 1 muscle activity was measured with the use of sEMG, in chapter 2 mfMRI was utilized. Generally it is accepted that when sEMG is used, cross talk of adjacent muscles may occur. Due to this cross talk phenomenon a rather diffuse view of the trunk extensor muscles will be obtained. In contrast, mfMRI is considered to be an evaluation technique which allows a more accurate differentiation among the various muscles. Hence, mfMRI could be more discriminative to detect specific changes in the lumbar muscles compared to sEMG.

* Taken together, the total amount of myoelectric activity of the posterior extensor muscles is not dependent by the type of contraction during these high load exercises. The lack of differences can be explained by the difference in exercise weight between the dynamic and dynamic-static exercise performance, which probably compensates for the differences in exercise duration. The difference in exercise weights was a necessary adjustment in order to perform the dynamic and dynamic-static extension exercises at an equal intensity level. While sEMG was not able to identify any influence of the contraction modality on the activation patterns, changes in the recruitment of the lumbar muscles could be established using mfMRI. The lumbar muscles were activated to a greater extent during dynamic-static exercises then during dynamic exercises. mfMRI seems more sensitive for the type of contraction during extension exercise. This is probably due to the fact that the extension exercises are mostly targeting the lumbar muscles and that mfMRI is more discriminative then sEMG to detect specific changes in the lumbar muscles. This
highlights the importance of both investigation methods, as the use of both techniques provide a complementary rather than a competitive view on the differences in the activity of the posterior extensor chain associated with the type of contraction.

In conclusion, all the muscles of the posterior extensor chain are activated during the various exercise conditions which were examined. Moreover, the type of exercise and contraction modality affect the activity of the posterior extensor chain muscles though at varying degrees. During trunk extension exercises the thoracic and lumbar extensors are activated at a higher extent than during leg extension exercises. The dynamic-static extension modality has the ability to specifically increase the recruitment of the lumbar extensor muscles. Hence, the dynamic-static trunk extension seems the most preferable exercise to target the lumbar muscles. In conclusion, all the muscles of the posterior extensor chain are activated during the various exercise conditions which were examined. Moreover, the type of exercise and contraction modality affect the activity of the posterior extensor chain muscles though at varying degrees.

Part 2: Relation between the predefined and actual activity of the posterior extensor chain during trunk extension exercises.

In order to determine the trunk extension exercise dosage both a direct and indirect method are frequently used by clinicians and trainers. In chapter 3 it was investigated whether the performance of a trunk extension exercise at varying intensities influences the activity levels and recruitment patterns of the trunk extensor muscles in healthy people and if these alterations depend on the dosage method used. Secondly, the study investigated whether the actual activity of the thoracic and lumbar extensors reflected the predefined intensity for each method separately. It was examined if both the direct and indirect dosage method can be used to accurately estimate the activity of the trunk extensors during trunk extension exercise. In order to investigate this, muscle activity levels of healthy people were examined by sEMG during dynamic trunk extension exercises. The trunk extension exercises were dosed in two ways. Firstly according to the indirect method and performed in prone position on a variable angle chair. Secondly, in accordance to the direct method and performed in semi-standing position in a rehabilitation device.

As expected, the lowest activity levels of TES, LES and LM were consistently demonstrated at 40% 1-RM, while the highest levels were shown at 100% of the 1-RM. However, the magnitude of the increments was dependent on the method used to calculate the exercise intensity. In addition, differences in the recruitment patterns due to higher exercise resistance were demonstrated. The augmentation in myoelectric signals is in
acCORDANCE WITH EARLIER FINDINGS AND CAN BE ELUCIDATED BY THE PROGRESSIVE MOTOR UNIT
RECRUITMENT RELATED TO HIGHER EXERCISE INTENSITIES (14;23;27). IT WAS SHOWN THAT WHEN TRUNK
EXTENSION EXERCISES WERE PERFORMED ON A REHABILITATION DEVICE AND THE EXERCISE RESISTANCE
WAS DETERMINED BY THE DIRECT METHOD, THE INCREMENTS IN TRUNK EXTENSOR MUSCLE ACTIVITY
WERE SLIGHTLY HIGHER THAN THE ACTUAL INCREASE IN EXERCISE LOAD. IN CONTRAST, WHEN THE TRUNK
EXTENSION WAS PERFORMED FROM PRONE LYING AND THE INDIRECT METHOD WAS USED TO
Determine THE EXERCISE LOAD, THE TRUNK EXTENSOR ACTIVITY INCREASED TO A LESSER EXTENT THAN
EXPECTED.

FURTHERMORE DIFFERENT PHENOMENA REGARDING THE TRUNK EXTENSOR ACTIVATION PATTERNS WERE
OBSERVED DEPENDING ON THE DOSAGE METHODS. DURING A LOW LOAD SEMI-STANDING TRUNK
EXTENSION EXERCISE DOSED BY THE DIRECT METHOD, THE IT SHOWED LOWER ACTIVITY LEVELS
COMpared TO THE LUMBAR MUSCLES (IL, LT AND LM). THIS PATTERN FADED UPON ASCENDING
INTENSITY. THE DIFFERENCE IN MUSCLE ACTIVITY BETWEEN THE IT AND IL DISAPPEARED AT A
RESISTANCE OF 60% 1-RM. AT 80% 1-RM THE DIFFERENCE WITH THE IT ALSO DISSIPATED AND THUS
ONLY THE LM DEMONSTRATED SIGNIFICANTLY HIGHER ACTIVITY LEVELS THAN THE IT. FINALLY A
HOMOGENEOUS RECRUITMENT OF THE TRUNK EXTENSORS WAS OBSERVED AT 100% 1-RM. THIS SHIFT
INDICATES A LARGER CONTRIBUTION OF THE IT IN ORDER TO ASSIST THE TRUNK EXTENSORS IN CREATING THE
EXTRA FORCE NECESSARY TO COMPLETE THE TRUNK EXTENSION AT HIGHER RESISTANCE LEVELS. THE
CONSISTENT HIGHER ACTIVITY OF THE LM UP TO AN EXERCISE INTENSITY OF 80% 1-RM WAS
DEMONSTRATED PREVIOUSLY USING mfMRI (11).

ON THE CONTRARY NO DIFFERENCES IN THE ACTIVATION PATTERNS AMONG THE TRUNK EXTENSOR
MUSCLES COULD BE DEMONSTRATED WHEN DOSAGE WAS BASED ON THE INDIRECT METHOD. THIS
DENOTES TO A SYNERGETIC WORK OF THORACIC AND LUMBAR EXTENSORS IN ORDER TO EXTEND THE
TRUNK, AS ONE LARGE LEVER ARM, REGARDLESS THE EXERCISE INTENSITY. NEVERTHELESS
DETAILED ANALYSIS OF OUR STUDY RESULTS REVEALED THAT THE THORACIC EXTENSORS CONTRIBUTED RELATIVELY
MORE TO THE TRUNK EXTENSION AT HIGHER INTENSITY LEVELS, ALTHOUGH THE DIFFERENCE IS NOT
STATISTICALLY SIGNIFICANT. THIS IS IN CONTRAST WITH THE RESULTS OF CHAPTER 1, IN WHICH A HIGHER
LUMBAR MUSCLE CONTRIBUTION DURING TRUNK EXTENSION AT AN INTENSITY OF 60% 1-RM WAS
DEMONSTRATED THAN WAS THE CASE IN CHAPTER 3. TO OVERCOME HIGHER LOADS IT IS SUGGESTED
THAT IN RELATION TO THE LUMBAR EXTENSORS, THE CONTRIBUTION OF OTHER EXTENSORS ENLARGED (2).
HOWEVER THIS HYPOTHESIS COULD NOT BE CONFIRMED AS THE PRESENT STUDY DID NOT ANALYZED
THE LD OR THE HIP EXTENSORS. FURTHER RESEARCH INVESTIGATING THE RELATIVE CONTRIBUTION OF ALL
TRUNK EXTENSORS WOULD BE RELEVANT. MOREOVER, THE ABSENCE OF DIFFERENCES IN THE ACTIVITY
LEVELS AMONG THE LUMBAR MUSCLES DURING PRONE TRUNK EXTENSIONS IN LOW LOAD AND HIGH
LOAD IS CONSISTENT WITH PRIOR REPORTED DATA (14). A STUDY EXAMINING THE RELATION BETWEEN
THE EXERCISE INTENSITY AND THE ACTIVITY OF THE THORACIC EXTENSORS DURING PRONE TRUNK
EXTENSION IS NON-EXISTENT.
Although we acknowledge the difference in test position, we believe that this has only a minor impact on our results. The range of motion of the total extension movement was identical in both test conditions as the trunk extension exercises were always performed from a hip angle of 45° flexion. Hence, from a biomechanical point of view, both trunk extension exercises are very similar. Therefore, we think that the variation in test posture did only slightly attribute to the observed differences in recruitment patterns between both test conditions. Furthermore, comparing the upright position with prone lying, it is obvious that gravity has a different impact. But since the exercises are performed against resistance and the determination of the dosage is conducted in a position identical compared to the experimental protocol, it is believed that this procedure compensated for the influence of gravity.

In conclusion, the activity of the thoracic and lumbar extensors was significantly influenced by the intensity level of a dynamic trunk extension exercise, regardless which dosage method was used. Furthermore, increasing the intensity of a trunk extension exercise altered the trunk extensor recruitment patterns, when the direct method was used to determine the exercise load. Using the indirect method, no differences in the activity among the thoracic or lumbar muscles could be established, independently of the resistance level.

Analyzing the thoracic and lumbar extensor muscle activity at the predefined exercise intensities demonstrated that the actual activity levels were not a close reflection of the estimated exercise intensity. Our results demonstrated that at each level of intensity the actual muscle work was overestimated in relation to the intended exercise intensity, except for the 100%-level determined by the direct method. This degree of overestimation was dependent on the dosage method used. When the indirect method was used, the differences between the actual and aimed exercise intensity increased with ascending intensity. Hence a striking overestimation of the posterior extensor chain activation during prone trunk extension exercises was observed at high intensity levels while the difference diminished at lower intensity levels. An opposite effect was established when the direct dosing method was used. The actual and predicted muscle activity values were more deviated at low intensity levels, and the difference dissipated as the intensity levels increased. From these observations it can be concluded that to predetermine the exercise dosage, the direct method is the most accurate for estimating high intensities while the indirect is the most accurate for determining low intensity levels.

