EFFECTS OF MOTOR CONTROL EXERCISE IN SUBJECTS WITH CHRONIC NONSPECIFIC LUMBOPELVIC PAIN

Motor Control Exercise for the reeducation of normal motor control in subjects with chronic nonspecific lumbopelvic pain:
Richardson vs. McGill Approaches

DISSERTATION SUBMITTED IN FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR IN SPORT SCIENCE BY THE FACULTY OF SPORT OF THE UNIVERSITY OF PORTO, PORTUGAL.

THESIS PREPARED UNDER THE SUPERVISION OF:

PROF. DR. JOÃO PAULO VILAS-BOAS

PROF. DR. MANUEL RUBIM SILVA SANTOS (CO-SUPERVISOR)

PAULO JOSÉ MEDEIROS DE CARVALHO

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ABSTRACT

Introduction: Considering the knowledge that subjects with chronic nonspecific lumbopelvic pain (LPP) suffer from impaired spine motor control, it seems pertinent to look to this matter in accordance to the approach that motor control exercise provides in the re-education of these subjects. In the literature there are some approaches related to exercise, as one of the best ways to reeducate the LPP, but almost all of them are based on the Queensland group (Richardson) and Stuart McGill approaches. Although, there is not enough scientific evidence to support the best motor control exercise approach to perform this reeducation in terms of motor control, aspects, like the muscles onset timing.

Purpose: To compare the effect of motor control exercise for dynamic stability according to the Richardson approach with the McGill approach on onset timing of electromyographic (EMG) onset of the abdominal muscles, during rapid arm movements, and pain intensity in subjects with chronic nonspecific lumbopelvic pain.

Methods: Experimental study with a sample of 59 subjects volunteers with chronic nonspecific lumbopelvic pain, randomly in Motor Control Exercise_Richardson Approach Group (MCE_R$_{ichardson}$) (n=20), Motor Control Exercise_McGill Approach Group (MCE_M$_{cGill}$) (n=20) and Control Group (CG) (n=19). To evaluate timing of EMG onset during rapid arm flexion (RAFM), abduction (RAAM) and extension (RAEM) movement was used surface electromyography of transversus abdominal/ internal oblique (TrA/IO), external oblique (EO), rectus abdominis (RA) and anterior, medium and posterior deltoids. The pain intensity was measured by visual analog scale. The experimental groups were subjected to different motor control exercise programs during 8 weeks, one according to the Richardson approach and another according to the McGill approach. The CG did not undertake any intervention. The assessments took place before and after 8 weeks of the application of exercise programs.

Results: After 8 weeks of completion the different motor control exercise programs (M_1), in RAFM, on $MCE\_R_{ichardson}$ group it was found that the timing of EMG onset of TrA/IO was significantly lower when compared to MCE_M_{cGill} and control groups. Also, in this movement, the MCE_M_{cGill} group presented a timing of EMG onset of EO and RA significantly lower when compared to CG. On $MCE\_R_{ichardson}$ group, in RAAM, the timing of EMG onset of TrA/IO was significantly lower comparing to CG. The timing of EMG onset of EO, in this movement, was significantly lower in MCE_M_{cGill} ($p<0.05$) comparing to the CG. Yet, in MCE_M_{cGill} group the timing of EMG onset of RA was significantly lower in the $MCE\_R_{ichardson}$ group and CG. In RAEM, on $MCE\_R_{ichardson}$ group, it was found that the timing of EMG onset of TrA/IO was significantly lower when compared to CG. At M_1 it was found that in $MCE\_R_{ichardson}$ and MCE_M_{cGill} group the pain intensity was significantly lower when compared to CG.

Conclusion: Globally, these main results related to both approaches of motor control exercise decreased the EMG onset timing of abdominal muscles verifying an improvement in the lumbopelvic dynamic stability. However, motor control exercise according to the Carloyn Richardson approach seems to have more effect on local stabilizing muscles (TrA/IO) while the approach of Stuart McGill appears to have more effect on global stabilizing muscles (EO and RA). Yet, both motor control exercise programs reduced the lumbopelvic pain intensity.

Abbreviations and Symbols

AD – Anterior Deltoid

APAs – Automatic Postural Adjustments

ASLR - Active Straight Leg Raise

ASLR_AB - Active Straight Leg Raise_Abdominal Bracing

ASLR_D - Active Straight Leg Raise_Drawing in

BD - Birddog

BF_Ipsi - Biceps Femoris Ipsilateral

CG - Control Group

CMRR - Common-Mode Rejection Ratio

CNS - Central Nervous System

CU - Curl-Up

EMG – Electromyography

EO – External Oblique

ES – Erector Spinae

ES_Contra - Erector Spinae Contralateral

ES_Ipsi - Erector Spinae Ipsilateral

FCT - Fundação para a Ciência e Tecnologia

GM - Gluteus Maximus

GM_Ipsi - Gluteus Maximus Ipsilateral

IO – Internal Oblique

LPP – Lumbopelvic Pain

LPP$_G$ – Lumbopelvic Pain Group

MCE_M$_{cGill}$ - Motor Control Exercise_McGill Approach

MCE_R$_{ichardson}$ - Motor Control Exercise_Richardson Approach

MD – Medial Deltoid

MU – Multifidus

MVIC - Maximal Voluntary Isometric Contraction

NLPP$_G$ – Non Lumbopelvic Pain Group

PD – Posterior Deltoid

PFM – Pelvic Floor Muscles

RA – Rectus Abdominis

RAAM – Rapid Arm Abduction Movement

RAEM – Rapid Arm Extension Movement

RAFM – Rapid Arm Flexion Movement

RAM – Rapid Arm Movement

RMS - Root Mean Square

SB - Side-Bridge

sEMG – Surface Electromyography

SPSS - Statistical Package for the Social Sciences

TrA – Transversus Abdominis

TrA/IO - Transversus Abdominis/Internal Oblique

VAS - Visual Analogic Scale

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Approximately 9.2% of the world population suffers from lumbar-pelvic pain (Vos et al., 2012). Despite some cases may be assigned to certain pathologies, about 90% are from nonspecific origin (Haldeman et al., 2012).

Back pain happens to almost everyone and, for some, is a life-changing occurrence. The causes are as many as there are structures capable of producing pain, and every tissue in the body is capable to giving us pain (Haldeman et al., 2012; Vos et al., 2012).

There are some professions, and Physiotherapy is one of them, that are passionate about discovering what is driving the problem and looking at how the whole body works together.

Optimal performance and moving with harmony, ease and flow comes from all body systems working synergistically, coordinated and conducted by the “maestro” (brain and central nervous system (CNS)), so we can have beautiful movements, just like an orchestra plays beautiful music. Each muscle is like an instrument in the orchestra and must be trained individually. However, beautiful music can only be heard when the maestro conducts the individual instruments (this play more, that one play less, this be quiet, that one play higher, this play lower). In the human body the nervous system is the maestro for our muscles and training the “maestro” is what we refer to as motor control training. We cannot strengthen a muscle that the brain is not using properly, therefore core training must come before core strengthening (Richardson, Hodges, & Hides, 2004).

According to motor control theory, the nervous system conducts exactly the right intensity and patterns of muscle activation, in the right time for any specific task that we perform. The net result of this synergy and coordination of muscles activation is that we are supported, yet still able to move, in other words, we have stability as well as mobility (Richardson et al., 2004).

“Core stability” has become a “buzzword” that everyone talks about. Indeed, a properly functioning core is essential for pain free optimal function and performance. However, there seems to be a multitude of different opinions and exercises about the best way to re-train the core and recover from back pain (Richardson et al., 2004).

The literature has showed significant differences in both the anatomy and function of the deep compared to the superficial muscles of the trunk. So, when we considered the best way to assess and re-train these muscles to recover from injury or to optimize performance, we needed to understand and considered those differences. Also, the central nervous system coordinates and controls the deep and the superficial muscles differently (McGill, 2004, 2007a; McGill & Karpowicz, 2009; Richardson, Hodges, & Hides, 1999; Richardson et al., 2004).

The Richardson approach is based on motor control of the lumbopelvic region. The model of inter-segmental stabilization exercises in order to revert the motor control problems of the deep muscles (local stabilization system) and to restore the balance/synergy between local and global systems. This approach gives a special emphasis on co-contraction of the deep muscles (TrA, Deep Multifidus, pelvic floor muscles and diaphragm) through the abdominal "drawing-in" (Hodges, 1999; Richardson et al., 1999, 2004).

The McGill approach defends the realization of abdominal “bracing”, since, gives equal importance to the three layers of the abdominal wall and because they play a crucial role in segmental stabilization in protecting the spine during the rotation and inclination movements, increasing its activity when the spine is placed under axial compression (McGill, 2004, 2007a; McGill & Karpowicz, 2009).

The term “core” is used in both the research and training literature to mean sometimes different things, so what is the core? Our core is located between the diaphragm, pelvic floor, abdominal (deep and superficial parts) and back muscles (McGill, 2007a).

Lumbopelvic stability is an important issue, especially given its potential link to mechanisms of injury and associated clinical efforts directed towards enhancing stability in patients (McGill, 2007a; Richardson et al., 2004).

The recruitment of Transversus Abdominis (TrA) through abdominal hollowing may be advantageous because it increases stability, without increasing the compressive load on the spine. Abdominal hollowing, so denominated because the navel is draw inward toward the spine, intending to only activate the TrA. In contrast, abdominal bracing is a technique where all muscles in abdominal wall are isometrically contracted, namely TrA, Internal Oblique (IO), External Oblique (EO) and Rectus Abdominis (RA), but in the way that does not change the abdomen shape. In both cases the lumbopelvic spine should be maintained in a neutral lumbopelvic position (McGill, Juker, & Kropf, 1996; Richardson et al., 2004; Richardson et al., 2002).

The clinic focus on TrA has been provided by the Queensland group who documented recruitment onset deficiencies in the activation of this muscles in those with a history of low back disorders (Hodges, Richardson, & Jull, 1996; Hodges & Richardson, 1996).

Hodges and Richardson (1997a, 1997b, 1999a, 1999b) research suggested that TrA responds with a pre-activation to upper limb movements in healthy people but this pre-activation is not present in those who had Lumbopelvic Pain (LPP) history (Hodges & Richardson, 1997b, 1997c, 1999a, 1999b). Though, Allison and Henry (2002), Newcomer (2002) do not confirm these findings (G. T. Allison & Henry, 2002; Newcomer et al., 2002).

There is also evidence that TrA is activated independently of other abdominal muscles, although it also seems to be a synergist of IO, especially for static and anticipated motions (McGill et al., 1996).

The loss of the feedforward muscle activation in the presence of lumbopelvic pain (LPP) is the foundation of the proposal theory that there is underlying motor control dysfunction of the deep abdominal muscles in subjects/individuals with LPP. This dysfunction results in suboptimal stability of the lumbopelvic region and, may be, a mechanical factor in the underlying pathogenesis (Hodges, 1999, 2001a; Hodges & Richardson, 1998, 1999a, 1999b; Richardson et al., 1999, 2004; Richardson & Jull, 1995).

LPP affect the motor control of trunk muscles that regulates spinal stability and movements. One indicator of motor control for the lumbopelvic region is the EMG onset timing of abdominal muscles when spinal stability is challenge by destabilizing forces (Hodges & Moseley, 2003; Hodges, Moseley, Gabrielsson, & Gandevia, 2003; Santos & Aruin, 2009; Vasseljen, Unsgaard-Tondel, Westad, & Mork, 2012). In response to expected postural perturbation, this activation occurs, in subjects without pain, in a feedforward manner, i.e., anticipatory muscle activation prior to the balance perturbation (Hodges, Moseley, et al., 2003; Santos & Aruin, 2009).

Delayed in feedforward activation of the deep abdominal muscles in response to postural perturbations induced by rapid arm movements (flexion, abduction and extension) has been observed in chronic and recurrent LPP patients (Hodges, Moseley, et al., 2003; Hodges & Richardson, 1998, 1999b; MacDonald, Moseley, & Hodges, 2009; Radebold, Cholewicki, Panjabi, & Patel, 2000; Radebold, Cholewicki, Polzhofer, & Greene, 2001; Santos & Aruin, 2009).

Motor control exercises have become increasingly popular in clinical rehabilitation of lumbopelvic pain. The rationale for the use of these exercises is that control of the spine is altered in patients with LPP (de Paula Lima, de Oliveira, Costa, & Laurentino, 2011).

Previous studies have also demonstrated that patients who recovered from an episode of acute Lumbopelvic Pain are more vulnerable to recurrence and chronicity in the deep abdominal wall muscles if were not treated with motor control exercises (Hides, Jull, & Richardson, 2001; Hodges & Richardson, 1997a, 1997b, 1997c; P. O'Sullivan, 2005).

The Queensland group have developed the abdominal hollowing or drawing-in as a TrA motor pattern re-training technique, but the question remains – is the isolated TrA recruitment resulting from this strategy an efficient stabilizer of lumbopelvic region or is the abdominal bracing, with the co-contraction of all trunk muscles, argued by Stuart McGill?

So one of the main incentives to initiate this research process was the possibility to contribute to this pertinent discussion. Hence, was established as the main goal of this PhD, the comparison and reflection on the effect of a motor control exercise program, with two different approaches (Richardson and McGill), in the EMG onset timing of the abdominal muscles and pain intensity in subjects with chronic nonspecific lumbopelvic pain.

In this PhD were also established other goals, namely:

- Compare subjects with and without lumbopelvic pain on the EMG onset timing and trunk muscles endurance capacity.
- Usefulness of the active straight leg raise test comparing subjects with and without lumbopelvic pain using different strategies (manual compression, abdominal bracing and drawing in) in order to provide lumbopelvic stability.
- Analyze some issues related to superficial electromyography – different electrodes location in Rectus Abdominis muscle.
- Analyze some issues related to motor control of Transversus Abdominis/Internal Oblique muscles.

1.1 THESIS ORGANIZATION

The following PhD Thesis presents a structural organization in order to provide answers to these goals (see Figure 1).

The hypothesis concerning the effect of the two motor control exercise approaches, in the EMG onset timing of the abdominal muscles and pain intensity in subjects with chronic nonspecific lumbopelvic pain were tested in the research studies presented in this thesis. Alongside with these studies were also developed other papers related to the theme addressed in this thesis:

- **Carvalho, P.**, Pereira, A., Santos, R. & Vilas Boas, J.P. (2011). EMG of the transverse abdominus and multifidus during Pilates exercises. In: Vilas-Boas, JP, Machado, L, Wangdo, K. Veloso, AP (eds.) Biomechanics in Sports 29, Portuguese Journal of Sport Sciences, 11 (Suppl. 2): 727-730 (see Appendix-I).
- **Carvalho, P.**, Moreira, C., Santos, R. & Vilas-Boas, J.P. **(2011).** Alterações no recrutamento dos músculos abdominais em indivíduos com história de dor lombopélvica em movimentos do membro superior. *Comunicação apresentada no 4º Congresso Nacional de Biomecânica*. **ISBN: 978-989-97161-0-0**, Coimbra, Portugal, Sociedade Portuguesa de Biomecânica, 4 e 5 de Fevereiro de 2011. pp: 137-144 (see Appendix-II).

There is also a section of literature review, followed by studies in full presentation. The global discussion, conclusions and future works are also presented in final part of this thesis.

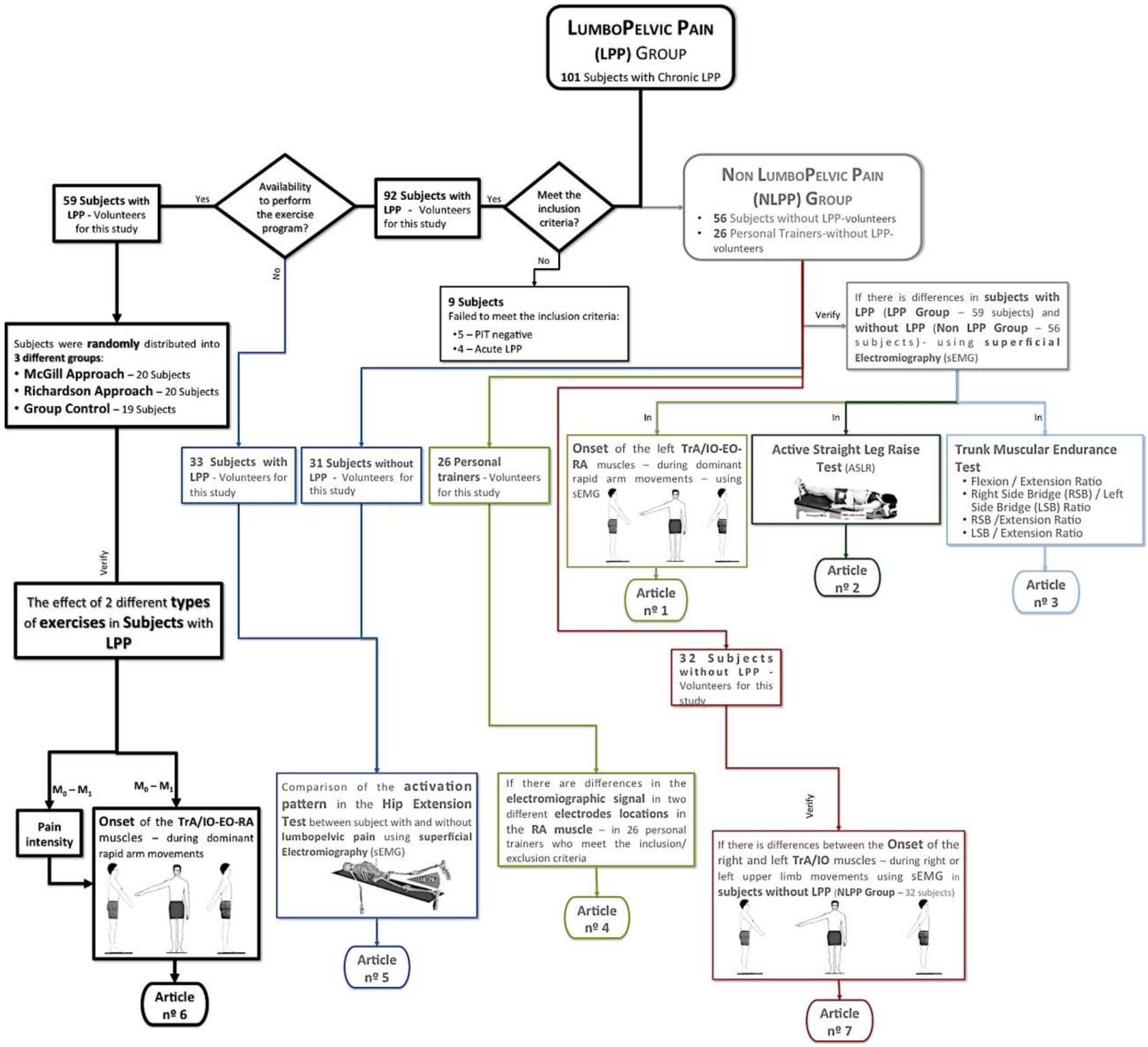

Figure 1. Flow Chart – Paulo Carvalho_PhD thesis

- The effect of 2 different **types** of **Motor Control exercises** on **Pain, Abdominal Muscles Onset** in **subjects** with **LumboPelvic Pain: Motor Control Exercise McGill** versus **Richardson Approaches**
- Differences between **subjects with LumboPelvic Pain** and **without LPP on Abdominal Muscles Onset**, **Active Straight Leg Raise Test**, **Trunk Muscular Endurance** and **Sequence of Muscle Activation** in the **Hip Extension Test**
- Some methodological aspects of **Rectus Abdominis EMG – 2 different electrodes location**
- Some aspects of **Transversus Abdominis Motor Control**

CHAPTER 2

LITERATURE REVIEW

2.1. EPIDEMIOLOGY AND ETIOLOGY OF LUMBOPELVIC PAIN

Current evidence in literature suggests that single definite causes of clinical Lumbopelvic Pain (LPP) remain inconclusive (Dagenais & Haldeman, 2012). The prevalence of LPP has been estimated at 25%, whereas the 1-year prevalence at 50% and in the lifetime about 85% (Airaksinen et al., 2006; Nielens et al., 2006). These statistics remain true with respect to age, sex, or country and varies only slightly between occupations. There is some evidence that suggest that everyone will at some point of their life experience LPP (Dagenais & Haldeman, 2012).

LPP etiology it's one of the greatest mysteries. In literature there are several studies, but not yet has been create a clear link between precise risk factors or a specific tissue injury and a particular symptoms. In fact, there are several theories and hypotheses about the origins of LPP, but a few this studies have withstood scientific scrutiny over time (van Tulder et al., 2006; van Tulder & Koes, 2006a, 2006b).

The number of studies performed in the last decades that attempted to evaluate potential risk factors for LPP is amazing, but their findings are diverse, nonspecific and also demonstrate a dispute between clinicians and researchers (Dagenais & Haldeman, 2012; Leboeuf-Yde, 2000; Leboeuf-Yde, Lauritsen, & Lauritzen, 1997).

Within the risk factors identified in the literature, which may be the cause of LPP, we can mention the following: genetics (J. D. Kang et al., 1996; McCarron, Wimpee, Hudkins, & Laros, 1987; Solovieva et al., 2004), physical loading (Ekstrom, Holm, Holm, & Hansson, 2004; Holm, Holm, Ekstrom, Karladani, & Hansson, 2004; A. Kaigle, Ekstrom, Holm, Rostedt, & Hansson, 1998), smoking (Leboeuf-Yde, 1999; Leboeuf-Yde, Kyvik, & Bruun, 1998), obesity (Leboeuf-Yde, Kyvik, & Bruun, 1999), psychological and psychosocial factors (Craig, Boardman, Mills, Daly-Jones, & Drake, 1993; Croft et al., 1995).

The LPP classification has been described in a consistent manner with temporal definitions associated at each phase. Different operational definitions have been reported in the literature, but the commonly accepted definitions is: (1) acute (0 to 1 month since the episode of LPP, (2) sub-acute (2 to 3 months since the episode of LPP) and (3) chronic phases (longer than 3 months since the episode of LPP) (Dagenais & Haldeman, 2012).

Up to 90% of the patients with LPP are expected to be pain free or to have a great improvement in signals and symptoms during the acute phase, and only 10% of them are expected to report chronic LPP (Dagenais & Haldeman, 2012).

LPP is a common experience in the lifetime, that can be chronic or recurrent, it is not surprising that is a significant cause of disability, and with a large impact on cost to society, and this cost are increasing exponentially (Burton & Erg, 1997; Dagenais & Haldeman, 2012; Stewart, Ricci, Chee, & Morganstein, 2003; Stewart, Ricci, Chee, Morganstein, & Lipton, 2003; Waddell, 1996; Walker, Muller, & Grant, 2004).

2.2. Motor Control Changes and Lumbopelvic Pain: causes or effects?

The available data in the literature on motor control in LPP are mainly cross-sectional in nature. It is therefore unknown whether differences in motor behaviour between individuals with and without LPP are a cause or a consequence of it (Hodges, Cholewicki, & van Dieen, 2013).

The differences in muscle activity between patients with LPP and healthy control subjects are inconsistent between studies (van Dieen, Selen, & Cholewicki, 2003). Most of the research in this area focused on activity of the lumbar erector spinae muscle (LES). A review showed that results were highly inconsistent, either in static or in dynamic situations, with some studies showing more activity in patients than in healthy controls, and other studies showing less (van Dieen, Selen, et al., 2003). In full flexion, most healthy subjects show a complete electromyographic silence of the LES. In many patients with LPP this phenomenon is absent and was associated with reduced intervertebral motion (A. M. Kaigle, Wessberg, & Hansson, 1998).

The activity of the multifidus muscle (MU) was decreased relative to the superficial muscles in concentric activity and LPP patients were less able to isometrically contract the muscle under visual (ultrasound-based) feedback than controls (Wallwork, Stanton, Freke, & Hides, 2009). In addition, activation of the deep, short-fibred part of the MU after self-induced perturbations was delayed in patients with recurrent LPP after the symptoms disappearance (MacDonald et al., 2009).

Among the abdominal muscles, the rectus abdominis muscle (RA) was found to be more active during gait in patients with LPP than in healthy controls (van der Hulst, Vollenbroek-Hutten, Rietman, & Hermens, 2010; van der Hulst, Vollenbroek-Hutten, Rietman, Schaake, et al., 2010). During an exercise called “abdominal hollowing”, activation levels of the internal oblique (IO) and RA muscles were not different between patients and controls, but the ratio of the two was different with a higher activation of RA relative to IO in the patient group (P. O'Sullivan, Twomey, Allison, Sinclair, & Miller, 1997). However, this finding was not confirmed during free planar motions through the upright posture and during ramp contractions (van Dieen, Cholewicki, & Radebold, 2003).

Transversus abdominis (TrA) muscle activity has been investigated in many studies (Hodges, 1999; Hodges & Moseley, 2003). Generally its activity in expected perturbations was delayed and there was a decrease in it activity levels. The delayed activity was associated with a reorganization of the motor cortex (Tsao, Galea, & Hodges, 2008). In addition, activation of this muscle in relation to a expected perturbation appeared less variable in timing in LPP patients compared with healthy controls (Jacobs, Henry, & Nagle, 2009; Jacobs, Lou, Kraakevik, & Horak, 2009). In standing, postural sway and time to recover balance after a perturbation are increased with LPP and this coincides with reduced trunk movements (Mok, Brauer, & Hodges, 2007).

From the literature reviewed it is evident that motor control and motor behaviour are different in patients with LPP, compared with the healthy controls. However, appears to exist substantial variability in motor behaviour between subjects with LPP. The variability, between individuals with LPP, in the way of moving and control their spine and pelvis may account for the lack of consensus between studies (Hodges, 1999; Hodges & Richardson, 1997a, 1997b, 1998, 1999b; McGill, 2007a; Mok et al., 2007; Richardson et al., 2004; Tsao & Hodges, 2007; Unsgaard-Tondel, Lund Nilsen, Magnussen, & Vasseljen, 2012; van der Hulst, Vollenbroek-Hutten, Rietman, Schaake, et al., 2010; van Dieen, Cholewicki, et al., 2003; van Dieen, Selen, et al., 2003).

The discussion about the viability of a causal relationship between motor control dysfunction and LPP is based on associations determined in observational studies and based on experimental studies that interrogate potential mechanisms through which motor control might cause LPP. A potential mechanism for this is through the effects that motor control has on tissue loading. This is perhaps the most intuitive theory because the idea that self-generated forces can damage tissue is well established and accepted, and even sub-failure injuries of tissue activate nociceptors and triggering inflammatory responses (Lynn, 1996). The role of mechanical tissue injury in LPP is indirectly supported by several clinical, epidemiological and experimental studies. It is very difficult, however, to confirm the presence of microtrauma or sub-injury noxious activity in lumbopelvic region, which makes the theory impossible to substantiate, at least with current investigative technologies (van der Hulst, Vollenbroek-Hutten, Rietman, Schaake, et al., 2010; van Dieen, Westebring-van der Putten, Kingma, & de Looze, 2009).

There is a large amount of theoretical literature that proposes instability of the spine to be a cause of high tissue strains and/or impingements, thereby causing injury and pain (D. Lee, 2004; Panjabi, 1992a, 1992b; van der Hulst, Vollenbroek-Hutten, Rietman, Schaake, et al., 2010; van Dieen et al., 2009). Given that the spine osteoligamentous are inherently unstable, loss of control over spinal curvature or spinal movement, due to motor control dysfunctions, could theoretically lead to instability (Cholewicki & McGill, 1996; D. Lee, 2004). The probability of such motor control dysfunctions is probably dependent on the individual quality of motor control skills (see Figure 2) (D. Lee, 2004).

Studies in cadaver have shown that high and repetitive compression, bending and torsion of the spine can cause injuries, and such injuries may *in*

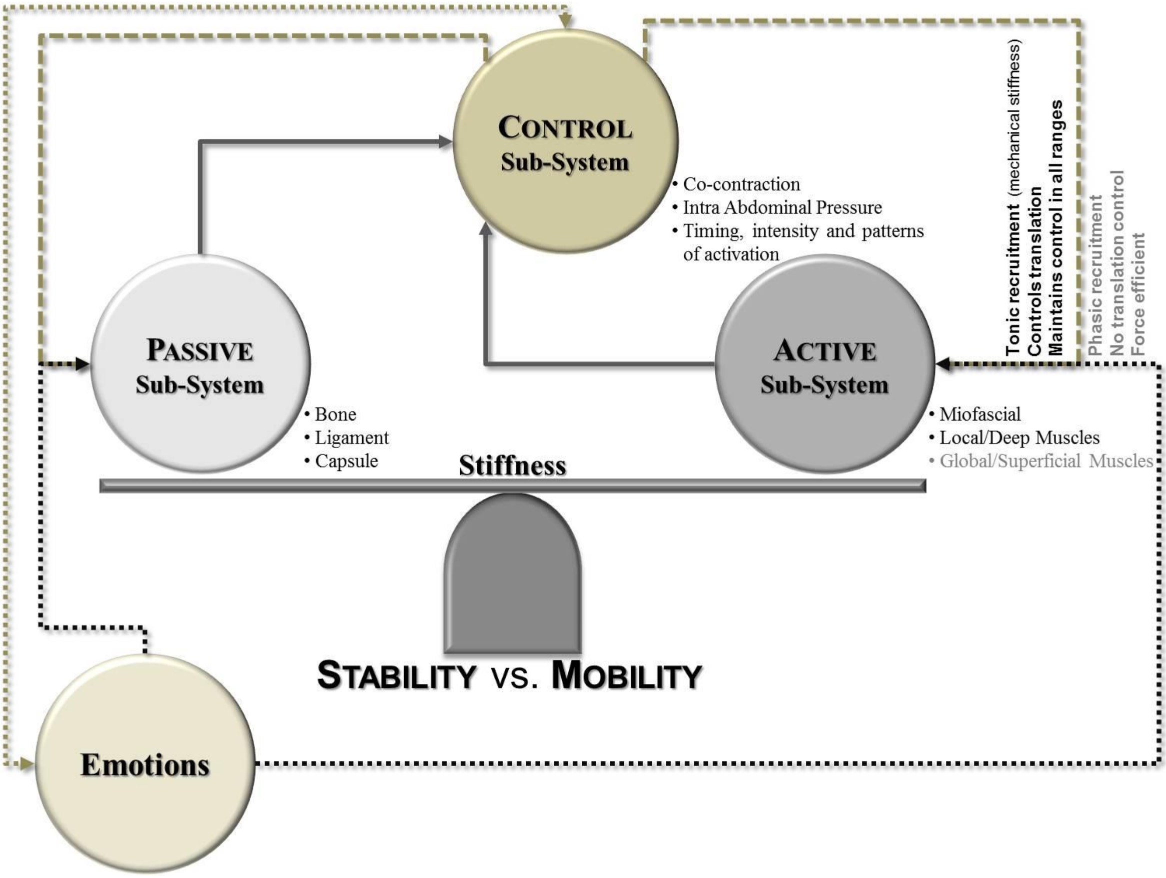

Figure 2. Stability versus Mobility. Adapted from .D. Lee (2004)

vivo be a cause of LPP (van Dieen, Weinans, & Toussaint, 1999; van Dieen et al., 2009). Specific motor habits, such as a flexed posture, might cause unnecessarily high, sustained or repeated loading and thus contribute to LPP. Also, habitually increased levels of trunk muscle co-activation may induce unnecessarily high loading without visible changes in motor behaviour (van Dieen et al., 1999; van Dieen et al., 2009).

A study in people with neck pain but no back pain showed that those with poor ability to perform a voluntary activation of the lower abdominal muscles, poor performance associated to the delay in the transversus abdominis activation during rapid arm movements (Hodges et al., 1996; Hodges & Richardson, 1996), were 3–6 times more probably to develop persistent or recurrent LPP in the following two years than those who performed well this task (G. L. Moseley, 2004b).

Cholewicki et al. (2005) found evidence for a small increased risk of LPP in athletes with slower responses of the trunk muscles to sudden postural perturbations. Trunk joint position sense (Silfies, Cholewicki, Reeves, & Greene, 2007) and seated balancing performance (Cholewicki et al., 2005) were not predictive of future LPP among athletes. Takala and Viikari-Juntura (2000) reported that poor balance control was a weak predictor of future LPP in a working population. The absence of the normal flexion–relaxation response in people with back pain was positively related to self-efficacy and fear avoidance beliefs (Watson, Booker, & Main, 1997) and double dissociation experiments show that trunk movement range can be altered in people with LPP by purely cognitive interventions in a manner that is consistent with a relationship between the movement and the perceived threat of injury (G. L. Moseley, 2004b).

In a model of spinal stability showed that instability might occur in tasks that impose low mechanical loads on the spine, while the spine would be stable in high mechanical loading (Cholewicki & McGill, 1996). However, it was later shown that the conclusion depends on the relation between muscle stiffness and force, suggesting that spine instability might also occur in tasks that impose very high loads on the spine (Brown, Howarth, & McGill, 2005; van der Burg, Casius, Kingma, van Dieen, & van Soest, 2005).

Several studies indicate a loss of control over spinal posture in less demanding, upright standing lifting tasks (van der Burg, Kingma, & van Dieen, 2003, 2004), probably due to a delay on the onset of trunk muscles (Cholewicki & McGill, 1996; Cholewicki, Simons, & Radebold, 2000; Stokes, Gardner-Morse, Henry, & Badger, 2000).

In addition to external perturbations, changes in the neuromusculoskeletal system may increase the probability of spinal instability. Theoretical considerations indicate that the probability of a loss of spine control in segmental motion, increases when degenerative changes or spinal injury have caused a segmental loss of stiffness (Panjabi, 1992a, 1992b). Experimental data suggest that the probability of a loss of control over spine motion might increase with additional challenges, such as correct breathing (Hodges, Heijnen, & Gandevia, 2001; McGill, Sharratt, & Seguin, 1995), when a cognitive dual task is performed (Brereton & McGill, 1999), after sustained spine bending has caused ligament creep (Sanchez-Zuriaga, Adams, & Dolan, 2010), or when occurred trunk muscles fatigue (Granata & Gottipati, 2008; van Dieen, 1996; van Dieen, van der Burg, Raaijmakers, & Toussaint, 1998). Also, perturbations of spine posture and motion have been associated with high tissue loading and occur when mechanical perturbations cause balance loss (Mannion, Adams, & Dolan, 2000; Oddsson, Persson, Cresswell, & Thorstensson, 1999; van der Burg, Pijnappels, & van Dieen, 2005), in line with the epidemiological association between balance loss and LPP.