When a detailed analysis of each muscle of the posterior extensor chain is conducted, the direct method seems to be the most valid method to dose the LM followed by the LL, IL and LT, whereas the direct method seems to be the least appropriate method for the estimation of the muscle work provided by IT. However, at a maximal exercise intensity of 100% the direct method is the most accurate dosage method for all extensor muscles.
that case the resistance is so high that all trunk extensors are required to contribute to the extension moment. In view of the different dosage methods, semi-standing trunk extension exercises at lower loads mainly target lumbar muscles.

Regardless of the slight overestimation of the actual trunk extensor muscle work, the use of the indirect method provided an accurate determination of the intensity of a prone trunk extension exercise at the lower resistance levels. Whereas when the goal was to activate the trunk extensors at a greater extent, the indirect method seems inappropriate, expect for the IL. In general, the indirect method can be reckoned as the most valid method for the IL, followed by the LL, LM and LT, whereas it was the least appropriate method to reflect the extension exercise intensity of the IT.

Taken together, the weakest agreement between the actual and estimated activity levels was observed for the IT. The reason why both methods were less capable to dose the thoracic extensor muscle at the predefined intensity can be found in the light of the principal effect of the exercise, namely targeting the lumbar muscles (as demonstrated in part 1). It should be noted that the trunk extensor activity levels observed in this study (chapter 3) were substantially lower than found in chapter 1, but in agreement with the results of chapter 4 where similar exercises were used. Since the physical characteristics between the investigated populations were comparable only differences in psychological factors could be considered as possible causes of the dissimilarity between both studies. These subjective psychological factors (motivation, anxiety, etc.) might also explain the consistent overestimation of the actual trunk extensor activity, except for the 100%-level determined by the direct method. In particular, the motivation of the person during the performance of strength measurements can influence the final results, especially when using submaximal tests (31).

Based on these results, none of the approaches seems to be superior in order to determine the exercise intensity. However, it can be concluded that the direct method is more accurate to determine the dosage of trunk extension exercises performed at high intensity levels, while the indirect method is more appropriate to compute the exercise load for low intensity exercises.

In this dissertation the activity levels of the trunk extensors were investigated during extension exercises at 60% 1-RM. The findings that the indirect method is appropriate to dose lumbar extension exercises are crucial since the indirect method was used to calculate the exercise load in other experiments within the current dissertation.
**Part 3: The effect of an active lumbopelvic stabilization strategy during prone lumbar extension exercises**

It has been described that lumbar hyperextension induces high spinal compression forces (32). As high spinal loads are related to the development of LBP, lumbar hyperextension should be avoided (33-35). One of the mechanisms proposed to limit excessive lumbar extension and protect the spinal joint during activities is the implementation of an active lumbopelvic stabilization strategy. To actively stabilize the lumbar spine subjects were trained to contract their lumbopelvic muscle corset. Several studies have demonstrated that contracting the lumbopelvic muscle corset alters the lumbar muscle recruitment and kinematics when performing low load exercises or daily activities (36-39). However, little is known about the influence of the implementation of this active stabilization strategy on the recruitment of the posterior extensor chain muscles and lumbopelvic kinematics during high load extension exercises. For this reason we intended to answer the following research question in chapter 3; “Does the implementation of an active lumbopelvic stabilization strategy during high load prone lumbar extension exercises affect the lumbopelvic kinematics and recruitment patterns of the posterior extensor muscles?”. To answer this question it was examined 1) how the activation levels of the posterior extensor chain during prone trunk and leg extension exercises were influenced by the use of a lumbopelvic stabilization strategy, and 2) if the implementation of this strategy during the exercises affects the thoracolumbar and lumbopelvic kinematics. As the biomechanics are different during trunk extension and bilateral leg extension, the results are discussed separately for each modality.

Our results demonstrated that the use of an active stabilization strategy during a high load prone trunk extension exercise influences the lumbopelvic and not the thoracolumbar kinematics. In detail, while the thoracic angle was similar during trunk extension exercises performed with and without the use of active lumbopelvic stabilization, a smaller lumbar angle and a larger hip angle were found when the stabilization strategy was implemented. The decreased lumbar angle due to the use of this strategy is in agreement with the observations from earlier investigations (36;40), and is proof of the effectiveness of the active lumbopelvic stabilization strategy in preventing lumbar hyperlordosis to some degree. In the light of the combined lumbo-pelvic-hip motion, the limited lumbar extension during the stabilized exercise condition will be compensated by an increased extension in the hip (41-43). These findings are supported by the alterations in the activity levels of the hip extensor muscles in chapter 4. The extra hip extension necessary to lift the trunk, when the trunk extension exercise is performed with an active lumbopelvic stabilization strategy, is reflected by the higher GM and BF activity. In line with the increased lever arm, the thoracic extensors attaching the thorax and pelvis (TES and LD) have a more stable basis to work on and will be able to pull up the trunk as one solid
segment. This assumption is confirmed by the significant increase in LD activity and the small increase in the activity of the TES, though not significant. These observations indicate that the LD assists the thoracic extensors in extending the trunk when the trunk extension is performed upon on a more stable base, therefore the net effect on the thoracic extensors is limited.

Previous findings suggested to stabilize the pelvis during seated or prone trunk extension in order to isolate the lumbar muscles (36;44-46). However, stabilizing the lumbopelvic region in our study could not significantly increase the recruitment of the thoracic or lumbar extensors during a high load prone extension exercise. The different stabilization techniques used in both studies may be the cause of the contrasting findings. In this dissertation an active stabilization strategy was used, while in earlier studies a passive pelvic fixation was applied.

Since the LES and, (the deep) LM in specific, are assumed to highly contribute to lumbar spine stability (47-50), an increased recruitment of these muscles was expected when the lumbopelvic muscle corset was contracted during the prone extension exercises. While our study results could not verify this hypothesis, a previous study could support this assumption by showing a higher lumbar muscle contribution when maintaining a neutral lumbar position during a dynamic trunk extension exercise (39). This inconsistency between our expectation and the results of the study of Mayer et al. (39) could be caused by three different elements: 1) the exercise intensity, 2) the type of stabilization strategy, and 3) the muscle evaluation technique.

In the study of Mayer et al. (39) the weight of the trunk was used as exercise load, which is probably lower than the intensity of 60% 1-RM used in our study. As a result of the high exercise intensity in our study, large levels of lumbar muscle activity were already generated in the non-stabilized condition. While in the study of Mayer et al. (39) subjects were instructed to maintain the lumbar spine in a neutral position, in our study subjects learned to actively contract the deep stabilizing muscles. Moreover, in our study, it was demonstrated that when an active stabilization strategy is used, the hip extensor activity increased, whereas Mayer et al. (39) found no influence of the instruction to maintain the lumbar position on the activity of the GM or hamstrings.

Subsequently, one could assume that the increased hip extensors recruitment in our study could have compensated for the expected higher lumbar muscle activity when stabilizing the lumbopelvic region. The combination of both the high exercise intensity and the increased hip extensor recruitment could explain the rather identical net contribution of the lumbar muscles during both exercise conditions. With regard to the evaluation technique, the use of sEMG to capture the signals of the LM or LES accurately is questioned earlier due to cross talk of adjacent muscles (51). This cross talk could have masked possible differences in the LM and LES caused by the active stabilization strategy.
It was showed that when a dynamic high load leg extension exercise was performed with and without the use of an active stabilization strategy, the implementation of the stabilization technique decreased the lumbar lordotic angle, whereas the thoracic and hip extension angles were not affected. Moreover, the relative activity levels of the LD and LT decreased, whereas the GM activity increased during the stabilized condition. No differences in the myoelectric activity of the IT, the lumbar extensors and the BF between both exercise conditions could be established in our study. As demonstrated in chapter 1, to complete the leg extension exercise the thoracic extensors are activated, likely causing an initial increase in the degree of lumbar lordosis. However, when stabilizing the lumbopelvic region the action of these muscles is partly inhibited, resulting in a reduced lumbar angle. In contrast to the trunk extension exercise, no compensation in the hip extension angle in order to reach the horizontal was observed. This can be explained by the fact that even in the non-stabilized leg extension exercise a large hip extension movement occurs. These changes in kinematics are supported by the alterations in the activity levels of the relevant muscles. As a consequence of the limited lumbar extension, the thoracic muscles, particularly the LD and LT, contribute less during a stabilized leg extension. Despite our expectations, there was no significant effect on the lumbar extensor muscle activity. As stated above this could be due to the high exercise intensity in our study, which will automatically induce high activity levels of the lumbar muscles. Although, there was no significant increase in hip extension, actively stabilizing the lumbopelvic region enhanced the activation of the GM, but not the BF. A possible explanation is that a decrease in lumbar angle is associated with a posterior pelvic tilt, which is mainly caused by the contraction of the GM (8), while the BF acts as prime mover and actually lifts the legs during the leg extension exercise.

Our results concerning the relative activity of thoracic, lumbar and hip extensors between the exercise conditions, can support the assumption that no trunk muscle is superior in controlling the spine during movements (49,52). The higher contribution of the large torque producing muscles during high load prone extension exercises indicates that the stabilization of the lumbar spine is not only achieved by the deep stabilizing muscles but also by the large torque producing muscles, which probably induce a more global stability. This co-operation between the deep stabilizing and large torque producing muscles will assist in the control of spinal buckling and intervertebral motion via compression. In this respect, the activity of the GM and LD will contribute to spinal stability through the FTL (9). Moreover, the higher contraction of the GM in the stabilized exercise conditions could help the deep stabilizing muscles to control the lordotic angle, by generating a posterior pelvic tilt in high load conditions.

A more detailed analysis of the lumbar angles showed that the degree of lumbar lordosis in our study varies from 31 to 43,5° during a non-stabilized trunk extension exercise.
conditions and from 35 to 43° in the non-stabilized leg extension. During the stabilized trunk extension lordotic angles between the 28 and 40° were demonstrated. Whereas only small variations in lumbar lordosis were demonstrated during the leg extension exercise (28 to 31°). This emphasizes that the effect of contracting the lumbopelvic muscle corset on the lordotic angle is higher during the leg extension exercise than during the trunk extension exercise. The large differences in the kinematics during a prone leg extension versus a prone trunk extension may be related to the freedom of movement of the pelvis. Whereas the pelvis rests on the table during prone trunk extension exercises, the pelvis is unsupported during the leg extension exercises and hence a larger movement range is possible in the latter condition. This is affirmed by the lordotic and hip extension angles demonstrated during leg extension. Although it was not an objective of this thesis to compare both exercises, this presumption could be observed in our data.

In conclusion, it is evidenced that the instruction to apply an active lumbopelvic stabilization strategy is able to reduce the lumbar lordosis during prone extension exercises in healthy individuals. Moreover, the alteration in kinematics is reflected by changes in the recruitment patterns of the posterior extensor chain. In particular, when the lumbopelvic stabilization technique is implemented, the recruitment of the large torque producing muscles is changed in order to complete the lumbar extension exercises. Moreover, based on our findings it can be assumed that both deep stabilizing muscles and large torque producing muscles are working harmoniously in order to control and move the lumbar spine during high load prone extension exercises.

2. CLINICAL CONSIDERATIONS

Our findings regarding the posterior extensor chain recruitment during several modifications of prone lumbar extension exercises and the exercise dosage method have several important clinical implications. This dissertation provides some directions to facilitate exercise selection for trunk extensor endurance and strength programs. Although these implications need to be considered when training healthy people, the observations cannot be directly extrapolated to LBP populations.

2.1. Designing a safe exercise program

From this dissertation differences in the electric and metabolic activity of the thoracic, lumbar and hip extensor can be allocated to various modifications of prone lumbar extension exercises. The findings that regardless which exercise modality was performed the thoracic and lumbar extensors are activated at a higher extent than LD and hip extensors (Chapter 1, 2, 4), might indicate that these exercises should be recommended when aimed at targeting specific training of the thoracic and lumbar extensors. In contrast
other exercises would be more appropriate to focus on LD and hip extensors. At the same time hip extensor contribution may not be neglected. GM and BF activity levels up to 44% and 43% of MVIC were provoked during trunk and leg extension respectively, which is considered sufficient to improve muscle endurance (26;53;54). As described in the introduction sufficient trunk extension strength is a prerequisite for optimal spine function and the prevention of LBP. In order to enhance basic muscle strength the prevailing opinion is that for concentric exercises intensity levels higher than 60% are required (53;55). In this dissertation recruitment levels of more than 60% of MVIC are obtained by all thoracic and lumbar muscles during the different types of exercises. This signifies that although the thoracic muscles were activated at a slightly lower degree compared to the lumbar muscles, each exercise modality can be used to induce strength improvements of the thoracic and lumbar extensors when the exercise intensity is set at 60% 1-RM, yet trunk extension elicited higher levels.

Furthermore, the results of our studies reveal that regardless of the intensity of the exercise, the thoracic and lumbar muscles are working rather homogenously during prone extension exercises (chapter 3). This suggests that these exercises are not appropriate for a differentiated training of the posterior extensor chain muscles, nor at low load nor at high load levels. However, due to elevated levels of metabolic stress, the dynamic-static trunk extension exercise can be considered as the most intensive and preferable to specifically induce lumbar muscle hypertrophy.

With respect to apparent large spinal loads associated with high trunk muscle activation and lumbar hyperextension, it is advisory to implement a stabilization technique in order to limit the lumbar lordosis during extension exercises. In this light our results demonstrate that an active lumbopelvic stabilization strategy which entails the instruction of an apprehended co-contraction of the deep segmental muscles, has the ability to decrease the lumbar lordotic angle during high load prone lumbar extension exercises. This finding is highly valuable for clinical practice as a safer lumbar extension exercise performance is obtained by contraction of the lumbopelvic muscle corset during training. This could highlight the importance of a good training program or an adequate instruction by the physical therapist or trainer prior to the exercises in order to enhance the attention to lumbopelvic stabilization. Our design however did not allow to differentiate between the value of the two elements separately. Related to the overall muscle activity, our results confirm the required co-operation between the deep segmental and superficial torque producing muscles in order to prevent excessive lumbar lordosis during prone lumbar extension.

From a clinical perspective it has already been stated that a systematic exercise progression is imperative in prevention and rehabilitation programs. A sufficient sensorimotor control can be considered as the ideal start. Based upon this foundation a progressive strengthening program can be given (54;55). A previous study showed that in the context of LBP rehabilitation
only a combined stabilization and strengthening program was shown to be efficient in inducing LM hypertrophy (57). In this perspective and based on our results, it may be advised to integrate prone extension exercises in a progressive training program. However, for most patients the exercise program should start with low load stabilization exercises in order to achieve appropriate sensorimotor control. The lumbar extension exercises should be integrated in the later stage of the exercise program.

Taken together, these high load lumbar extension exercises are appropriate to include in an endurance or strengthening program which is aimed at targeting the total posterior extensor chain in healthy populations. However, when it is required to target the thoracic or lumbar muscles more specifically, no specific guidelines for selecting the most suited exercise modality can be provided. To achieve a safer exercise performance (limit excessive lumbar lordosis) an active lumbopelvic stabilization technique should be implemented.

2.2. Estimating exercise dosage
Our results indicate that in order to determine the exercise dosage of a dynamic trunk extension a direct and indirect method can be used in practice. Although actual trunk extensor activity levels were overestimated, it was demonstrated that the direct method was more accurate for high intensity levels, whereas the indirect method seemed more appropriate for low intensity levels. The slight underestimation of actual muscle activity in relation to the predefined exercise intensity must be taken into account when designing a progressive resistance program.

3. Clinical implications
3.1. Evaluation
As described in the introduction of this dissertation, exercise programs are beneficial for the prevention and rehabilitation of LBP. Creating one overall training program however is impossible as the specific needs of the individual and the possible dysfunction of the trunk extensors can be different among various persons.

In most LBP patients impaired sensorimotor control and/or decreased endurance/strength of the trunk extensors are related to their back pain (61;71;72) In order to restore these dysfunctions various training goals could be set ahead. In this light we have made an algorithm which has the intention to guide us during the evaluation and rehabilitation of the functioning of the back muscles (figure 1). This algorithm is based on clinical experience and literature regarding low back rehabilitation, combined with general training principles and new insights derived from this dissertation.
As a decreased trunk extensor strength has been shown to be a risk factor in the development of LBP (61,71) and in most LBP patients the trunk extensor strength has been shown to be lower than in healthy individuals, the strength capacity of the trunk extensors needs to be evaluated. The maximal strength of the trunk extensors can be determined directly or indirectly. The method to determine the maximal trunk extensor strength directly is described in the general introduction (section 4.3) and chapter 3. Using this method the trunk extension is usually performed on a rehabilitation device. The indirect determination of the 1-RM is based on a submaximal trunk extensor test as described in the introduction (section 4.3). This submaximal test is more appropriate in a clinical setting. Trunk extensions at moderate or submaximal levels from prone position are usually performed for this reason (64,69). Based on this testing procedure (direct or indirect), the strength of the trunk extensors can be evaluated. It is valuable to note that even in case of sufficient strength, an optional resistance training program for the trunk extensors could be advisable.

**Figure 1** Evaluation algorithm of the functioning of the back muscles.
In case of impaired trunk extensor strength a more detailed evaluation is necessary in order to detect a possible dysbalance between the muscles of the posterior extensors chain, which is also described as an important risk factor for low back injuries (72). In this light it should be evaluated whether an imbalance exists between the thoracic and lumbar extensors. A dominance of the thoracic extensors over the lumbar back muscles may be present. The dysbalance between these synergistic extensors muscles can be evaluated objectively by evaluating the muscle recruitment pattern (the use of surface EMG) or can be subjectively observed by a visual evaluation of the quality of movement during a prone trunk extension. The dominance of the thoracic over the lumbar extensors is visualized by a clinical significant increase of the lumbar lordosis during the performance of a dynamic (-static) trunk extension exercise. This increased lordosis might be the result of the inability of the trunk muscles, in particular the lumbar muscles, to stabilize the lumbopelvic region sufficiently when lifting the trunk, which is primarily established by the strong thoracic extensors (3). Interesting to mention is that due to a larger trunk extensor lever arm, the increase of the lumbar lordosis will be manifested more quickly during trunk extension from a prone lying starting position than during extension from a semi-seated position. Based on the objective EMG evaluation of muscle recruitment patterns or the subjective estimation of the capacity to control the lumbopelvic region, it can be concluded whether there is an imbalance between the thoracic and lumbar extensors or not. More specifically a too high ratio between the activity of the thoracic and lumbar muscles, or an excessive lumbar lordosis during a high load trunk extension exercise point to a dysbalance between the thoracic and lumbar muscles.

Within this context, it is good to discuss the idea that this dysbalance can be related to two different aspects. A real lack of lumbar extensor strength and/or an impaired sensorimotor control (proprioception and neuromuscular control). In order to distinguish between both possible problems, we suggest to evaluate the quality of the sensorimotor control. This should be done in low load conditions. In order to test the quality of sensorimotor control, a dissociation test evaluating the ability to dissociate the lumbopelvic movement from that of thoracolumbar junction was recently suggested and a specific clinical test for this reason was developed (73). This dissociation test assesses the persons’ ability to perform an anterior or posterior pelvic tilt in sitting while a constant position of the thoracolumbar junction is maintained. Five different criteria are rated by a numeric value (maximum 10) corresponding a measure of quality of movement performance using features such as timing, coordination and muscle activity. The test has been shown to be valid (74) and has a good reliability (73). Based on this testing procedure, the therapist can conclude whether there is just a lack of strength of the lumbar muscles (compared to the thoracic extensors), or that the lack of strength is accompanied by a deficit in lumbopelvic control.