Considering what was referred above is possible that the way we move and control our trunk muscles might cause excessive strains of spinal tissues, and thus contribute to the development of LPP. The probability of such a loss of control would be determined by both individual characteristics (motor skill) and situational factors (presence of degenerative changes, fatigue, etc.) (Hodges et al., 2013).

At this time, we may conclude that the causal relationships are biologically plausible but far from being proven (Hodges et al., 2013).

Motor control changes might be a result of the nociceptive signal itself, of pain, or of associated cognitive factors such as fear (Hodges et al., 2013).

Experimentally induced pain through injection of hypertonic saline in the LES coincided with an increase in LES activity in sitting, which appeared to be correlated with pain intensity, and during gait, a pattern of activation similar to that observed in people with chronic LPP (Arendt-Nielsen, Graven-Nielsen, Svarrer, & Svensson, 1996; Lamoth et al., 2004). Furthermore, was found an increased LES activity in the end-of-range of flexion movement (Zedka, Prochazka, Knight, Gillard, & Gauthier, 1999). However, Zedka et al. (1999) found no effects on LES stretch reflex amplitude, no changes during trunk bending movements and even a reduced LES activity during trunk extension movements. However, a consistent fact in the literature is the delayed activation of the TrA muscle during voluntary arm movements, in a similar manner to that observed in people with chronic LPP (Hodges & Moseley, 2003; Hodges, Moseley, et al., 2003; G. L. Moseley, 2004b).

In Reeves, Cholewicki, and Silfies (2006) study, it was found that the imbalance between the activation of LES and TES was not expressed before the onset of LPP, suggesting that this imbalance was a consequence rather than a LPP cause. However, the imbalance remained after the recovery from LPP, indicating that the presence of pain does not determine directly the change in motor control.

Cholewicki et al. (2002) found that, in trunk muscle responses to trunk perturbations, was present a delayed responses after recovery from LPP. In a later study, Cholewicki et al. (2005), revealed that these were also predictive of future LPP, suggesting that the changes are a cause, rather than an effect of LPP.

Several studies found a delayed activation of the TrA muscle relative to the onset timing of the perturbation (Hodges et al., 1996; Hodges & Richardson, 1996, 1997a, 1997b, 1998). Similarly, MacDonald et al. (2009) studied extensor muscle activation in response to self-induced and externally induced, unpredictable trunk perturbations during remission of LPP. The deep parts of the multifidus muscle were active earlier than the more superficial parts in the healthy participants and on the non-painful side in the remission group, but not on the previously painful side in the remission group, despite the resolution of symptoms.

Longitudinal studies show that some motor control changes may remain after pain disappeared, indicating that these motor control changes are not a direct effect of pain presence, but leaves the possibility that they are effects of noxious stimulation, or cognitions, often associated with pain. However, effects of experimentally induced and clinical pain were not replicated by performance of a cognitive stressful task (G. L. Moseley, 2004b), anticipated experimental back pain did replicate the effect of pain, at least with regard to postural activation of the trunk muscles during voluntary rapid arm movements (G. L. Moseley, 2004a). Another studies that support an indirect relationship between pain and motor control changes through pain-related cognitions is the finding that pain coping strategies (catastrophizing and distraction) are related to motor control changes in subjects with LPP (van der Hulst, Vollenbroek-Hutten, Schreurs, Rietman, & Hermens, 2010), but pain intensity does not (van der Hulst, Vollenbroek-Hutten, Rietman, Schaake, et al., 2010).

The motor control changes with LPP indicate, also, that these may have long-term consequences, such as increased muscle fatigue (van Dieen et al., 2009), increased joint loading (Healey, Fowler, Burden, & McEwan, 2005; Marras, Davis, Ferguson, Lucas, & Gupta, 2001; Marras, Ferguson, Burr, Davis, & Gupta, 2004), and impaired balance control (Mok, Brauer, & Hodges, 2004; Mok et al., 2007). Pain may coincide with a reduction in motor variability. The acute pain is often adaptive and helpful but chronic pain is often not, motor control changes may be similarly helpful in the short term but problematic later. In clinical practice the variance of motor control changes, between LPP patients, may also be relevant clinically (Jacobs, Henry, et al., 2009; G. L. Moseley & Hodges, 2006).

The evidence suggests a limited contribution of individual motor skill and therefore primary prevention efforts through motor control training are unlikely to be cost-effective. However, in secondary prevention, there may be a role for motor control training to avoid loss of control and to redress inefficient control strategies. To support clinical decision-making, longitudinal studies are needed to disentangle the adaptive and maladaptive aspects of motor control changes that coincide with pain (Jacobs, Henry, et al., 2009; G. L. Moseley, 2004a; G. L. Moseley & Hodges, 2006).

2.3. Spine Motor Control and Pain

Despite the apparent divergence of opinion between the approaches under study in this thesis, in the understanding of normal and abnormal spine control, and the extrapolation to design of clinical interventions to aim spine control, there is in fact considerable agreement on fundamental concepts that support LPP management. There are several points of agreement between the two approaches, namely in: (1) the spine control (no single muscle is the most important for spine control, existing a control by a complex interplay of many muscles); (2) the changing the way in which a patient controls the spine and pelvis is probably beneficial in the reeducation of LPP; (3) the fact that spine motor control can be changed with treatment/exercise; (4) treatment goals involves consideration of more than a uni-dimensional focus on a single muscle or muscle activation strategy; (5) in order to improve the performance of the activities of daily living require treatment/exercise progression (Hodges & Cholewicki, 2007; McGill, 2007a; Richardson et al., 2004).

There is a consensus in literature that the debated relates to which muscles provide the *greatest* contribution to spine and pelvis stability is a wrong question. It is clear that each muscle in the complex set of muscles that surrounds or attaches to the spine and pelvis or adjacent regions provides a contribution to the control of lumbopelvic movement and stiffness (Cholewicki, Panjabi, & Khachatryan, 1997; Hodges & Richardson, 1997b; McGill, Grenier, Kavcic, & Cholewicki, 2003). However this fact has often been lost in the reporting of observations carried out in research. Although, the studies related to the postural adjustment associated with arm movement are often cited as evidence that transversus abdominis (TrA) (Hodges & Richardson, 1997b), lumbar multifidus (LM) (G. L. Moseley, Hodges, & Gandevia, 2002), diaphragm (Hodges & Richardson, 1997a, 1997b, 1997c) and pelvic floor muscles (Hodges, Sapsford, & Pengel, 2007) have a unique contribution to spine control, these studies also provide evidence of the important contribution of other abdominal and back muscles. These other muscles act predictably to control the spine and pelvis in a manner essentially linked to the direction of the reactive moments (Cholewicki et al., 1997; Hodges & Richardson, 1997a, 1997b; Hodges et al., 2007; McGill et al., 2003; G. L. Moseley et al., 2002).

The spine is controlled dynamically by the interplay of activity of the multiple muscles, and this control operates at two levels: (1) control of the body segments that influences joint loading arising from posture and movement; (2) stiffen control of the spinal joints (such as those micro-movements with the potential to irritate nociceptors, because of tissue damage). Optimal spine control requires a balance between stiffness and movement and this balance will depend on the activities. However, the demands of some tasks will be optimally met by increased stiffness (displacement control), and in the others tasks may be better served by dynamic solution, such as optimized for cushioning (velocity control). These strategies require different muscle activation strategies. Failure to match the right or a less than ideal solution to a specific context is improbably to be ideal and may be a potential target for reeducation (Hodges & Cholewicki, 2007; McGill, 2007a; Richardson et al., 2004).

The morphology and behaviour (delayed, increased or decreased activity) of a set of muscles, could negatively impact lumbopelvic health. In both cases the argument can be reduced to consideration of suboptimal loading of the tissues. Has been presented in the literature several studies that have demonstrated that reduced or compromised activity may lead to increases in load as a result of less than “ideal” motion control or insufficient stiffness, in TrA (Hodges et al., 2007), LM (MacDonald et al., 2009), psoas (Ploumis et al., 2011), gluteus maximus (Hungerford, Gilleard, & Hodges, 2003), although some appear to be prevalent in the lumbopelvic pain population. In the case of an increased activity, the load on the spinal structures may be increased via greater compressive force, compromised shock absorption excessive stiffening or altered velocity control (Hodges et al., 2013; Hodges, Kaigle Holm, et al., 2003;

Hodges, Moseley, et al., 2003; van Dieen, Cholewicki, et al., 2003; van Dieen, Selen, et al., 2003). An important consideration is whether the increased activity is required (to compensate the decreased in spine passive control, leading to unwanted joint movement, perhaps due to injury (Panjabi, 1992a, 1992b)) or is problematic (with the additional load a cause of pain persistence or recurrence (Hides et al., 2001; Hodges & Tucker, 2011)). Both alternatives may be plausible, but the relative balance between positive and negative effects may depend on the patient capacity to tolerate different compressive load and bending motion, joint laxity and therapeutic stiffening/compliance requirements that must be considered in treatment planning (Hicks, Fritz, Delitto, & Mishock, 2003; Hodges, Kaigle Holm, et al., 2003; Hodges & Moseley, 2003).

A fundamental key concept in motor control training approaches is that clinical benefit can be acquired if motor control can be changed to optimize the load on structures of the spine and pelvis and in the stiffness between them. The approach aims to change the function of any aspect of the motor control system, responsible for suboptimal loading or insufficient stiffness, instead training to improve coordination, strength, endurance, etc. of a single muscle, or single strategy. Focus on a specific muscle or multiple muscle co-activation strategy is not the single intervention, but may be an important component of restoring ideal motor control. It makes biological sense that management should require careful consideration of all aspects of motor control, including posture, movement and muscle activation strategies, identification of the aspects that require correction, and then implementation of a reeducation program to achieve, restore and rectify this control (Hicks et al., 2003; Hodges et al., 2013; Hodges, Kaigle Holm, et al., 2003; Hodges & Moseley, 2003).

Lumbopelvic control is likely to be less than optimal when the contribution of any muscle is decreased or increased, or when the posture and/or movement of the spine loads structures in a manner that is not “ideal”, or even dysfunctional. However, the effect of changes in muscle activity in lumbopelvic pain is most likely to be effective if addressed in a manner that is specific to the task, specific to the individual, and also specific to the environmental context

(Hicks et al., 2003; Hodges et al., 2013; Hodges, Kaigle Holm, et al., 2003; Hodges & Moseley, 2003).

A further point of consensus is that rehabilitation should follow a progression beginning with rectify and recovery of the best strategy for motor control: muscle activation (timing, intensity and sequence), posture and movement. This first phase could involve the identification of the most appropriate patterns/sequences of muscle activation, posture and/or movement that eliminate or reduce pain (Hicks et al., 2003; Hodges et al., 2013; Hodges, Kaigle Holm, et al., 2003; Hodges & Moseley, 2003; McGill, 2007a; Richardson et al., 2004).

The initial step is to identify which aspects: movement, posture and muscle activation may be relevant to symptoms. The next is to find the optimal solution to change these aspects in a way that is matched to the patient and their functional requirements.

It is unlikely to be any single aspect of motor control that should be universally targeted in exercise management, although some features may need to be addressed more commonly than others (control of motion in a specific direction; control of a specific component of the spine; activation or deactivation of specific muscles or muscle groups). What remains is disagreement about some of the features of muscle activation that should be assessed and targeted with intervention. A key aspect of this disagreement is whether attention should be placed on assessment and training of some of the deeper muscles of the trunk (TrA, LM, pelvic floor and diaphragm muscles), which forms a basic part of reeducation programs described by some authors (M. L. Ferreira, Ferreira, Latimer, et al., 2007; Hides et al., 2001; Richardson et al., 1999, 2004) but not by others (McGill, 2007a). Attention should be focused on exercises that encourage specific sequences of activation (bracing of the trunk muscles), again emphasized by some authors (McGill, 2007a), but not by others (M. L. Ferreira, Ferreira, Latimer, et al., 2007; Hides et al., 2001; Richardson et al., 1999, 2004).

An important consideration is that the biological contribution of abnormal loading to persistence/recurrence of pain is not a universally held opinion.

One interpretation of changes in motor control is that the observations that co-exist with the pain but are neither sufficient nor necessary for the perpetuation of symptoms. Although there is evidence that changes in movement, posture and muscle activation induce changes in load on spinal structures and can lead to injury, there is, as yet, limited data confirming a direct relationship between this dysfunction and pain. A recent report of four case studies documented immediate relief of pain by controlling the spine loading and stiffness by adjustment to muscular bracing patterns and spine and hip postures/movements (Ikeda & McGill, 2012).

Unfortunately, the clinical observation in pain reduction after implementing a change in motor control with a therapeutic intervention does not confirm that the change in mechanics was the critical feature. This is because many other explanations can be provided from the literature. The debate regarding the relevance of biological changes in loading and pain is of vital importance to work progress in this field. Priority needs to be placed on finding methods to assess the relevance of suboptimal loading, secondary to suboptimal motor control, and its restoration to the development, persistence, recurrence and resolution of LPP (Hodges et al., 2013).

Even if a biological link can be confirmed, a critical element that must be considered is that persistent or recurrent LPP is multi-factorial and the biological aspects must be considered in a biopsychosocial framework, and the relative importance of biological, psychological and social aspects must be considered as specific to the individual. Although restoration of optimal mechanical control of the lumbopelvic region may be a primary target in one individual, but it may have a less important role in another who has a dominant contribution of unhealthy attitudes about pain such as fear avoidance, or dominant social features. Thus, characterization of patients across multiple domains and judgment of the relative importance of each for their presentation is essential for development of a multidisciplinary rehabilitation program (Hodges et al., 2013).

Research is required to clarify such a targeted treatment approach and its efficacy. For instance, attitudes and beliefs about pain can moderate the effect of pain on motor control parameters (G. L. Moseley, Nicholas, & Hodges, 2004). Interdependence of the biopsychosocial domains in LPP is only beginning to be understood and should be a focus of future investigation.

The specific features of motor control that are addressed in different approaches may differ, there is agreement in the opinion that motor control can be changed with exercise and that improvements in motor control can be transfer to function. Evidence is emerging to confirm that this is the case (Scannell & McGill, 2003; Tsao & Hodges, 2007) and other work is beginning to highlight the neural processes that may sustain this recovery (Tsao, Druitt, Schollum, & Hodges, 2010).

One issue of some debate is how to best achieve restoration/modification of motor control strategies. Several options have been presented, and these include: (1) practice of complex functional tasks with correction of the component considered to be in dysfunction (P. O'Sullivan, 2005); (2) attention to specific muscles (selective deep muscle contraction (Richardson et al., 1999, 2004)) or muscle activation strategies (coached movement (McGill, 2007a)); (3) indirect training using automatic strategies (walking on unstable surfaces to encourage changes in motor patterns of proximal muscles (Bullock-Saxton, Janda, & Bullock, 1993)); (4) identifying the painful movement and altering the movement pattern coupled with muscular bracing to reduce reported pain (Ikeda & McGill, 2012).

The question of which intervention is most effective and whether the most effective intervention differs between individuals has not been completely resolved. However, there is evidence for some of these approaches. For instance, specific attention to muscle activation can change motor control in terms of the augmented (Tsao & Hodges, 2007) or reduced (Tsao, Druitt, et al., 2010) activation of those muscles in a functional task. It is important to reinforce that although this strategy can change muscle activation, this is never intended to be the complete intervention and other strategies must be utilized as part of a comprehensive treatment package to restore other aspects of motor function (correction of postural dysfunction).

One issue to consider further is that although practice of voluntary contraction of specific muscles or patterns of muscle activity has been shown to change motor control, this voluntary approach has been criticized on two grounds. First, one argument is stated that the brain controls muscles rather than movements and focus on muscle is a fundamental departure from this property of central nervous system organization. This argument can be countered by evidence that the nervous system organizes motor control both in terms of movements and muscles (Kakei, Hoffman, & Strick, 1999). Second, it is argued that control of the trunk is normally coordinated automatically without the requirement for conscious input, and by inference, the argument has been put forward that practice of voluntary contraction involving input from primary motor cortex is unlikely to influence postural strategies. Yet there is sound evidence that inputs from the primary motor cortex contribute to control of the postural function and it has been shown in a number of studies with a range of experimental methods including investigation of temporal parameters of automatic activation of the deep muscles in association with arm movements (Tsao & Hodges, 2007), spatial features of trunk muscle activity in gait (Tsao et al., 2008), and organization of neuron networks in the motor cortex (Tsao, Galea, & Hodges, 2010) that motor control can be resolved by repeated voluntary muscle activation. This highlights that the cognitive approach of voluntary practice of a task leads to improved control, and this is associated with clinical improvement (P. H. Ferreira et al., 2010). This does not exclude the possibility that other techniques could also achieve a change, although other interventions must be subjected to evaluation. It is likely that a range of approaches will be required to change control depending on the patient, the nature of their change in control, and the specific motor tasks that are affected (Hodges et al., 2013).

A feature common to different motor control approaches is the use of multiple methods to enhance the restoration of control of posture, movement and muscle activation. In addition to voluntary correction of aspects that are considered to be in dysfunction, training may include other techniques such as application of tape to the skin, use of exercise equipment to enhance challenge, electrical stimulation of muscle, soft tissue techniques and manual therapy, etc. However, many questions remain unresolved about the efficacy of many of these adjunctive treatments (Hodges et al., 2013).

A common misconception presented in the literature is that some exercise approaches have a universal and uni-dimensional focus on a single solution for the management of LPP. This is a common misconception of the place of bracing or isolation of deep muscle activation/hollowing in treatment. This misconception is likely to be founded on several issues. First, the protagonists of each approach often aim to emphasize the aspects of their approach that differ from others in order to highlight unique aspects. Unfortunately this can lead to the assumption that the highlighted component is the ‘whole approach’ and other aspects are excluded. Second, some degree of reductionism is commonplace in the literature to efficiently translate a message to clinical practice or common use and it is common for the media (magazine articles of core stability exercise) to present the “best” exercise, and this could never replicate the complexity of a comprehensive rehabilitation approach. It is when it becomes assumed that this is the “whole” approach that the issues arise. Third, authors aiming to discredit a management philosophy often use the technique of oversimplification in order to impair the intellectual integrity of an approach (Lederman, 2010; McGill, 2011).

An extrapolation of these reductionist views is that it is assumed that the protagonists of the approaches advocate the use of the universal solution to trunk control for function. For instance, it has been suggested that the intention of training a patient to isolate TrA activation from the other abdominal muscles is for this to be the strategy trained for function. This is not the intention of training independent activation of TrA (Richardson et al., 1999, 2004) and isolated activation of this muscle has been shown to compromise spine control. Instead, the intention of training independent TrA activation aims to re-train the activation of this muscle, such that it can then be incorporated in function, as a component of the complex interaction of multiple muscles (Tsao & Hodges, 2007). Likewise, the suggestion to encourage abdominal bracing to 30% of a maximal effort (McGill, 2007a) was not intended to imply that patients should maintain this level of activation throughout all functions; this is neither achievable or sustainable. Contraction of this intensity cannot be maintained beyond a timescale of seconds. Training such activation as a component of an exercise program is intended to make this muscle activation pattern available for function and to enhance the capacity for its use as function demanded.

It is almost universally agreed that it is unlikely that rehabilitation of a single or few muscles will be sufficient to rehabilitate low back and pelvic pain. Although the observation of changes in the deep muscles is common, this does not diminish the likely importance of changes in other parts of the system – other muscles, postural changes and movement patterns. Although there may be some consistency in the adaptation of the deep muscles, there are specific changes in the other aspects of the system. As highlighted above this may include increased or reduced activity of other muscles; changes in the coordination between hip and spine motion (Van Dillen, Gombatto, Collins, Engsberg, & Sahrmann, 2007); or changes in movement or posture (Mitchell, O'Sullivan, Burnett, Straker, & Smith, 2008). There is considerable evidence that many or most of these factors are specific to individuals/subgroups. Some have been related to clinically identified subgroups of people with spinal pain (Astfalck et al., 2010). It appears reasonable to conclude that rehabilitation of the whole system will be ideal, that this would need to be individualized to the patient, and that attempts to increase and decrease activation of specific muscles may be important components of a comprehensive approach.

It is well known that better transfer to function is achieved with practice of the task as close as possible to the real life activities and situations. It follows that early phases of rehabilitation of motor control of the trunk for treatment of LPP are followed by progression beyond the retraining of optimal control strategies, to complex function. This necessitates not only the reinforcement of use of ideal strategies of muscle activation, posture and movement in function, but also improvement in the capacity of the system to meet higher functional loads (muscle strength, muscle endurance, cardiovascular fitness) (Hodges et al., 2013).

The progression eventually incorporates enhancement of skilled execution of activities of daily living and these tasks are different for each individual, thus each individual will have a different “end point” in rehabilitation process. The progression to this functional level necessitates consideration of other aspects relevant to function such as resolution of psychosocial elements relevant to perpetuation of symptoms such as fear of movement/pain/(re)injury, and other biological aspects such as balance and sensory function. These factors may be addressed by functional training or may require specific attention with separate interventions incorporated into the comprehensive management of the patient (Hodges et al., 2013).

Although it is generally agreed that aspects of motor control modified in a patient with LPP should be addressed in exercise interventions, opinion does not converge whether activation of the deeper muscles forms part of this consideration.

Clinical trials are known to have relatively blunt outcomes and rarely find differences between treatments (Macedo, Maher, Latimer, & McAuley, 2009). The current status of evidence from systematic reviews concludes that training that *includes* attention focused to activation of the deep muscles reduces pain and disability and decreases recurrence of pain (P. H. Ferreira, Ferreira, Maher, Herbert, & Refshauge, 2006) and is more effective than placebo treatment (Costa et al., 2009). However, there is limited evidence that this type of intervention is better than other interventions. Importantly, although large effects have been identified in specific sub-groups of LPP (Hides et al., 2001; P. B. O'Sullivan, Phyty, Twomey, & Allison, 1997; Stuge, Laerum, Kirkesola, & Vollestad, 2004), smaller effects have been identified in non-specific LPP groups and it is this latter group that has been used to compare interventions. Future work may identify characteristics of individuals who respond best to motor control treatments and how it is best targeted to the individual. There is preliminary evidence that poor control of deep muscles predicts good response to motor control interventions (P. H. Ferreira et al., 2010; Unsgaard-Tondel et al., 2012).

Some work has identified differences between patient subgroups (Kiesel, Underwood, Mattacola, Nitz, & Malone, 2007). Thus, further work is required to determine whether reduced contribution of TrA and LM leads to changes in the health of the spine such as injury and pain and to identify the prevalence of changes in morphology and behaviour of these muscles in people with LPP. This latter issue requires the development of less invasive and easier methods to study the morphology and behaviour of these muscles (P. H. Ferreira, Ferreira, & Hodges, 2004; Kiesel et al., 2007; Mannion et al., 2008; Vasseljen, Fladmark, Westad, & Torp, 2009).

2.4. Muscle Activation

Muscle activation strategies are generally considered relevant to the presentation of lumbopelvic pain in two extremes – muscle activity that may be diminished, or greater than that considered to be ideal for optimal function of the spine and pelvis. This may present as clinically determined “under” or “over-activity” of a specific muscle or group of muscles, or the adoption of muscle activation patterns that are considered to be inappropriate for optimal loading (Hodges et al., 2013).

Muscle activation is challenging to assess due to the specific pattern of muscle changes are generally unique to the patient movement, posture or task that is performing. There will not be one strategy of muscle activation that is universally “ideal” for the control of spine and pelvis, and not one strategy universally adopted by all the patients in pain. A spectrum of muscle activation solutions is required for optimal function (Hodges et al., 2013). At one end of the spectrum are strategies that aim to stiffen the spine to maintain an optimal alignment through co-contraction of large muscles (bracing). At the other end are more dynamic solutions that encourage movement. The nervous system will select strategies based on the task demands. Assessment and rehabilitation of motor control of the spine requires consideration of this spectrum of motor control choices, and evaluation of whether the muscle activation strategy matches the demands of the task and the needs of the patient's system (Hodges et al., 2013).

There are limited methods available to make objective judgments of muscle activation and most have some limitations for interpretation. Some standard options include manual muscle tests, observation and palpation (of muscle activity directly, or estimation of muscle activation based on observation/palpation of posture and movement), electromyography, ultrasound imaging, and numerous other tools such standardized clinical tests of control: (1) control of the spine with incremental increases in leg load (Sahrmann, 2002); (2) holding time for specific postures such as a side-bridge (McGill, 2007a); (3) ability to contract one muscle independently from others (Richardson et al., 2004); (4) or in patterns of activation (Janda, 1996; (McGill, 2007a). Although tests that provide basic information of strength of major muscles that cross the region are available, there are many other muscles and aspects of muscle function that may be important to consider. These include aspects such as the activation timing, the relative activity of different muscles, and the ability to recruit a muscle in a specific pattern, or in a specific manner during function.

The aims for muscle activation treatment are variable. In some cases the target is to reduce excessive activity, and optimize their activity to match the demands of the task, in combination with the increased of the activity of any muscle that is considered to be compromised (Richardson et al., 2004). Other approaches aim to increase the activity of specific patterns of muscle activity to control motion (McGill, 2007b; Page, Frank, & Lardner, 2010). Another alternative approach is to optimize muscle activity by the attention to the quality of control of the other components and to the symptoms control (control of pelvic alignment during rotation or sagittal motion of the hip) (Hoffman, Johnson, Zou, Harris-Hayes, & Van Dillen, 2011; Sahrmann, 2002; Scholtes, Norton, Lang, & Van Dillen, 2010).

It is clear that changes in movement, posture and muscle activity are common in LPP; but where should intervention begin? Different clinical approaches place different emphasis on the three. Currently the decision of which component to address first is largely based on the approach/system with which the clinician is familiar. Ultimately, it would seem plausible that the choice of strategy to optimize control should be that which is likely to achieve the greatest change and in the shortest period of time. This could vary between individuals on the basis of many issues including: (1) pain presentation/movement dysfunction; (2) response; and (3) their preference. Future tools may guide clinical decisions regarding which component(s) to target first. Regardless, it is critical to remember that the movement, posture and muscle activation are linked (see Figure 3) and it is impossible to change one without an effect on the others (Hodges & Cholewicki, 2007).

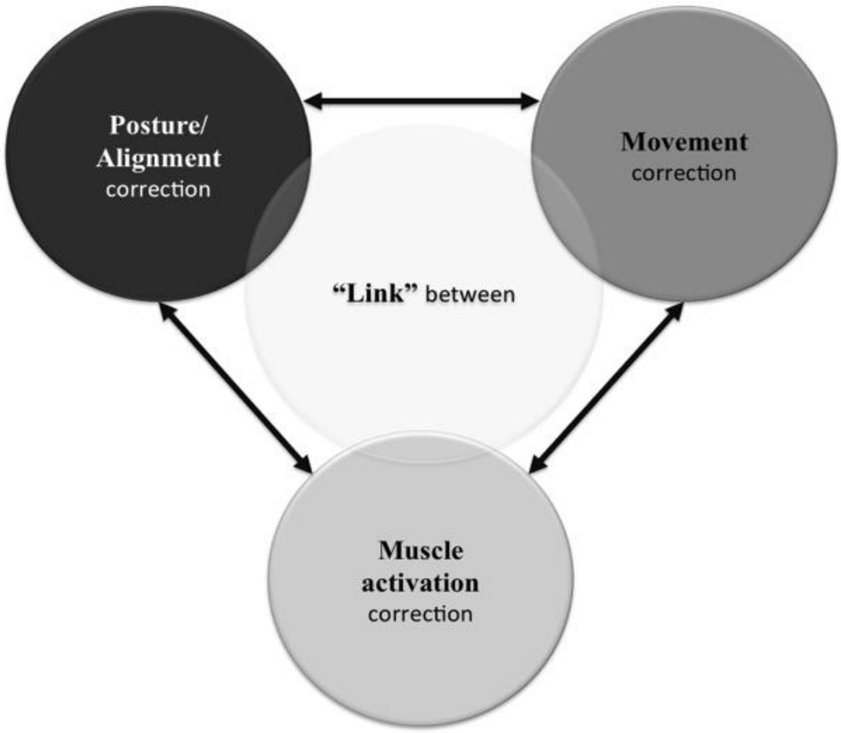

Figure 3. The management of the motor control issues in lumbopelvic pain involves assessment and reeducation of posture/alignment, muscle activation and movement. Adapted from Hodges et al. (2013).

2.5. ASSESSMENT

One area where consensus has not yet been reached is related to which tests should be included in patient assessment. The approaches converge in the view that assessment needs to be comprehensive and extend across a number of domains of posture/alignment, movement and muscle activation, in addition features such as psychosocial issues and sensory function. However, the tests that are used to interpret motor control dysfunctions, and to make clinical decisions for management, differ considerably. For instance, the Sahrmann (2002) approach includes a range of tests that assess the interaction between the movement of the extremities and spine and also the movement of different regions of the spine. Other approaches have a greater focus on assessing of specific sequences of muscle recruitment in order to obtain an interpretation about the quality of muscle control (Hodges, Ferreira, & Ferreira, 2009; Richardson et al., 2004; Sahrmann, 2002).

2.6. (RE-)TRAINING APPROACH

There is a considerable convergence in the techniques used for (re-)training. Although, the emphasis on specific targets for reeducation may differ between approaches (see Figure 4). Across the different approaches, there is a widespread tendency in applying motor learning approach, where the specific deficit in posture, movement and muscle activation is highlighted and the performance is corrected with techniques such as a combination of verbal/visual instruction, feedback and manual guidance. This is followed by progression into increasingly challenging situations in the direction of full function. Some approaches highlight the necessity to incorporate other interventions to facilitate this process: (1) use tape for feedback and to modify posture, muscle activation or movement; (2) manual therapy techniques to treat pain and movement dysfunction; (3) techniques to reduce muscle activity such as manual therapy techniques and dry needling; and (4) electrical muscle stimulation to improve learning of muscle activation (Hodges & Cholewicki, 2007; Hodges et al., 2013; McGill, 2007a; Richardson et al., 2004).

An important consideration is that motor learning requires a change in "exercise" concept in both, patients and therapists, from the common conventional interpretation of "strength and endurance training" to one of "control, coordination and precision". Motor learning involves the achievement of a permanent change in motor control. Traditionally motor learning has been considered in terms of rehabilitation of movement and posture in patients with neurological disorders, and skill training for sports performance. The growing of motor learning principles is being applied to the reeducation of musculoskeletal pain and dysfunction (P.W. Hodges et al., 2009; Tsao, Druitt, et al., 2010; Tsao, Galea, et al., 2010; Tsao & Hodges, 2007). Although the basic motor learning principles involves transition through three clinical phases: (1) initial "cognitive" phase with conscious attention to the details and correction of errors; (2) "associative" phase with attention to the consistency of performance in more challenging contexts; and (3) "autonomous" phase where the transfer to automatic control is encouraged (Hodges & Cholewicki, 2007; Hodges et al., 2013). Underlying to this motor learning strategy, are clinical principles that are commonly used to facilitate the learning process. These include principles such as "segmentation" (practice of individual components of a certain task before practice of the whole task), "simplification" (practice with reduced demand to enable better quality in performance) and use of "increased feedback" (P.W. Hodges et al., 2009).

Recommended exercise training parameters differs across approaches, ranging from frequent short periods of training to a smaller number of longer sessions with focus on quality. Both approaches may lead to motor learning and different patients may respond better to one approach than another (Hodges et al., 2013).

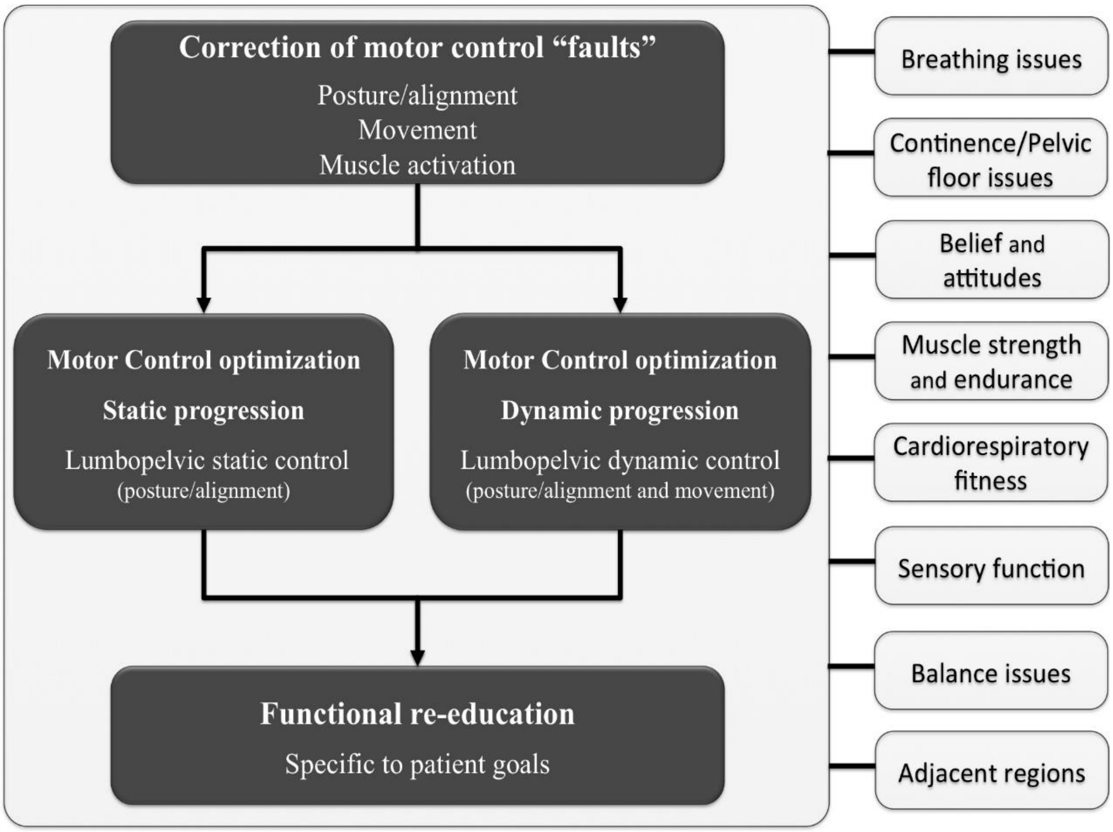

Figure 4. Integrated model of motor control intervention for lumbopelvic pain. The boxed area (left) provides an overview of the basic process of progression and the intervening steps through static and dynamic training. On the right are the additional issues that are necessary to consider in reeducation of individual patients. Adapted from Hodges et al. (2013).

The success of motor learning will depend on the patient's adherence to the intervention and progression. It's very important and crucial to use all necessary means to encourage the patient compromise to high quality and frequent practice with attention to quality of performance. Multiple methods have been suggested, such as design of an exercise program that maintain motivation with frequent updates and progression of exercise, training in a group environment and other mechanisms. It is the responsibility of the therapist to identify the objectives of training (which aspects of posture/alignment, movement, and muscle activation that should be changed), find the appropriate training approach to achieve motor learning and design a exercise program that maintains the motivation of the patient to progress to a sufficiently high level and to achieve long-lasting change (P.W. Hodges et al., 2009; Macedo et al., 2009; McGill, 2004, 2007a; Richardson et al., 2004).

Most approaches aiming to train motor control, although not all, are based on explicit learning techniques by which patients are provided with tools to consciously correct the aspects that are considered to be problematic such as the posture, movement or muscle activation.

The evidence for use of a cognitive approach is that: (1) cognitive training is associated with changes in activation of trunk muscles in untrained postural and gait tasks and changes in organization of the motor map on the cortex (Tsao, Druitt, et al., 2010; Tsao et al., 2008; Tsao & Hodges, 2007); (2) cognitive attention to muscle activation correction induces greater change in behaviour of the muscle and cortical brain map organization compared to the exercise that activates the muscles to a similar amplitude, but without any conscious attention to the muscle, or without cognitive intention to change the muscle recruitment/behavior (Tsao, Druitt, et al., 2010; Tsao et al., 2008; Tsao & Hodges, 2007); and (3) skill training with attention to a task leads to greater cortical changes than strength training (Remple, Bruneau, VandenBerg, Goertzen, & Kleim, 2001).

Some studies showed that although functional automatic training with attention to overall performance (load lifted, distance a ball is kicked) may be suitable for individuals who have already gained basic abilities (McNevin, Shea, & Wulf, 2003; Perkins-Ceccato, Passmore, & Lee, 2003), those with more novice performance skills benefit from attention to detail (Perkins-Ceccato et al., 2003), such as specific features of muscle activation, posture and movement. The use of conscious attention to control posture, movement and muscle activation appears to be an effective approach to reeducation. This does not mean that cognitive attention is the only way to change control, but it does indicate that this approach is one way that is known to be able to achieve change (Tsao, Druitt, et al., 2010; Tsao, Galea, et al., 2010; Tsao & Hodges, 2007).

The literature provides a wide variety of clinical guidance on issues such as: segmentation, simplification (practice of task elements in a simplified context, such as slower speed, greater base of body support, etc.), feedback (consideration of which type of feedback is most helpful at a specific phase in recovery of function), training volume and methods to optimize transfer to function (Shumway-Cook & Woollacott, 2006).

An alternative approach would be to find methods that change motor control strategies in a more implicit manner, without attention to error correction by the patient. Janda (1996) used sensory stimulation (walking on unstable shoes) with the goal to change recruitment of proximal muscles (Janda, 1996; Page et al., 2010). Others train higher-level tasks such as sitting on balls or functional movements. There is some evidence that these strategies can lead to changes in muscle activation (Bullock-Saxton et al., 1993), but it is unclear whether these changes are significant.

Some work investigates whether passive techniques, such as joint mobilization and manipulation, induce recovery of motor function (Fritz et al., 2011). However, despite some results indicating that are small immediate improvements in specific aspects of motor control (Marshall & Murphy, 2006), this was not been observed in all studies (M. L. Ferreira, Ferreira, & Hodges, 2007) and clinical trials have not supported the assumption that passive treatment leads to recovery of motor control behaviour (P. H. Ferreira et al., 2004; P. H. Ferreira et al., 2010).

2.7. Who Benefits from Rehabilitation of Spine and Pelvis Motor Control?

Until now the answer to this question remains unclear. Some authors proposed that patients might be selected on the basis of clinical issues that suggest instability (Hicks, Fritz, Delitto, & McGill, 2005; Kiesel et al., 2007). The factors proposed to identify this group include a “prone shear instability test”, hypermobility, joints tests, and questionnaires developed to be related to clinical instability (Cook, Brismee, & Sizer, 2006). There are some results demonstrate that people who satisfy such criteria do better than others, when treated with exercise aimed to optimize motor control of the spine and pelvis (Hicks et al., 2005).

The motor control training approaches may be appropriate not only for individuals who are considered to have poor stability, but also to a range of patients who may have poor load control of the spine and pelvis tissues (Hodges & Cholewicki, 2007). O’Sullivan (2005) argues that relevance for such intervention depends on exclusion of psychosocial characteristics as a dominant aspect of their presentation (P. O'Sullivan, 2005). This issue is central to consideration of whether a patient may benefit from allocation to a treatment that aims motor control issues, or one that has a focus in the psychosocial domain such as graded activity using the principles of cognitive behavioural therapy (Macedo et al., 2012).

In this context it is reasonable to speculate that there will be individuals who respond better to one or other approach. A key issue from the clinical trials is that when motor control interventions for spine and pelvis motor control are applied to non-specific LPP groups the size of the clinical effect is smaller (M. L. Ferreira, Ferreira, Latimer, et al., 2007; Goldby, Moore, Doust, & Trew, 2006), compared when the intervention is applied to specific subgroups (acute unilateral LPP (Hides et al., 2001), spondylolisthesis (P. B. O'Sullivan et al., 1997), pregnancy-related pelvic girdle pain (Stuge et al., 2004).

There is, for the future, a clear challenge to identify, which patients may benefit from rehabilitation of spine and pelvis motor control.

Evidence is emerging that treatment targeted to the individual based on their movement subgroup leads to better outcomes. A critical consideration of subgrouping and targeting interventions is the relative weight of biological and psychosocial elements in a patient’s presentation. The relative importance of each of these aspects is likely to influence the responsiveness to the intervention (Fersum et al., 2010).

There will always be individuals who do not benefit from motor control (re-)training and in these cases, motor control may not be the complete answer, but may provide sufficient functional improvement to patient's quality of life (Hodges et al., 2013).

There are numerous factors that can influence the selection of a specific clinical direction. This will include the clinician experience and preconception, the experience and preferences of the patient, and their characteristics, which may be more adequate to one clinical approach than another. Just as much as different approaches adjust to different patients, different clinicians adjust to different approaches (Hodges et al., 2013).

2.8. TRUNK MUSCLE ENDURANCE

Endurance is worthy of discussion separately from strength given that spine stability requires co-contraction of trunk muscles for substantial durations, but at relatively low levels. This is an endurance and motor control challenge – not a strength challenge. Generally, the guideline is to constrain the duration of isometric stabilization exercises under 10 seconds, and build endurance with repetitions, not by increasing the duration of the holds. Near infrared Spectroscopy of the trunk muscles has shown that this method builds endurance without the muscles cramping that can be experienced with oxygen starvation and acid accumulation (McGill, Hughson, & Parks, 2000). The "Russian descending pyramid" is often used in an attempt to preserve exercise technique as fatigue builds. In this approach the repetitions of each exercise are reduced in each subsequent series (McGill & Karpowicz, 2009; McGill, Karpowicz, Fenwick, & Brown, 2009; McGill, McDermott, & Fenwick, 2009). In an impeccable way also creates a greater volume of tolerable training because the joints are spared of the load associated with deviated postures and inadequate muscle activation levels (McGill & Karpowicz, 2009).

Endurance has also been suggested by several studies to play some predictive role with respect to individuals who will develop back pain in the future.

For example, not only is a lack of extensor endurance predictive (Biering-Sorensen, 1984), but also the balance of endurance between the anterior torso muscles and the side and the back muscles is associated with those who have repeated episodes when compared to matched controls without pain (McGill, 2007a; McGill et al., 2003). Imbalances in strength, endurance and range of motion, not surprisingly, have been associated with prediction of many musculoskeletal injury types (Knapik, Bauman, Jones, Harris, & Vaughan, 1991; Van Dillen, Bloom, Gombatto, & Susco, 2008). Specific tests that measure endurance together with some cut-off scores for different populations have been described by McGill (Knapik et al., 1991; McGill, 2004, 2007a; McGill & Karpowicz, 2009; McGill, Karpowicz, et al., 2009; McGill, McDermott, et al., 2009; Vera-Garcia, Moreside, & McGill, 2010).

True strengthening for the purpose of enhancing athletic objectives requires muscle overload, is associated with elevated risk, and is not considered for the patient with LPP. Such training is reserved for a time after the pain has been eliminated. Many people, whether they have athletic objectives (such as wanting to play golf) or have physically demanding occupations, will fall into this category. On the other hand, many patients confuse health objectives (minimizing pain, developing joint sparing strategies) with performance objectives (which require risk) and compromise their progress by initiating specific strength training too early in their recovery/rehabilitation. Many exercises typically prescribed to patients with LPP are done so without the therapist having knowledge of the spine load and associated muscle activation levels. For this reason, exercises in McGill's approach have been quantified with respect to load and activation levels to allow evidence-based decisions when planning optimal exercise progressions. Finally, training involving movement patterns creates balances of trunk strength and functional capacity (McGill & Karpowicz, 2009; McGill, Karpowicz, et al., 2009).

CHAPTER 3

RESEARCH STUDIES

3.1. Study I – Abdominal Muscle Recruitment Pattern during Rapid Arm Movements in Subjects With and Without Lumbopelvic Pain

Paulo Carvalho*[1,2], António Mesquita Montes[1,2], Carlos Crasto[1], Rubim Santos[2], João Paulo Vilas-Boas[3]

[1] *Physical Therapy Department – School of Allied Health Sciences of Porto/Porto Polytechnic Institute (ESTSP/IPP), Vila Nova de Gaia, Portugal*

[2] *Center of Study for the Movement and Human Activity (CEMAH) - ESTSP/IPP, Vila Nova de Gaia, Portugal*

[3] *Porto Biomechanics Laboratory (LABIOMEP), Faculty of Sport, CIFI2D, University of Porto, Porto, Portugal*

***Corresponding author:**

Physical Therapy Department – School of Allied Health Sciences of Porto/Porto Polytechnic Institute (ESTSP/IPP), Vila Nova de Gaia, Portugal
Rua Valente Perfeito, 322
4400-330, Vila Nova de Gaia, Portugal.
E-mail address: pmc@estsp.ipp.pt (Paulo de Carvalho).

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ABSTRACT

Background: The stability may change due to a delay in the electromyography (EMG) onset timing and/or muscle activation sequence and/or activation intensity, predisposing the individual to motor control disorders, including lumbopelvic pain (LPP). The surface electromyography (sEMG) it's a way to assess these parameters.

Aim: Verify the existence of differences in the EMG onset timing and muscle activation sequence of the transversus abdominis/internal oblique (TrA/IO), rectus abdominis (RA) and external oblique (EO), using sEMG, during rapid arm flexion, abduction and extension movements, in subjects with and without lumbopelvic pain.

Methods: Cross-sectional study in which the sample was constituted by a group of 56 subjects that never experienced lumbopelvic pain (Non Lumbopelvic Pain group –$NLPP_G$) and by another group of 59 subjects who had at least one episode of lumbopelvic pain (LPP_G) in the last 6 months. Through sEMG it was collected the electromyographic signal of the deltoid (anterior/medial/posterior fibers), TrA/IO, EO and RA muscles. It was analysed the onset timing and respective sequence of activation. Statistical data was processed in the SPSS software, version 20.0 for MAC OS, with a significance degree of 0.05.

Results: Were found significant differences between the two groups on the EMG onset timing of TrA/IO (t=-15.842; p<0.001), EO (t=-3.080; p=0.008) and RA (t=-3.646; p=0.001) during rapid flexion movement; TrA/IO (t=-12.073; p<0.001), EO (t=-3.238; p=0.005) during rapid abduction movement; TrA/IO (t=-29.757; p<0.001), EO (t=-12.308; p<0.001) and RA (t=-4.180; p<0.001) during rapid extension movement.

In both groups, there were significative differences in the analysis between all pairs of muscles (p<0.001).

Conclusion: It was observed that the LPP_G showed a significant delay in the EMG onset timing of TrA/IO, EO and RA, during all movements, and there

was a consistent sequence of muscle activation between the two groups, with the exception for the extension movement. Also, in LPP_G it was found a similar pattern of activation between the superficial/global and deep/local muscles of the lumbopelvic region in all directions of movement performed.

Key-words: Lumbopelvic pain, Motor control, Feedforward, Surface electromyography

INTRODUCTION

The simultaneous stability and movement of the spine represents a highly significant challenge to the Central Nervous System (CNS), due to the continuous requirement for an adequate response to predictable and unpredictable challenges (Richardson et al., 1999, 2004).

The lumbopelvic stability is controlled by anticipatory mechanisms (feedforward) whenever a challenge presented to the subject is predictable. The feedforward control is a mechanism that includes the anticipatory postural adjustments, which minimize the perturbation caused by a self-generated motion, maintaining the stability. These mechanisms are activated before the beginning of the main movement. On the other hand, the feedback mechanism maintains the postural adjustment as a reaction to external disturbances (Radebold et al., 2000; Radebold et al., 2001).

The activation of the local stabilizing muscles (transversus abdominis (TrA) and multifidus (Mu)) occurs previously to the activation of the muscles responsible for the upper (Hodges & Richardson, 1997b, 1999a) and lower (Hodges & Richardson, 1997a) limbs movements, as well as, before a predictable challenge added to the trunk (Hodges & Richardson, 1999a, 1999b; Radebold et al., 2000). In these conditions, the CNS predicts the effect that the movement will have on the human body and plans a sequence of muscles activation in order to respond to the perturbation (Hodges, 1999, 2001a; Hodges & Richardson, 1999a, 1999b; Radebold et al., 2000).

The TrA is primarily activated, independently of the direction of the trunk movement, the direction of forces applied by the disturbance and the direction of the center of mass displacement (Hodges & Richardson, 1997b, 1999b; Radebold et al., 2000). Therefore, by the feedforward mechanism, the CNS controls the intervertebral movement through the local stabilizing muscles activity, which is independent of the direction of movement, controlling the global movements of the trunk. On the other hand, the global stabilizing muscles and mobilizers are recruited in anticipation to an event, depending on the direction of the forces acting on the trunk (Hodges, Moseley, et al., 2003; Hodges & Richardson, 1997b, 1999a, 1999b; Radebold et al., 2000).

The most consistent data described in the literature regarding the motor control impairments in subjects with chronic lumbopelvic pain, is the delay in the activation of the TrA during upper and lower limbs movements in all directions (Hodges & Richardson, 1997b, 1997c; Radebold et al., 2001). A decrease in the amplitude of the Mu activity in subjects with lumbopelvic pain is also referred, which is consistent with the reported morphological changes (changes detected in the fibers' composition and a decrease in the cross-sectional area) and increased fatigue. Moreover, there is evidence that the Mu does not recover spontaneously after the remission of the pain symptoms (Hides, Stokes, Saide, Jull, & Cooper, 1994; Richardson et al., 1999, 2004). In addition to the decreased activity of the deep muscles, an increase in the overall activity of the superficial muscles is reported too (Hodges & Moseley, 2003; Hodges, Moseley, et al., 2003; Hodges & Richardson, 1996, 1999a, 1999b; Richardson et al., 1999, 2004).

Dieen, Cholewicki Radebold (2003), propose the hypothesis that the increased activity of the global stabilizing muscles results from an attempt to compensate the decreased stability of the spine, which may be caused by a disruption in the local stabilizing muscles' function.

Several authors report the existence of impairments in the motor control of trunk muscles in subjects with lumbopelvic pain. Although there is no consensus on the nature of those changes, some evidence points to impairments in specific local and global muscles of the lumbopelvic region (Hodges & Moseley, 2003; Hodges, Moseley, et al., 2003; Hodges & Richardson, 1996, 1999a, 1999b; Radebold et al., 2000; Radebold et al., 2001; Richardson et al., 2002; Tsao & Hodges, 2007). However, there's no data relating the referred impairments with the pain reported by the subjects. Furthermore, the extent to which the pain is responsible for the motor control impairments is still unknown.

Bogduk (2005) and Panjabi (1992) presented models suggesting that deficits in motor control are responsible for inadequate control of joint movement, leading to repeated microtrauma and pain (Bogduk, 2005; Panjabi, 1992a, 1992b). However, there are studies demonstrating that pain itself may be responsible for impairments in motor control (Hodges & Moseley, 2003; Hodges, Moseley, et al., 2003; Radebold et al., 2001).

Several studies using experimental pain induction, reproduced changes in motor control similar to those identified in individuals with lumbopelvic pain (Hodges & Moseley, 2003; Hodges, Moseley, et al., 2003; Radebold et al., 2001). There is also strong evidence that pain has a direct effect on the cerebral cortex (Derbyshire et al., 1997), leading to changes that include the activation of the anterior cingulate cortex in subjects with chronic lumbopelvic pain (Derbyshire et al., 1997; Hsieh, Belfrage, Stone-Elander, Hansson, & Ingvar, 1995).

There are several cortical areas that process the painful stimuli, such as, the primary and secondary somatosensory cortex, parietal operculum, insula, anterior cingulate cortex and prefrontal cortex. Also, the basal ganglia may be involved in the sensory-discriminative dimension of pain, affective and cognitive dimensions of pain, modulation of nociceptive information and sensory gating of nociceptive information to higher motor areas (Hodges & Moseley, 2003; G. L Moseley & Hodges, 2001; Rainville, 2002; Vlaeyen & Linton, 2000, 2012).

Therefore, the referred data support the hypothesis of a cortical and subcortical structural reorganization as a consequence of nociception, which may be related to the chronification process and unpleasantness of pain (affective components and intensity of pain correlate with structural differences in gray matter in chronic back pain patients). Chronic pain may change the structure of the brain. However, there mechanisms responsible for the morphological changes remain unclear. The absence of a linear relationship between pain activations and deactivations suggests that the brain signal changes underlie different aspects of the pain experience (Hodges & Moseley, 2003; G. L Moseley & Hodges, 2001; Rainville, 2002; Vlaeyen & Linton, 2000, 2012).

Other studies support the hypothesis that stress (Jones & Cale, 1997) and fear (G. L Moseley & Hodges, 2001; Vlaeyen & Linton, 2000, 2012) may also contribute to motor control dysfunction.

Given the high prevalence of LPP, it is important to assess the muscles' recruitment pattern, since the possible existence of impairments in motor control is an important factor in the recurrence of pain (Hodges & Moseley, 2003; Richardson et al., 2004).

This study aimed to assess TrA/IO, RA and EO EMG onset timings, using sEMG, during rapid arm flexion, abduction and extension movements, in subjects with and without lumbopelvic pain. Moreover, it aimed to verify the activation sequence of the referred muscles.

METHODS

Study Design

Cross-sectional study with a sample constituted by 115 subjects, volunteers for this study, divided in two groups: one without lumbopelvic pain ($NLPP_G$) and the other with lumbopelvic pain (LPP_G). All groups were submitted a three different tasks in a single assessment moment.

Sample

The target population consisted in volunteer subjects, aged between 18 and 30 years with and without chronic nonspecific lumbopelvic pain.

In this study, the inclusion criteria for the LPP_G were: recurrent episodes of lumbopelvic pain for a period greater than three months, while for the group without lumbopelvic pain could not have experienced pain in this region (Arab, Ghamkhar, Emami, & Nourbakhsh, 2011; Silfies, Squillante, Maurer, Westcott, & Karduna, 2005).

Were excluded in both groups, individuals who had: scoliosis, discrepancy of the lower limbs or postural asymmetries, history of spine, abdominal and gynaecologic surgery in the last year, neurological disorders and/or cardiorespiratory diseases, pregnancy or post-delivery in last 6 months, receiving physiotherapy treatment in order to resolve the LPP, conditions that interfere with data collection, such as history of dominant upper limb injury; and suprailiac skin fold higher than 20 mm (Paul Bruno, Bagust, Cook, & Osborne, 2008; Jacobs, Henry, Jones, Hitt, & Bunn, 2011; G. J. Lehman, Lennon, Tresidder, Rayfield, & Poschar, 2004; Marshall & Murphy, 2003; Tateuchi, Taniguchi, Mori, & Ichihashi, 2012).

The final sample was composed by 115 subjects, divided in $NLPP_G$ – 56 subjects – and LPP_G – 59 subjects.

Instruments

Sample characterization

An electronic questionnaire was given to the subjects in order to be sure that every participant fulfill the selection criteria of this study, as well as to gather some sociodemographic information and pain duration.

The pain intensity in LPP_G was evaluated by using the visual analogue scale (VAS), which consist in a horizontal line with 100 millimetres, from “No pain” to “Maximal pain” written in the extremities (Carlsson, 1983; Ferreira-Valente, Pais-Ribeiro, & Jensen, 2011; Hawker, Mian, Kendzerska, & French, 2011).

Anthropometric measures, height (meters) and body mass (kilograms), were taken by a seca® 222 stadiometer, with an accuracy of 1 millimetres, and a seca® 760 balance, with a accuracy of 1 kilogram (seca – Medical Scales and Measuring Systems®, Birmingham, United Kingdom), respectively.

Surface Electromyograhy

Surface electromyography (sEMG) was collected through the BioPLUX research device (Plux® wireless biosignals SA, 2630-369 Arruda dos Vinhos, Portugal), with 8 channels and a sampling frequency of 1000Hz, using double differential electrode leads (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000; Kamen & Gabriel, 2009; Roberto Merletti, 1999). Muscular activity of rectus abdominis (RA), external oblique (EO), transversus abdominis/internal oblique (TrA/IO) and anterior (AD), medial (MD) and posterior (PD) deltoids was evaluated. The sEMG signal was collected in the contralateral dominant side, exception deltoids.

Self-adhesive Ag/AgCl dual snap (Noraxon® Scottsdale, Arizona, United States of America) disposable electrodes for sEMG were used. The electrodes characteristics were 4 x 2.2 centimetres of adhesive area, diameter of each of the two circular conductive areas were 1 centimetre, and 2 centimetres inter-electrode distance (Criswell, 2011; Hermens et al., 2000; Kamen & Gabriel, 2009). These electrodes were connected to the bipolar active sensors emgPLUX (Plux® wireless biosignals SA, 2630-369 Arruda dos Vinhos, Portugal), with a gain of 1000, an analogue filter at 25 to 500 Hz and a commom-mode rejection ratio of 110 db. For reference electrode was used self-adhesive Ag/AgCl snap (Noraxon® Scottsdale, Arizona, United States of America) disposable electrodes for surface EMG with diameter of the circular adhesive area were 3.8 centimetres and diameter of the circular conductive area were 1 centimetre. In turn, the sensors were connected to the sEMG device, with connection via Bluetooth to a laptop. Yet, it was used MonitorPlux® version 2.0 software (Plux® wireless biosignals SA, 2630-369 Arruda dos Vinhos, Portugal) in order to visualize and acquire the sEMG signal. Finally, to check the skin impedance level an electrode impedance checker was used (Noraxon®, Scottsdale, Arizona, United States of America) (Basmajian & De Luca, 1985; Criswell, 2011; Hermens et al., 2000; Kamen & Gabriel, 2009).

Procedures

Data Collection Protocol

Study procedures took place in biomechanical laboratory and was performed in a controlled environment.

In order to selection and characterize the sample, an electronic questionnaire was given to all the subjects, including the assessment of pain intensity, using for this purpose the VAS. Subjects in LPP_G also pointed a cross in the line from visual analogue scale, where they thought it represented their pain intensity. The value was considered the distance, in millimetres, between the start and the cross. After that procedure, every selected participant were submitted to a body mass and height measures. No information about any expected results, current evidence or any way to change muscular recruitment was given to the subjects.

The participants practiced the evaluated tasks, in order to understand the desired movement. Then, the skin hair was removed and an abrasive pad was used for removing death cells from the skin superficial layer. The skin was clean with isopropyl alcohol (70%), removing the skin oiliness and the remaining death cells (Garry T. Allison, Godfrey, & Robinson, 1998; Clancy, Morin, & Merletti, 2002; Criswell, 2011; Kamen & Gabriel, 2009). After skin preparation, the bioimpedance was checked, using electrode impedance checker, in order to guarantee that impedance levels were below 5KΩ, and thus ensure a good EMG signal acquisition (Basmajian & De Luca, 1985; Criswell, 2011; Kamen & Gabriel, 2009).

Self-adhesive electrodes were placed in the orthostatic position five minutes after skin preparation. These were placed parallel to the muscle fibers orientation, according to the references described in Table 1, confirmed by palpation and muscular contraction (Marshall & Murphy, 2003). The reference electrode was placed in the superior iliac spine (ASIS) of contralateral dominant side (Garry T. Allison et al., 1998; Basmajian & De Luca, 1985; Criswell, 2011; Hermens et al., 2000; Kamen & Gabriel, 2009). All electrodes were tested in order to control the crossed muscular signal and electrical noise.

After this, a five minutes wait period was taken for sEMG signal collection stars (Criswell, 2011; Kamen & Gabriel, 2009; Marshall & Murphy, 2003). sEMG signal was collected and analyzed in both groups during the dominant arm rapid movements: flexion, abduction and extension. The amplitude of these movements was approximately 40º, 40º and 60º, respectively. Movements order was randomized. In orthostatic position with knees in lose pack position (5º of flexion approximately) and arms along the trunk, the participant was instructed for maintaining extension elbow and performed the movements as fast as possible, after the turn on of a led light. All participants were notified for importance of the velocity over amplitude. Three trials were done and collected for each movement. Rest period between trials was 1 minute, giving the chance to completely recover (Hodges & Richardson, 1997b, 1999a).

Table 1. Electrode placement' sites.

Muscle	Electrode local placement
TrA/IO	2cm medially and below the anterior superior iliac spine (ASIS) - In this site, TrA and IO muscle fibers are mixed, so it is impossible to distinguish sEMG activity of both. For this reason, the EMG signal collected is considered from TrA/IO.
EO	13 cm superior the umbilicus, in a direct line to the ribs.
RA	3 cm superior to the umbilicus and 2 cm lateral to the midline.
Deltoid (Anterior/Medial/Posterior)	Muscle belly centre - The electrodes were placed on the respective prime mover's fibres for each task: anterior fibres for **flexion**, medial fibres for **abduction**, and posterior fibres for **extension**.

Data Processing

Data collected by Monitor PLUX® version 2.0 was converted and processed through a routine developed in MatLab® student version software. In this way, were applied, to the EMG signal, a 2nd order digital filter Infinite Impulse Response – Butterworth, one of 10Hz (high pass) and the another of 450Hz (low pass), in order to remove electrical noise and/or cable movement; and the last one of 30Hz (high pass), in order to remove cardiac signal from EMG signal (Kamen & Gabriel, 2009; Lu et al., 2009). Than the root mean square (RMS) was calculated (Basmajian & De Luca, 1985; Clancy et al., 2002; Criswell, 2011; Drake & Callaghan, 2006; Kamen & Gabriel, 2009; Mello, Oliveira, & Nadal, 2007).

sEMG signal analysis was done with Acknowledge® version 4.0 for Mac OS X software (Biopac Systems Inc.®, Goleta CA, United States of America). EMG onset timing was defined as the time wasted between each TrA/IO, EO and RA EMG activity start relatively to anterior, medial and posterior deltoid, the muscle responsible for the movement production. EMG onset timing visually analyzed was identified as the point at which the mean RMS of 50 consecutive frames (50 ms) exceeded baseline signal for 2 standard deviations. Rest EMG activity was determined in a 50 ms period, 500 ms prior to the turn on of the led light. Feedforward activation was considered when onset timings were found between 100 ms before and 50 ms after deltoid's onset timing (Hodges & Richardson, 1997a, 1997b, 1999a).

All traces were visually inspected to ensure that the onset was not obscured by movement artifact or an electrocardiogram (<7% of trials) (Hodges & Bui, 1996; Lu et al., 2009). Finally, mean onset timing of the three movement test repetitions was determined (Drake & Callaghan, 2006; Hodges & Bui, 1996; Kamen & Gabriel, 2009).

Ethics

The study were conducted in accordance with the declaration of Helsinki and approved by the Institutional Research Ethics Committee, and each individual provided a written informed consent before participation.

Statistics

The descriptive and inferential statistical analysis of the data, was performed using the statistical program *IBM SPSS Statistics®* version 20 (IBM Corporation®, New York, United States), with a significance level 0.05.

T-test for independent samples was used to compare age, height, body mass and EMG onset timing, and fisher exact test for sex. To detect differences between muscles it was used t-test for paired samples with a Bonferroni correction.

RESULTS

Sample

The final sample was constituted by 115 subjects' volunteers for this study, 56 in the $NLPP_G$ (with 44 females) and 59 in the LPP_G (with 46 female) and in respect of sample characterization (Table 2), the groups were comparable as there were no differences with a statistic signification regarding sex, age, height and weight ($p > 0.05$).

Table 2. Sample characteristics: demographic and anthropometric data of both groups with the respective mean values, standard deviation (SD), test value (t) and p value ($NLLP_G$ – Non Lumbopelvic Pain group; LPP_G – LumboPelvic Pain group). LPP_G characterization regarding duration and intensity of pain (VAS – Visual Analogic Scale) with the respective mean values and standard deviation.

	Age (Years)		Body Mass (Kg)		Height (m)		Pain Duration (Years)	VAS Pain Scores (mm)
	$NLPP_G$ (n=56)	**LPP_G** (n=59)	**$NLPP_G$** (n=56)	**LPP_G** (n=59)	**$NLPP_G$** (n=56)	**LPP_G** (n=59)	**LPP_G** (n=56)	**LPP_G** (n=59)
Mean	23.60	24.66	61.49	62.23	1.66	1.67	7.50	53.70
SD	2.06	2.07	8.62	7.88	0.08	0.08	1.67	6.63
Minimum	21.00	22.00	51.80	52.30	1.58	1.58	5.00	36.00
Maximum	29.00	30.00	81.50	81.50	1.85	1.85	11.00	62.00
t-test	-2.708		-0.472		-0.351			
p value	0.008		0.638		0.726			

Lumbopelvic Pain Group versus Non Lumbopelvic Pain Group

In the intergroup comparison, it was found that muscle activation timings, in the $NLPP_G$ was significantly lower than the LPP_G, in TrA/IO (t=-15.842, p<0.001), EO (t=-3.080, p=0.008) and RA (t=-3.646, p=0.001) muscles in the flexion upper limb rapid movement; in TrA/IO (t=-12.073, p<0.001) and EO (t=-3.238, p=0.005) muscles in the abduction upper limb rapid movement; in TrA/IO (t=-29.757, p<0.001), the EO (t=-12.308, p<0.001) and RA (t=-4180, p<0.001) muscles in the extension upper limb rapid movement (see Figure 1).

Intra-group activation pattern

During rapid arm flexion, the $NLPP_G$ has owned, according to the mean, the following pattern of muscle activation: (1) TrA/IO, (2) RA and (3) EO. However, in the LPP group, RA precedes the TrA/IO (see Figure 1).

As to the rapid arm abduction, the sequence based on the average in the two groups was: (1) TrA/IO, (2) EO and (3) RA muscles, maintaining the same sequence in $NLPP_G$ for the rapid arm extension. However in the LPP_G there was a complete reversal of the sequence, and the RA muscle has been the first to be activated, followed by the EO and finally the TrA/IO muscles (see Figure 1).

In both groups, there were significant differences between all pairs of muscles, in all planes of motion (p<0.001) (see Figure 1).

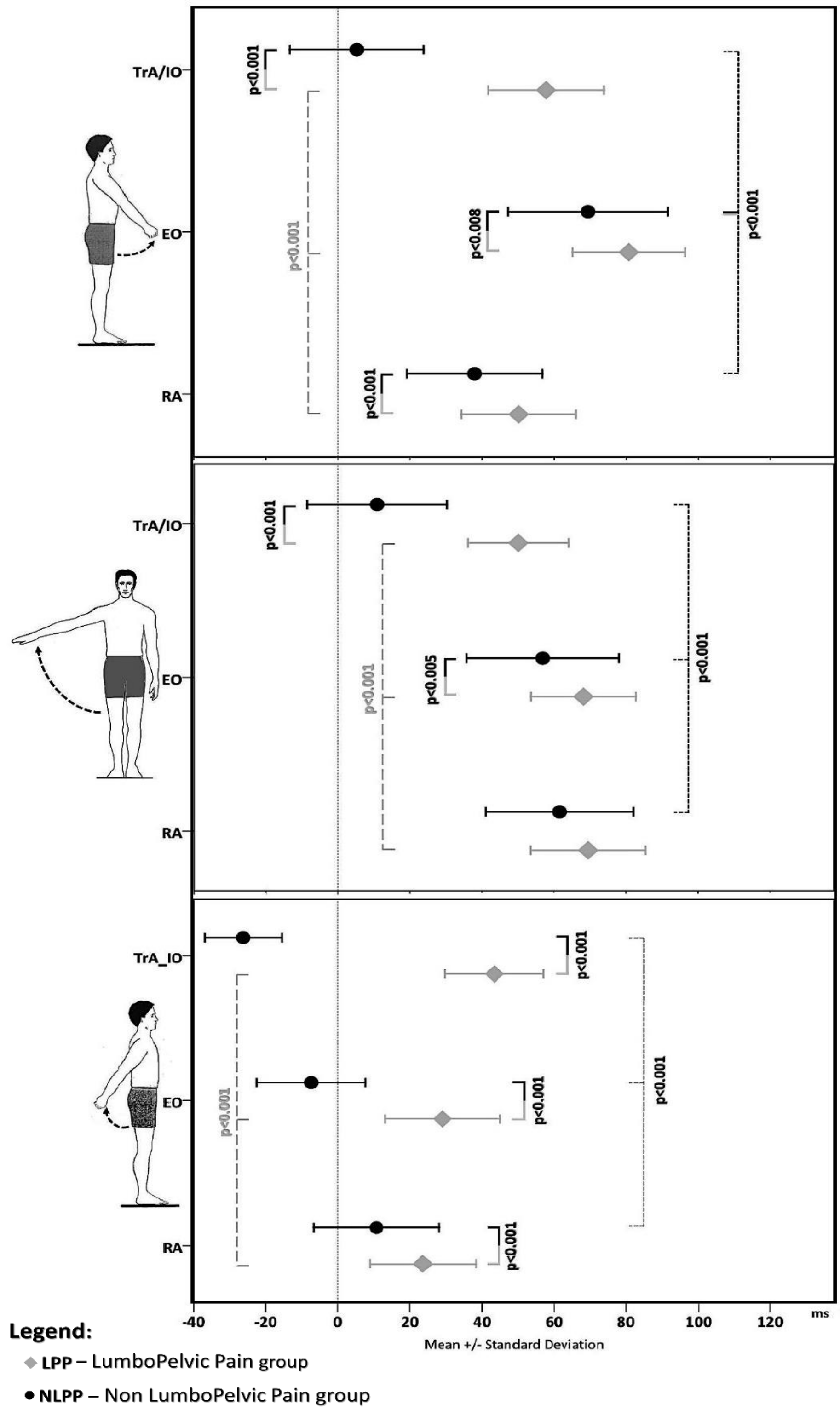

Figure 1. Comparison the activation time (ms) of the Transversus Abdominis/Internal Oblique (TrA/IO), External Oblique (EO) and Rectus Abdominis (RA) muscles between the two groups, Low Back Pain (LPP_G) versus Non Low Back Pain ($NLPP_G$), and intra-group comparison.