In addition, to evaluate more specifically the sensorimotor control in the extension direction we can also rely on specific dissociation tests as proposed by Luomajoki et al.
The extension movement control can be assessed during the pelvic tilt, rocking forwards in quadruped position and prone knee bending. The focus during these tests is to maintain the neutral lumbar spine position during extension related activities. This means that during the tests the hip should be extended without any movement in the lower back, which will be evaluated by a therapist. These movement control tests are shown to have a good reliability (76). The scores on the lumbopelvic control test (73) and/or the extension movement control test (75) determine whether there is indeed an impaired sensorimotor control (negative scores), and/or rather a real loss of lumbar extension strength (positive scores).

The lack of sensorimotor control can be caused by insufficient proprioception and/or a disturbed neuromotor control of the muscles surrounding the lumbopelvic region, of which the LM is a crucial one.

To evaluate more specifically the proprioception, evaluation sheets to score the quality of lumbopelvic proprioception in sitting and standing are recently available. The quality of proprioception is based on the ability to duplicate the initial (neutral) lumbopelvic position. In other words, the ability to reposition the lumbopelvic region in the initial position after several pelvic anterior/posterior pelvic tilts (position-reposition) is evaluated in both sitting and standing position separately. The rating scale (maximum score of 10) is firstly focusing on the lumbopelvic position-reposition accuracy. The second focus is directed to the evaluation of the position-reposition accuracy of adjacent regions (thoracic, knees).

In order to evaluate the neuromotor control of the LM, different features will be evaluated during a selective voluntary tonic contraction of the MF in prone. The evaluation consists of the palpation by the therapist (77). The rating scale considers the quality of the contraction, the amount of substitution of more superficial extensor muscles, the symmetry of the contraction, the ability to maintain a normal breathing pattern during contraction, and the duration of the contraction (more or less than 10 seconds). The inability to contract the lumbar multifidus sufficiently without substitutions and a normal breathing pattern points to a lack of neuromuscular control of that specific muscle.

### 3.2. Treatment

Based on the outcome of this evaluation algorithm, four different training strategies can be proposed. Three strengthening training regimes (optional resistance training, a general reconditioning training, a specific reconditioning training) and one specific neuromuscular control program (sensorimotor training) (figure 2).

When the subject lacks sufficient lumbopelvic sensorimotor control, a specific sensorimotor control training program is suggested. As described by Danneels and Vanthillo (77) this program is aimed at adequate controlling the lumbopelvic region during low load activities. Prior to the motor learning program, proprioception exercises to facilitate the
input to the central nervous system, in order to acquire a better control over pelvic tilt and lumbar spine position, are performed. Subsequently during the perception phase the deep spinal muscles are facilitated by instructing an accurate type of contraction, namely a slow tonic contraction without any substitutions of large muscles. In order to contract LM, the anatomical position will be explained and the muscle will be palpated at first. As described in this dissertation the LM can be palpated laterally next to the spinous process of L3-L5 (chapter 4). In the phase of precision the correct selective contraction of the lumbar stabilizers is practiced. At first the precise contraction is analytically trained, afterwards a co-contraction of the lumbar stabilizers in different positions is intended. For the LM it is asked to slowly contract the lower back from prone. If the person is able to maintain a proper contraction for 10 times 10 seconds, the co-contraction is taught in more functional postures as there are sitting and standing. In the next phase the interplay with the large torque producing muscles will be increased, for example by an arm or leg movement in the different starting positions. Furthermore the complexity of the exercises will be increased (based on different aspects as there are velocity, weight, base of support etc.) and the participant will be more and more challenged.

Once a sufficient lumbopelvic sensorimotor control in order to optimally stabilize the lumbopelvic region is achieved (foundation of training program), further training at the level of endurance and strength (i.e. high load) can be accomplished. In other words, one can proceed from this program to the specific reconditioning, general reconditioning program or optional resistance training depending on the individual needs.

The specific reconditioning training is designed for subjects who can stabilize the lumbopelvic region in low load conditions but not in high load conditions, due to a lack of strength of the lumbar muscles. Therefore, in these subjects specific strength training of the lumbar extensors is required prior to a general training of the trunk extensors. As in this situation the lumbar extensors are weaker than the thoracic extensors, the primary focus of this specific strengthening program is to improve the strength capacity of the lumbar extensors specifically. In this light, the current dissertation provides evidence for a specific choice in exercises.

Since the findings of this dissertation show that semi-seated trunk extension exercises at 40% and progressively up to 60% 1-RM activate the lumbar muscles and in particular the LM at a higher degree than the thoracic extensors, these exercises are ideal to target the lumbar extensors as required. Based on previous research, three sets of 12 repetitions, with 1 minute of rest are required to enhance muscle strength (55,77,78).

In a next phase one should proceed to the more intensive prone dynamic-static trunk extension exercises at 60% 1-RM. These exercises evoke lumbar muscle activity levels up to 70% MVIC. Moreover, it is assumed that the static component during these exercises can induce lumbar muscle hypertrophy (57). As progressive overload is required to improve muscle strength, the intensity of these exercises should be gradually increased.
In order to conduct these exercises in a safe manner, the neutral lumbar spine position should be preserved during the performance of these exercises. This means that prior and during the exercises one should be instructed to actively stabilize the lumbopelvic region. Once the muscle imbalance is restored, the subjects may participate in the general reconditioning program of the trunk extensors.

The general reconditioning training is suitable for individuals who are characterized by a decreased trunk extensor strength capacity without a dysbalans between the thoracic and lumbar extensors. In other words for those who have the ability to stabilize the lumbopelvic region during the high load extension exercise conditions (no increase in lumbar lordosis). As stated above and in agreement with a traditional strength training program proposed by Danneels (79), a sufficient foundation (stabilization) is already established in these patients (79). Therefore high load exercises to increase the strength of the trunk extensor muscles can directly be implemented into the training program. In order to enhance the strength of all trunk extensors prone trunk and leg extension exercises at 60% 1-RM are appropriate (55;78).

Based on the findings of this dissertation the general reconditioning program should start with prone dynamic leg extension exercises at 60% 1-RM which activates the trunk extensors ranging from 50 to 60% MVIC. Subsequently one may proceed to prone dynamic-static leg extension and dynamic trunk extension exercises, which are activating...
the trunk extensors at a higher degree (resp > 60% and > 65% MVIC). In the initial phase, when the goal is to improve basic strength, these exercises should be conducted at an intensity of 60%-1-RM. Regarding basic training principles the patient needs to perform 3 sets of 12 repetitions, with 1 minute of rest in between the sets (55;77;78). Afterwards the load of the extension exercise must to be increased progressively up to 80% 1-RM. In the next phase, in order to improve maximal trunk extensor strength, trunk extension exercises in semi-seated position at 80% are shown to be appropriate. In this phase 3 sets of 8 repetitions with 3-5 minutes of rest must be performed. In order to limit the spinal pressures associated with these high load extension exercises, subjects need to maintain the neutral lumbar spine position during the performance of these exercises.

Even in case the strength of the trunk extensors is not decreased one can participate in an optional resistance training program. This program is aimed at an additional strength improvement of the trunk extensors in general, which is required in some athletes. Based on the findings of this dissertation all prone extension exercises can be implemented for this reason. However, to gain strength these exercises should be performed at high intensity levels. As described earlier for maximal strength purposes an exercise intensity of more than 80% 1-RM is required and can be increased up to 100% 1-RM. In this phase 3 sets of 8 repetitions with 3-5 minutes of rest must be performed.

4. STRENGTH AND LIMITATIONS

When interpreting the results of the studies included in this dissertation several strengths and limitations regarding the study protocols must be taken into account. They will be discussed within the following paragraphs.

4.1. Research populations
Although it is a strength that objective evaluation techniques for muscle recruitment were used, the use of these techniques can be time consuming and expensive. These drawbacks limit the possibility to examine large sample sizes. As a consequence a relatively small number of young healthy participants was investigated. The group size varied from 13 to 14 subjects, and the age ranged from 19 to 28 years. Subjects were free from back pain at the time of study participation and did not consult a physician regarding LBP in the year prior to their study participation. Subjects were not allowed to intensively participate in sports. Therefore care should be taken with the generalization of the findings from this dissertation, especially to other populations such as elderly, LBP patients or elite athletes. This consideration is highlighted by the fact that changes in muscle function and recruitment are related to age (58-60), the presence of pain (61-64), and the intensity and type of sport performance (65).
4.2. Research in high load conditions

The exercise intensity in this dissertation was set at 60% 1-RM, except for chapter 3 where varying intensities were used. An intensity of 60% 1-RM is considered to be sufficient to enhance muscle strength and endurance (26). Previous studies investigated lumbar extensor recruitment in low load conditions (66) or did not really standardize the exact exercise intensity. In contrast the present studies provide valuable information regarding the effect of changing the posterior extensor muscle recruitment patterns through the modification of high load prone lumbar extension exercises. However, as high spinal compressive forces can occur when high load prone lumbar extension exercises are performed, care should be taken with the use of these exercises in training programs. These exercises may be appropriate in order to enhance muscle endurance and strength, when no maladaptive trunk muscle recruitment patterns and sufficient sensorimotor control are present. Hence, these exercises seem not advisable during the first phase of LBP rehabilitation programs.

Despite the widespread use of prone lumbar extension exercises in clinical settings, knowledge about the way the posterior extensor chain activity is affected by various exercise modalities is limited. Our studies were the first to provide insight in the relative activity levels of all posterior extensor chain muscles involved in lumbar extension. This gives a more detailed insight in the actual contribution and possible compensations of the posterior extensors during high load extension exercises. Our studies are unique in comparing the recruitment of the posterior extensor chain during various prone lumbar extension exercise modalities. Based on these comparisons a better comprehension of the effect of the exercise modality and the type of contraction on the activity level of each muscle of the posterior extensor chain can be obtained. These detailed insights allow therapists to select the appropriate extension exercise and enable to address the preferred muscle at a certain intensity.