DISCUSSION

The results of this study indicate that the onset timing of the abdominal muscles, associated to the right rapid arm flexion, abduction and extension movements, were altered in the LPP_G. This change was manifested by the TrA/IO delayed onset in all directions of the dominant upper limb movements analyzed, as well as, the loss of the independent activation between the deep and superficial abdominal stabilizing muscles.

In the $NLPP_G$, the TrA/IO was pre-activated in all directions of the dominant upper limb movements analyzed and the muscle recruitment pattern remained independent of the direction of motion. The EO and RA were pre-activated only during the extension movement. These findings agree with previous studies indicating that the TrA has an anticipatory response with the same magnitude, regardless of the direction of the movement (Hodges & Richardson, 1996, 1997b, 1999a, 1999b). This muscle activity contributes significantly to the control of the forces applied to the lumbopelvic region, in response to the extremities' motion, besides contributing to the control of the center of mass displacement, as a result from changes in body configuration (Richardson et al., 2004; Richardson et al., 2002).

The superficial stabilizing muscles are only pre-activated in specific directions of movement (Hodges & Richardson, 1997c, 1999a, 1999b). The anticipatory recruitment of the superficial stabilizing muscles by the CNS occurs when their action oppose the direction of the forces acting on the spine. Thus, by the feedforward mechanism, the CNS controls the intervertebral movement through the activity of local stabilizing muscles, whose tonic activity is independent of the direction of motion. It also controls the vertebral orientation by the specific activity of the global stabilizing muscles (Richardson et al., 2004; Richardson et al., 2002).

In the LPP_G, the TrA/IO presented an activation pattern similar to the superficial stabilizing muscles, and was only pre-activated during the extension movement.

The results of this study on the assessment of muscle onset and activation pattern in subjects with LPP, are in accordance with similar studies already carried out, with an average of more than 7 years of pain and a presence of at least one pain episode per year (Hodges & Richardson, 1996, 1997a, 1997b, 1999a, 1999b). Similar changes have also been reproduced in experimental pain induction (Hodges, 2001a; Hodges, Moseley, et al., 2003; G. L Moseley & Hodges, 2001). Other studies showed evidence of a delay in relaxing the superficial stabilizing muscles, particularly the OE, when unexpectedly a weight was placed on the trunk (Radebold et al., 2000); great activity during trunk rotation (Ng, Richardson, Parnianpour, & Kippers, 2002); decreased tonic activity of the TrA and an increase in the activation threshold (Hodges, 1999; Hodges & Moseley, 2003; Richardson et al., 2004). The maintained activity of the erector spine at the end of the spinal flexion range is another consistent finding, as normally this muscle is not active in this range of motion (Tsao & Hodges, 2007).

The typical strategy occurring during limb movements consists of a differential activation of the superficial and deep stabilizing muscles, involving postural adjustments. The impairments found in the muscle recruitment patterns in subjects with LPP, with loss of the independent activation of superficial and deep stabilizing muscles, may compromise the optimal function of the spine (Hodges, 1999; Hodges & Richardson, 1999b; Richardson et al., 1999, 2004).

The TrA, the posterior fibers of the IO and the deep fibers of the lumbar multifidus, play a crucial role in the functional stability of the vertebral joints, through a continuous activation of low intensity, in all directions of movement and in all joints' positions. These muscles' activity tends to increase the muscle stiffness at a segmental level, especially in the neutral position, whereas the passive support, provided by the ligaments and joints' capsule, is minimum (Bogduk, 2005; Panjabi, 1992a, 1992b).

The importance of the TrA's activity has been widely studied and it has been questioned if the delay in its activation (in milliseconds), may have significant influence on the vertebral control (Hodges, 1999; Richardson et al., 2004). It is universally accepted that the pre-activation of the TrA is essential when the global stabilizing muscles and mobilizers are not able to provide selective stability to each intervertebral segment and have a limited capacity to provide stability to the sacroiliac joint (Hodges, 1999; Richardson et al., 2004; Richardson et al., 2002). Due to the instability of the spine, particularly in the neutral zone, the impairments in the recruitment patterns expose the vertebral structures to an increased risk of micro-trauma and injury, and seem to be a relevant factor in the recurrence of lumbopelvic pain (Hodges, 1999; Richardson et al., 2004; Richardson et al., 2002).

Identifying motor control dysfunctions in subjects with LPP bring to us the importance of including motor planning strategies when rehabilitating these subjects (Hodges, 1999; Richardson et al., 2004; Richardson et al., 2002). However, there is limited evidence of the effectiveness of training in the feedforward mechanism. Moreover, there is unclear evidence about the type of exercises that should be performed. Tsao and Hodges (2007) conducted a study to investigate whether training involving voluntary muscle activation could reverse the modified feedforward mechanisms in subjects with LPP and how these could be influenced by different exercises. The activation pattern of the trunk muscles was assessed in 22 subjects with LPP before and after the performance of a set of exercises. One group trained the voluntary muscle activation of the TrA, through the drawing-in maneuver, and the other group through the curl-up exercise with the combined abdominal muscle activation. The muscles' activity was monitored by intramuscular electromyography during the exercises' performance. Only the group that performed the isolated activation of the transversus abdominis, showed a pattern of activation similar to those without pain at the end of the training. These results showed that isolated muscle activation training could change the feedforward activation and that the magnitude of the effects was influenced by the type and quality of the neuromuscular rehabilitation (Tsao & Hodges, 2007).

Another study, by Koumantakis, Watson, and Oldham (2005) showed that both exercises involving isolated muscle activation or the simultaneous activation of the abdominal muscles reduce symptoms and incapacity. However, these authors did not evaluate the neuromuscular recruitment.

One of the weaknesses of the present study is to evaluate only the electromyographic onset of the abdominal muscles on the contralateral side to the right arm that performs the movements fore mentioned. This because, more recent studies have demonstrated that TrA/IO onset doesn't occur in a bilateral and symmetrical way, as it was determined in the past. Based on the studies conducted by Morris et al. (2012, 2013), it is known that, during limb movements, TrA/IO has a predominantly unilateral and contralateral feedforward activity (Morris, Lay, & Allison, 2012, 2013).

CONCLUSION

In the present study we observed that the LPP_G showed a significant delay in the onset of TrA/IO, EO and RA, during all movements, and there is a consistent sequence of muscle activation between the two groups, with the exception for the extension movement.

Also, in LPP_G it was found a similar pattern of activation between the superficial/global and deep/local muscles of the lumbopelvic region in all directions of movement performed, with the consequent loss of the independent activation between these muscle groups.

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3.2. STUDY II – MANUAL PELVIC COMPRESSION, ABDOMINAL BRACING AND DRAWING-IN DURING ACTIVE STRAIGHT LEG RAISING IN SUBJECTS WITH AND WITHOUT LUMBOPELVIC PAIN

PAULO CARVALHO*[1,2], CARLOS CRASTO[1], ANA MONTEIRO[1],
ANTÓNIO MESQUITA MONTES[1,2], RUBIM SANTOS[2], JOÃO PAULO VILAS-BOAS[3]

[1] *Physical Therapy Department – School of Allied Health Sciences of Porto/Porto Polytechnic Institute (ESTSP/IPP), Vila Nova de Gaia, Portugal*

[2] *Center of Study for the Movement and Human Activity (CEMAH) - ESTSP/IPP, Vila Nova de Gaia, Portugal*

[3] *Porto Biomechanics Laboratory (LABIOMEP), Faculty of Sport, CIFI2D, University of Porto, Porto, Portugal*

***Corresponding author:**

Physical Therapy Department – School of Allied Health Sciences of Porto/Porto Polytechnic Institute (ESTSP/IPP), Vila Nova de Gaia, Portugal
Rua Valente Perfeito, 322
4400-330, Vila Nova de Gaia, Portugal.
E-mail address: pmc@estsp.ipp.pt (Paulo de Carvalho).

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ABSTRACT

Background: Active Straight Leg Raising (ASLR) test has been suggested as clinical indicator of lumbopelvic instability. Passive and active stabilization strategies can be used for reducing ASLR impairment, yet no comparison between them was made.

Aim: to compare the effects of manual pelvic compression, abdominal bracing and drawing-in manoeuvre during Active Straight Leg Raising test in subjects with and without chronic nonspecific lumbopelvic pain

Methods: Cross-sectional study with 56 volunteers for the without lumbopelvic pain group ($NLPP_G$), and 59 volunteers for the lumbopelvic pain group (LPP_G). ASLR impairment score was assessed in 3 conditions: a standard ASLR, an ASLR with drawing-in (ASLR_D) and an ASLR with abdominal bracing (ASLR_AB).

T-test and Mann-Whitney test were used for group comparison and Kruskal-Wallis test for the three ASLR conditions. Significance level was set to 0.05.

Results: LPP group presented significantly higher ASLR score than $NLPP_G$ (z=-9,361; p<0,001). In LPP group, pelvic compression, abdominal bracing and drawing-in during ASLR had significantly lower score than standard ASLR (p<0,001). Abdominal bracing had significantly lower score than pelvic compression and drawing-in (p<0,001).

Conclusion: In this study it was identified that active straight leg raising test score could differentiate subjects with and without lumbopelvic pain. Any stabilization strategy added to ASLR reduced difficulty perception in performing the task, especially abdominal bracing who add better results than the others.

Key-words: Lumbopelvic pain; ASLR; manual pelvic compression; drawing-in; abdominal bracing.

INTRODUCTION

Lumbopelvic pain is a dysfunction that affects approximately 9.2% of the world population, and is one of the main reasons for disability worldwide, imposing great healthcare costs and productivity loss. Although in some cases lumbopelvic pain come from a specific pathology, in 90% of the cases cause is nonspecific. This is a pain with tendency to become persistent and recurrent often reaching a chronic state (Hodges, van den Hoorn, Dawson, & Cholewicki, 2009; Roussel, Nijs, Truijen, Smeuninx, & Stassijns, 2007; A. Wong, Parent, Funabashi, Stanton, & Kawchuk, 2013).

It is thought that lumbopelvic pain occurrence is related to changes in motor control and muscle function, including changes in muscle activation timing and muscle contraction thickness noted in transversus abdominis muscle and histological changes observed in multifidus muscle. Both muscles play an important role on intersegmental spine stability and their miss function could be a part of the lumbopelvic instability found in these subjects (Hodges & Richardson, 1999a; Key, 2010; Teyhen et al., 2009; Yanik, Keyik, & Conkbayir, 2013).

Active Straight Leg Raising test has been suggested as clinical indicator of this instability. In addition to motor control changes during this test, like inability to control lumbar rotation, altered muscle activation and impaired respiratory function, subjects with lumbopelvic pain also reported a subjective feeling of heavy leg, being more difficult to perform the task and so present higher ASLR score (Beales, O'Sullivan, & Briffa, 2010; Liebenson, Karpowicz, Brown, Howarth, & McGill, 2009; P. B. O'Sullivan et al., 2002). This heaviness was significantly reduced when manual pelvic compression was added during the test, which probably compensated the lack of stability found in these subjects (Beales et al., 2010).

Active strategies can also increase lumbopelvic stability, for example through drawing-in and abdominal bracing manoeuvres. The first tries to increase lumbopelvic stability based on transversus abdominis and multifidus isolated muscle contraction and the second on all abdominal muscles contraction while maintaining lumbar neutral position (McGill, 2007a; Richardson et al., 2004).

Abdominal bracing has been already studied during ASLR and proved that reduces lumbar rotation, a lumbopelvic stability indicator, however no research had assessed drawing-in manoeuvre during this task (Liebenson et al., 2009).

Therefore, this study aims to compare the effects of manual pelvic compression, abdominal bracing and drawing-in manoeuvre during Active Straight Leg Raising test in individuals with and without chronic nonspecific lumbopelvic pain.

METHODS

Sample

Cross-sectional study with a final sample of 115 volunteered subjects, divided in two groups: 56 subjects (44 females) for the without lumbopelvic pain group ($NLPP_G$), and 59 subjects (46 females) for the with lumbopelvic pain group (LPP_G).

The target population consisted in volunteers subjects, aged between 18 and 30 years with and without chronic nonspecific lumbopelvic pain.

In this study, the inclusion criteria for the LPP_G were: recurrent episodes of lumbopelvic pain for a period greater than three months, while for $NLPP_G$ could not have experienced pain in this region. (Arab et al., 2011; Silfies et al., 2005).

Were excluded subjects who had: scoliosis, discrepancy of the lower limbs or postural asymmetries, history of spinal, abdominal or gynaecological surgery in last year, neurological disorders and/or inflammatory or cardio-respiratory diseases, pregnancy or post-delivery in last 6 months; practice exercise for core abdominal in last year; receiving physiotherapy treatment in order to resolve the lumbopelvic pain; and subjects who did regular exercise, more than 45 minutes a day, three days a week for a period exceeding one.

Instruments

An electronic questionnaire was given to the subjects in order to be sure that every participant fulfils the selection criteria of this study, as well as to gather some sociodemographic information and lumbopelvic pain duration. Pain intensity in LPP_G was evaluated by using the visual analogue scale (VAS), which consist in a horizontal line with 100 millimetres, from “No pain” to “Maximal pain” written in the extremities (Carlsson, 1983; Ferreira-Valente et al., 2011; Hawker et al., 2011). Anthropometric measures, height (meters) and body mass (kilograms), were measured by a Seca® 222 stadiometer with an accuracy of 1 millimetre and a Seca® 760 balance with an accuracy of 1 kilogram (Seca - Medical Scales and Measuring Systems ®, Birmingham, United Kingdom), respectively.

Pressure biofeedback unit, *Stabilizer* (*Chattanooga Group Inc®., Hixson TN, EUA*) was used to ensure neutral lumbar position during the Active Straight Leg Raising (ASLR)

Procedures

Data Collection Protocol

Study procedures took place in biomechanical laboratory and were performed in a controlled environment.

In order to select and characterize the sample, an electronic questionnaire was given to all the subjects and if selected they were measured and weighted. Subjects in LPP group also pointed a cross in the line from visual analogue scale, where they thought it represented their pain intensity. The value was considered the distance, in millimetres, between the start and the cross.

All participants had to perform a standard Active Straight Leg Raising (ASLR), an ASLR together with a drawing-in manoeuvre (ASLR_D) and an ASLR with abdominal bracing (ASLR_AB) separated by 1 minute interval. The order of assessment was random.

To perform an ASLR the participants, from a supine position, had to elevate their dominant lower limb, with the knee extended, until touching a metal bar with the ankle located 20 centimetres above the ground. Dominant limb was established as one that individuals used to kick a ball.

Drawing-in and abdominal bracing manoeuvers were taught to the participants prior to data collection by a physiotherapist expert in motor control approaches and its proper execution was confirmed by palpation and by the use of the pressure biofeedback unit, which confirmed the maintenance in a lumbar neutral position.

In each ASLR, subjects were asked to score impairment on a six point scale (0=not difficult at all; 1=minimally difficult; 2=somewhat difficult; 3=fairly difficult; 4=very difficult; and 5=unable to do) (Mens, Vleeming, Snijders, Koes, & Stam, 2001).

Ethics

The study were conducted in accordance with the declaration of Helsinki and approved by the Institutional Research Ethics Committee. Each individual provided a written informed consent before participation.

Statistics

The descriptive and inferential statistical analysis of the data, was performed using the statistical program *IBM SPSS Statistics*® version 20 (IBM Corporation®, New York, United States), with a significance level 0.05.

T-test was used to compare age, body mass and height between groups, and Mann-Whitney U test for ASLR score. Within groups, to identify differences between the three ASLR conditions it was used Kruskal-Wallis one-way analysis of variance test, followed by Dunn test as a Post-Hoc. The use of non-parametric test in ASLR score was due to the ordinal nature of the variable (Marôco, 2010).

RESULTS

Regarding height and weight no statistically significant differences were observed between groups. As for age it was found significant differences between groups, however, the mean difference was just one year and therefore they were considered comparable. Demographic and anthropometric data as well as pain duration and intensity are showed in Table 1.

Table 1. Sample characteristics: demographic and anthropometric data of both groups and pain duration and intensity for LPP_G with the respective mean values, standard deviation (SD), test value (t) and p value ($NLLP_G$ – Non Lumbopelvic Pain group; LPP_G – LumboPelvic Pain group).

	Age (Years)		Body Mass (Kg)		Height (m)		Pain Duration (Years)	VAS Pain Scores (mm)
	$NLPP_G$ (n=56)	LPP_G (n=59)	$NLPP_G$ (n=56)	LPP_G (n=59)	$NLPP_G$ (n=56)	LPP_G (n=59)	LPP_G (n=56)	LPP_G (n=59)
Mean	23.60	24.66	61.49	62.23	1.66	1.67	7.50	53.70
SD	2.06	2.07	8.62	7.88	0.08	0.08	1.67	6.63
Minimum	21.00	22.00	51.80	52.30	1.58	1.58	5.00	36.00
Maximum	29.00	30.00	81.50	81.50	1.85	1.85	11.00	62.00
t-test	-2 708		-0.472		-0.351			
p value	0.008		0.638		0.726			

With respect to standard ASLR, LPP group presented significantly higher score than $NLPP_G$ (z=-9,361; p<0,001). All NLPP group, except 4 subjects, had no difficulty (score=0) performing ASLR.

In the other 3 conditions, that is ASLR with manual pelvic compression, abdominal bracing and drawing-in, all NLPP group had a score equal to 0, which did not allow further between groups comparison.

As for LPP group there were statistical differences between all ASLR conditions ($\chi2$=143,862; p<0,001). Post-hoc analysis revealed that both pelvic compression, abdominal bracing and drawing-in during ASLR had significantly lower score than standard ASLR (p<0,001). In addition it also revealed that abdominal bracing had significantly lower score than pelvic compression and drawing-in (p<0,001) as showed in Figure 1.

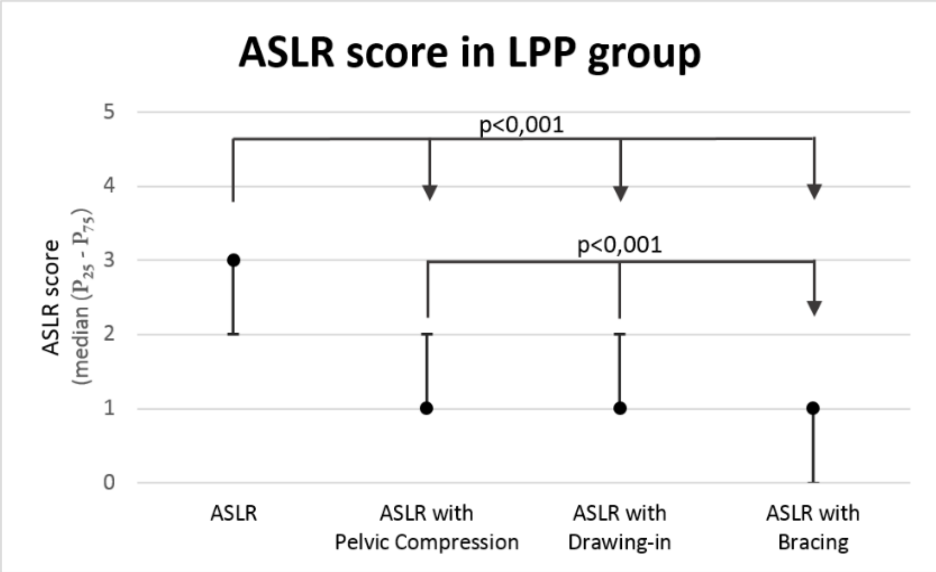

Figure 1. ASLR score in lumbopelvic pain group (LPP_G); median and percentile 25 (P_{25}) and 75 (P_{75}).

DISCUSSION

In the last years, several studies have analysed ASLR in subjects with lumbopelvic pain, and some more specifically with sacroiliac pain. O'Sullivan et al. (2002) with 13 subjects with and 13 without sacroiliac pain, identified changes in motor control strategies and respiratory function, and hypothesized that it could be a neuromuscular compensatory strategy to increase force closure that was reduced in these subjects. Despite these authors did not objectively assess ASLR score, they reported a heaviness of the leg present in lumbopelvic pain group. This fact was here confirmed in the present study, showing significantly higher ASLR scores in lumbopelvic pain group. The same results were already been confirmed by Mens et al. (2001) but in 200 woman with and 50 without posterior pelvic pain since pregnancy.

Although this test has already proved useful for differentiating patients with and without lumbopelvic pain, no further study compared the effect of 3 stabilization strategies during this task, which was manual pelvic compression, drawing-in manoeuvre and abdominal bracing. Each of this stabilization strategies proved, in the present study, to decrease ASLR score.

As for pelvic compression these results were in agreement with P. B. O'Sullivan et al. (2002) and Beales et al. (2010). P. B. O'Sullivan et al. (2002) when added manual pelvic compression to ASLR evidenced a normalization of both respiratory and motor pattern as well as reported, although not objectively controlled, a decrease in heaviness of the leg. Beales et al. (2010) assessing 12 females with unilateral sacroiliac pain verified a reduction in ASLR score when added pelvic compression. They also evaluated electromyography muscle activity and intra-abdominal pressure, yet no statistical differences were found. Possibly, manual pelvic compression had beneficial effect on ASLR score since it compensated force and/or form closure impairment present on subjects with lumbopelvic pain or even because it increased lumbopelvic stiffness which could relieved sensitized ligament structures allowing normalized motor control responses during ASLR (Beales et al., 2010; P. B. O'Sullivan et al., 2002).

The differences found with drawing-in manoeuvre were similar to those observed with manual pelvic compression. As previously stated, there were no studies found which had implemented drawing-in manoeuvre to ASLR. However, it is known that this is a stabilization manoeuvre commonly used to improve lumbopelvic stability that based on transversus abdominis and multifidus muscles coactivation can increase lumbopelvic stiffness (N. G. Lee et al., 2011; Teyhen et al., 2009).

This study also found that abdominal bracing compared to standard ASLR as well as the manual pelvic compression and the drawing-in, managed to obtain significantly lower ASLR score. Abdominal bracing during ASLR was previously studied by Liebenson et al. (2009) in 14 subjects without lumbopelvic pain, concluding that it improved lumbopelvic stability by reducing lumbar rotation during ASLR.

Since abdominal bracing consist in a contraction of all abdominal muscles while maintaining lumbar neutral position it is a more intense activity than drawing-in, and maybe because of that could influence subject perception of stability, having a lower ASLR score.

Considering that these stabilization strategies are often used in lumbopelvic subjects to reduce their pain, this results suggest that an active strategy (drawing-in or abdominal bracing) could have equal to better results, in respect to ASLR difficulty perception, than a passive one (pelvic compression).

Due to the subjectivity inherent to ASLR score it is suggested as a future study to do a trunk muscle electromyographic assessment while performing ASLR with different stabilization manoeuvres in subjects with and without lumbopelvic pain, aiming to compare recruitment patterns and muscle activation.

Conclusion

In this study it was identified that active straight leg raising test score could differentiate subjects with and without lumbopelvic pain. Any stabilization strategy added to ASLR reduced difficulty perception in performing the task, especially abdominal bracing who add better results than the others.

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3.3. Study III – Trunk muscles endurance and ratios in subjects with and without lumbopelvic pain

Paulo Carvalho*[1,2], Carlos Crasto[1], Ana Magalhães[1], António Mesquita Montes[1,2], Rubim Santos[2], João Paulo Vilas-Boas[3]

[1] *Physical Therapy Department – School of Allied Health Sciences of Porto/Porto Polytechnic Institute (ESTSP/IPP), Vila Nova de Gaia, Portugal*

[2] *Center of Study for the Movement and Human Activity (CEMAH) - ESTSP/IPP, Vila Nova de Gaia, Portugal*

[3] *Porto Biomechanics Laboratory (LABIOMEP), Faculty of Sport, CIFI2D, University of Porto, Porto, Portugal*

*Corresponding author:

Physical Therapy Department – School of Allied Health Sciences of Porto/Porto Polytechnic Institute (ESTSP/IPP), Vila Nova de Gaia, Portugal
Rua Valente Perfeito, 322
4400-330, Vila Nova de Gaia, Portugal.
E-mail address: pmc@estsp.ipp.pt (Paulo de Carvalho).

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ABSTRACT

Background: Trunk muscles endurance has been known to be impaired in subjects with lumbopelvic pain. It is recommended to assess both endurance times of all trunk muscle groups as well as the ratio between them.

Aim: to detect differences in trunk muscles endurance times and ratios in subjects with and without chronic lumbopelvic pain.

Methods: Cross-sectional study with 56 volunteers for the without lumbopelvic pain group ($NLPP_G$), and 59 volunteers for the lumbopelvic pain group (LPP_G).

Flexors, extensors and lateral flexors endurance tests were performed and both the endurance times and the ratios between tests were analysed.

T-test were used for group comparison with a significance level set to 0.05.

Results: LPP group presented significantly higher ASLR score than $NLPP_G$ (z=-9,361; p<0,001). In LPP group, both pelvic compression, abdominal bracing and drawing-in during ASLR had significantly lower score than standard ASLR (p<0,001). Abdominal bracing had significantly lower score than pelvic compression and drawing-in (p<0,001).

It was found that subjects with lumbopelvic pain had all endurance tests times significantly lower than subjects without pain (p <0.001). The same result was found when compared all endurance ratios (p=0.001).

Conclusion: Subjects with lumbopelvic pain present lower trunk muscle endurance and smaller endurance ratios. Some endurance ratios, in subjects with lumbopelvic pain, were not in agreement with the standard values suggested in the literature.

Key-words: Lumbopelvic pain, trunk muscle endurance

INTRODUCTION

Lumbopelvic pain is considered worldwide to be the main reason for reduced productivity and work absence, having a negative socio-economic impact on society (Delitto et al., 2012; Tekin et al., 2009). The prevalence ranges from 15% to 45% in the general population and in fact 50 to 80% of the population will experience at least one episode of lumbopelvic pain at some point in their life (Davarian, Maroufi, Ebrahimi, Farahmand, & Parnianpour, 2012; Ledoux, Dubois, & Descarreaux, 2012; Roussel et al., 2007; Tekin et al., 2009).

Although both isometric strength and endurance of the trunk muscles are decreased in subjects with lumbopelvic, clinically decreased strength is a problem for some and decreased endurance a problem for all (Key, 2010). Alaranta, Luoto, Heliovaara, and Hurri (1995) and Biering-Sorensen (1984) reported that decreased endurance of trunk extensors muscles are associated with lumbopelvic pain. McGill (2007a) also refer the importance of assessing both extensors, flexors and lateral trunk muscles, as well as ratios between them. This author suggested that endurance ratios associated with lumbopelvic pain correspond to a ratio greater than 1 for flexors and extensors, lower than 0.95 and higher than 1.05 between lateral muscles, and lower than 0.25 and higher than 1.75 for the right or left side flexors and extensors (McGill, 2007a, 2009; McGill, Childs, & Liebenson, 1999).

For assessing trunk muscle endurance equipment's like sitting dynamometer tests (using Biodex), or isometric dynamometer can be used, however, they are not accessible to all clinical environments mainly because they are too expensive (Moreau, Green, Johnson, & Moreau, 2001). Thus, McGill (2007a) suggests several tests, easy to perform with reduced cost and without requiring special equipment.

In the literature, there was only found one study comparing trunk endurance times between subjects with and without lumbopelvic pain (Ito et al., 1996). However, this research did not include lateral trunk muscles endurance assessment and ratios determination between the three muscle groups - flexors, extensors, and lateral flexors.

Thus, it is pertinent to this study to detect differences in trunk muscles endurance times and ratios in subjects with and without chronic lumbopelvic pain.

METHODS

Sample

Cross-sectional study with a final sample of 111 volunteered subjects, divided in two groups: 56 subjects (44 females) for the without lumbopelvic pain group ($NLPP_G$), and 59 subjects (46 females) for the with lumbopelvic pain group (LPP_G).

The target population consisted in volunteers subjects, aged between 18 and 30 years with and without chronic nonspecific lumbopelvic pain.

In this study, the inclusion criteria for the LPP_G were: recurrent episodes of lumbopelvic pain for a period greater than three months, while for $NLPP_G$ could not have experienced pain in this region. (Arab et al., 2011; Silfies et al., 2005).

Were excluded subjects who had: scoliosis, discrepancy of the lower limbs or postural asymmetries, history of spinal, abdominal or gynaecological surgery in last year, neurological disorders and/or inflammatory or cardio-respiratory diseases, pregnancy or post-delivery in last 6 months; practice exercise for core abdominal in last year; receiving physiotherapy treatment in order to resolve the lumbopelvic pain; and subjects who did regular exercise, more than 45 minutes a day, three days a week for a period exceeding one.

Instruments

An electronic questionnaire was given to the subjects in order to be sure that every participant fulfils the selection criteria of this study, as well as to gather some sociodemographic information and lumbopelvic pain duration. Pain intensity in LPP_G was evaluated by using the visual analogue scale (VAS), which consist in a horizontal line with 100 millimetres, from “No pain” to “Maximal pain” written in the extremities (Carlsson, 1983; Ferreira-Valente et al., 2011; Hawker et al., 2011)

Anthropometric measures, height (meters) and body mass (kilograms), were measured by a Seca® 222 stadiometer with an accuracy of 1 millimetre and a Seca® 760 balance with an accuracy of 1 kilogram (Seca - Medical Scales and Measuring Systems ®, Birmingham, United Kingdom), respectively.

It was also used a Baseline® bubble inclinometer (Fabrication Enterpises Inc., White Plains, New York, United States of America) to measure and verify the angle maintenance when assessing extensors muscles endurance, and a stopwatch (Casio® HS-80TW-1, Casio Electronics Co. Ltd.) to measure the holding time in all endurance tests.

Procedures

Data Collection Protocol

Study procedures took place in biomechanical laboratory and were performed in a controlled environment.

In order to select and characterize the sample, an electronic questionnaire was given to all the subjects and if selected they were measured and weighted. Subjects in LPP group also pointed a cross in the line from visual analogue scale, where they thought it represented their pain intensity. The value was considered the distance, in millimetres, between the start and the cross.

All participants had to perform the endurance tests for trunk flexors, extensors and lateral flexors.

For the trunk flexors endurance test the subjects were in a sit-up posture with their back resting against a wedge angled at 60º from the floor. Both knees and hips were 90º flexed, arms crossed across the chest with the hands placed over the opposite shoulder, and the feet stabilized in a Swedish bars. The test started when the wedge was pulled back 10 centimetres and the subject stood on an isometric posture as long as possible. The test stopped when any part of the subject's back touched the wedge (McGill, 2007a, 2009).

Regarding trunk extensors, they were tested in the "Biering-Sorensen position" with the upper body out over the end of a table, while the pelvic region, distal third of the thigh and legs were stabilized with support bands. The upper limbs were held across the chest with the hands on the opposite shoulders. The test stopped when the upper body dropped from the horizontal position. Were allowed during the test oscillations between -5º to +5º, measured with an inclinometer placed over the first thoracic vertebrae (McGill, 2007a, 2009).

The lateral musculature was tested with the subject lying in the full side-bridge position. Legs were in extension, and the top foot was placed in front of the lower foot for better support. Subjects support themselves on one elbow and on their feet while lifting their hips off the floor to create a straight line over their body length. The uninvolved arm was held across the chest with the hand placed on the opposite shoulder. The test stopped when the subject lost the straight-back posture and the hip returned to the ground (McGill, 2007a, 2009; McGill et al., 1999).

The order of assessment was random, and there was a 15 minutes resting interval between tests. The tests duration was registered in seconds and these values were used to calculate the ratios between flexors/extensors; right lateral flexors/left lateral flexors; right lateral flexors/extensors; and left lateral flexors/extensors.

Ethics

The study were conducted in accordance with the declaration of Helsinki and approved by the Institutional Research Ethics Committee. Each individual provided a written informed consent before participation.

Statistics

The descriptive and inferential statistical analysis of the data, was performed using the statistical program *IBM SPSS Statistics®* version 20 (IBM Corporation®, New York, United States), with a significance level of 0.05.

T-test for independent samples was used for group comparison (Marôco, 2010).

RESULTS

With regard to height and weight no statistically significant differences were observed between groups. As for age it was found significant differences between groups, however, the mean difference was just one year and thus they were considered comparable. Demographic and anthropometric data as well as pain duration and intensity are showed in Table 1.

Table 1. Sample characteristics: demographic and anthropometric data of both groups and pain duration and intensity for LPP_G with the respective mean values, standard deviation (SD), test value (t) and p value ($NLLP_G$ – Non Lumbopelvic Pain group; LPP_G – LumboPelvic Pain group).

	Age (Years)		Body Mass (Kg)		Height (m)		Pain Duration (Years)	VAS Pain Scores (mm)
	$NLPP_G$ (n=56)	LPP_G (n=59)	$NLPP_G$ (n=56)	LPP_G (n=59)	$NLPP_G$ (n=56)	LPP_G (n=59)	LPP_G (n=56)	LPP_G (n=59)
Mean	23.60	24.66	61.49	62.23	1.66	1.67	7.50	53.70
SD	2.06	2.07	8.62	7.88	0.08	0.08	1.67	6.63
Minimum	21.00	22.00	51.80	52.30	1.58	1.58	5.00	36.00
Maximum	29.00	30.00	81.50	81.50	1.85	1.85	11.00	62.00
t-test	-2 708		-0.472		-0.351			
p value	0.008		0.638		0.726			

When groups were compared, it was found that subjects with lumbopelvic pain had extensors, flexors, and left and right lateral flexors endurance times significantly lower than subjects without pain (p <0.001). The same was found when compared endurance ratios, specifically for flexors/extensors (p<0.001); right lateral flexor/left lateral flexor (p=0.001); right lateral flexor/extensors (p<0.001) and left lateral flexor/extensors ratios (p<0.001).