The exercise dosage in this dissertation was determined with the use of the indirect method, which has been shown to be appropriate to elicit trunk extensor activity comparable with the intended intensity (chapter 3) especially at lower intensity levels. However, when interpreting our data a slight overestimation must be taken into account as the obtained muscle activity levels were consistently smaller than the estimated intensity levels.

This was the first study to evaluate the efficiency of different methods to determine exercise dosage. Caution in comparing both methods and interpretation of our results should be taken into account as dissimilarities in the accuracy to predict the actual trunk extensor activity and the trunk extensor recruitment patterns may possibly be associated with the different exercise and test positions.
4.3. Exercise dosage method
Although the study of chapter 3 was not designed to compare both dosage methods, a direct comparison between both would be valuable. Comparing the indirect method to dose trunk extension exercises with the direct dosage method, would give the opportunity to validate the use of the indirect method to determine the exercise load of a dynamic trunk extension. In order to enable such a comparison one should be tested in the same starting position and using identical fixation points. However, the different body position (in relation to gravity) during both methods used in this dissertation does not allow to make this comparison. Moreover, the difference in fixation points between both test conditions could also have an important influence on trunk extensor muscle recruitment patterns. Therefore, a future study should be designed to validate the indirect method, using the direct dosage method as a golden standard. As mentioned above there are some downsides to the study protocol in chapter 3. More specifically the difference in start position during both test conditions. As a different start position could have an important influence on trunk extensor muscle activation patterns, the mismatch does not allow a comparison between both exercise conditions. Therefore, this dissertation failed validate and compare the use of the direct and indirect method to dose trunk extension exercises accurately.

4.4. Stabilization strategy
Chapter 4 revealed that lumbopelvic kinematics and posterior extensor recruitment patterns can be changed by the instruction to actively stabilize the lumbopelvic region during prone extension exercise in healthy individuals. By measuring relevant deep stabilizing and large torque producing extensors a clear view on the redistribution of activity, mostly related to the altered kinematics, upon stabilization is obtained. Despite only small significant differences were found, we believe that the stabilization strategy is effective in controlling the lumbopelvic region during high load extension exercises. However, some careful considerations need to be made as we could not document objectively that proper stabilization was performed during the exercises.

After a short stabilization training program, the ability to contract the deep stabilizing muscles independently of more superficial muscles was judged via observation and palpation by the researchers. Total agreement about the correct performance of the stabilization technique between researchers was a prerequisite to allow study participation. Ultrasound may have provided a more accurate indication. However, since the palpation technique is a commonly used method in clinical settings, we preferred this method. The recruitment patterns were examined during prone extension exercises with and without the instruction to apply the active stabilization strategy. An absence of stabilization related changes in the recruitment of the LES and LM was observed and could be explained by the fact that high exercise intensity were performed. Exercises with a high intensity...
immediately activate these muscles at a high degree, and additional support is provided by activation of the large torque producing muscles in order to maintain spinal stability during the lumbar extension exercises. Moreover, it could be that the use of sEMG is not accurate enough to measure deep muscle activity. In this light, the utilization of fine wire EMG or mfMRI to evaluate deep muscle work would be more appropriate to identify possible differences among the LES and LM. This shortcoming is likely to be resolved in the near future, as at present the author is analyzing the data of an identical mfMRI study. Finally, evidence suggest that ratios (deep/superficial) of muscle activity during low load exercises alter after a short stabilization program (67). Analysis of these ratios could have induced more interesting comparisons and provided a better understanding of the observations. The present study did not investigated muscle ratios, which may considered as a limitation.

4.5. Evaluation of the recruitment of the posterior extensor musculature
To date sEMG has been widely considered as a essential and reliable technique to measure muscle activation patterns. However it has been discussed that sEMG does not correctly reflect the activity of the deep paraspinal muscles, as crosstalk of adjacent muscles is assumed. Recently mfMRI, has been proposed as novel technique to accurately map activity of deep muscles and superficial muscles at the same time. In this dissertation mfMRI was used for the first time to determine the amount of TES activity (chapter 2), and new insights were provided. However, the validity of mfMRI to map TES has not been established yet. While sEMG is sensitive to real time electric changes in muscle activity, mfMRI is a post-exercise evaluation technique which maps the exercise induced metabolic changes in recently activated muscles (20;68-70). Therefore, sEMG enables the examination of temporal characteristics, while mfMRI is restricted to the assessment of spatial characteristics. This highlights that although the inherent advantages and disadvantages, both techniques should be seen as complementary. Therefore the combination of both techniques to evaluate muscle activity in chapter 1 is a strength of this dissertation. In contrast to our studies in which sEMG was used (chapters 1, 3), due to technical constraints the mfMRI study (chapter 2) only evaluated thoracic and lumbar extensors recruitment without measuring hip extensor activity.

5. FUTURE DIRECTIONS
5.1. Populations
The different studies in the current dissertation aimed at examining the posterior extensor chain activity during various extension exercises and different modalities in healthy individuals. These new insights regarding the recruitment patterns of the posterior
extensor chain in healthy people during different prone lumbar extension exercises and at
different exercises intensities, enable to investigate whether LBP patients show similar or
altered recruitment patterns in response to the different extension exercises modalities as
healthy people. Since, alterations in trunk muscle function related to LBP have been
demonstrated by several researchers (10;61;63;71;80-83), future research would be valuable
in order to obtain more insight in how our findings are represented in a LBP population.
Moreover, additional research should target both healthy and LBP patients to allow an
adequate comparison. The present investigated populations consisted mainly of young
healthy individuals. However, to allow generalization of our findings, research in larger and
more heterogeneous (regarding age, sex, profession, sport status) population is required.

5.2. Extension exercises
At an intensity of 60% 1-RM, the extension modality and the type of contraction appeared
to alter the recruitment of the thoracic and lumbar muscles, while the activity of the LD
and GM were not significantly influenced (chapters 1 and 2). However, it is possible that
the recruitment patterns are different at lower or higher exercise intensities. Therefore, it
would be interesting to study these different intensities. In order to investigate this,
dynamic and dynamic-static trunk and leg extension exercises could be performed at
different intensities (between 40-80% 1-RM). This would enable a clear insight in the
influence of the exercise modality and contraction type on the recruitment patterns of
the posterior extensor chain muscles in relation to varying intensities. Moreover it would
be interesting for future studies to investigate the activation of the hip extensors in
addition to the thoracic and lumbar extensors (using mfMRI) in order to fully understand
the contribution of the global trunk extensor chain.

Regarding the dosage method used to determine the exercise intensity, it is assumed that
a more homogeneous muscle pattern is induced when the exercise intensity, determined
by the direct method, is increased (chapter 3). Further research however is needed in
order to validate the use of the indirect dosage method and to ascertain that the variances
in recruitment patterns were not dependent on the difference in position during both
tests, but are associated with the method chosen to dose the extension exercises. In order
to validate the indirect dosing method (which uses the Holten formula), the use of this
method to dose lumbar extension exercises should be compared to the use of the direct
dosage method, which can be considered as the golden standard. In order to make an
appropriate comparison, the extension exercise intensity should be determined by both
the indirect and direct method in a similar exercise condition. In other words, in an
identical position and on the same device.
In order to apply the direct and indirect method in an identical manner, the semi-seated position seems a possible starting position on which the strength tests can be performed safely. Following the indirect approach the subject has to perform as many dynamic trunk extensions as possible with a submaximal weight, for example on the Tergumed device. Afterwards the 1-RM can be determined via the Holten formula. In case prone extension should be used to compare both dosage methods, the 1-RM, could be determined by performing a maximal trunk extension force against a load cell or other dynamometers. This however is less safe and appropriate in a patient population.

Moreover, seeing the acute influence of the different exercise modalities on the recruitment of the posterior extensor chain in this dissertation, it would be interesting to study the effect of a training program on the recruitment of the posterior extensor chain muscles. Furthermore, a comparison between exercise programs using dynamic-static trunk extension exercises versus programs using the dynamic exercise modality would be useful. This comparison could underpin our assumptions regarding the preference of dynamic-static exercise programs to induce lumbar muscle hypertrophy.

In this dissertation, the amount of posterior extensor chain activity was assessed by either sEMG (chapters 1, 3 and 4) or mfMRI (chapter 2). To elucidate our physiological assumptions, the application of techniques evaluating the blood flow and the metabolic side products could add value to the interpretation of the present results.

5.3. Stabilization strategy
The lack of higher recruitment of the LM and LES in response to an active lumbopelvic stabilization strategy (chapter 4) was in contrast with the assumption that this strategy facilitates and enhances deep lumbar muscle activity. Possible effects however could be masked as a consequence of the high exercise intensity. In this respect, further investigations could be targeted at low load prone extension exercises in order to improve our knowledge.

The lack of differences among the lumbar muscles could also be attributed to the use of surface electrodes. Surface electrodes record electrical signals from several muscles at the same time (cross talk) and may move relative to the measured muscles during movements. To determine the activity of the LM accurately, intra-muscular (fine wire) EMG is required (36). Another option to evaluate the lumbar muscle activity is the use of mfMRI. We have conducted an mfMRI study to investigate the effect of an active lumbopelvic stabilization strategy on muscle recruitment. Preliminary results regarding the specific responses within the deep and superficial parts of the LM are presented in the Appendix of this dissertation.
Although acute effects of actively stabilizing the lumbopelvic region were also demonstrated in an earlier study (40), it is still unclear whether these changes were only induced because of the instruction itself at the moment of testing, and/or because of the specific training. In other words since the comparison between the non-stabilized and the stabilized condition was performed after a period of training, it might be possible that even in the “non-stabilized” condition of the experiment, muscle recruitment had already changed as a consequence of training. To increase our insights regarding this issue, the addition of a pre-training test moment in individuals who are not familiar with the concept of stabilization could provide a clear control condition.