Table 2. Endurance times and ratios between group comparisons (NLLP$_G$ – Non Lumbopelvic Pain group; LPP$_G$ – LumboPelvic Pain group).

			Mean	Standard Deviation	t-test	p value
Endurance Time (in seconds)	Extensors	NLPP$_G$	139.81	34.69	21.471	<0.001
		LPP$_G$	34.21	7.83		
	Flexors	NLPP$_G$	120.60	25.16	26.737	<0.001
		LPP$_G$	24.17	7.02		
	Right lateral flexors	NLPP$_G$	72.03	23.75	17.440	<0.001
		LPP$_G$	14.00	3.63		
	Left lateral flexors	NLPP$_G$	75.62	25.03	17.751	<0.001
		LPP$_G$	15.47	3.85		
Endurance Ratios	Flexors/Extensors	NLPP$_G$	0.87	0.07	7.064	<0.001
		LPP$_G$	0.72	0.16		
	Right/Left lateral flexors	NLPP$_G$	0.95	0.04	3.462	0.001
		LPP$_G$	0.91	0.09		
	Right lateral flexors/Extensors	NLPP$_G$	0.51	0.08	5.601	<0.001
		LPP$_G$	0.42	0.09		
	Left lateral flexors/Extensors	NLPP$_G$	0.53	0.09	3.886	<0.001
		LPP$_G$	0.46	0.11		

DISCUSSION

The aim of this study was to compare trunk muscles endurance times and ratios in subjects with and without lumbopelvic pain.

In this study, it was found that individuals with lumbopelvic pain had lower endurance time of all trunk muscle groups.

Endurance tests recruit both local as global muscles. In subjects with lumbopelvic pain, pre-activation of erector spinae, internal oblique and transversus abdominis is absent or delayed when a disturb occur (Hodges, 2001a; Hodges, Butler, McKenzie, & Gandevia, 1997; Hodges & Richardson, 1999a; Mannion et al., 2008). These changes in trunk muscle control, in which global muscles have increased activation, can cause increased load on spine elevating injury risk and even pain intensity (Arokoski, Valta, Airaksinen, & Kankaanpaa, 2001; Hodges & Richardson, 1999a).

In fact, related to the decreased local muscle activation in presence of pain, multifidus, one of the key muscles in lumbar spine intersegmental stabilization, presented less cross-section area and showed evidences of fat and connective tissue infiltration (Key, 2010; Mengiardi et al., 2006; Yanik et al., 2013).

Therefore, with less contribution of local stabilization muscles during the endurance tests, more global muscles activation are required. Considering that this muscles are mostly intended for mobility and are composed manly by type II fibres, they are more likely to fatigue and as a result could explain the lower endurance test times in subjects with lumbopelvic pain (Key, 2010)

Ito et al. (1996) who assessed trunk flexors and extensors endurance time in 100 subjects with lumbopelvic pain and 90 without pain observed the same results as this study. This investigation did not evaluate lateral flexors endurance time and ratios between muscle groups, that accordingly to McGill (2007) are essential for a better evaluation of spine stability.

In the present study all ratios were inferior on the lumbopelvic pain group, including flexors/extensors ratio (0.72±0.16) that differs from the values mentioned by McGill (2007) for this group (higher than 1). This ratio was a consequence of a strong decrease of both trunk flexors and extensors, but in similar proportions. The lateral flexors/extensors ratios for the lumbopelvic pain group also differed from the proposed by McGill (2007), that instead of being less than 0.25 or higher then 1.75, was similar to the non lumbopelvic pain group around 0.5. The other ratios were in agreement with this author, including all ratios for healthy subjects.

No sample size determination was considered a study limitation, yet it was found statistical differences in all variables. Is still necessary to conduct a longitudinal study to assess whether a motor control exercise program is able to counteract the differences between the groups with and without lumbopelvic pain with regard to trunk muscles endurance times and ratios.

CONCLUSION

In this study it was identified that subjects with lumbopelvic pain had lower trunk muscle endurance and lesser endurance ratios. Some endurance ratios in subjects with lumbopelvic pain were not in agreement with the Stuart McGill referenced standard values.

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3.4. Study IV – Effect of the Electrodes' Location on the Surface Electromyographic Signal of the Rectus Abdominis Muscle

PAULO CARVALHO*[1,2], ANTÓNIO MESQUITA MONTES[1,2], CARLOS CRASTO[1], RUBIM SANTOS[2], JOÃO PAULO VILAS-BOAS[3]

[1] *Physical Therapy Department – School of Allied Health Sciences of Porto/Porto Polytechnic Institute (ESTSP/IPP), Vila Nova de Gaia, Portugal*

[2] *Center of Study for the Movement and Human Activity (CEMAH) - ESTSP/IPP, Vila Nova de Gaia, Portugal*

[3] *Porto Biomechanics Laboratory (LABIOMEP), Faculty of Sport, CIFI2D, University of Porto, Porto, Portugal*

***Corresponding author:**

Physical Therapy Department – School of Allied Health Sciences of Porto/Porto Polytechnic Institute (ESTSP/IPP), Vila Nova de Gaia, Portugal

Rua Valente Perfeito, 322

4400-330, Vila Nova de Gaia, Portugal.

E-mail address: pmc@estsp.ipp.pt (Paulo de Carvalho).

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ABSTRACT

Aim: To determine the existence of differences in the electromyographic (EMG) signal amplitude and relative muscle activation, obtained in two different electrodes' locations, using surface electromyography in the right rectus abdominis muscle.

Methods: Cross-sectional study with a sample composed by 26 volunteer gymnasium instructors. The electromyographic signal was recorded with surface electromyography in two locations of the right rectus abdominis: L_1 – 5cm lower to the xiphoid process and 3cm lateral to the midline; L_2 – 3cm superior to the umbilicus and 2cm lateral to the midline. Each subject performed 3 reps of each exercise: Curl-Up (CU), Side-Bridge (SB) (four variations – SB_1; SB_2; SB_3 and SB_4) and Birddog (BD) (four variations – BD_1; BD_2; BD_3 and BD_4) in a total of 9 conditions. The analysed signal was collected during 3 seconds in the isometric phase of the exercises. The EMG signal amplitude was assessed through the root mean square (RMS) and the relative muscle activation was obtained through the normalization to the maximal voluntary contraction. Statistical data was processed in the SPSS software, version 20.0 for MAC OS, with a significance degree of 0.05.

Results: In all the studied variables were found significant differences between RMS obtained in L_1 and L_2. In L_1 the registered signal was significant ($p<0.05$) higher than in L_2. In relation to the percentage of relative muscle activation, we observed that, in all the studied variables, there were no significant differences between the two locations ($p<0.05$).

Conclusion: For the right rectus abdominis, the absolute electromyographic signal amplitude registered in the pair of electrodes placed in L_1 was significantly higher than the value obtained in L_2. However, after normalization to the maximal voluntary contraction, no significant differences were found between the signals obtained in the two locations.

Key words: Surface electromyography, Electrodes' location, Rectus Abdominis.

INTRODUCTION

Electromyography (EMG) is an instrument that, in the last 45 years, has assumed an essential role in the neuromuscular activity analysis in different research areas, such as the rehabilitation medicine, ergonomics and sports (Criswell, 2011; Hogrel, Duchêne, & Marini, 1998; Kamen & Gabriel, 2009; Mesin, Merletti, & Rainoldi, 2009).

This EMG device allows analyse the spatial and temporal pattern of the electrical activity of the motor units located near the detection area (Basmajian & De Luca, 1985; Clancy et al., 2002; Kamen & Gabriel, 2009). The electrodes placed outside the muscle, on the skin surface, registering the summation of the active muscle fibers potentials, which are conducted, to the surface through the fluids and surrounding tissues is a procedure named surface electromyography (sEMG) (Basmajian & De Luca, 1985; Clancy et al., 2002).

In biomechanics, the sEMG has been the researchers' preferred mode of data collection and analysis as it facilitates the researcher's control and handling, with a greater comfort to the participant. Moreover, it allows the global analysis of the muscle behaviour, contrary to the intra-muscular EMG that only assesses the reduced number of motor units that are near the detection surface, not being representative of the muscle global activity (Basmajian & De Luca, 1985; Criswell, 2011; Kamen & Gabriel, 2009). It has also been verified a greater reproduction of the sEMG signal in comparison to the intra-muscular electrodes, in signals collected in the same day, as well as, in different days (Basmajian & De Luca, 1985; Criswell, 2011; Kamen & Gabriel, 2009). However, the sEMG presents some limitations. In the last years, some authors have referred the influence of the area where the electrodes are placed on the quality of the electromyographic signal collected, namely on the signal amplitude (Cescon, Rebecchi, & Merletti, 2008; Mesin et al., 2009).

The complexity of the sEMG signal has created the need of the development of several protocols and methods of signal analysis used in different studies (Hogrel et al., 1998). Between 1997 and 1999, the European Project – Surface Electromyography for Non-Invasive Assessment of Muscles

(SENIAM), has been developed a significant effort in order to standardize the electrodes' placement for some muscles. However, it has been difficult to reach a consensus concerning the abdominal muscles (Hermens et al., 2000; Roberto Merletti & Hermens, 2000; Mesin et al., 2009). Nevertheless, the sEMG has been widely used to analyse the muscles' activity, namely the abdominal muscles, in order to understand their function (onset timing, relative and sequence of muscle activation) in different postures and movement sequences (Cescon et al., 2008; Mesin et al., 2009).

McGill and Karpowicz (2009) described nine variations of three main abdominal exercises: the Curl-Up, Side-Bridge and Birddog. According to McGill (2004, 2007), through these exercises, maintaining a global co-contraction of the abdominal wall muscles (bracing) and the neutral position of the lumbar spine, it is possible to work the abdominal muscles, which are important to the lumbopelvic stability, preventing the lesion occurrence and increasing the functionality (McGill, 2007a, 2009; Vera-Garcia, Grenier, & McGill, 2000).

The present study aimed to determine the existence of differences in the electromyographic (EMG) signal, amplitude and relative muscle activation, in the right rectus abdominis (RA) muscle, during the Curl-Up (CU), Side-Bridge (SB) and Bird-Dog (BD) performance, obtained in two different surface electrodes' locations: first location (L_1) used by Allison, Godfrey and Robinson (1998) and O'Sullivan, Twomey and Allison (1998) and the second location (L_2) used by Marshall and Murphy (2003).

METHODS

Sample

This was a cross-sectional study, with a single group that was evaluated in a single moment. The sample consisted of 26 volunteered personal trainers, who were instructors of diverse gymnasium modalities, 12 males and 14 females. The main sample characteristics' are presented in Table 1.

Table 1. Sample characteristics': demographic and anthropometric data with the respective mean values, standard deviation, minimum and maximum.

	Mean ± Standard Deviation	**Minimum**	**Maximum**
Age (years)	26 ± 2.97	21	30
Body mass (Kg)	68.34 ± 16.27	48	98
Height (m)	1.71 ± 0.10	1.58	1.92

The defined inclusion criteria were: education in sports or physical education, namely gymnasium instructors, with at least five years of practical experience. These professionals have a better knowledge of the body scheme and movement, which allows a more precise execution of the proposed exercises (Gregory J. Lehman & McGill, 2001).

The exclusion criteria defined were: history of low back pain, pregnancy, any spinal, neurologic, metabolic, respiratory or cardiovascular pathology, history in both shoulders of injury and history of thoracic, abdomen or shoulder surgery (Garry T. Allison et al., 1998; Hodges & Richardson, 1999b; Marshall & Murphy, 2003; Morris et al., 2013).

Instruments

The instruments used to characterise the sample were the force platform FP4060-10 (Bertec® – Bertec corporation, Columbus, OH, United States of America (USA)) to record the weight, the stadiometer (Seca®, Vila Verde, Sintra, Portugal) to assess the subjects' height and a questionnaire to collect sociodemographic information and verify study' participation criteria.

In order to check the skin impedance level was used an electrode impedance checker (Noraxon®, Scottsdale, Arizona, USA) (Hermens et al., 2000; Kamen & Gabriel, 2009; Roberto Merletti, 1999).

Surface electromyography (sEMG) was collected through the BioPLUX® research device (Plux wireless biosignals SA, Arruda dos Vinhos, Portugal), with 8 channels and a sampling frequency of 1000Hz, using double differential electrode leads (CMRR-110db) (Hermens et al., 2000; Kamen & Gabriel, 2009; Roberto Merletti, 1999). The electrodes sensors were connected to the BioPLUX® research device using wireless connectivity, by Bluetooth on a range of 100 m, and have a gain of 1000 and an analogue filter at 25 to 500Hz. Self-adhesive Ag/AgCl dual snap Noraxon® disposable electrodes for surface EMG were attached to BioPLUX sensors. The electrodes characteristics were 4 cm x 2.2 cm of adhesive area, diameter of each of the two circular conductive areas was 1 cm. For reference electrode we use self-adhesive Ag/AgCl snap Noraxon® disposable electrodes for surface EMG with diameter of the circular adhesive area were 3.8 cm, with the same circular conductive area. The MonitorPlux® v2.0 software was used to visualize and acquire the electromyographic signal. The electromyographic signal was processed and analysed through a routine designed to MATLAB® student version R2012a (MathWorks Inc., Massachusetts, United States of America).

The exercises' execution was video recorded and synchronized by a led signal with the electromyographic signal. A metronome on-line was used to set the time and rhythm of the execution of each exercise's phase.

Procedures

This study's procedures took place at a biomechanics laboratory and were performed in a controlled environment. First, the subjects were instructed and trained to perform the rectus abdominis maximal voluntary isometric contraction (MVIC), according the positions described in Kendall (2005) manual muscle testing (Kendall, McCreary, Provance, Rodgers, & Romani, 2005; Vera-Garcia et al., 2010), and the abdominal bracing in all exercises, as proposed by McGill (2004, 2007).

The skin was prepared to reduce the skin impedance too less than 5KΩ (Garry T. Allison et al., 1998; Criswell, 2011; Kamen & Gabriel, 2009). Therefore, the hair was removed, an abrasive pad was used and the skin was clean with isopropyl alcohol (70%), removing the skin oiliness and the remaining death cells (Garry T. Allison et al., 1998; Clancy et al., 2002; Criswell, 2011; Kamen & Gabriel, 2009). After skin preparation, the bioimpedance was checked, using electrode impedance checker, in order to guarantee that impedance levels were below 5 KΩ, and thus ensure a good EMG signal acquisition (Basmajian & De Luca, 1985; Criswell, 2011; Kamen & Gabriel, 2009). After the electrodes' placement, in order to reduce the skin's impedance, a time interval superior to 5 minutes was performed before the start of the data acquisition (Criswell, 2011; Kamen & Gabriel, 2009).

The electrodes were placed 5 cm below the xiphoid process and 3 cm lateral to the midline for the first location (L_1), as used by Allison et al. (1998) and O'Sullivan, Twomey, & Allison (1998). For de second location (L_2), as used by Marshall & Murphy (2003), the electrodes were placed 3 cm above the umbilicus and 2 cm lateral to the midline. The reference locations marked the middle point of the interelectrodes' distance, that is, the distance center to center between the pair of electrodes (Clancy et al., 2002). The pairs of electrodes were placed parallel to the expected muscle fibers orientation and the inter-electrode distance was 2cm (Basmajian & De Luca, 1985; Clancy et al., 2002; Criswell, 2011; Kamen & Gabriel, 2009). The reference electrode was placed in the anterior superior iliac spine (ASIS) (Garry T. Allison et al., 1998; Basmajian & De Luca, 1985; Criswell, 2011; Hermens et al., 2000; Kamen & Gabriel, 2009). The electrodes' placement is illustrated in Figure 1. During this process, all subjects remained in supine (Hermens et al., 2000).

For the signal collection, each subject performed a total of 3 reps in all the exercises. The exercises were the Curl-Up (CU), Side-Bridge (SB) and Bird-Dog (BD) described by McGill and Karpowicz (2009). The subjects were instructed to maintain the abdominal bracing during the exercises' execution (McGill, 1998, 2007a, 2009; McGill & Karpowicz, 2009).

In the CU exercise, the subjects were in supine position, with the arms crossed over the thorax and hands on the contralateral shoulder, with the knee flexed and the feet on the floor. The subjects were instructed to elevate the upper trunk until the scapulae were completely detached off the ground, focusing on the thoracic motion, without neck or lumbar flexion (McGill, 1998, 2007a, 2009; McGill & Karpowicz, 2009), maintaining the position for 5 seconds. In Figure 2, the final position of the exercise is exemplified.

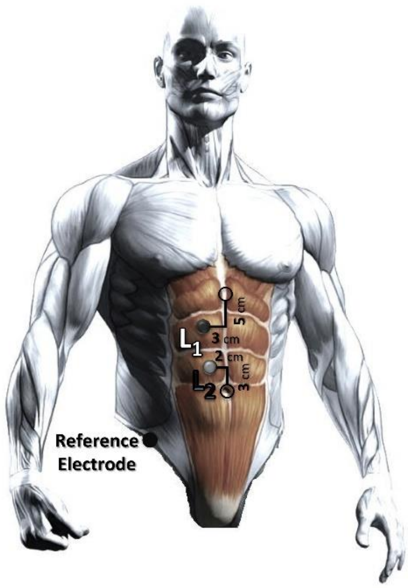

Figure 1. The two different electrode locations: **L_1**-used by Allison, Godfrey and Robinson (1998) and by O'Sullivan, Twomey and Allison (1998); **L_2**-referred by Marshall and Murphy (2003). Picture adapted from http://uscfitness.files.wordpress.com

In the SB exercise, the subjects were in lateral position, supporting the trunk with the hip and elbow, maintaining the shoulder abducted at about 90º and aligned with the elbow flexed at 90º. The hips remained in 45º of flexion. Then, the subjects were instructed to elevate the hip through the hips' extension movement ("squatting") till the lumbopelvic is in the neutral position. This exercise was performed in 4 variations: (1) trunk elevation with the knees flexed at 90º over the left side (SB_1); (2) trunk elevation with the knees flexed at 90º over the right side (SB_2); (3) trunk elevation with the knees in extension over the left side (SB_3); and (4) trunk elevation with the knees in extension over the right side (SB_4) (McGill, 1998, 2007a, 2009; McGill & Karpowicz, 2009). The final position for each of the variations was maintained for 5 seconds. In Figure 3, the final position of SB_4 exercise is exemplified.

In the BD exercise, the subjects were in quadruped position, with shoulders flexed at 90º, elbows slightly flexed (avoiding close-pack position) and hands supported on the floor aligned with the shoulders. The knees were flexed at 90º, vertically aligned with the hips. The initial exercise consisted of the lower limb's extension to the neutral position of the hip and knee. After that, the subjects were instructed to keep the lower limb extended and simultaneously elevate the upper limb to 180º of shoulder flexion, avoiding crossing of the horizontal line. This exercise was performed in 4 variations: (1) extension of the left lower limb (BD_1); (2) extension of the right lower limb (BD_2); (3) extension of the left lower limb and elevation of the right upper limb (BD_3); and (4) extension of the right lower limb and elevation of the left upper limb (BD_4) (McGill, 1998, 2007a, 2009; McGill & Karpowicz, 2009). During the exercise performance, the neutral position of the neck and lumbar spine was maintained. The final position for each of the variations was maintained for 5 seconds. In Figures 4 and 5, the final position of the BD_2 and BD_4 are exemplified, respectively.

The exercises' order was random and for each exercise variation, subjects performed 3 reps, emphasizing normal breathing (avoiding apnoea).

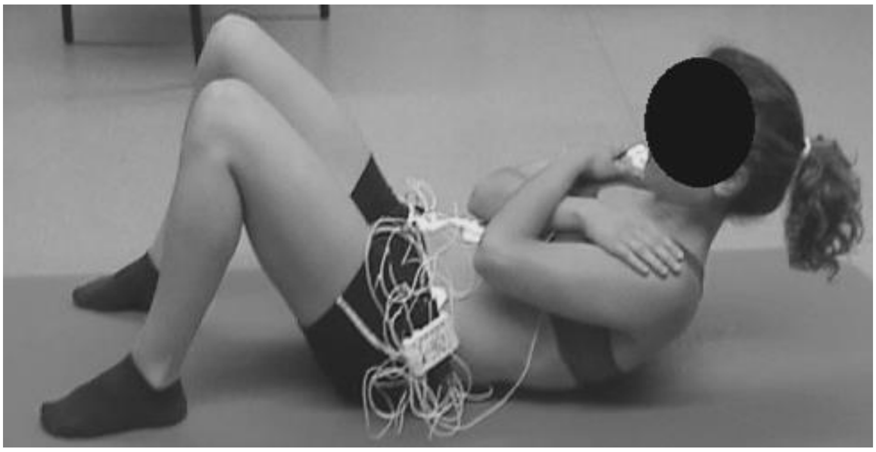

Figure 2. Final position of the Curl-Up Exercise.

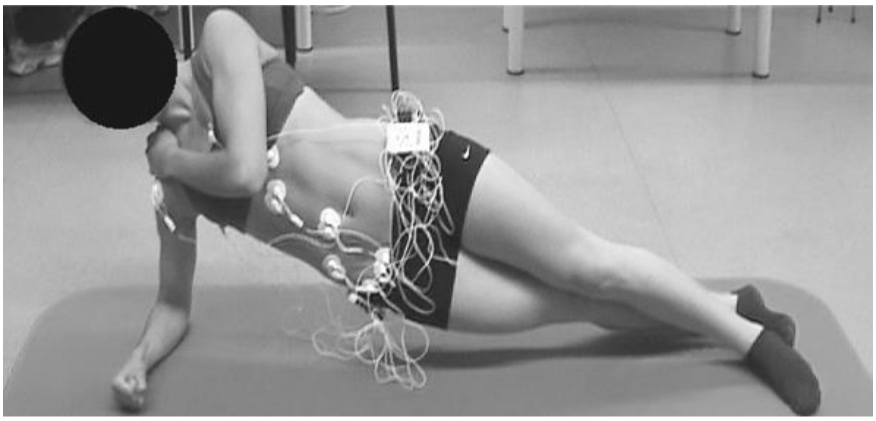

Figure 3. Final position of the right Side-Bridge Exercise (SB_4).

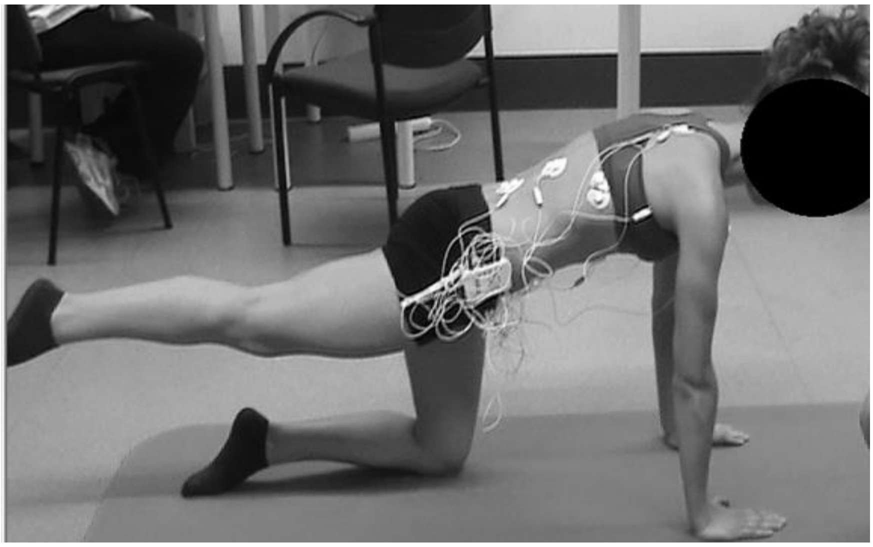

Figure 4. The Bird-Dog Exercise with the right extension of the lower limb (BD_2).

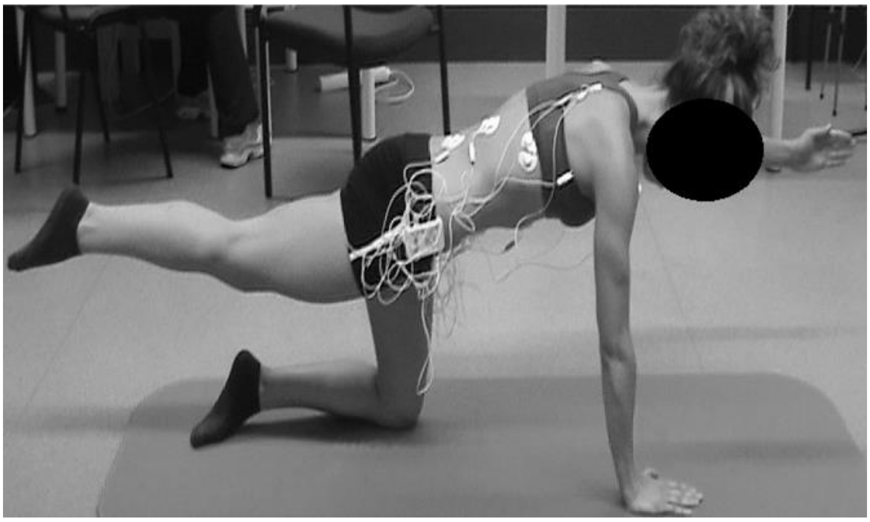

Figure 5. The final position of Brid-Dog Exercise (BD_4).

Three repetitions of the MVIC test were performed to obtain the maximum amplitude of the rectus abdominis. The test consisted of the Curl-Up and the final position was maintained for 5 seconds with an isometric contraction, resisting a force applied to the chest in the opposite direction of the movement (Kendall et al., 2005; Vera-Garcia et al., 2010).

The data collected by Monitor PLUX® was then converted and processed through a routine developed in MatLab® student version software. In this way, were applied, to the EMG signal, a 2nd order digital filter Infinite Impulse

Response – Butterworth, one of 10Hz (high pass) and the another of 450Hz (low pass), in order to remove electrical noise and/or cable movement; and the last one of 30Hz (high pass), in order to remove cardiac signal from EMG signal. Than the root mean square (RMS) at 10 samples was calculated (Basmajian & De Luca, 1985; Clancy et al., 2002; Criswell, 2011; Kamen & Gabriel, 2009).

The electromyographic (EMG) signal amplitude used for the analysis was taken from the 3 intermediate seconds of each exercise repetition, recording the RMS within this time interval (Basmajian & De Luca, 1985; Criswell, 2011; Kamen & Gabriel, 2009).

For EMG normalization we used the 3 MVICs performed by each subject, than we determined the RMS amplitude recorded over a 300ms window, which represented 100% of MVIC amplitude. For each exercise condition, we calculated the RMS amplitude for each repetition and expressed each as a percentage of the MVIC (% MVIC) (Bamman, Ingram, Caruso, & Greenisen, 1997; Basmajian & De Luca, 1985; Criswell, 2011; Kamen & Gabriel, 2009).

Ethics

The study were conducted in accordance with the declaration of Helsinki and approved by the Institutional Research Ethics Committee, and each individual provided a written informed consent before participation.

Statistics

Descriptive and inferential statistics analysis were done using IBM SPSS Statistics® version 20.0 (IBM Corp.®, New York, United States), for Mac OS X (64-bit), with a 95% confidence interval (α=0.05).

Since the sample was less than 30 subjects we used the Wilcoxon test to calculate all p-values. (Marôco, 2011).

To determine whether there were significant differences between the data obtained from the two different locations (L_1 vs. L_2) in respect to the electromyographic signal amplitude and the %MVIC obtained, the t-test for paired samples was performed in variables whose difference followed the normal distribution. For other variables, the Wilcoxon test was applied (Marôco, 2011).

RESULTS

For the electromyographic signal amplitude, measured by the RMS values, were found significant differences between the signal amplitudes in L_1 and L_2, through the Wilcoxon test. The EMG signal obtained in L_1 was higher, compared to L_2 ($p<0.05$). The RMS results obtained in the two different locations are illustrated in Table 2.

Regarding the relative muscle activation, measured through the %MVIC, the Wilcoxon test demonstrated the non-existence of significant differences from the signal obtained in the two different locations (L_1 vs. L_2) ($p>0.05$). The %MVIC results obtained in the two different locations are illustrated in Table 3.

Table 2. RMS values (median, interquartile deviation and p-value) obtained from the different electrodes' location.

Exercise	Electrodes' location	RMS Median (mV)	Interquartile deviation	p-value Wilcoxon Test
Curl-Up	L1	0.06078	0.02464	**0.001**
	L2	0.03756	0.01964	
BD_1	L1	0.00997	0.00831	**0.016**
	L2	0.00579	0.0031	
BD_2	L1	0.01072	0.00194	**0.005**
	L2	0.00624	0.00260	
BD_3	L1	0.00775	0.00823	**0.002**
	L2	0.00696	0.00311	
BD_4	L1	0.01155	0.00528	**0.0005**
	L2	0.00569	0.00220	
SB_1	L1	0.01048	0.01023	**0.004**
	L2	0.00568	0.00700	
SB_2	L1	0.03624	0.02675	**0.019**
	L2	0.02521	0.01900	
SB_3	L1	0.01649	0.01254	**0.001**
	L2	0.01109	0.00997	
SB_4	L1	0.03514	0.02640	**0.021**
	L2	0.02286	0.01100	

Legend:
L1 – 5 cm inferior to the xiphoid process and 3 cm lateral to the midline
L2 – 3 cm superior to the umbilicus and 2 cm lateral to the midline
SB_2 – *Side-Bridge*-Exercise over the right side with the knees flexed at 90º
SB_3 – *Side-Bridge*-Exercise over the left side with the knees in extension
BD_1 – *Bird-Dog*-Exercise with the left lower limb extended
BD_2 –*Bird-Dog* Exercise-with the right lower limb extended
BD_4 – *Bird-Dog*-Exercise with the right lower limb extended and elevation of the left lower limb
SB_1 – *Side-Bridge*-Exercise over the left side with the knees flexed at 90º
SB_4 – *Side-Bridge*-Exercise over the right side with the knees in extension
BD_3 – *Bird-Dog*-Exercise with extension of the left lower limb and elevation of the right upper limb
RMS – Root mean square

Table 3. Percentage of the Maximal Voluntary Isometric Contraction (%MVIC) values obtained from the two different electrodes' location.

Exercise	Electrodes' location	Median of %MVIC (%)	Interquartile deviation	p-value Wilcoxon Test
Curl-Up	L1	20.73	12.66	**0.481**
	L2	20.93	7.67	
BD_1	L1	2.64	1.77	**0.284**
	L2	3.04	2.06	
BD_2	L1	3.07	1.39	**0.485**
	L2	3.13	0.87	
BD_3	L1	3.02	1.46	**0.500**
	L2	2.51	1.09	
BD_4	L1	3.66	0.48	**0.137**
	L2	2.72	1.10	
SB_1	L1	3.41	3.68	**0.122**
	L2	2.84	4.01	
SB_2	L1	9.25	1.62	**0.188**
	L2	11.29	1.72	
SB_3	L1	4.45	3.91	**0.232**
	L2	4.97	4.10	
SB_4	L1	6.31	8.71	**0.382**
	L2	10.15	3.06	

Legend:

L1 – 5 cm inferior to the xiphoid process and 3 cm lateral to the midline
L2 – 3 cm superior to the umbilicus and 2 cm lateral to the midline
SB_2 – *Side-Bridge*-Exercise over the right side with the knees flexed at 90º
SB_3 – *Side-Bridge*-Exercise over the left side with the knees in extension
BD_1 – *Bird-Dog*-Exercise with the left lower limb in extension
SB_1 –*Side-Bridge*-Exercise over the left side with the knees flexed at 90º
SB_4 – *Side-Bridge*-Exercise over the right side with the knees in extension
BD_2 – *Bird-Dog*-Exercise with the right lower limb in extension
BD_3 – *Bird-Dog*-Exercise with extension of the left lower limb and elevation of the right upper limb
BD_4 – *Bird-Dog*-Exercise with the right lower limb extended and the elevation of the left upper limb
%MVIC – Percentage of maximal voluntary isometric contraction

DISCUSSION

Kamen & Gabriel (2009) report that the amplitude of the EMG signal varies according to the muscle electrical activity detected by the electrodes at each moment, providing information on the muscle activation (Kamen & Gabriel, 2009).

Quantification of the electromyographic signal is the condition under which the EMG can be used in many experimental situations, since the reliance on the parameters of the raw EMG trace and give little objective information. For a more accurate and objective assessment, different ways to quantify the signal are used. One of the most commonly used parameters to measure the electromyographic signal amplitude is the root mean square (RMS) (Garry T. Allison et al., 1998; Basmajian & De Luca, 1985; Clancy et al., 2002; Criswell, 2011; Kamen & Gabriel, 2009; Roberto Merletti, 1999; Roberto Merletti & Hermens, 2000).

The present study meant to determine the existence of differences in values obtained from the electromyographic signal amplitude, in the right rectus abdominis, in two different electrodes' location. The EMG signal amplitude was assessed through the RMS and the signal was collected during the isometric phase of the executed exercises. Significant differences were found on the results of the electromyographic signal amplitude obtained in L_1 and L_2. In L_1 was registered a higher amplitude of the electromyographic curve.

According to published data, the variation of the electromyographic signal amplitude can arise from several factors, namely the presence of motor points and tendon areas, or the existence of a higher density of subcutaneous tissue between the sensing surface and the muscle, that leads to a lower electromyographic amplitude in the electromyographic curve (Beck, Housh, Cramer, & Weir, 2008; Cescon et al., 2008; Hermens et al., 2000; Hogrel et al., 1998).

When we place the electrodes on the centre of the muscle belly or near the motor endplate, it becomes easier to achieve higher EMG signal amplitudes (Basmajian & De Luca, 1985; Criswell, 2011; Hermens et al., 2000; Kamen &

Gabriel, 2009). However, current knowledge indicates that the signal collected at or near the area of the motor endplate, cannot be considered appropriate, since it is unstable and small variations in the location of the electrodes can reflect on large changes in signal amplitude (Beck et al., 2008; Hermens et al., 2000; Roberto Merletti & Hermens, 2000).