Finally, in the designed experiments, the active lumbopelvic stabilization strategy was primarily applied to limit excessive lumbar extension (lordotic angle) and to avoid high spinal loads (32;84;85). Since, coactivation of the stabilizing muscles is assumed to induce an increase in the intra-abdominal pressure, which consequently has the ability to unload the spine (86), future studies could try to quantify this effect.

5.4. mfMRI

To confirm our results it would be interesting to further investigate technical parameters of the mfMRI in order to improve the quality of the thoracic muscle imaging. In particular respiratory artefacts should be diminished to allow a more accurate evaluation of the thoracic muscles.

The possibility of investigating a larger number of muscles simultaneously, for example the GM, would enhance our insight in the recruitment patterns and could elucidate some of our sEMG findings.

6. FINAL CONCLUSIONS

The objective of this dissertation was to unravel a part of the puzzle of prone lumbar extension exercises, which are widely used in clinical settings and to investigate the accuracy of two dosage methods in determining the actual muscle activity levels. In order to reach this goal, the effect of several modifications of a lumbar extension exercise on the recruitment patterns of the posterior extensor chain was investigated. The muscle recruitment was evaluated by both sEMG and mfMRI.

At an intensity of 60% 1-RM the posterior chain extensors are activated at a higher degree during trunk than during leg extension. The contraction modality did not affect real time electrical muscle activity but significant differences in the metabolic responses of the lumbar muscles between the contraction types were demonstrated. With regard to the recruitment patterns, all exercises activated the thoracic and lumbar extensors at high
levels which is necessary in order to obtain training effects regarding strength and endurance. Due to high metabolic stress in combination with the high activity levels, performing prone trunk extension exercises in a dynamic-static way is preferable to induce lumbar muscle hypertrophy.

Regardless which exercise modality was used, the GM was recruited at a more moderate level, which indicates that lumbar extension exercises are not the most preferred exercises to enhance the strength of this muscle, but can be used to improve the endurance capacity of the GM. Indeed, the basic principles of training indicate that high levels of activity are necessary to train muscle strength, while the moderate levels are sufficient to enhance muscle endurance.

Although the LD contributes to the performance of the lumbar extension movement, this muscle is not recruited at sufficient levels during prone extension exercises in order to enhance its strength or endurance.

To dose a dynamic trunk extension exercise both the direct method and indirect method can be used. However, the direct method seems more accurate to estimate the actual trunk extensor activity levels during high load trunk extension exercises, whereas the indirect method seems more appropriate at the lower intensity levels.

Moreover, the trunk extensor recruitment during a dynamic trunk extension exercise is influenced by the exercise intensity level. Independently of the chosen exercise intensity, thoracic and lumbar muscles worked homogeneously when trunk extension exercises are performed in prone position and dosed indirectly. During a dynamic trunk extension, performed in a semi-standing position and dosed in a direct manner, the trunk extensor recruitment changed from a differentiated pattern in low load conditions to a more balanced pattern at higher intensities.

The implementation of an active lumbopelvic stabilization strategy was effective in reducing the lordotic angle and altered the trunk muscle recruitment patterns during dynamic prone trunk and leg extension.

These new insights will hopefully assist therapists, trainers and coaches in optimizing training, prevention and treatment programs by selecting the most appropriate exercise and to consider how these choices will influence the recruitment patterns of the posterior extensor chain.
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Appendix

Active stabilization strategy during extension exercises: influence on the recruitment of the superficial and deep multifidus

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Abstract

**Background:** Insufficient lumbar spinal stability has been shown to be highly related to low back pain. Although all lumbar muscles contribute to the lumbar spine stability, it is assumed that the lumbar multifidus is responsible for 2/3 of the spinal stiffness. The lumbar multifidus is composed of a superficial and deep component, which can be distinguished based on anatomical, biomechanical and histological differences. Stabilization exercises, based in the co-contraction of the deep stabilizing muscles, has shown to be beneficial in low back pain prevention and rehabilitation programs. No previous study has investigated the effect of the implementation of a lumbopelvic stabilization instruction during high load extension exercises.

**Aim:** The present study examined whether the ratio of the recruitment of the superficial/deep fibers of the lumbar multifidus was influenced by the use of an active lumbopelvic stabilization strategy during lumbar extension exercises.

**Methods:** Thirteen healthy individuals performed a dynamic trunk and leg extension exercise with and without the implementation of an active lumbopelvic stabilization strategy (co-contracting the deep stabilizing muscles). Muscle functional magnetic resonance imaging scans were used to measure the activity of the deep and superficial lumbar multifidus. The evaluation was based on the differences in water relaxation values (T2-relaxation) before and after exercise (T2-shift). Before the actual investigation subjects underwent a short stabilization training program (three exercise sessions).

**Results:** Linear mixed model analysis revealed a significant influence of the active lumbopelvic stabilization technique on the ratio superficial/deep lumbar multifidus recruitment (p=0.043), regardless the type of extension exercise performed. In general the ratio is lower during the stabilized exercise conditions compared to the non-stabilized conditions (resp. 0.77 versus 1.2). However, a trend to a significant relation between the exercise type and lumbopelvic stabilization exists (p=0.073). During trunk extension the difference in ratio between stabilized and non-stabilized extension exercise conditions is smaller (resp. 1.17 versus 1.24) than during the leg extension exercises (resp. 0.37 versus 1.43).

**Conclusion:** Performing an active lumbopelvic stabilization strategy during extension exercises in healthy people, influences the ratio superficial/deep lumbar multifidus recruitment in both extension exercises. The ratio during the stabilized extension exercises is lower than during the non-stabilized conditions. This indicates that the contribution of the deep part of the lumbar multifidus is higher during the stabilized conditions, which confirms their involvement in providing lumbar spine stability.
ENGLISH SUMMARY
GENERAL INTRODUCTION

An optimal condition of the posterior extensor chain is essential while performing daily and sports-related activities. Moreover, several studies point to the importance of a proper functioning of this chain in the prevention and rehabilitation of low back pain (LBP). The posterior extensor chain consists of the thoracic and lumbar parts of the erector spinae, the lumbar multifidus, the latissimus dorsi, the gluteus maximus and biceps femoris.

Earlier studies have showed that impaired endurance and strength capacity of the posterior extensor chain is related to the development, maintenance and recurrence of LBP. Other investigations consider a dysbalans between the extensor muscles and a malfunctioning of the posterior extensor chain as a possible cause of reduced sport performances. In order to optimize and evaluate the function of this chain clinicians and therapists frequently use prone lumbar extension exercises. Numerous variations of these exercises have already been described. In general prone trunk or bilateral leg extension exercises are performed in a dynamic or dynamic-static manner. However, a comparative study of the effect of these different modalities on the recruitment of the posterior extensor chain is lacking.

It is generally accepted that the exercise intensity is related to a specific training effect. It was shown that in order to increase muscle strength, an exercise resistance of at least 60% of the maximal voluntary isometric contraction (MVIC) is required. In this respect, an optimal determination of the exercise dosage is crucial to create adequate muscle training programs. The exercise intensity can be estimated using a direct or indirect method. To date, however, the accuracy of these methods in dosing trunk extension exercises has not yet been investigated. In addition, it is has not been studied how different exercises intensities influence the recruitment patterns of the muscles of the posterior extensor chain.

During these kind of lumbar extension exercises relative high loads and high spinal pressures are observed. In this context, sufficient sensorimotor control is a prerequisite to implement these exercises in muscle training or rehabilitation programs. Furthermore, in order to reduce highspinal loads excessive lumbar lordosis should be prevented. It has been suggested that active lumbopelvic stabilization strategies can be effectively used to control the lumbar posture during exercise performance. One of these stabilization strategies is based on the co-contraction of the deep stabilizing muscles, namely the lumbar multifidus, transversus abdominis and pelvic floor muscles. However, the effectiveness of this technique to limit the amount of lumbar lordosis has only been investigated in low load exercise conditions. In addition, it is has not been studied if the implementation of this stabilization strategy has an influence on the recruitment patterns of the posterior extensor chain.
Taken together, various prone lumbar extension exercise modalities have been used to evaluate and enhance the strength and endurance of muscles from the posterior extensor chain. The use of different modalities complicates the comparison between research studies and generalization of study findings. Consequently selecting the most appropriate exercise in order to achieve a specific training goal is a complex task for clinicians and trainers.

In this light a better understanding of how the posterior extensor chain activity is influenced by the different prone lumbar extension exercise modalities, would be valuable.

AIM OF THE DISSERTATION

The aim of this dissertation is to examine the effect of various exercise modalities, the exercise dosage, and the implementation of an active lumbopelvic strategy during lumbar extension exercises on the activity level of the posterior extensor chain. To achieve this objective, the findings of this dissertation were structured in three parts. The first part focused on the recruitment of the posterior extensor chain during various lumbar extension exercises. Hence, two observational studies in healthy volunteers were conducted. In these studies the posterior extensor chain activity was measured during four different modalities of prone lumbar extension exercises. The muscle activity was evaluated using two complementary methods, namely surface EMG (chapter 1) and muscle functional MRI (chapter 2).

In part 2 it was examined to which extent the predefined exercise intensity corresponds with the actual activity of the posterior extensor chain during dynamic trunk extension exercises. The exercise intensity, usually expressed as a percentage of the one repetition maximum (1-RM), was determined on the basis of a direct and indirect dosage method. The amount of activity and the recruitment patterns of the posterior extensor chain were evaluated by sEMG. In order to determine the 1-RM directly, the trunk extension exercise was performed in semi-standing position on a rehabilitation device. The 1-RM in this method reflects the maximum weight with which only a single exercise can be conducted properly. The 1-RM was determined indirectly from prone position. In this respect the Holten diagram is used to calculate the 1-RM. In this diagram the relation between the maximum number of repetitions performed with a submaximal weight and the exercise intensity (expressed as a percentage of the 1-RM) is expressed. The results are presented in chapter 3.