Currently, it is established that to obtain higher electromyographic signal amplitudes without the occurrence of large variations, the electrodes should be placed outside the region of the muscle innervation and centred on the muscle belly (Beck et al., 2008; Criswell, 2011; Hermens et al., 2000; Kamen & Gabriel, 2009).

Lately, studies have been developed on the distribution of motor endplates in the muscles, using electrodes arrays (Roberto Merletti, Farina, & Gazzoni, 2003). However, no study has been published relatively to the abdominal area. Nevertheless, Stevenson et al (2002), in a study of the anatomy of the abdominal region, which included 12 cadavers, found that there was a great variation on the distribution of the nerve trunks in the rectus abdominis muscle, as well as, the distribution of the muscle tendon regions (Yap, Stevenson, Whiten, & Forster, 2002). Despite this variability, we observed that in the first location, the EMG signal amplitude was significantly higher, compared with the second location.

Studies also indicate the existence of a large variability in the amplitude of the electromyographic signal among the different muscles of the body, as well as, between the same muscle in different subjects or between the same subject on diverse days, using the same references for the electrodes' location (Criswell, 2011; Kamen & Gabriel, 2009; Gregory J. Lehman & McGill, 2001). Due to this fact, to quantitatively compare the activity of a muscle, some studies have analysed the muscle activity using the normalization to the maximum of the electromyographic signal of the muscle (Criswell, 2011; Kamen & Gabriel, 2009; Gregory J. Lehman & McGill, 2001).

The normalization of the EMG signal in relation to percentage of maximal voluntary isometric contraction, represent the degree (in percentage) in which the muscle is working relatively to its maximum activity, allowing the quantitative comparison of the muscular activity among different subjects, or in the same subject in different days or even between different muscles (Basmajian & De Luca, 1985; Criswell, 2011; Kamen & Gabriel, 2009; Gregory J. Lehman & McGill, 2001).

Studies on the effect of the electrodes' location have been more focused on the EMG signal amplitude, conduction velocity and mean power frequency (Beck et al., 2008; Cescon et al., 2008; Hogrel et al., 1998; Mercer, Bezodis, DeLion, Zachry, & Rubley, 2006; Mesin et al., 2009). However, no study has mentioned the effect of the electrodes' location after the normalization of the EMG signal to the maximum activity of the muscle.

Given the results obtained in this study, it should been taken into consideration the reference used in the electrodes' location when comparing studies that intend to withdraw their conclusions from the EMG signal amplitude values.

CONCLUSION

In this study it was found that, in the right rectus abdominis, the EMG signal amplitude obtained in two different locations used to collect the EMG signal was different. Therefore, in the uppermost pair of electrodes (L_1), the electromyographic signal amplitude was significantly higher than in the lower location (L_2). However, despite this difference found in the electromyographic signal amplitude, after the normalization of the signal to the maximum voluntary isometric contraction, no significant differences were found between the relative muscle activation values obtained for each location.

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3.5. STUDY V – ANALYSIS OF DIFFERENT ACTIVATION PATTERNS USED DURING PRONE HIP EXTENSION BETWEEN SUBJECTS WITH AND WITHOUT CHRONIC LUMBOPELVIC PAIN

PAULO CARVALHO*[1,2], JORGE TEIXEIRA[1,3], ANTÓNIO MESQUITA MONTES[1,2], RUBIM SANTOS[2], JOÃO PAULO VILAS-BOAS[4]

[1] *Physical Therapy Department – School of Allied Health Sciences of Porto/Porto Polytechnic Institute (ESTSP/IPP), Vila Nova de Gaia, Portugal*

[2] *Center of Study for the Movement and Human Activity (CEMAH) - ESTSP/IPP, Vila Nova de Gaia, Portugal*

[3] *Private clinical practice*

[4] *Porto Biomechanics Laboratory (LABIOMEP), Faculty of Sport, CIFI2D, University of Porto, Porto, Portugal*

***Corresponding author:**

Physical Therapy Department – School of Allied Health Sciences of Porto/Porto Polytechnic Institute (ESTSP/IPP), Vila Nova de Gaia, Portugal
Rua Valente Perfeito, 322
4400-330, Vila Nova de Gaia, Portugal.
E-mail address: pmc@estsp.ipp.pt (Paulo de Carvalho).

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ABSTRACT

Background: The movement pattern may change due to a delay in the onset timing and/or muscle activation sequence, predisposing the individual to motor control disorders, including lumbopelvic pain (LPP). The surface electromyography (sEMG) it's a way to assess these parameters. **Objective:** To describe and compare the onset timing and muscle activation sequence of ipsilateral Gluteus Maximus (GM_Ipsi), ipsilateral Biceps Femoris (BF_Ipsi) and ipsilateral (ES_Ipsi) and contralateral (ES_Contra) Erector Spinae muscles, during the hip extension movement of the dominant lower limb, in subjects with and without chronic lumbopelvic pain. We also intend to investigate the presence of muscle activation sequence considered "ideal" and the relation between the pelvic tilt and the muscle activation sequence, in both groups. **Methods:** Cross sectional study, with a sample composed by 64 volunteer college students, divided in two groups: 31 without lumbopelvic pain (NLPP group) and 33 with lumbopelvic pain (LPP group). Through sEMG it was collected the electromyographic signal of the GM_Ipsi, BF_Ipsi, ES_Ipsi and ES_Contra muscles. It was analysed the onset timing and respective orders of activation. Additionally pelvic tilt was measured, with palpation meter-PALM, in the both groups. Statistical data was processed in the SPSS software, version 20.0 for MAC OS, with a significance degree of 0.05. **Results:** The group with LPP presented a delay in the onset timing of GM_Ipsi ($t=-3.171;p=0.002$) and BF_Ipsi ($t=-2.092;p=0.041$) compared with the NLPP group. There was an association between the 5 most frequent orders of muscle activation sequence and the presence of lumbopelvic pain ($x_f^2=11.54;p=0.015$). The "ideal" order of muscle activation sequence (GM_Ipsi>BF_Ipsi>ES_Contra>ES_Ipsi) was never used. It was found that the BF_Ipsi was mostly the first to be activated and the GM_Ipsi was the last in both groups. The subjects that activate first the BF_Ipsi have a significantly higher pelvic tilt (LPP group: $U=51$; $p=0.001$ and NLPP group: $U=41;p=0.001$). **Conclusion:** It was found a consistent pattern of activation in each group. It was not possible to support or refute the theory that a delay in activation of the Gluteus Maximus is associated with lumbopelvic pain, since it was the last to be activated in both groups, although it was found a higher

delay in the LPP group. This information's are important to the investigators/clinicians who use the test as an assessment tool and/or as an rehabilitation exercise.

Key Words: EMG, Lumbopelvic Pain, Low Back Pain, Prone Hip Extension, Pelvic Tilt.

INTRODUCTION

The chronic nonspecific lumbopelvic pain is the most often clinical situation that affects the axial skeleton, being defined as any chronic or recurrent pain in this region. This condition is the leading cause of limitation of physical activity before age 45 and the second between 45 and 65 years (Paul Bruno & Bagust, 2006; Ponte, 2005). Corresponds to the second cause of consultation in general practice and the first in rheumatology, which implies high costs for health and social systems, leading to high rates of absenteeism and incapacity for work (Arab et al., 2011; Paul Bruno & Bagust, 2006; Paul Bruno et al., 2008; Ponte, 2005).

Despite its high incidence and its adverse effects on activities of daily living, their exact causes are not yet fully understood and there is a reportedly effective approach to its diagnosis and treatment (Arab et al., 2011). However, in recent decades, there has been further evidence in the rehabilitation of low back muscles in order to intervene in the motor control of this region (Arab et al., 2011; Paul Bruno & Bagust, 2006; Lederman, 2010).

The motor control refers to the use of the correct onset timing, muscle activation sequence and intensity of activation to achieve specific patterns of movement, being the result of coordinated activity of the synergistic, agonistic and antagonistic muscles (Arab et al., 2011; Paul Bruno & Bagust, 2006; Paul Bruno et al., 2008; Jouffroy & Médina, 2006; Lederman, 2010; Lieberman, Raichlen, Pontzer, Bramble, & Cutright-Smith, 2006; Sakamoto, Teixeira-Salmela, Rodrigues de Paula, Guimarães, & Faria, 2009). However, it's noteworthy that the Gluteus Maximus (GM) muscle is active primarily in activities involving the lumbopelvic stabilization and tasks such as climbing stairs and running (Jouffroy & Médina, 2006; Lieberman et al., 2006; Ward, Winters, & Blemker, 2010; Wilson, Ferris, Heckler, Maitland, & Taylor, 2005).

Therefore, it is pertinent to analyse the activity of the muscle and his synergists, to observe how they act in lumbopelvic stabilization during activities of daily living. The evaluation of this muscle activity can be accomplished by some clinical tests such as the hip extension test (Arab et al., 2011; Lewis & Sahrmann, 2009; Tateuchi et al., 2012). This test was developed by Vladimir Janda, in 1987, and is a common and valid test, specially in clinical practice, selected to simulate the extension of the hip in the standing position and to determine the pattern of muscle activation of the lumbopelvic region (Paul Bruno et al., 2008; G. J. Lehman et al., 2004; Page et al., 2010; Takasaki, Iizawa, Hall, Nakamura, & Kaneko, 2009).

It has been theorized that there is a "ideal" pattern of muscle activation sequence during this functional test: Gluteus Maximus ipsilateral (GM_Ipsi) > Biceps Femoris ipsilateral (BF_Ipsi) > Erector Spinae contralateral (ES_Contra) > Erector Spinae ipsilateral (ES_Ipsi) (Paul Bruno & Bagust, 2007; Paul Bruno et al., 2008; G. J. Lehman et al., 2004; Sahrmann, 2002). The same theory holds that changes in patterns of lumbopelvic motion, as a result of changes in the timing and intensity of muscle activation, may be due to repetitive movements and abnormal postures in the long term, which will change the characteristics of muscle tissue and might cause dysfunction (Lewis & Sahrmann, 2009; Sahrmann, 2002).

One of the most common disorders occurs when the hamstrings and erector spine (ES) activate during the first movement, in order to compensate the delay in activation of the gluteus maximus (GM), favouring the occurrence of anterior pelvic tilt and excessive lumbar extension, resulting in increased compressive and anterior shear force on the lumbar spine and lumbosacral joint (Evcik & Yucel, 2003; Guimarães, Sakamoto, Laurentino, & Teixeira-Salmela, 2010; S. Y. Kang, Jeon, Kwon, Cynn, & Choi, 2013; J. H. Lee & Yoo, 2011; Tateuchi et al., 2012). Therefore, the LPP may arise or be perpetuated by nociceptive mechanical stress and tension surrounding tissues, due to the asymmetry of the pelvic girdle, making the role of the muscles responsible for stabilizing the region, developing a vicious cycle (J. H. Lee & Yoo, 2012; Sarikaya, Ozdolap, Gumustass, & Koc, 2007).

Studies that address motor control and lumbopelvic postural asymmetries are needed in order to facilitate the implementation of preventive measures and effective intervention for the clear differentiation of a particular activation pattern in individuals with and without LPP is still controversial (Herrington, 2011; Juhl, Ippolito Cremin, & Russell, 2004; Sahrmann, 2002). The evidence is also scarce, regarding the association between muscle activation sequence and postural deficits in motor control (Paul Bruno & Bagust, 2006; G. J. Lehman et al., 2004; Takasaki et al., 2009).

Therefore, the aim of this study was to investigate the onset timing and muscle activation sequence of GM_Ipsi, BF_Ipsi, ES_Ipsi and ES_Contra muscles, during the hip extension movement, of the dominant limb, in individuals with and without LPP. It is intended, also, observe the existence of the muscle activation sequence considered "ideal" and the relationship between the muscle activation sequence and the pelvic tilt, in both individuals.

METHODS

Sample

The study design was observational, analytical and cross-sectional.

The sample consisted of 64 individuals, volunteers for this study, within age between 18 and 35 years, divided in two groups, one without lumbopelvic pain (NLPP) – 31 subjects, and the other with lumbopelvic pain (LPP) – 33 subjects.

In this study, the inclusion criteria for the LPP group were: recurrent episodes of lumbopelvic pain for a period greater than three months, while for the group without lumbopelvic pain could not have experienced pain in this region. (Arab et al., 2011; Silfies et al., 2005). In the NLPP group were included individuals who not have story of LPP, which prevented the performance of normal activities for at least one day in the last three months (Paul Bruno et al., 2008; Jacobs et al., 2011).

Were excluded in both groups, individuals who had: history of injury or trauma of the hip joint, history of lumbar spine surgery, history of spondyloarthropathies diagnosed, history of brain injury or neuromuscular disease; pain during the hip extension test, history of pregnancy; individuals who were receiving physiotherapy treatment in order to resolve the LPP (Paul Bruno et al., 2008; Jacobs et al., 2011; G. J. Lehman et al., 2004; Tateuchi et al., 2012).

Instruments

The sample selection and characterization was conducted through a questionnaire, to ascertain the inclusion and exclusion participation criteria, and also, information about the individuals' sociodemographic data.

Anthropometric measurements were assessed using a force platform Bertec® FP4060-10 (Bertec® – Bertec corporation, Columbus, OH, USA) to record body mass and a stadiometer Seca® 222 (Seca® – Medical Scales and Measuring Systems, Birmingham, United Kingdom) to record the height.

Surface electromyography (sEMG) was collected through the BioPLUX® research device (Plux wireless biosignals SA, 2630-369 Arruda dos Vinhos, Portugal), with 8 channels and a sampling frequency of 1000Hz, using double differential electrode leads (CMRR-110db) (Hermens et al., 2000; Kamen & Gabriel, 2009; Roberto Merletti, 1999).

The electrodes sensors were connected to the BioPLUX® research device using wireless connectivity, by Bluetooth on a range of 100m, and have a gain of 1000 and an analogue filter at 25 to 500Hz.

Self-adhesive Ag/AgCl dual snap Noraxon® disposable electrodes for surface EMG were attached to BioPLUX sensors. The electrodes characteristics were 4cm x 2.2cm of adhesive area, diameter of each of the two circular conductive areas - 1 cm, and the inter-electrode distance - 2cm. For reference electrode we use self-adhesive Ag/AgCl snap Noraxon® disposable electrodes for surface EMG with diameter of the circular adhesive area were 3.8cm; diameter of the circular conductive area were 1cm.

We use the MonitorPlux® software version 2.0 in order to visualize and acquire the electromyographic signal.

In order to check the skin impedance level was used an electrode impedance checker (Noraxon®, Scottsdale, Arizona, USA) (Hermens et al., 2000; Kamen & Gabriel, 2009).

The beginning of motion was allowed by a Light-Emitting Diode (LED) and detected by two pressure transducer TSD111® (Biopac® Systems, Inc., California, USA) placed one at the anterior proximal third of the thigh and another at the anterior distal third of the tibia. The range of motion was measured using a Biopac® electrogoniometer (model - TSD130B). This data were acquired using a Biopac® MP150WSW Data Acquisition System (Biopac® Systems, Inc., California, USA) with a sampling frequency of 100Hz and the data collected through the Acqknowledge® software version 4.0 (Biopac® Systems Inc., California, USA). In order to synchronize the two acquisition and research systems was used a cable to allowed the connection between the BioPLUX® and the Biopac® MP150WSW Data Acquisition Systems. To provide final range feedback to the individuals (20º measured by electrogoniometer), we used photovoltaic cells sensors Brower Timing Systems® IRD-T175 (Brower Timing Systems®, Utah, USA).

The pelvis position in the sagittal plane was measured with a palpation meter PALM (Performance Attainment Associates®, Minnesota, USA). This instrument has been used in many other studies and proved to be useful to measure the angle between the upper anterior iliac spine (ASIS) and posterior superior iliac spine (PSIS) (Gnat, Saulicz, Biały, & Kłaptocz, 2009; Krawiec, Denegar, Hertel, Salvaterra, & Buckley, 2003).

To evaluate the pain intensity of LPP group, in the last pain episode, was used the Visual Analogue Scale (VAS) (Carlsson, 1983; Ferreira-Valente et al., 2011; Ponte, 2005).

Procedures

This study's procedures took place in a biomechanics laboratory and were performed in a controlled environment.

Initially, in addition to the evaluation of anthropometric characteristics, height and body mass, we performed a musculoskeletal examination, which included motion tests (namely, the active flexion of the hip with the knee in extension and the passive hip flexion with active and passive hip adduction and medial rotation) (Lewis & Sahrmann, 2009). During this motion test, individuals were instructed to rate their pain using the VAS and as referred were excluded in presence of pain (Lewis & Sahrmann, 2009).

The skin was prepared, reducing the skin impedance too less than 5KΩ. Therefore, the hair was removed, an abrasive pad was used and the skin was clean with isopropyl alcohol (70%), removing the skin oiliness and the remaining death cells (Paul Bruno & Bagust, 2007; Hermens et al., 2000; Kamen & Gabriel, 2009; Lewis & Sahrmann, 2009).

After skin preparation, the adhesive electrodes were placed in the testing position in order to prevent the skin movement. The individuals were positioned in the prone position on a table, with their arms along the body, and the feet aligned with the shoulders and the ankle in neutral position (Paul Bruno & Bagust, 2006; P. Bruno & Murphy, 2011; Page et al., 2010). A stabilize band was used, in order to stabilize the pelvis and limit the movement only at the hip joint (Lewis & Sahrmann, 2009). Data were collected in the dominant lower limb, identified by the preference in the activity of "kicking a ball" (Boren et al., 2011; Chance-Larsen, Littlewood, & Garth, 2010).

The electrodes were placed in accordance to the guidelines of Criswell (2011): for GM_Ipsi were placed at the midpoint of the line drawn from the last sacral vertebrae to the greater trochanter; in ES_Contra and ES_Ipsi were placed bilaterally about 2 cm to the level of the spinous process of L3, parallel to the spine on the muscle; and in BF_Ipsi were placed at the midpoint of the line between the ischium tuberosity and the lateral epicondyle of the tibia. The reference electrode was placed on the lateral malleolus of the non-dominant side (Arab et al., 2011; Boren et al., 2011; Criswell, 2011; Tateuchi et al., 2012).

It has established a time lag between placement of the electrodes and the beginning of the collection of the EMG signal of 5 minutes. All locations for placing the electrodes were confirmed by palpation and its activity was confirmed by viewing the signal during the application of a manual resistance for each muscle (Arab et al., 2011; Boren et al., 2011; Chance-Larsen et al., 2010; Tateuchi et al., 2012).

Individuals were instructed to perform the hip extension movement, after the visualization of LED activation, up to 20°, keeping the knee in extension, ankle in neutral position and without hip rotation (Tateuchi et al., 2012). In order to maintain knee extension during the movement it was placed tape, at the level of the anterior tibial tuberosity, crossing the knee joint, acting as a tactile feedback (Arab et al., 2011; Lewis & Sahrmann, 2009). The individuals were trained to perform this movement smoothly. Subsequently, were recorded three repetitions for subsequent analysis and calculation of its mean onset timing (Arab et al., 2011; Paul Bruno & Bagust, 2006; Tateuchi et al., 2012).

After the EMG data collection, the pelvic tilt was evaluated in an upright posture, with the individuals with the arms crossed over their chest, the weight distributed and feet 30 cm apart, looking at the skyline, in order to control the postural sway (Herrington, 2011; J. H. Lee & Yoo, 2011). Subsequently, the investigator palpated and marked the reference points of the ipsilateral ASIS and PSIS of the dominant lower limb and placed the PALM to measure the angle of pelvic tilt (Gnat et al., 2009; Herrington, 2011; Krawiec et al., 2003; Stovall & Kumar, 2010).

Data Processing

For each repetition of the motion test, the data were submitted to the same procedure, aiming to determine the onset timing and the sequence of muscle activation. The synchronization of apparatus and processing of EMG signal was performed using a routine developed in MatLab® student version software and their analysis was accomplished in software Acqknowlegde® version 4.0.

In this way, were applied, to the EMG signal, a 2nd order digital filter Infinite Impulse Response – Butterworth, one of 10Hz (high pass) and the another of 450 Hz (low pass), in order to remove electrical noise and/or cable movement. Than, the root mean square (RMS), a 10 samples, was calculated (Criswell, 2011; Kamen & Gabriel, 2009).

Through the MatLab® routine we identify the point where the pressure registered in the transducer, derived from baseline. The timing of muscle activation was defined as the interval time between this point and the onset of EMG activity of each of the muscles recorded (Paul Bruno et al., 2008; Chance-Larsen et al., 2010; Lewis & Sahrmann, 2009).

EMG onset timing was considered as the time when mean RMS of 30 consecutive frames (30 ms) exceeded baseline for 2 standard deviations. Base line EMG activity was determined in a 50 ms period, 500 ms before the point (-500 to -450 msec) in which the EMG activity clearly derived from baseline. All traces were evaluated visually inspected in software Acqknowlegde® version 4.0 to ensure that the onset was not obscured by movement artifact or an electrocardiogram (<7% of trials) (Paul Bruno & Bagust, 2007; Paul Bruno et al., 2008; Hodges & Bui, 1996). Than was determined the average muscle activation timings of the three repetitions of the movement test (Park et al., 2011).

The pelvic tilt is defined as the angle formed by a horizontal line drawn between ASIS and PSIS. The mean of the three measurements was determined (Gnat et al., 2009; Herrington, 2011).

Ethics

The study were conducted in accordance with the declaration of Helsinki and approved by the Institutional Research Ethics Committee, and each individual provided a written informed consent before participation.

Statistics

Descriptive and inferential statistics analysis of this study was done by IBM SPSS Statistics® version 20.0 (IBM Corp.®, New York, United States), for Mac OS X (64-bit), with a 95% confidence interval (significance level of 0.05).

In sample characterization and most study variables, the respective mean, standard deviation, maximum and minimum were used as descriptive statistics (Marôco, 2011). For the comparison between groups (in the pelvic tilt and muscles onset timings) we used the t-test for two independent samples. The assumptions of t-tests were guaranteed by the central limit theorem, since each group consisted of more than 30 subjects (Marôco, 2011). The analysis of the order and sequence of muscle activation was performed resorting to the comparison of absolute and relative frequencies of each group. To verify the existence of a significant association between the 5 sequences of muscle activation more frequently used and their respective group was used the Fisher exact test (chi-square assumptions were not insured) (Marôco, 2011). Also, to attest how certain sequences of muscle activation influences the pelvic tilt was used the Mann-Whitney-U nonparametric test, due to the low sample size in each sequence. In this last comparison, the variables was characterized by median and interquartile deviation (Marôco, 2011).

RESULTS

Sample

The NLPP group comprised 19 females, and in its turn, the LPP group consisted of 22 females. In the LPP group was observed an average pain intensity of 50.6 ± 0.86 mm (in the VAS scale) and a mean duration of 6.94 ± 1.90 years. The demographic and anthropometric data of the both groups (Table 1) showed no significant differences (p>0,05), and therefore, the groups were comparable.

Study Results

In Figure 1, it can be seen the mean and standard deviation values of the onset timings. In LPP group compared with the NLPP group, observed that the GM_Ipsi (t=-3.171, p=0.002) and BF_Ipsi (t=-2.092, p=0.041) muscles activated significantly later. There were not significant differences between the two groups in the ES_Ipsi and ES_Contra muscles (p>0.05). Additionally, it was observed

Table 1. Characteristics of demographic and anthropometric data of the sample with the respective mean, standard deviation (SD), minimum and maximum values. NLPP – Group without lumbopelvic pain; LPP – Group with lumbopelvic pain.

		Age (years)		Body Mass (Kg)		Height (meters)	
		NLPP (n=31)	LPP (n=33)	NLPP (n=31)	LPP (n=33)	NLPP (n=31)	LPP (n=33)
Mean		23.87	24.97	63.25	65.06	1.69	1.70
SD		2.25	2.17	9.02	9.54	0.08	0.08
Minimum		21.00	21.00	50.30	51.70	1.58	1.57
Maximum		29.00	30.00	80.40	84.60	1.85	1.87
Inter-group Comparison	**p-value**	0.055		0,440		0.659	

that the onset timing of the most muscles occurs before the movement initiation. The exception was the GM_Ipsi muscle, where in the onset timing of the NLPP group occured almost in simultaneous with the movement initiation, contrasting with the delay in LPP group.

Regarding the sequence of muscle activation (Table 2) there was a great variability in both groups (NLPP group: 10 of 24 possible sequences; LPP group: 9 of 24 possible sequences). Despite this variability, there was a significant association between the 5 sequences of muscle activation, more frequently used, and the presence of lumbopelvic pain (X_f^2=11.54, p=0.015).

Therefore, it was noted that the difference in the commom activation sequences in both groups is only in the order of activation of the erector spinae muscles. Also, it was noted that, in none of the groups, the “ideal” sequence (GM_Ipsi>BF_Ipsi>ES_Contra >ES_Ipsi) not was used.

Based on the activation sequences, we also analysed which muscles activated in first and last. Observing Table 3 it can be seen that the BF_Ipsi is usually the first activating muscle in both groups. It can be seen, also, that GM_Ipsi is mostly the last muscle to be activated in the hip extension test.

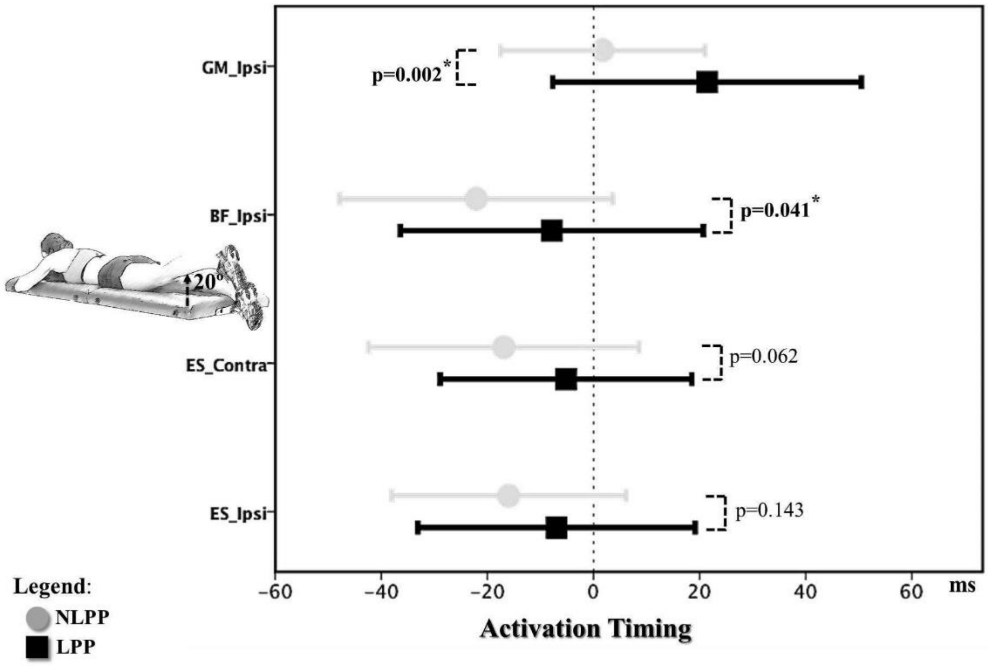

Figure 1. Comparison the onset timings of the Gluteus Maximus Ipsilateral(GM_Ipsi), Biceps Femoris Ipsilateral (BF_Ipsi), Erector Spinae Ipsilateral (ES_Ipsi) and Contralateral (EC_Contra) between the two groups. NLPP – Non Lumbopelvic pain group; LPP – Lumbopelvic pain group. *Significant difference (p<0.05).

Table 2. The 5 most common muscles activating sequences in each group (NLPP – Group without lumbopelvic pain; LPP – Group with lumbopelvic pain) and their respective ranking. The results are presented as relative and absolute frequencies. BF_Ipsi – Biceps Femoris Ipsilateral; ES_Contra – Erector Spinae Contralateral; ES_Ipsi - Erector Spinae Ipsilateral; GM_Ipsi – Gluteus Maximus Ipsilateral.

Sequences (5 most used)	NLPP (n=31)			LPP (n=33)		
	Ranking	Frequency	%	Ranking	Frequency	%
BF_Ipsi>ES_Contra>ES_Ipsi>GM_Ipsi	1	11	**35.5**	3	3	**9.1**
BF_Ipsi>ES_Ipsi>ES_Contra>GM_Ipsi	2	5	**16.1**	1	11	**33.3**
ES_Contra>BF_Ipsi>ES_Ipsi>GM_Ipsi	3	4	**12.9**	2	5	**15.2**
GM_Ipsi>BF_Ipsi>ES_Ipsi>ES_Contra	3	4	**12.9**	4	2	**6.1**
ES_Ipsi>BF_Ipsi>ES_Contra>GM_Ipsi	4	2	**6.5**	2	5	**15.2**
"Ideal" sequence GM_Ipsi>BF_Ipsi>ES_Contra>ES_Ipsi	**Not used**			**Not used**		
p-value	**0,015***					

Table 3. The muscles that had a higher frequency of activation in the first and last place in the activation sequence. The results are presented as relative and absolute frequencies. BF_Ipsi–Biceps Femoris Ipsilateral; ES_Contra–Erector Spinae Contralateral; ES_Ipsi–Erector Spinae Ipsilateral; GM_Ipsi–Gluteus Maximus Ipsilateral; NLPP–Group without lumbopelvic pain; LPP–Group with lumbopelvic pain.

	NLPP (n=31)		LPP (n=33)	
Muscle	**1st Muscle**		**1st Muscle**	
	Frequency	%	Frequency	%
BF_Ipsi	16	**51.6**	16	**48.5**
ES_Contra	7	**22.6**	9	**27.3**
ES_Ipsi	4	**12.9**	8	**24**
GM_Ipsi	4	**12.9**	0	**0.0**
Muscle	**Last Muscle**		**Last Muscle**	
	Frequency	%	Frequency	%
GM_Ipsi	24	**77.4**	29	**87.9**
ES_Contra	5	**16.1**	2	**6.1**
BF_Ipsi	2	**6.5**	1	**3.0**
ES_Ipsi	0	**0.0**	1	**3.0**

Table 4. The onset timing of the first and the last muscle in the sequence in both groups (NLPP – Group without lumbopelvic pain; LPP – Group with lumbopelvic pain). Presents the respective values of mean, standard deviation (SD), confidence interval, test value and p-value. *Significant differences (p<0.05).

Muscle	Group	Mean	SD	Confidence interval	Test value	p-value
Onset Timing **1st Muscle**	**NLPP** (n=31)	-24.85	25.05	[-24.69; 0.48]	-1.923	0.059
	LPP (n=33)	-12.74	25.29			
Onset Timing **4th Muscle**	**NLPP** (n=31)	3.41	18.43	[-30.33: -6.21]	-3.035	**0.004***
	LPP (n=33)	21.68	28.87			
Onset Timing **1st – 4th Muscle**	**LPP** (n=33)	-28.26	15.54	[-0.52; 12.85]	1.849	0.070
	NLPP (n=31)	-34.42	10.45			

For the pelvic tilt (Table 5), not significant differences between groups were verified. However, pelvic tilt values were higher in the LPP group. Although significant differences in the individuals that activate BF_Ipsi in first place were verified. These participants had a significantly higher pelvic tilt in comparison to the individuals who use other muscle as first strategy. This occurred in both groups.

Table 5. The pelvic tilt values in both groups (NLPP – Group without lumbopelvic pain; LPP – Group with lumbopelvic pain) relative to sequence of muscle activation and to the Group. Presents the respective values of median, interquartile deviation (ID), mean, standard deviation (SD), test value and p-value. *Significant differences ($p<0.05$). BF_Ipsi – Biceps Femoris Ipsilateral.

Group	Sequence	*Pelvic Tilt* vs. Sequence				*Pelvic Tilt* vs. Group			
		Median	ID	Test Value	p-value	Mean	SD	Test Value	p-value
NLPP (n=31)	1st BF_Ipsi	10.50	2.25	41.00	**0.001***	8.74	0.52	-1.074	0.287
	Other	7.00	2.50						
LPP (n=33)	1st BF_Ipsi	11.50	2.75	51.00	**0.001***	9.48	0.46		
	Other	8.00	1.00						

DISCUSSION

In accordance with the objectives of this study we observed that the individuals, in the LPP group, showed a delay in the onset timing of biceps femoris (BF_Ipsi) and gluteus maximus (GM_Ipsi). It was observed, also, that the “normal” sequence of muscle activation has never been used, however, and despite of some variability observed, the five most frequently used sequences of muscle activation were common in both groups, and each group showed a predominant activation sequence. In both groups, the BF_Ipsi was the muscle that was activated, more times, in first place, and the GM_Ipsi was more frequently the last. Finally, it was observed that individuals, who recruited BF_Ipsi muscle in the first place, had higher anterior pelvic tilt. These results seem to be important in understanding how the muscular system may contribute to lumbopelvic stability. The muscles’ mechanical properties of this region, gives the ability to the joint structures resist to deformation and the its stiffness is changed dynamically by the level of muscle activation (Lederman, 2010). However, changes in motor control may cause an inappropriate recruitment, interfering with the sequences of muscle activation, which compromises the ability to perform, in an automatic way, a proper movement pattern. This change may have an impact on the physiological joint load, changing the direction and magnitude of the imposed forces, originating the onset of lumbopelvic pain (Lewis & Sahrmann, 2009; Sahrmann, 2002; Silfies et al., 2005).

Thus, it's pertinent evaluate the onset timing. In this study we observed significant differences in the onset timing of GM_Ipsi and BF_Ipsi muscles between the two groups, with a delayed onset of these muscles in the LPP group. Analysing the values of onset timing, relative to the movement initiation, we observed that the onset timing of GM_Ipsi was clearly after the beginning of it in the LPP group, unlike the NLPP group wherein the onset timing was near the movement initiation. The remaining muscles began their activity before motion occurs. Similar results were observed in the studies of Bruno et al., (2008), performed in 27 individuals without lumbopelvic pain, and Bruno & Bagust, (2007) which used a sample of 51 individuals (20 with lumbopelvic pain), both with an similar methodology to the present study. In the study of Chance-Larsen et al. (2010), performed in 20 healthy subjects, revealed also, the same results, despite the aim being different.

The delay in the onset timing verified in the LPP group may stem from pain, by alterations in motor control (Paul Bruno & Bagust, 2007; P. Bruno & Murphy, 2011; Hodges, 2001a; Hodges, Moseley, et al., 2003). The proposed theory is that pain causes reflex spasm of the deep muscles surrounding the painful area, causing muscle imbalances and altered motor patterns. These patterns cause abnormal stresses on joints and surrounding structures, which may cause injuries and repetitive traumas, further inhibiting of these muscles and an increase of superficial muscles activity, resulting in a vicious cycle, and may consequently lead to the development and/or perpetuation of the lumbopelvic pain (Hodges, 2003; Vogt, Pfeifer, & Banzer, 2003).

For preventing this cascade of events, becomes important study of the sequence by which the muscles are recruited throughout the movement. In the present study, we observed that the individuals of the LPP group used 9 of the 24 possible sequences of muscle activation, and in the NLPP group this number was 10 sequences. Despite the minimal difference between the groups, we can considered that the lowest variability in LPP group, may be a protective mechanism, used by the body, to restrict movement patterns available to avoid further damage and consequently lead to an increase of pain intensity (Paul Bruno & Bagust, 2007). The study of Bruno & Bagust (2007), mentioned earlier, found similar results, and was also notorious a greater inconsistency in subjects without lumbopelvic pain.

The literature has proposed that there is a more efficient activation sequence for performing hip extension movement (Paul Bruno & Bagust, 2007; Paul Bruno et al., 2008; G. J. Lehman et al., 2004; Page et al., 2010; Sahrmann, 2002). This theory argues that the GM_Ipsi muscle is the main muscle responsible for this movement and an important functional link between lumbopelvic region and lower limbs, being subsequently aided by the BF_Ipsi muscle. Immediately after contraction of these muscles, there is the activation of the contralateral erector spinae (ES_Contra) and then the ipsilateral erector spinae (ES_Ipsi), to help in the stabilization of the lumbopelvic region (Page et al., 2010; Panayi, 2010).

In the present study, this “ideal” sequence of activation was not used by any of the two groups. Similar results were found in a study of Bruno & Bagust (2006) conducted in healthy subjects in which the sequence was used only once in 300 repetitions. In another study, conducted by the same authors, which was attended by individuals with and without lumbopelvic pain, this sequence of muscle activation was not used in a total of 310 repetitions (Paul Bruno & Bagust, 2007).

It is postulated that these changes in muscle activation patterns in the LPP group are an adaptation to the underlying vertebral instability resulting from osteoligamentar laxity, injury and/or muscle dysfunction, as well as inefficient neuromuscular control. To emphasize that, despite the NLPP group not showing symptoms, individuals may have also deficits in motor control (Silfies et al., 2005).

Although the “ideal" sequence was not used in a total of 192 repetitions, but we observe observed that there is a distinct sequence of muscle activation in each group, once there was a significant association between the five most frequent sequences of muscle activation and the respective group. However, the sequence of muscle activation most similar to the "ideal" sequence was the one that was used by most individuals in the NLPP group. The sequence of ES activation was correct, first the ES_Contra and than the ES_Ipsi, in order to stabilize the movement and protect the lumbopelvic region, as contrasted with the LPP group of pain, in which there is a sequence of ES activation inverted.

These results agree with the study of Vogt and Banzer (1997), realized on a sample of 15 healthy individuals, with a similar methodology to the present study, but with more muscles evaluated, and the study of Sakamoto et al. (2009), with 31 healthy volunteers, in which was evaluated the EMG activity for four modalities of therapeutic exercises. However, this was not observed in the Bruno and Bagust (2006), Bruno and Bagust (2007) and Lehman et al. (2004) studies. This inconsistency of results may be due to methodological differences across studies, the number of individuals and the specific set of muscles studied.

Generally, the analysis of the sequence of muscle activation shown that activation of the muscles BF_Ipsi, ES_Contra and ES_Ipsi tend to become active before the GM_Ipsi, the differences between these three muscles was reduced to the predominance for the activation in first place of BF_Ipsi. The GM_Ipsi muscle, which should be the first to be activated, was the last muscle in most subjects in both groups, residing the exception in a small percentage of individuals of NLPP group.

These results are similar to the study of Bruno & Bagust, (2006) which showed that BF_Ipsi was the first to turn up in 34.3% of the 300 repetitions and GM_Ipsi was the last to be activated in 81.3% of these repetitions. More recently, a study carried out by the same authors showed that the BF_Ipsi was the first and GM_Ipsi was the last to turn up, respectively, in 49.7% and 81.3% of 310 repetitions in healthy subjects. In individuals with lumbopelvic pain, the BF_Ipsi was the first to turn up in 61.5% and the GM_Ipsi was the last in 99.0% of the repetitions (Paul Bruno & Bagust, 2007).

Given these findings, it has become pertinent to compare the onset timings of muscle activation in relation to each other's, reinforcing the idea of a significant delay in the activation of GM_Ipsi in the LPP group. The same results were observed in the study performed by Bruno et al. (2008). It can be hypothesized that these muscles are activated early, in order to stabilize the spine before the onset of the GM_Ipsi. If this is the case, then it is possible that a delay in the GM_Ipsi onset, may lead to a compensatory strategy, by the other muscles, such as the activation in the first place but also exhibit an increased activity. This strategy may result in greater load on the lumbar spine due to the increased in tensions and loads transmitted to this region during everyday activities, indicating a possible mechanism underlying the development and/or perpetuation of lumbopelvic pain (Paul Bruno & Bagust, 2007; Lewis & Sahrmann, 2009; Tateuchi et al., 2012).

Given this assumption, it is expected that, only in the individuals with lumbopelvic pain, the GM_Ipsi was the last muscle to be activated, compared with individuals without lumbopelvic pain. However, the findings of this study do not corroborate this assumption, since in the NLPP group, the GM_Ipsi was also mostly the last muscle to be recruited, the great difference resides only in the onset timing, which was lower in this group. Thus, the delay appears to be a normal finding, consisting of a stabilization strategy of the lumbopelvic region, changing the transfer of forces through the pelvis (Arumugam, Milosavljevic, Woodley, & Sole, 2012; Guimarães et al., 2010; Hungerford et al., 2003; Tateuchi et al., 2012).

The weakness or inhibition of the GM_Ipsi may be the result of a muscle injury or hyperactivity of an antagonist and/or synergist muscle (Sahrmann, 2002; Ward et al., 2010). Complementing this mechanical weakness or inhibition of GM_Ipsi may be associated with a neurological inhibition due to changes in the sequence of muscle activation. The new sequence is stored in cerebellum, which also contributes to the inhibition of GM_Ipsi (Sahrmann, 2002). In most of the times, this weakness or inhibition is associated with the stiffness of the hip flexors, the lack of motor control and the dominant muscle activity of the ES_Ipsi, ES_Contra and BF_Ipsi, can contribute to the excessive anterior pelvic tilt, during hip extension, and subsequent hyperextension of the lumbar spine (S. Y. Kang et al., 2013; Oh, Cynn, Won, Kwon, & Yi, 2007; Page et al., 2010). These changes can cause excessive stresses in the lumbar spine and sacroiliac joint during gait, due to a deficiency in the mechanism of shock absorption (S. Y. Kang et al., 2013; Sahrmann, 2002).

This hypothesis was confirmed in this study, since the individuals who activate BF_Ipsi in the first place showed a greater pelvic tilt and consequently a greater pelvic anteversion and an increased of the lumbar lordosis. These results can be explained by the interaction between the dominance of the synergistic muscles which act in force couple, as is the case of GM and BFi, since these two muscles have different characteristics with respect to changes in the muscle lever arm in accordance with the change of the flexion-extension hip angle (S. Y. Kang et al., 2013; Tateuchi et al., 2012). The GM lever arm increases with the increase of the angle of extension of the hip and the opposite is true in BF (Tateuchi et al., 2012). Based on these observations, it appears that the GM has a relative advantage in provide extension force, although both muscles are shortened in the hip extension. Consequently, BF tends to be recruited sooner, increasing pelvic tilt and the extension of the lumbar spine (Hossain & Nokes, 2005; Hungerford et al., 2003; S. Y. Kang et al., 2013; Tateuchi et al., 2012).

All these results allow us to conclude that the use of functional tests, with the aid of biofeedback units, can help the physiotherapist to detect and understand the presence of muscle imbalances. Despite the existence of an "ideal" sequence of muscle activation is still controversial, changes in these tests, may serve as an indicator, to initiate an intervention aimed in optimize the motor control and restore the lumbopelvic stability. The changes in motor control may have a negative impact in lumbopelvic stabilization. This doesn’t suggest, that all individuals with alterations in sequence of muscle activation exhibit the same deficit in motor control, and require the same level of intervention.

Therefore, the intervention programs must be compatible with the individual demands and requirements of each patient.

The innovation of this study compared to previous ones is that of investigating the association between the sequence of muscle activation and pelvic tilt, allowing, in this way, verify how the onset timing and their sequence influence the position of the pelvis in the sagittal plane.

CONCLUSION

In the present study we observed that the LPP group showed a significant delay in the activation of GM_Ipsi and BF_Ipsi, and there is a consistent sequence of muscle activation in each group. However, the results seem to refute the "ideal" sequence of muscle activation, since this has not been observed in both groups.

It was found that GM_Ipsi muscle was the last to be active in both groups. However, this finding does not allow support or refute the prevailing theory that a delay in the activation of this muscle during movement is associated with lumbopelvic pain, because it was observed in both groups. However, this delay in the onset timing was higher in the LPP group.

Also, it was observed that the BF_Ipsi muscle was the first to be active, and the individuals who activate this muscle in the first place, have a significantly higher pelvic tilt.

Although, future research is needed to confirm these findings in individuals with lumbopelvic pain, it seems that this test can be a tool, to determine if the GM can be a potential cause for the changes in motor control strategies, in patients with lumbopelvic pain, and can be used as an indicator for the prescription of therapeutic programs that aim restoring the normal sequence of GM activation.

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3.6. Study VI – Motor Control Exercises on Abdominal Muscles Recruitment Pattern during Rapid Arm Movements and Pain Intensity in Subjects with Chronic Nonspecific Lumbopelvic Pain

Paulo Carvalho*[1,2], António Mesquita Montes[1,2], Carlos Crasto[1], Rubim Santos[2], João Paulo Vilas-Boas[3]

[1] *Physical Therapy Department – School of Allied Health Sciences of Porto/Porto Polytechnic Institute (ESTSP/IPP), Vila Nova de Gaia, Portugal*

[2] *Center of Study for the Movement and Human Activity (CEMAH) - ESTSP/IPP, Vila Nova de Gaia, Portugal*

[3] *Porto Biomechanics Laboratory (LABIOMEP), Faculty of Sport, CIFI2D, University of Porto, Porto, Portugal*

***Corresponding author:**

Physical Therapy Department – School of Allied Health Sciences of Porto/Porto Polytechnic Institute (ESTSP/IPP), Vila Nova de Gaia, Portugal
Rua Valente Perfeito, 322
4400-330, Vila Nova de Gaia, Portugal.
E-mail address: pmc@estsp.ipp.pt (Paulo de Carvalho).

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ABSTRACT

Background: Nonspecific chronic lumbopelvic pain leads to impaired motor control and function of the trunk muscles. Different approaches for motor control exercise, like Carolyn Richardson and Stuart McGill, improve the core abdominal function in a long-term, providing lumbopelvic dynamic stability. However, no consensus regarding the intervention on deep muscles feedforward delay.

Aim: To compare the effect of motor control exercise for dynamic stability according to the Richardson approach with the McGill approach on timing of elctromyographic (EMG) onset of the abdominal muscles, during rapid arm movements, and pain intensity in subjects with chronic nonspecific lumbopelvic pain.

Methods: Experimental study with a sample of 59 volunteers with chronic nonspecific lumbopelvic pain, randomly in Motor Control Exercise_Richardson Approach Group ($\text{MCE\_R}_{\text{ichardson}}$) (n=20), Motor Control Exercise_McGill Approach Group ($\text{MCE\_M}_{\text{cGill}}$) (n=20) and Control Group (CG) (n=19). To evaluate timing of EMG onset during rapid arm flexion (RAFM), abduction (RAAM) and extension (RAEM) movement was used surface electromyography of transversus abdominal/ internal oblique (TrA/IO), external oblique (EO), rectus abdominis (RA) and anterior, medium and posterior deltoids. The pain intensity was measured by visual analog scale. The experimental groups were subjected to different motor control exercise programs during 8 weeks, one according to the Richardson approach and another according to the McGill approach. The CG did not undertake any intervention. The assessments took place before and after 8 weeks of the application of exercise programs. To comparison between groups was used Kruskal-Wallis one-way analysis of variance test and to compare time points in each group Wilcoxon signed-rank test was used, with a significance level 0.05.

Results: After 8 weeks of completion the different motor control exercise programs (M_1), in RAFM, on $\text{MCE\_R}_{\text{ichardson}}$ group it was found that the timing of EMG onset of TrA/IO was significantly lower when compared to $\text{MCE\_M}_{\text{cGill}}$

and control groups ($p<0.05$). Also, in this movement, the MCE_M$_{cGill}$ group presented a timing of EMG onset of EO and RA ($p<0.05$) significantly lower when compared to CG. On MCE_R$_{ichardson}$ group, in RAAM, the timing of EMG onset of TrA/IO was significantly lower comparing to CG ($p<0.01$). The timing of EMG onset of EO, in this movement, was significantly lower in MCE_M$_{cGill}$ ($p<0.05$) comparing to the CG. Yet, in MCE_M$_{cGill}$ group the timing of EMG onset of RA was significantly lower in the MCE_R$_{ichardson}$ group and CG ($p<0.05$). In RAEM, on MCE_R$_{ichardson}$ group, it was found that the timing of EMG onset of TrA/IO ($p<0.001$) was significantly lower when compared to CG. At M_1 it was found that in MCE_R$_{ichardson}$ and MCE_M$_{cGill}$ group the pain intensity was significantly lower when compared to CG ($p<0.001$).

Conclusion: Both approaches motor control exercise decreased timing of EMG onset of abdominal muscles verifying an improvement in the lumbopelvic dynamic stability. However, motor control exercise according to the Carloyn Richardson approach seems to have more effect on local stabilizing muscles (TrA/IO) while the approach of Stuart McGill appears to have more effect on global stabilizing muscles (EO and RA). Yet, both motor control exercise programs reduced the lumbopelvic pain intensity.

Key-words: Lumbopelvic pain, core abdominal, timing of EMG onset, motor control exercise, Richardson approach, McGill approach

INTRODUCTION

Nearly 9.2% of the world population suffers from lumbopelvic pain Vos et al. (2012), being 90% of the occurrences have a nonspecific cause Haldeman et al. (2012). So the nonspecific chronic lumbopelvic pain (LPP) is a pathological condition that involves high costs for health and social systems representing high rates of absenteeism and disability work (Arab et al., 2011; Paul Bruno & Bagust, 2006; Paul Bruno et al., 2008).

Despite the high incidence and the consequent harmful effects on society, the factors associated to the appearance of LPP are not yet completely understood (Delitto et al., 2012). However, impaired motor control and function of the trunk muscles are important predisposing factors and results of this pathological condition (Dagenais & Haldeman, 2012). There is no consensus on the nature of these alterations but some evidence reported impairments in local and global lumbopelvic stability muscles systems (A. Y. Wong, Parent, Funabashi, & Kawchuk, 2013). A transversus abdominis and multifidus compromised activation and function (delayed feedforward activation, loss of tonic function and reduced contraction thickness) has been shown in subjects with LPP (Hodges, Moseley, et al., 2003; Hodges & Richardson, 1999a; Kiesel et al., 2007; Macedo et al., 2012; Richardson et al., 2004; Wallwork et al., 2009). Also, morphological and histological changes (adaptation of the fibres composition, fat infiltration and decrease in the cross-sectional area) and increased fatigue were found in multifidus muscle (Hides et al., 1994; Richardson et al., 2004). These modifications in deep muscles decrease the segmental control and the stiffness of the lumbopelvic region, impairing dynamic stability (Freeman, Woodham, & Woodham, 2010; Hides et al., 2001). An increase in the overall activity of the superficial muscles is reported too, as a result for this impairment (Hodges, 2001a; Hodges & Cholewicki, 2007; Hodges, Moseley, et al., 2003).

Although the most effective approach to diagnosis and intervention in LPP not be established. Therapeutic exercise based on rehabilitation of core abdominal muscles appears as an intervention directed to the impaired motor control of lumbopelvic region (Dagenais & Haldeman, 2012; Delitto et al., 2012). Motor control exercises according Carolyn Richardson and Stuart McGill approaches are concepts, which stand out in the literature.

Both approaches require the same basic principles of motor control intervention: developing local and/or global muscle systems contraction and spinal position awareness and maintenance of normal ventilation pattern; progressing control in simple patterns and exercises to complex exercises; finally by demonstrating automatic maintenance of spinal stability and control in a progressing of simple functional activities to complex and unplanned situations (McGill, 2007a; Richardson et al., 2004). However, Carolyn Richardson and

Stuart McGill approaches differing in terms of core abdominal activation techniques.

The hollowing, characteristic of Carolyn Richardson approach, is more selective in the co-activation of deep muscles, transversus abdominis and multifidus, with a minimal activity in superficial muscles (Richardson et al., 2004). This technique allows increase the intra-abdominal pressure, by abdominal wall internal displacement and tension development on thoracolumbar fascia (acting like a girdle of support around the abdomen and lumbar vertebrae) (Hodges et al., 1996). In contrast, the bracing used by Stuart McGill approach arises by setting the abdominals and actively flaring out laterally around the spine, there is a more general response of the core abdominal and consequently increased intra-abdominal pressure (McGill, 2007a).

Several studies report that motor control exercise, regardless of the exercise approach, improves the core abdominal function in a long-term, providing lumbopelvic dynamic stability (Hides et al., 2001). However, the literature is scarce regarding the possibility of revert the inefficient motor control programs (deep muscles feedforward delay) in subjects with chronic nonspecific lumbopelvic pain (A. Y. Wong et al., 2013). Thus, the aim of this study was to compare the effect of motor control exercise for dynamic stability according to the Richardson approach with the McGill approach on timing of EMG onset of the abdominal muscles, during rapid arm movements, and pain intensity in subjects with chronic nonspecific lumbopelvic pain.

METHODS

Study design

Experimental study with a sample composed by volunteers subjects with chronic nonspecific lumbopelvic pain, randomly in three groups: two experimental groups one Motor Control Exercise_Richardson Approach Group

(MCE_R$_{ichardson}$) and one Motor Control Exercise_McGill Approach Group (MCE_M$_{cGill}$), and one Control Group (CG).

The experimental groups were subjected to different motor control exercise programs during 8 weeks, one according to the Richardson approach and another according to the McGill approach. The CG did not undertake any intervention. All groups were submitted a three different tasks in two moments of assessments which took place before and after 8 weeks of the application of exercise programs.

Sample

The target population consisted in volunteers subjects, aged between 18 and 30 years with chronic nonspecific lumbopelvic pain.

In this study, the inclusion criteria were: subjects with recurrent episodes of lumbopelvic pain for a period greater than three months (Garry T. Allison et al., 1998; Basmajian & De Luca, 1985; Criswell, 2011; Hermens et al., 2000; Kamen & Gabriel, 2009); and the active straight leg raising (ASLR) and prone instability (PIT) tests positive (Hicks et al., 2003; Magee, 2008).

Were excluded subjects who had: suprailiac skin fold higher than 20 millimetres; scoliosis, discrepancy of the lower limbs or postural asymmetries, history of spinal, abdominal or gynaecological surgery in last year, neurological disorders and/or inflammatory or cardio-respiratory diseases, pregnancy or post-delivery in last 6 months; practice exercise for core abdominal in last year; receiving physiotherapy treatment in order to resolve the lumbopelvic pain; who did regular exercise, more than 45 minutes a day, three days a week for a period exceeding one year, and with conditions that interfere with data collection, such as history of dominant upper limb injury (Paul Bruno et al., 2008; Jacobs et al., 2011; G. J. Lehman et al., 2004; Marshall & Murphy, 2003; Tateuchi et al., 2012)

The final sample was composed by 59 subjects divided in: MCE_R$_{ichardson}$ – 20 subjects -, MCE_M$_{cGill}$ – 20 subjects - and Control Group – 19 subjects.

Instruments

Sample Characterization

An electronic questionnaire was given to the subjects in order to be sure that every participant fulfils the selection criteria of this study, as well as to gather some sociodemographic information and LPP duration.

Anthropometric measures, height (meters) and body mass (kilograms), were taken by a Seca® 222 stadiometer with an accuracy of 1 millimetres and a Seca® 760 balance with an accuracy of 1 kilogram (Seca - Medical Scales and Measuring Systems ®, Birmingham, United Kingdom), respectively.

Surface electromyography

Surface electromyography (sEMG) was collected through the BioPLUX research device (Plux® wireless biosignals SA, 2630-369 Arruda dos Vinhos, Portugal), with analogue channels of 12 bits and a sampling frequency of 1000 Hz, using double differential electrode leads (Hermens et al., 2000; Kamen & Gabriel, 2009; Roberto Merletti, 1999). Muscular activity of transversus abdominal/internal oblique (TrA/IO), external oblique (EO), rectus abdominis (RA) and anterior, medium and posterior deltoids was evaluated. The sEMG signal was collected in the contralateral dominant side, exception deltoids.

Self-adhesive Ag/AgCl dual snap (Noraxon®, Scottsdale, Arizona, United States of America) disposable electrodes for sEMG were used. The electrodes characteristics were 4x2.2 centimetres of adhesive area, diameter of each of the two circular conductive areas were 1 centimetres, and 2 centimetres inter-electrode distance (Criswell, 2011; Hermens et al., 2000; Kamen & Gabriel, 2009). These electrodes were connected to bipolar active sensors emgPLUX (Plux® wireless biosignals SA, 2630-369 Arruda dos Vinhos, Portugal), with a gain of 1000, an analogue filter at 25 to 500 Hz and commom-mode rejection ratio of 110 db. For reference electrode was used self-adhesive Ag/AgCl snap (Noraxon®, Scottsdale, Arizona, United States of America) disposable electrode for sEMG with diameter of the circular adhesive area of 3.8 centimetres and diameter of the circular conductive area of 1centimetre. In turn, the sensors were connected to the sEMG device with connection via bluetooth to a laptop. Yet, it was used a MonitorPLUX version 2.0 software (Plux® wireless biosignals SA, 2630-369 Arruda dos Vinhos, Portugal) in order to visualize and acquire the electromyographic signal. Finally to check the skin impedance level an electrode impedance checker was used (Noraxon®, Scottsdale, Arizona, United States of America) (Basmajian & De Luca, 1985; Criswell, 2011; Hermens et al., 2000; Kamen & Gabriel, 2009).

Visual Analogue Scale

The pain intensity in LPP_G was evaluated by using the visual analogue scale (VAS), which consist in a horizontal line with 100 millimetres, from “No pain” to “Maximal pain” written in the extremities (Carlsson, 1983; Ferreira-Valente et al., 2011; Hawker et al., 2011).

Procedures

Data Collection Protocol

Study procedures took place in biomechanical laboratory and were performed in a controlled environment.

In order to selection and characterize the sample, an electronic questionnaire was given to all the subjects, including the assessment of pain intensity, using VAS. ASLR and PIT tests were performed for selection the study final sample, in all subjects who fulfils the others participation criteria. If the both tests were positives the subject was included. In the VAS the subjects pointed a cross or a cross dash in the line that represents their pain intensity. To obtain pain intensity numeric value it was measured the distance, in millimetres, between the top of the line, which representing zero, to the cross (Hawker et al., 2011).

After this, height and body mass was measured in selected subject. Before tests’ procedures, the participants practiced the evaluated tasks, in order to understand the desired movement.

Then the skin hair was removed and an abrasive pad was used for removing death cells from the skin superficial layer. The skin was clean with isopropyl alcohol (70%), removing the skin oiliness and the remaining death cells (Garry T. Allison et al., 1998; Clancy et al., 2002; Criswell, 2011; Kamen & Gabriel, 2009). After skin preparation, the bioimpedance was checked, using electrode impedance checker, in order to guarantee that impedance levels were below 5KΩ, and thus ensure a good EMG signal acquisition (Basmajian & De Luca, 1985; Criswell, 2011; Kamen & Gabriel, 2009).

Self-adhesive electrodes were placed in the orthostatic position five minutes after skin preparation. These were placed parallel to the muscle fibers orientation, according to the references described in Table 1, confirmed by palpation and muscular contraction (Marshall & Murphy, 2003). The reference electrode was placed in the anterior superior iliac spine (ASIS) of contralateral dominant side (Garry T. Allison et al., 1998; Basmajian & De Luca, 1985; Criswell, 2011; Hermens et al., 2000; Kamen & Gabriel, 2009). All electrodes were tested in order to control the cross-muscular signal and electrical noise.

After this, a five minutes wait period was taken for sEMG signal collection start (Criswell, 2011; Kamen & Gabriel, 2009; Marshall & Murphy, 2003). sEMG signal was collected and analyzed in both groups during the rapid dominant arm movements: flexion, abduction and extension. The amplitude of these movements was approximately 40º, 40º and 60º, respectively. Movements order was randomized.

In orthotastic position, knees in loose pack position (5º of flextion) and upper limb along the trunk the participant was instructed for mantaining the extension elbow and performed the movements as fast as possible, after the turn on of a led light. All participants were notified for importance of the velocity over amplitude. Three trials were done and collected for each movement. Rest period between trials was 1 minute, giving the chance to completely recover (Hodges & Richardson, 1997b, 1999a).

Table 1. Recommendations for electrodes placement according Marshall and Murphy (2003).

Muscle	Electrode local placement
TrA/IO	2cm medially and below the anterior superior iliac spine (ASIS) - In this site, TrA and IO muscle fibers are mixed, so it is impossible to distinguish sEMG activity of both. For this reason, the EMG signal collected is considered from TrA/IO.
EO	13 cm superior the umbilicus, in a direct line to the ribs.
RA	3 cm superior to the umbilicus and 2 cm lateral to the midline.
Deltoid (Anterior/Medial/Posterior)	Muscle belly centre - The electrodes were placed on the respective prime mover's fibres for each task: anterior fibres for **flexion**, medial fibres for **abduction**, and posterior fibres for **extension**.

After the first assessment moment, distincts motor control exercise programs were performed 3 times a week during 8 weeks, acordingly to which experimental group.

Motor Control Exercise Program – McGill Approach

In the Stuart McGill concept, spine stability should be the primary focus and to achieve stability, argues three fundamental principles: maintaining neutral spine, breath coordination with abdominal activity and abdominal bracing (Liebenson, 2008a, 2008b, 2008c; McGill, 2007a, 2007b).

To optimize the training of lumbopelvic stability, McGill has developed five steps in the rehabilitation process of the core muscles, being the first three steps related to the corrective exercise and trunk endurance and stability, in order to aid in prevention of spinal injury, while the last two (strength, speed and agility) are more related to enhancing the performance of athletes (McGill, 2007a, 2007b, 2009).

According to McGill (2007a, 2007b) endurance is achieved through repetitions, advocating the use of an inverted pyramid for the resistance training without inducing fatigue. Therefore McGill (2007), in order to optimize the muscle activity while minimizing the compressive forces imposed on the spine, created a set of exercises that allow an increase in endurance of the abdominal wall and improve neuromuscular pre-activation and control of the three layers of abdominal wall. This concept includes three basic exercises: curl-up, front plank/side bridge and cross-crawl. The subjects were advised not to perform any exercise that causes pain and all the components of progression were introduced only when the subjects had apprehended the competences of the exercise that was being performed. Regarding the exercise program sessions of motor control exercise_McGill approach, they had duration of 45 minutes and were performed three times a week (McGill, 2007a, 2007b, 2009; McGill & Karpowicz, 2009). The principal characteristic of the motor control exercise_McGill approach is described in the Table 2.

<u>Exercises</u>

Curl-Up

Description - subjects were in supine position with both hands placed under the lumbar spine providing neutral curve feedback. They were instructed to rotate around the sternum and lift the scapulae off the mat while maintaining a neutral head/neck position for 5 seconds (McGill, 2007a, 2007b, 2009; McGill & Karpowicz, 2009).

Table 2. Characteristics of the motor control exercise program_McGill approach.

	Sets	Repetitions	Holding time (seconds)	Rest between sets (minutes)
1st Week	3x	1x – 5 rep 1x – 4 rep 1x – 3 rep	8-10	2
2nd Week	3x	1x – 5 rep 1x – 4 rep 1x – 3 rep	8-10	2
3rd Week	3x	1x – 6 rep 1x – 5 rep 1x – 4 rep	8-10	2
4th Week	3x	1x – 7 rep 1x – 6 rep 1x – 5 rep	8-10	2
5th Week	3x	1x – 9 rep 1x – 8 rep 1x – 7 rep	10	2
6th Week	3x	1x – 11 rep 1x – 10 rep 1x – 9 rep	10	2
7th Week	3x	1x – 13 rep 1x – 12 rep 1x – 11 rep	10	2
8th Week	3x	1x – 15 rep 1x – 14 rep 1x – 13 rep	10	2

Progression - elevate the elbows from the mat, pre-bracing (stiffening) the abdominal wall, and deep breathing during the exercise. The instruction for bracing was the same in all exercises (McGill, 2007a, 2007b, 2009; McGill & Karpowicz, 2009).

Bracing facilitation - the clinician rakes the fascia to stimulate the oblique's muscles, carefully to not encroach on the rectus, with the ends of the fingers so that the subjects contract the abdominal wall, neither drawing-in nor pushing out (McGill, 2007a, 2007b, 2009; McGill & Karpowicz, 2009).

In this way of performing the curl-up, very little movement occurs in an effort to protect the disks from damage or pain exacerbation. A progression in abdominal challenge started with a curl-up just to elevate the head/neck/shoulders slightly while the elbows were on the mat. The progression continued with raising the elbows from the mat. According to McGill & Karpowicz

(2009) stiffening the trunk with an abdominal bracing increased the activation of both external and internal oblique, with the internal oblique approaching 30% of the Maximal Voluntary Contraction (MVC) during bracing.

Dead Bug

Description - subjects were in supine position with the right hand placed under the lumbar spine. They started with the hips, knees, and shoulders flexed to 90° and slowly extended the right hip and knee and left shoulder until both were completely extended level to horizontal but slightly elevated from the mat. This posture was held for 5 seconds. After, the subjects returned to the starting position (McGill, 2007a, 2007b, 2009; McGill & Karpowicz, 2009).

Progression - from the extension position mentioned above the subjects flexed the left/right shoulder and right/left hip. First with slow and small amplitude movement (10º-20º), progressing to movements of greater amplitude (50º-60º in the lower limbs / 80º-90º in the upper limbs) and then to faster movements (this progression was initiated in the 2nd week of the exercise program). The intention was to first stiffen the trunk and then ballistically contracted in such a way that movement occurs only in the shoulder and hip, and not in the trunk (McGill, 2007a, 2007b, 2009; McGill & Karpowicz, 2009).

Side-Bridge

Description - the easiest way to perform this exercise was using the knees support (shorter lever arm): subject lying on the right/left side supported by the right/left hip and elbow/forearm (flexed to 90°). Performed extension of the hips, as if they perform a squat, and at the same time lift the hips from the mat, getting supported by the distal half of the thigh, right/left knee and right/left elbow/forearm. The left/right hand was positioned over the right/left shoulder and the arm drawn across the chest to stabilize the shoulder (McGill, 2007a, 2007b, 2009; McGill & Karpowicz, 2009).

Progression - subjects progressed by removing the hand from the shoulder and placing the left/right arm over the trunk and the hand on the pelvis.

In the full side-bridge, the legs were extended, and the top leg foot was placed in front of the lower leg foot for support. Subjects support themselves on the right/left elbow/forearm and on their feet while lifting their hips off the mat to create a straight line over the length of their body. The right/left hand was placed first on the opposite shoulder and after on the pelvis. They started the full side-bridge exercise in the 5th week of the exercise program. In the final progression (7th week), subjects were instructed to roll from the left/right side-bridge into the plank position (prone, supported on elbows and feet toes), and out of the plank into a right/left side-bridge. Corrections and feedback was given to eliminate the twisting between the ribcage and pelvis (McGill, 2007a, 2007b, 2009; McGill & Karpowicz, 2009).

Birddog

Description - subjects initiate this exercise in a quadruped position. Initially, participants lifted only the left/right arm, and then progressed to the right/left leg only. Next, the left/right arm and right/left leg were lifted simultaneously with an abdominal bracing (McGill, 2007a, 2007b, 2009; McGill & Karpowicz, 2009).

Progression - subjects progressed as follows: just arm elevation, just leg elevation, both arm and leg (full birddog), in all this variations the subjects performed conscious abdominal bracing, and finally the drawing circles and squares with the hand and foot, creating shoulder and hip motion. These final movements increased the upper back extensors from 23% to 35% of the MVC. Finally subjects drawing circles first and than squares with the hand and foot, restricting motion to the shoulder and hip joints (McGill, 2007a, 2007b, 2009; McGill & Karpowicz, 2009).

For more details about this exercise program see appendix-III.

Motor Control Exercise Program – Richardson Approach

The program had two phases and the goals were: (i) Retraining the motor control and ability of the deep muscles of the lumbopelvic region (specifically transversus abdominis (TrA), inferior fibers of the internal oblique (IO) multifidus (MU), Diaphragm (D) and the pelvic floor muscles (PFM)); (ii) re-educate motor control of the superficial muscles of the lumbopelvic region (specifically external oblique (EO), rectus abdominis (RA), Erector Spinae (ES)); (iii) encourage postures and patterns of movement that reduce pain; (iv) retraining coordination between deep and superficial muscles of the lumbopelvic region during static and dynamic tasks; (v) retraining of breath control with trunk motor control strategies; (vi) progress training for function (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

The basic treatment process involved the initial identification and correction of deficits in control of the trunk muscles (both deep and superficial), progressing to the coordination training of the trunk muscles in function.