The final part existing of chapter 4 studied if the implementation of an active lumbopelvic stabilization strategy during dynamic prone lumbar extension exercises, affects the lumbopelvic kinematics (thoracic, lumbar and hip angle) and the posterior extensor chain recruitment. This active lumbopelvic strategy entailed the contraction of the deep stabilizing muscles, namely the lumbar multifidus, transversus abdominis and the pelvic floor muscles. Hence, dynamic prone trunk and leg extension exercises were
performed with and without the instruction to actively stabilize the lumbopelvic region. Afterwards, the altered lumbopelvic kinematics and differences in recruitment patterns were examined using video-analysis and sEMG.

**FINDINGS AND IMPLICATIONS**

In the different studies from this dissertation it was observed that, regardless of the extension exercise modality, all muscles of the posterior extensor chain were activated during the prone lumbar extension exercises, although at varying degrees. The prone lumbar extension exercises mainly target the lumbar muscles and subsequently the thoracic muscles. In contrast the latissimus dorsi and hip extensors are recruited at a lesser extent during these exercises.

The results of part 1 revealed that the electrical and metabolic activity of the posterior extensor chain type varies upon the used exercise modality. Performing prone trunk extension exercises evoked higher activity levels of the extensor chain muscles than performing prone leg extension exercises. The increased recruitment can be explained by the differences in biomechanics and specific muscle function between both exercise modalities. With respect to the contraction modality no significant influence on the electrophysiological muscle activity could be established. In contrast, higher metabolic activity of the lumbar muscles was provoked during a dynamic-static lumbar extension modality. Taken together, a prone dynamic-static trunk extension exercise can be considered as the most appropriate exercise to enhance the strength capacity of the lumbar muscles.

In part 2 we found that with regard to the accuracy of the dosage methods, none of the studies methods was superior in order to estimate the actual trunk extensor activity during dynamic trunk extension exercises. However, the results suggest that when it is aimed to activate the trunk extensors at low intensity levels the indirect method appeared is the most appropriate, while the direct method is more suited to estimate trunk extension exercises at high intensity levels. It must be mentioned that regardless of which dosage method was used a slight overestimation of the actual trunk extensor activity should be taken into account, except when the trunk extension intensity is set at 100% 1-RM and dosed directly.

As expected the resistance level of the extension exercises had a clear impact on the recruitment of the trunk extensors. When the direct dosage method was used, a shift from a differentiated pattern in low load conditions towards a more homogeneous recruitment pattern at higher exercise intensities was observed. This points to the fact that the thoracic muscles will assist the lumbar muscles when the intensity of a trunk extension in semi-stand increases. When the indirect method was used, a homogeneous recruitment
pattern was observed. Hence, in prone position the trunk extensors work as a whole to lift the trunk dynamically, even at low intensity levels.

Finally, in part 3 it was demonstrated that the use of an active lumbopelvic stabilization strategy, by means of co-contraction of the deep stabilizing muscles, is effective in reducing the degree of lumbar lordosis during dynamic lumbar extension exercises from prone position. During trunk extension, the smaller lumbar lordosis is compensated by an increase of the hip extension angle in order to reach the horizontal position. Whereas during the stabilized leg extension exercise the hip angle was not affected. The differences in kinematics between the non-stabilized and stabilized dynamic lumbar extension exercises were accompanied by changes in the recruitment of the posterior extensor chain. In particular, the gluteus maximus, biceps femoris, iliocostalis pars thoracic and latissimus dorsi activity were influenced. More specifically, during both trunk and leg extension the gluteus maximus was activated at a higher extent when the active stabilization strategy was implemented. The activity of the biceps femoris was higher when the trunk extension was performed with the active lumbopelvic stabilization strategy. In order to lift the trunk in the stabilized condition the activity levels of the latissimus dorsi were increased compared to the non-stabilized condition. Whereas during a stabilized leg extension the recruitment of latissimus dorsi and iliocostalis pars thoracic were lower than when the leg extension exercise was performed without lumbopelvic stabilization.

**CONCLUSION**

Our results enhance the insights in to the recruitment of the posterior extensor chain during several prone lumbar extension exercises at 60% of the MVIC.

The high activation of the lumbar and thoracic muscles during these kind of extension exercises, implies that these exercises can be mainly used in order to train the trunk extensors. In this respect, the trunk extension exercises seems to activate the muscle of the posterior extensor chain at a higher degree than the leg extension exercises. In contrast, only the metabolic activity of the lumbar muscles was found to be influenced by the exercise modality. These findings are interesting and show that a dynamic-static trunk extension exercise can be used to enhance the strength capacity of the lumbar muscles. When the goal is to improve the strength of the LD and hip extensors prone lumbar extension exercises are not sufficient.

In order to determine the intensity of a trunk extension exercise a direct and indirect dosage method can be used. The direct method should be applied when a high exercise intensity is intended, whereas the use of indirect method represented the actual trunk extensor activity more accurately at lower intensity levels. However, a slight overestimation of the actual muscle activity must be taken into account when using both methods.
Finally, the results of this dissertation indicate that the implementation of an active stabilization strategy during prone lumbar extension exercises can be considered as essential in order to perform these exercises in a responsible way. The use of this strategy will lead to a decreased lumbar lordotic angle during the prone lumbar extension exercises and can alter the recruitment of the posterior extensor chain. In particular the GM was activated at a higher extent during the stabilized exercise conditions. These new insights can assist therapists and trainers in selecting the most appropriate exercise to enhance the strength and endurance of the posterior extensor chain.
ALGEMENE INLEIDING

Het optimaal functioneren van de posterieure spierketen is cruciaal voor het uitvoeren van dagdagelijkse en sport gerelateerde activiteiten alsook in de preventie en revalidatie van lage rugpijn. Deze posterieure spierketen die verantwoordelijk is voor de lumbale extensie beweging wordt opgebouwd uit de thoracale en lumbale delen van de erector spinae (iliocostalis lumborum en longissimus thoracic), de lumbale multifidus, de latissimus dorsi, de gluteus maximus and biceps femoris.

Eerdere studies toonden aan dat een gedaalde uithouding en kracht van de posterieure extensor keten gerelateerd is aan het onstaan, het behouden en het recidiveren van lage rugpijn. Sommige onderzoeken beschouwen een verminderde functie van de posterieure extensor keten en een dysbalans tussen de verschillende rugextensoren als mogelijke oorzaak van verminderde sportprestaties. Met het oog op het optimaliseren en het evalueren van de functie van de posterieure spierketen wordt frequent gebruik gemaakt van lumbale extensie oefeningen vanuit buiklig. In de literatuur zijn reeds vele variaties van dit type oefeningen beschreven. Meestal worden romp- en bilaterale beenextensie oefening uit buiklig op een statische, dynamische of dynamisch-statische manier uitgevoerd. Een vergelijkende studie naar het effect van deze verschillende oefen modaliteiten op de rekrutering van de posterieure extensie keten ontbreekt echter.

Er wordt aangenomen dat het intensiteitsniveau van een oefening bepalend is voor het bereiken van een specifiek trainingseffect. Zo werd reeds aangetoond dat wanneer men krachttoename als doel heeft, een oefenbelasting van minstens 60% van de maximale isometrische kracht noodzakelijk is. In dit opzicht is een precieze bepaling van de intensiteit waaraan men train een essentiële voorwaarde voor het opstellen van adequate spiertrainingsprogramma’s. Voor het doseren van oefeningen wordt in de praktijk frequent gebruik gemaakt van een directe of indirecte methode. Tot op heden werd echter nog geen onderzoek verricht naar de accuraatheid van deze methoden voor het doseren van rompextensie oefeningen voor het trainen van de posterieure spierketen.

Tijdens dergelijke lumbale extensie oefeningen worden relatief hoge belastingen en grote spinale drukken waargenomen. Daarom is het essentieel dat men over voldoende sensorimotorische controle beschikt vooraleer men deze oefeningen implementeert in een spiertraining- of revalidatieprogramma. Tevens is het belangrijk dat een excessieve lumbale hyperlordose vermeden wordt tijdens het uitvoeren van deze oefeningen. Het werd reeds gessugereerd dat een actieve lumbopelvische stabilisatie strategie gebruikt kan worden om de mate van lumbale lordose te controleren tijdens het oefenen. Een van deze stabilisatietactieken bestaat uit de co-contractie van de segmentaal stabiliserende spieren met name de lumbale multifidus, transversus abdominis en voorste bekkenbodemspieren.
De effectiviteit van deze techniek in het reduceren van de lumbale lordose werd tot op heden echter enkel onderzocht tijdens oefeningen aan een lage belasting. Daarnaast werd er nog geen onderzoek verricht naar het effect van het implementeren van deze actieve lumbopelvische stabilisatie techniek op de rekrutering van de posterieure spierketen.

Kortom, gerbuiken clinici en therapeuten verschillende modaliteiten van de lumbale extensie oefeningen uit buiklig om de extensoren van de posterieure spierketen te evalueren en hun kracht en uithouding te verbeteren. Het gebruik van verschillende oefenmodaliteiten bemoedigt de vergelijking van verschillende studieresultaten en generalisatie van de bevindingen. Als een gevolg hiervan, is het kiezen van de meest geschikte oefening voor het bereiken van een specifiek doel, een complexe taak voor trainers en clinici.

In dit opzicht zou een beter inzicht in het effect van de verschillende oefenmodaliteiten op de werking van de posterieure extensor keten zeer waardevol zijn.

**DOEL VAN DE STUDIE**

Het doel van dit proefschrift bestaat erin de invloed van verschillende modaliteiten van de lumbale extensie oefening, de dosering, en het effect van een actieve stabilisatie strategie op het activiteitsniveau van de posterieure extensor keten na te gaan. Om dit objectief te bereiken werden de bevindingen van deze thesis in drie delen gestructureerd. Het eerste deel is gericht op het onderzoeken van de invloed van verschillende modaliteiten van een lumbale extensie oefening op de werking van de posterieure extensor keten. Met behulp van twee observationele studies werd het verschil in spieractiviteit en rekruteringspatroon van de extensoren tijdens vier verschillende oefenmodaliteiten van lumbale extensie oefeningen onderzocht bij gezonden jong volwassenen. De spierwerking werd in kaart gebracht met behulp van twee complementaire evaluatiemethoden, namelijk op basis van oppervlakte EMG (Hoofdstuk 1) en spierfunctionele MRI (Hoofdstuk 2).

In deel 2 wordt bestudeerd in welke mate de geschatte oefenintensiteit overeenkomt met de werkelijke activiteit van de posterieure extensor keten tijdens de uitvoering van een dynamische rompextensie oefening. De intensiteit van een oefening wordt meestal beschreven als een percentage van de one repetition maximum (1-RM) en kan worden bepaald aan de hand van een directe of indirecte doseringsmethode. De 1-RM reflecteert de maximale kracht van een spier of spiergroep tijdens een oefening. In dit hoofdstuk wordt de mate van activiteit en het activeringspatroon van de posterieure extensoren geëvalueerd door middel van oppervlakte EMG. Voor de directe bepaling van de 1-RM werd de rompextensie uitgevoerd in semi-stand. Voor de directe bepaling van de 1-RM direct zoekt men het gewicht waarmee maximaal één correcte herhaling van de oefening kan worden uitgevoerd. De indirecte bepaling van de 1-RM gebeurde in buiklig. Hiervoor werd gebruikt gemaakt van een submaximale test en de Holten curve.
geeft de relatie weer tussen maximaal aantal herhalingen dat kan worden uitgevoerd met een submaximaal gewicht en de intensiteit van de oefening (uitgedrukt als een % van de 1-RM). Op basis van deze relatie kan men dan de 1-RM berekenen.

In het laatste deel wordt onderzocht in welke mate de contractie van het lumbopelvisch spiercorset tijdens de uitvoering van lumbale extensie oefeningen effect heeft op de heup, lumbale en thoracale hoek, alsook op de rekrutering van de posterieure extensor keten. In deze studie werden dynamische romp- en billaterale beenextensie oefeningen uitgevoerd in buiklig met en zonder de instructie om actief de lumbopelvische regio te stabiliseren. Vervolgens werden de verschillen in kinematica en rekruteringspatronen onderzocht aan de hand van video analyse en oppervlakte EMG.

BEVINDINGEN EN IMPLICATIES

In de verschillende studies van dit proefschrift werd opgemerkt dat, ongeacht de oefenmodaliteit, alle spieren van de posterieure extensor keten werden geactiveerd doch in verschillende mate. Zo kon duidelijk worden aangetoond dat voornamelijk de lumbale extensoren, en vervolgens de thoracale extensoren, werden aangesproken. Dit in tegenstelling tot de latissimus dorsi en de heupextensoren, die in mindere mate werden gerekvrued tijdens lumbale extensie oefeningen. Meer specifiek, werd er vastgesteld dat de modaliteit van een lumbale extensie oefening een significant effect heeft op de elektrische en metabole activiteit van de extensor keten. Zo kon worden gedemonstreerd dat in vergelijking met de billaterale beenextensie oefeningen het uitvoeren van rompextensie oefeningen leidde tot een hogere activatie van de thoracale en lumbale extensoren. Deze verschillen kunnen verklaard worden op basis van biomechanische verschillend en de specifieke functie van de spieren tijdens beide oefenmodaliteiten. Met betrekking tot de contractievorm van de lumbale extensie oefeningen kon electrofysiologisch gezien geen significante verschil in het activiteitsniveau van de extensor keten worden vastgesteld. Daarentegen werd er echter wel aangetoond dat de dynamisch-statische oefenvorm een hogere metabole activiteit uitlokte van de lumbale extensoren. Hieruit zouden we kunnen besluiten dat de dynamisch-statische rompextensie de meest aangewezen oefening is om de lumbale extensoren te trainen.

Met betrekking tot de accuraatheid van de doseringsmethoden kon worden aangetoond dat geen van beide methoden superieur is in het bepalen van de werkelijke intensiteit van een rompextensie oefening. Echter, wanneer men de rompextensoren wil activeren aan relatief lage weerstand (60% van de maximale isometrische contractie) blijkt de indirecte methode meer geschikt om de rompextensie oefening te doseren. Daarentegen, indien een hogere activiteit van de rompextensoren wordt nagestreefd, is het gebruik van de directe methode meer aangewezen. Ongeacht welke doseringsmethode werd gehanteerd,
kon er een overschatting van de reële activiteit van de rompextensoren worden opgemerkt, met uitzondering van de rompextensie oefening aan 100% 1-RM gedoseerd via de directe methode. Zoals verondersteld had het weerstandsniveau van de oefening een duidelijke invloed op de rekruteringspatroon van de rompextensoren. Wanneer de directe methode werd gebruikt, kon een verschuiving van een gedifferentieerd rekruteringspatroon op de lagere niveau’s, meerbepaald verschil tussen thoracale en lumbale extensoren, naar een homogene spierwerking aan de hogere intensiteiten worden waargenomen. Dit wijst op het feit dat wanneer een dynamische rompextensie in semi-stand moet worden uitgeoefend aan hogere belasting de thoracale extensoren, de lumbale extensoren zullen assisteren om de gewenste kracht uit te oefenen. Tijdens een dynamische rompextensie in buiklig dienen de rompextensoren reeds op lagere niveau’s samen te werken om de romp te kunnen heffen.

Tot slot kon worden aangetoond dat het toepassen van een actieve stabilisatiestrategie, door middel van een contractie van het lumbopelvisch spiercorset, effectief is voor het reduceren van de lumbale lordose tijdens romp- en beenextensie oefeningen vanuit buiklig. Deze verandering in kinematica tijdens de rompextensie oefeningen worden gecompenseerd door een toename van de heupextensie hoek, zodat de horizontale positie nog steeds kan worden bereikt. De verschillen in kinematica tussen de gestabiliseerde en niet-gestabiliseerde oefeningen werd eveneens gereflecteerd door veranderingen in de spieractiviteit. Met name de gluteus maximus vertoont een hogere activiteit wanneer de romp- en beenextensie oefeningen worden uitgevoerd met een actieve stabilisatie van de lumbopelvische regio. De biceps femoris zal eveneens meer werken tijdens een gestabiliseerde been extensie oefeningen dan tijdens een niet-gestabiliseerde beenextensie. Om de romp te heffen tijdens een rompextensie met lumbopelvische stabilisatie, is de activiteit van de latissimus dorsi hoger dan wanneer er geen stabilisatie strategie wordt toegepast tijdens deze oefening. Daarentegen is de activiteit van de latissimus dorsi en het thoracale deel van de iliocostalis lager tijdens een gestabiliseerde beenextensie oefening dan tijdens een niet-gestabiliseerde been extensie.

CONCLUSIE

Onze resultaten dragen bij tot het verduidelijken van de rekruterings van de posterieure extensie keten tijdens verscheidene lumbale extensie oefeningen aan 60% van de maximale isometrische contractie. De hoge activierung van de lumbale en thoracale extensoren tijdens lumbale extensie oefeningen vanuit buiklig impliceert dat deze oefeningen voornamelijk kunnen gebruikt worden voor het trainen van de thoracale en lumbale extensoren. In dit opzicht kan gesteld worden dat de rompextensie oefeningen de extensoren in hogere mate rekruteren dan
de billaterale been extensie oefeningen. De contractievorm blijkt echter enkel de activatie van de lumbale extensoren te verhogen. Dit is een interessante bevinding en toont aan dat een dynamisch-statische rompextensie de meest geschikte oefening is om specifiek de lumbale extensoren te trainen. Echter, wanneer het doel is om de kracht van de latissimus dorsi of heupextensoren te verbeteren, blijken lumbale extensie oefeningen niet toereikend.

Om de lumbale extensie oefeningen te doseren, kan gebruik gemaakt worden van een directe en indirecte methode. De directe methode lijkt echter meer geschikt wanneer een hoge oefenintensiteit wordt beoogd, de indirecte methode accurater is voor het bepalen van de werkelijke activiteit voor oefeningen op een lager intensiteitsniveau’s. Doch beide methoden, geven een lichte overschatting van de werkelijke activiteit van de rompextensoren, een gegeven waarmee men rekening dient te houden.

Tot besluit tonen de resultaten van dit doctoraat aan dat het toepassen van een actieve stabilisatie strategie, meerbepaald het aanspannen van het lumbo-pelvisch spiercorset, als essentieel kan beschouwd worden om deze oefeningen op een verantwoorde manier uit te kunnen voeren. Het toepassen van deze stabilisatie techniek tijdens extensie oefeningen kan de mate van lumbale lordose limiteren en beïnvloedt ook het rekruting-spatroon van de posterieure spierketen. Zo kon vooral een hogere werking van de gluteus maximus tijdens de extensie oefeningen met lumbopelvische stabilisatie worden vastgesteld.

Deze nieuwe inzichten kunnen therapeuten en trainers assisteren bij het selecteren van de meest geschikte oefening voor het trainen van de uithouding en kracht van de posterieure spierketen.
LIST OF ABBREVIATIONS

1-RM  One repetition maximum
BF    m. Biceps Femoris
BMI   Body mass index
CSA   Cross sectional area
EMG   Electromyography
ES    Erector Spinae muscles
FOV   Field of view
FTL   Fascia Thoracolumbalis
GM    m. Gluteus Maximus
IL or ILL m. Iliocostalis Lumborum pars Lumborum
IT or ILT m. Iliocostalis Lumborum pars Thoracic
LBP   Low back pain
LD    m. Latissimus Dorsi
LES   Lumbar Erector Spinae muscles (LL and IL)
LL or LTL m. Longissimus thoracis pars Lumborum
LM or MF m. Multifidus
LT or LTT m. Longissimus thoracis pars Thoracic
mfMRI Muscle functional magnetic resonance imaging
MV(I)C Maximal voluntary (isometric) contraction
RMS   Root mean square
ROI   Region of interest
ROM   Range of motion
SD    Standard deviation
sEMG  surface Electromyography
TA    m. Transversus Abdominis
TES   Thoracic Erector spine muscles (LT and IT)
US    Ultrasound
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