The objectives in phase-I were: (i) Confident/independent/cognitive contraction of deep/local muscles; (ii) progressive feedback reduction; (iii) minimal effort; (iv) holding time - 10s; (v) able to maintain optimal relaxed breathing pattern; (vi) co-activation of deep muscles; (vii) correct posture and movement pattern; (viii) correction of relative flexibility (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

In phase-II - progression of exercise to function was achieved by progression through exercises of increasing complexity, again specific to the patient's presentation and with attention to the breath pattern and posture (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

The static control training goals were: (i) integration training between deep/local and superficial/global muscles; and (ii) retraining the control of lumbopelvic orientation/alignment. The key in this phase was to pre-activate the deep muscles system, hold this activation tonically (5 to 10s), and then use load and resistance to initiate superficial muscles activity. The underlying principle was that once load was applied to the limbs or trunk, activation of the global muscles was required to control the alignment (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

More complex than static control, but essential for progression to function, was the requirement to train control of the spine and pelvis in dynamic situations. The key element was to pre-activate the deep muscles and hold this tonically while the movement is performed (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Regarding the exercise program sessions of motor control exercise_Richardson approach, they had duration of 45 minutes and were performed three times a week. In all the exercises were performed 3 series of 6 to10 repetitions (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Some examples of the exercises performed:

Leg-loading - the requirements were: (i) keep the pressure as steady as possible (40 mmHg in the digital pressure biofeedback unity) (ii) maintaining the deep muscle corset action (drawing in). Subjects were positioned in supine crook lying and the load was applied in a progressive manner by moving the legs in different planes of motion, maintaining the position of the spine and pelvis. Subjects watch the pressure dial feedback and by drawing in the abdominal wall, keeping the pressure level steady throughout the movement. The progression of leg load exercise was: Level 1 - single leg slide, contralateral leg support. Leg slide with heel support to full extension and return (repeat with the opposite leg). Level 2 - single leg slide, contralateral leg unsupported (heel is held approximately 5 cm from mat) (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Rhythmic stabilizations (proprioceptive neuromuscular facilitation) - in sitting position with neutral alignment rotary force (low force-30%) was applied to the shoulders in alternating directions (slowly in the first 4 weeks and then progressive increased). During the direction change, the activation of the superficial muscles alternates over the tonically maintained activation of the deeper muscles (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Four-point kneeling with arm and leg extension - the patient controls the neutral spinal posture and pelvic position. The subject activates first the deep muscles by drawing in the lower abdominal wall and holding this contraction throughout the exercise. Load is applied first through short levers (flexed limbs) and then through longer levers with the limbs straight. The leg is slowly extended, the patient focusing not on lifting the leg but on maintaining the lumbopelvic position. When controlling this position, the arm is raised, with a similar focus on trunk and girdle control. The position was held for up to 5s-10s and the exercise was repeated using the opposite diagonal. The exercise was progressed by challenging trunk stability through the use of unstable surfaces (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Bridging - from the crook lying position was used as a basic exercise. Prior to the bridge, the deep muscle co-contraction was performed and the subject focusing on lifting the pelvis and extending the hips with a gluteal contraction, keeping the spine and pelvis in a neutral position and being held for 5s-10s (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

This exercise progression was made by the reduction of the base of support through a single leg extension, with the emphasis on maintaining the spine and pelvis in a neutral position and being held for 5s. In the 7th week the progression was performed through the increase of speed, which challenges the global muscles to be working phasically while the deep muscles hold their isometric contraction. The subject focuses on keeping the abdomen flat and the lumbopelvic in neutral while rhythmically extending alternate legs. This was done slowly in the first 4 weeks; as the subject gains control, the speed was increased gradually (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Some **Clinical Pilates** exercises was also performed: (i) **the hundred** – started in table top position with the neutral spine and head alignment, the hips and knee flexed at 90º, arms along the body, with the hands down on the mat. Prior to the flexion the cervical to mid-thoracic spine, reaching the arms off the mat in line with the shoulders. Holding time was 5s; (ii) **swimming** – started in prone position with the arms overhead, the legs in extension, ankles in plantar flexion and the spine and pelvis in neutral position. Lift the right upper limb/left lower limb off the mat, maintaining neutral spine and pelvis, with scapular stabilization, holding this position for 5s and than lift the opposite upper and lower limb; (iii) **one-leg circle** – started in the supine position with the spine and pelvis in neutral position, one lower limb extended in the air and the other with hip and knee flexed to 90º and the foot on the mat; arms along the side with the hands on the mat. Maintain neutral pelvis, was made a circle to dissociated the hip from the pelvis and spine; (iv) **push-ups** (static and then dynamic) - first 5 weeks with the knees down on the mat and than in the plank position (Smith & Smith, 2005).

For more details about this exercise program see appendix-IV.

Data Processing

Data collected by Monitor PLUX version 2.0 was converted and processed through a routine developed in MatLab® student version software. In this way, were applied, to the sEMG signal, a 2nd order digital filter Infinite Impulse Response – Butterworth, one of 10Hz (high pass) and the another of 450Hz (low pass), in order to remove electrical noise and/or cable movement; and the last one of 30Hz (high pass), in order to remove cardiac signal from sEMG signal. Than the root mean square (RMS) 10 samples was calculated.

sEMG signal analysis was done with Acknowledge used (Biopac Systems Inc.®, Goleta CA, United States of America) version 4.0 for Mac OS X software. Onset timing was defined as the time wasted between each TrA/IO, EO and RA sEMG activity start relatively to anterior, medial and posterior deltoid, the muscles responsible for the movement production. sEMG onset timing visually analyzed was identified as the point at which the mean RMS of 50 consecutive frames (50ms) exceeded baseline signal for 2 standard deviations. Rest sEMG activity was determined in a 50ms period, 500ms prior to the turn on of the led light. Feedforward activation was considered when onset timings were found between 100 ms before and 50 ms after deltoid's onset timing. All traces were visually inspected to ensure that the onset was not obscured by movement artifact or an electrocardiogram (<7% of trials). Finally, mean onset timing of the three movement test repetitions was determined.

Ethics

The study were conducted in accordance with the declaration of Helsinki and approved by the Institutional Research Ethics Committee. Each subject provided a written informed consent before participation. At the end of the study was given to CG the opportunity to perform one of the motor control exercise approaches.

Statistics

The descriptive and inferential statistical analysis of the data, was performed using the statistical program *IBM SPSS Statistics®* version 20 (IBM Corporation®, New York, United States), with a significance level 0.05.

To test the normality of the variables was used Shapiro-Wilk Test. For all variables descriptive non-parametric statistics, including measures of central tendency, the median, and dispersion, interquartile deviation was used (Marôco, 2011).

For quantitative variables characterizing the sample, the Kruskal-Wallis one-way analysis of variance test was used in order to verify the homogeneity between groups. Although the Chi-Square test for qualitative variables (nominal) with the same purpose was used (Marôco, 2011).

For the remaining variables, the Kruskal-Wallis one-way analysis of variance test was performed in order to verify the existence of significant differences between groups at each evaluation time. As a post-hoc analysis we used the Dunn test. Still, we performed the Wilcoxon signed-rank test in order to verify the existence of significant differences between time points in each group (Marôco, 2011).

RESULTS

Sample

The final sample was constituted by 59 subjects' volunteers, 20 in the MCE_Richardson (with 15 females), 20 in the MCE_McGill (with 17 females), and 19 in the CG (with 14 females). Concerning sample characterization (Table-3), the groups were comparable as there was no differences with a statistic signification regarding sex, age, body mass, height and pain duration (p>0.05).

Table 3. Sample characteristics: demographic and anthropometric data of sample with the respective median values, interquartile deviation, minimum, maximum, statistical value and p-value (MCE_Richardson – Motor Control Exercise_Richardson Approach Group; MCE_McGill – Motor Control Exercise_McGill Approach Group; CG – Control Group).

		Age (Years)			Body Mass (Kg)			Height (m)			Duration (Years)		
		MCE_Richardson (n=20)	MCE_McGill (n=20)	CG (n=19)	MCE_Richardson (n=20)	MCE_McGill (n=20)	CG (n=19)	MCE_Richardson (n=20)	MCE_McGill (n=20)	CG (n=19)	MCE_Richardson (n=20)	MCE_McGill (n=20)	CG (n=19)
Median		24.00	24.00	24.00	58.75	59.90	60.30	1.63	1.64	1.64	7.50	8.00	8.00
Interquartile Deviation		1.50	1.50	1.50	7.46	1.38	6.45	0.08	0.02	0.07	1.38	1.50	1.00
Minimum		22.00	22.00	22.00	52.30	53.30	53.20	1.58	1.59	1.58	5.00	5.00	6.00
Maximum		30.00	29.00	29.00	81.50	77.20	76.70	1.85	1.80	1.83	11.00	11.00	11.00
Inter-group Comparison	Statistical Value	0.530			0.463			0.322			0.286		
	p-value	0.767			0.793			0.851			0.867		

Comparison between groups

<u>EMG onset timing</u>

At baseline (M_0), there were no significant differences between groups in the timing of EMG onset in all of the muscles, in any of all rapid arm movements (p>0.05), so the groups are comparable.

After 8 weeks of completion the different motor control exercise programs (M_1), we observed significant differences between groups in the timing of EMG onset in all of the muscles, in any of all rapid arm movements ($p<0.05$), except the timing of EMG onset of EO and RA muscles in the rapid arm extension movement.

In the rapid arm flexion movement, on MCE_R$_{ichardson}$ group, it was found that the timing of EMG onset of TrA/IO was significantly lower when compared to MCE_M$_{cGill}$ group (Z=-15.100; p=0.016) e CG (Z=-27.113; p<0.001). Also, in this movement, the MCE_M$_{cGill}$ group presented a timing of EMG onset of EO (Z=-16.805; p=0.007) and RA (Z=-17.728; p=0.04) significantly lower when compared to CG.

On MCE_R$_{ichardson}$ group, in the rapid arm abduction movement, the timing of EMG onset of TrA/IO (Z=-23.011; p<0.001) was significantly lower comparing to CG. The timing of EMG onset of EO, in this movement, was significantly lower in MCE_M$_{cGill}$ (Z=-14.142; p=0.030) comparing to the CG. Yet, in MCE_M$_{cGill}$ group the timing of EMG onset of RA was significantly lower in the MCE_R$_{ichardson}$ group (Z=13.150; p=0.046) and CG (Z=-19.850; p=0.001).

Finally, in the rapid arm extension movement, on MCE_R$_{ichardson}$ group, it was found that the timing of EMG onset of TrA/IO (Z =-22.928, p<0.001) was significantly lower when compared to CG. These data are given in Figure 1.

Pain intensity

In M_0, there were no significant differences between groups in pain intensity ($p> 0.05$), so the study groups can be comparable.

In M_1, it was observed significant differences between groups in pain intensity ($p<0.05$) (see Table 4). In both groups, MCE_R$_{ichardson}$ (Z=-32.297, p<0.001) and MCE_McG$_{ill}$ (Z=-26.547, p<0.001), the intensity of pain was significantly lower when compared to CG.

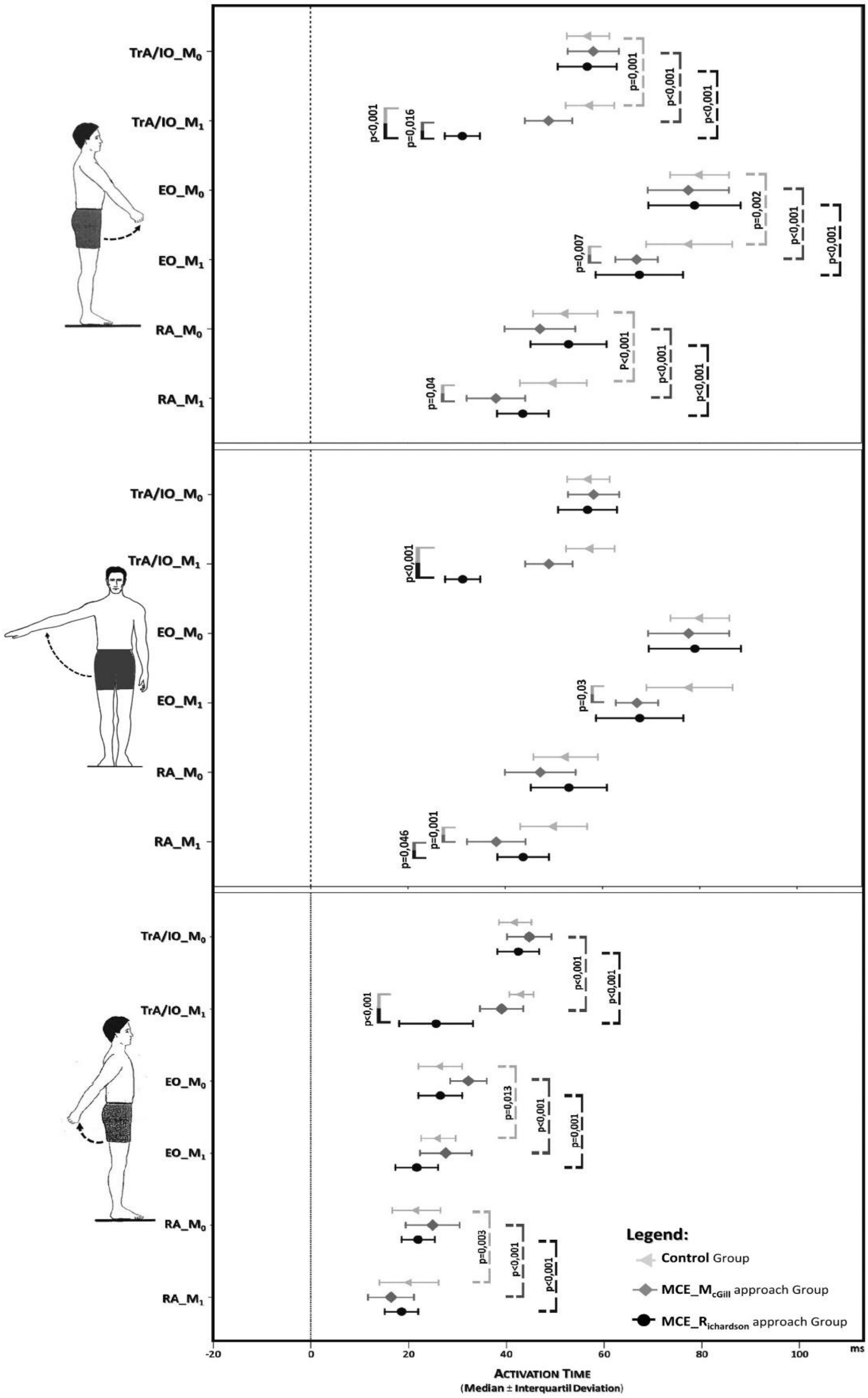

Figure 1. Comparison between groups and assessment moments, at M0 to M1, during rapid arm flexion, abduction and extension movements, in the timing of EMG onset (ms) of the Transversus Abdominis/Internal Oblique (TrA/IO), External Oblique (EO) and Rectus Abdominis (RA) muscles, with the respective median values, interquartile deviation and p-value. MCE_R$_{ichardson}$ - Motor Control Exercise_Richardson Approach, MCE_M$_{cGill}$ - Motor Control Exercise_McGill Approach Group and CG - Control Group.

Tabela 4. Comparison between groups of pain intensity, at baseline (M_0) and final moment (M_1), in millimetres, with the respective median values, interquartile deviation, statistical value and p-value. MCE_R$_{ichardson}$ - Motor Control Exercise_Richardson Approach, MCE_M$_{cGill}$ - Motor Control Exercise_McGill Approach Group and CG - Control Group.

		INTENSITY M_0		**INTENSITY M_1**			
		Median (mm)	Interquartile Deviation (mm)	**Median** (mm)	Interquartile Deviation (mm)	**Statistical value** (Wilcoxon signed-rank test)	**p-value**
MCE_R$_{ichardson}$ (n=20)		56,50	4,13	21,50	3,38	-3.928	<0.001
MCE_M$_{cGill}$ (n=20)		55,50	3,38	23,50	2,38	-3.926	<0.001
CG (n=19)		54,00	4,50	33,00	2,50	-3.839	<0.001
Statistical value (Kruskal Wallis test)		0,849		39,081			
p-value		0,654		**<0,001***			
Post-Hoc	CG/MCE_R$_{ichardson}$	----		**p<0,001***			
	CG/MCE_M$_{cGill}$			**p<0,001***			
	MCE_R$_{ichardson}$/MCE_M$_{cGill}$			p=0,866			

Intra-group Comparison

<u>EMG onset timing</u>

On MCE_R$_{ichardson}$ and MCE_M$_{cGill}$ groups, it was found a significant decrease in the timing of EMG onset in all of the muscles, in any of all rapid arm movements ($p>0.05$).

Regarding CG in the rapid arm flexion movement, the timing of EMG onset muscle of TrA/IO significantly increased from M_0 to M_1 ($Z=-3.018$, $p=0.001$), on the contrary, the timing of EMG onset of EO ($Z=-2.938$, $p=0.002$) and RA ($Z=-3.260$, $p<0.001$) decreased. Moreover, we identified no significant differences in the rapid arm abduction movement in the timing of EMG onset in all of the muscles ($p>0.05$). Finally, in the rapid arm extension movement, the timing of EMG onset of EO ($Z=-2.435$, $p=0.013$) and RA ($Z=-2.798$, $p=0.003$) in CG significantly decreased (see Figure 8).

Pain Intensity

In an intra-group comparison we observed that all groups $MCE\_R_{ichardson}$ ($Z=-3.928$, $p<0.001$), MCE_M_{cGill} ($Z=-3.926$, $p<0.001$) and CG ($Z=-3.839$, $p<0.001$) were a significantly decrease in pain intensity.

DISCUSSION

Motor control exercise programs have been proved to enhance core abdominal function (strength and endurance), increasing lumbopelvic dynamic stability and reducing pain (Hides et al., 2001). However, in subjects with chronic nonspecific lumbopelvic pain, the effect on recruitment pattern and onset timing of the abdominal muscles is still controversial. A systematic review done by A. Y. Wong et al. (2013) highlighted that changes in transversus abdominis activation following conservative treatments tend not to be associated with corresponding changes in clinical outcomes. Nevertheless in the present study both motor control exercise approaches were able to reduce EMG onset timing of the abdominal muscles during postural disturbing (rapid arm movement) together with a pain intensity decrease. However, a different response accordingly to experimental group was noted.

The Carolyn Richardson approach significantly decreased TrA/IO EMG onset timing in all rapid arm movements, while Stuart McGill approach significantly decreased superficial muscles (EO and RA) in rapid arm flexion and abduction movements. When taking into account core abdominal activation techniques (drawing-in and bracing, respectively) and the specificity training principle these results have been expected. In fact, Urquhart, Hodges, Allen, and Story (2005) reported a selective activation of transversus abdominis with a drawing-in manoeuvre and a global abdominal activation with bracing. Although both manoeuvres increase lumbopelvic stiffness, it is thought that different core abdominal activation awareness was integrated by the experimental groups in “internal model of body dynamics”. This could generate a specific orientated response of the abdominal muscles according to the training approach, which was local muscle system stabilization for Carolyn Richardson approach and global muscle system stabilization for Stuart McGill approach (Richardson et al., 2004).

In CG, the results observed in this research were expected. The poor motor control due to deep muscles delay (significant increase TrA/IO EMG onset timing in rapid arm flexion movement) was compensated by a decrease in EMG onset timing of the superficial muscles (EO and RA), which is in agreement with the literature (Hodges, 2001a; Hodges & Cholewicki, 2007; Hodges, Moseley, et al., 2003).

Regarding pain intensity, all group showed a significant reduction. However, since it was found that both intervention groups had significantly lower values then CG it is possible to assume that both motor control exercise approaches improved pain intensity. It was supposed that the dynamic stability improvement of the abdominal muscles with increased lumbopelvic stiffness in both experimental groups decreases nociceptors activity by controlling spine neutral zone (Hodges, 2011). These results were in agreenment with a recent meta-analysis of randomized, controlled trials, which reported that motor control exercise reduces pain and disability comparing to other interventions in chronic and recurrent low back pain (Bystrom, Rasmussen-Barr, & Grooten, 2013).

One of the weaknesses in the present study was the absence of bilateral electromyographic evaluation during rapid arm movement, since transversus abdominis response was proven not to be symmetrical. However, during this task, Morris et al. (2013) found a predominant contralateral feedforward activity of the transversus abdominis.

CONCLUSION

In the present study we observed that both approaches motor control exercise decreased timing of EMG onset of abdominal muscles verifying an improvement in the lumbopelvic dynamic stability. However, motor control exercise according to the Carloyn Richardson approach seems to have more effect on local stabilizing muscles (TrA/IO) while the approach of Stuart McGill appears to have more effect on global stabilizing muscles (EO and RA). Yet, both motor control exercise programs reduced the lumbopelvic pain intensity.

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3.7. Study VII – Bilateral analysis of the onset timing of Transversus Abdominis and Internal Oblique muscles during rapid arm flexion movement of dominant and non-dominant sides

Paulo Carvalho*[1,2], António Mesquita Montes[1,2], Ruben Ferreira[1,3], Rubim Santos[2], João Paulo Vilas-Boas[4]

[1] *Physical Therapy Department – School of Allied Health Sciences of Porto/Porto Polytechnic Institute (ESTSP/IPP), Vila Nova de Gaia, Portugal*

[2] *Center of Study for the Movement and Human Activity (CEMAH) - ESTSP/IPP, Vila Nova de Gaia, Portugal*

[3] *Sporting Clube de Braga Futebol SAD – Medical Department*

[4] *Porto Biomechanics Laboratory (LABIOMEP), Faculty of Sport, CIFI2D, University of Porto, Porto, Portugal*

***Corresponding author:**

Physical Therapy Department – School of Allied Health Sciences of Porto/Porto Polytechnic Institute (ESTSP/IPP), Vila Nova de Gaia, Portugal
Rua Valente Perfeito, 322
4400-330, Vila Nova de Gaia, Portugal.
E-mail address: pmc@estsp.ipp.pt (Paulo de Carvalho).

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ABSTRACT

Background: For more than one decade was told that the *transversus abdominis*/internal oblique (TrA/IO) act as an unique muscle, bilaterally pre-activating simultaneously to increase stiffness to the low back, giving segmental stability during upper limb movements. Nowadays, we know that "corset" mechanism doesn't happen, once TrA/IO reveals a feedforward activation mechanism mostly contralateral to the moved limb. Beside the non-dominant side TrA/IO being thicker than the dominant side, nothing is known about the dominant side influence on the TrA/IO's onset timing.

Objectives: the aim of this research was to analyse TrA/IO's bilateral onset timing during rapid arm flexion movement of each of the upper limbs, investigating a possible side dominance influence as well.

Methods: Cross-sectional study in which the sample was constituted by a group of 32 volunteer subjects. The data was collected by surface electromyographic, evaluating TrA/IO's onset timing bilaterally, during left and right RAFM. Statistical data (ANOVA for repeated measures) was processed in the SPSS software (with a significance degree of 0.05).

Results: Were found significant differences on right and left TrA/IO's onset timing during both RAFM (ANOVA: $F=291.087$; $p<0.001$). Contralateral onset timing of TrA/IO's was lower than the ipsilateral, during right and left RAFM (4.71 (±17.32)ms vs. 29.15 (±13.15)ms; 12.20 (±17.40)ms vs. 31.98 (±12.50)ms, respectively) (Post Hoc Bonferroni test: $p<0.001$). Contralateral TrA/IO's onset timing during right RAFM was lower, compared with the left RAFM ($p<0.001$). Ipsilateral TrA/IO's onset timing during right RAFM was lower, compared with the left RAFM ($p<0.001$).

Conclusion: We concluded that the onset of right and left TrA/IO muscles is not performed simultaneously, during RAFM, although this occurs within a feedforward window. We observed, also, that the onset of right and left TrA/IO muscles is related with the arm dominance.

Key-Words: *Transversus Abdominis/Internal Oblique, Onset, Motor control, Feedforward, Upper-limb, Dominance*

INTRODUCTION

The study of the factors that influence lumbopelvic and spinal stability has been object of research for more than three decades, even so, it’s still found some controversy or lack of certainty about those factors, as well as the mechanisms underneath spinal stabilization. There are several theories and models designed to explain this phenomenon, anyway, in the core of all those explanatory models, it seems practically consensual the importance given to the deep abdominal muscles for anticipatory postural adjustments (APAs) (Barr, Griggs, & Cadby, 2005).

APAs are involuntary and automatic adjustments to expected postural disturbances. This adjustments arise at postural disturbances caused by movement, acting with a feedforward mechanism, being responsible to control the body’ center of mass, segmental stability and movement production capability as well (G. T. Allison, Morris, & Lay, 2008).

So, the dynamic control mechanism is warranted by the postural muscles, who onset previously, by feedforward, to the onset of the muscle responsible for movement production. Feedforward activation is considered when the onset timing of a postural muscle occurs between 100ms before and 50ms after the onset of the muscle responsible for movement production, providing segmental stability to the disturbances caused by the movement (Hodges & Richardson, 1997b).

Between all that muscles, and specifically among abdominal’ deep muscles, the literature available highlights the role of TrA and multifidus muscles in stabilizing the lumbar spine during static and dynamic tasks, done by the spine or by the lower or upper limbs (Hodges & Richardson, 1997a, 1997b).

Transversus Abdominis/Internal Oblique’s (TrA/IO) onset timing during upper and lower limbs movements has been widely studied for the past decades, creating several theoretical models to explain the mechanisms underlying spinal stabilization, as well as providing support to rehabilitation and prophylactic methodologies (Hodges & Richardson, 1997b; Morris et al., 2012).

This way, the “Corset Hypothesis” emerged through the results obtained by Hodges & Richardson (1997), demonstrating TrA/IO’s relevance as a spinal stabilizer. This theory assumes that TrA/IO behaves as a “corset”, protecting and increasing spinal stiffness during voluntary limb movements through bilateral early onset, acting as a unique muscle (Hodges & Richardson, 1997a, 1997b, 1999a, 1999b). Since then, huge amounts of athletes and patients were trained with this kind of methodological believes as a way to stabilize the lumbar spine, in therapeutic and prophylactic ways (Morris et al., 2012).

Besides that, recent studies have been showing that TrA/IO’s onset doesn’t happens in a bilateral and symmetric way, neither that muscles act as a unique muscle belly as we were told. According to the most recent evidence available, during extremities movement, TrA/IO muscles has a predominant unilateral and contralateral feedforward onset, suggesting some controversy with the past studies that gave life to the rehabilitation and prevention training methodologies applied nowadays (Morris et al., 2012).

Based on these assumptions and some recent evidence, other theories have been emerging, giving a predominantly neurophysiological/motor control importance to the contralateral TrA/IO rather than a biomechanical function. These theories highlight the role that this deep muscle acting as a prime-activator of a global muscular synergy along with other trunk and lower limb muscles (Morris et al., 2013).

Recent investigations still support that TrA/IO’s onset timing is side-independent during rapid arm movement, but there is no available data concerning its dominance/non-dominance onset timing effect. In fact, the only information about dominant/non-dominant side relationships regarding TrA/IO muscles is about muscle hypertrophy. According to those studies, non-dominant side TrA/IO is thicker than the dominant side one, remaining the doubt if those differences are also noticed in its onset timings (Dorado, Calbet, Lopez-Gordillo, Alayon, & Sanchis-Moysi, 2012; Sanchis-Moysi, Idoate, Izquierdo, Calbet, & Dorado, 2013).

For this reason, the aim of this research was to analyse TrA/IO's bilateral onset timing during rapid arm flexion movement of each of the upper limbs, investigating a possible side dominance influence as well.

METHODS

Sample

Cross-sectional study with a single group, constituted by 32 volunteers, wherin 22 of them were male. Demographic and anthropometric data is described in Table 1. This group was submitted to two tasks at a single assessment moment.

Table 1. Sample's demographic and anthropometric data with mean, standard deviation (SD), minimum and maximum.

	Age (years)	Body Mass (Kg)	Height (meters)
Mean	23.81	64.02	1.68
SD	2.32	10.175	0.978
Minimum	20	51.80	1.58
Maximum	29	81.50	1.85

Inclusion criteria employed in this study were right handed subjects with ages between 18-30 years. Every subject with history of low back pain who needed health cares or changed their daily routine in the last 12 months, any spinal, neurological or cardiovascular pathology, history in one or both shoulders injury and history of thoracic, abdomen or shoulder surgery; were excluded (Hodges, Moseley, et al., 2003; Hodges & Richardson, 1999a; Morris et al., 2012).

Instruments

A questionnaire was given to the subjects in order to be sure that every participant fulfilled the selection criteria of this study, as well as to gather some sociodemographic information.

Anthropometric measures were taken by a Bertec® force platform (Bertec Corporation – FP4060-10, 6185 Huntley Road, Suite B, Columbus, OH 43229, EUA) to assess the body mass of each subject, and a SECA® s761 stadiometer (Seca®, Vila Verde, Sintra, Portugal) to check their heights.

Surface electromyography (sEMG) was collected through the BioPLUX research device (Plux® wireless biosignals SA, 2630-369 Arruda dos Vinhos, Portugal), with 8 channels and a sampling frequency of 1000Hz, using double differential electrode leads (CMRR-110db) (Hermens et al., 2000; Kamen & Gabriel, 2009; Roberto Merletti, 1999). The use of sEMG to detect muscular contractions is well documented, being precise and valid (Basmajian & De Luca, 1985; Criswell, 2011; Hermens et al., 2000; Kamen & Gabriel, 2009). In order to check the skin impedance level an electrode impedance checker was used (Noraxon®, Scottsdale, Arizona, USA) (Basmajian & De Luca, 1985; Criswell, 2011; Hermens et al., 2000; Kamen & Gabriel, 2009).

The electrodes sensors were connected to the BioPLUX® research device using wireless connectivity, by Bluetooth on a range of 100m, and have a gain of 1000 and an analogue filter at 25 to 500Hz.

Self-adhesive Ag/AgCl dual snap Noraxon® disposable electrodes for surface EMG were attached to BioPLUX sensors. The electrodes characteristics were 4cm x 2.2cm of adhesive area, diameter of each of the two circular conductive areas were 1cm, and 2 cm inter-electrode distance (Criswell, 2011; Hermens et al., 2000; Kamen & Gabriel, 2009).

For reference electrode we use self-adhesive Ag/AgCl snap Noraxon® disposable electrodes for surface EMG with diameter of the circular adhesive area were 3.8cm; diameter of the circular conductive area were 1cm.

We use the MonitorPlux® v2.0 software in order to visualize and acquire the electromyographic signal. In order to process and analyse de EMG signal, the Acqknowledge® software version 4.1 was used (Biopac Systems Inc., Goleta, CA, USA)(Hermens et al., 2000).

Through the MatLab® routine we identify the point where the pressure registered in the transducer, derived from baseline. The timing of muscle activation was defined as the interval time between this point and the onset of

EMG activity of each of the muscles recorded (Hodges & Bui, 1996; Hodges, Moseley, et al., 2003; Hodges & Richardson, 1997a, 1997b).

Procedures

Data Collection Protocol

This study's procedures took place in biomechanical laboratory and was performed in a controlled environment.

In order to characterize the sample, an characterization questionnaire was given to all the subjects. After that procedure, every selected participant were submited to a body mass and height measures. No information about any expected results, current evidence or any way to change muscular recruitment was given to the subjects.

The skin hair was removed and an abrasive pad was used for removing death cells from the skin superficial layer. The skin was clean with isopropyl alcohol (70%), removing the skin oiliness and the remaining death cells (Garry T. Allison et al., 1998; Clancy et al., 2002; Criswell, 2011; Kamen & Gabriel, 2009). After skin preparation, the bioimpedance was checked, using electrode impedance checker, in order to guarantee that impedance levels were below 5KΩ, and thus ensure a good EMG signal acquisition (Basmajian & De Luca, 1985; Criswell, 2011; Kamen & Gabriel, 2009).

Five minutes after skin cleaning, the electrodes were placed in the orthostatic position. This were placed parallel to the muscle fibers orientation according to the references described in Table 2, confirmed by palpation and muscular contraction. In the end of this step, a five minutes wait period was taken between electrode placement and sEMG collection start (Criswell, 2011; Kamen & Gabriel, 2009; Marshall & Murphy, 2003).

The reference electrode was placed in the anterior superior iliac spine (ASIS) (Garry T. Allison et al., 1998; Basmajian & De Luca, 1985; Criswell, 2011; Hermens et al., 2000; Kamen & Gabriel, 2009). The reference locations marked the middle point of the interelectrodes' distance, that is, the distance center to center between the pair of electrodes (Clancy et al., 2002).

EMG activity was collected and analysed bilaterally during rapid arm flexion movements of each of the upper limbs. Movements' order was randomized, as well as they were also done as fast as possible until approximately 60º after verbal command. Rest period between repetitions were 1 minute, giving the chance to completely recover from the exercise. Three repetitions of each movement was done and collected (Hodges & Richardson, 1997b, 1999a).

Table 2. Electrode placement' sites.

Muscle	Electrode Placement
TrA/IO	2cm medially and below the anterior superior iliac spine (ASIS) In this site, TrA and IO muscle fibers are mixed, so it is impossible to distinguish sEMG activity of both. For this reason, the EMG signal collected is considered from TrA/IO (Marshall & Murphy, 2003).
Anterior Deltoid	Muscle belly centre (Marshall & Murphy, 2003).

Data Processing

Data collected by Monitor PLUX® version 2.0 was converted and processed through a routine developed in MatLab® student version software. In this way, were applied, to the EMG signal, a 2nd order digital filter Infinite Impulse Response – Butterworth, one of 10Hz (high pass) and the another of 450Hz (low pass), in order to remove electrical noise and/or cable movement; and the last one of 30Hz (high pass), in order to remove cardiac signal from EMG signal. Than the root mean square (RMS) was calculated (Basmajian & De Luca, 1985; Clancy et al., 2002; Criswell, 2011; Drake & Callaghan, 2006; Kamen & Gabriel, 2009; Mello et al., 2007).

EMG signal analysis was done with Acknowledge® version 4.0 for Mac OS X software. Onset timing was defined as the time wasted between each TrA/IO EMG activity start relatively to anterior deltoid, the muscle responsible for the movement production. EMG onset timing was considered as the time when mean RMS of 50 consecutive frames (50ms) exceeded baseline for 3 standard deviations. Rest EMG activity was determined in a 50ms period, 500ms before the point in which the anterior deltoid EMG activity clearly derives from the baseline. All traces were visually inspected to ensure that the onset was not obscured by movement artifact or an electrocardiogram (<7% of trials) (Hodges & Bui, 1996). Finally, mean onset timing of the three movement test repetitions was determined (Drake & Callaghan, 2006; Kamen & Gabriel, 2009). Feedforward activation was considered when onset timings were found between 100 ms before and 50 ms after anterior deltoid's onset timing (Hodges & Richardson, 1997a, 1997b, 1999a).

Ethics

The study were conducted in accordance with the declaration of Helsinki and approved by the Institutional Research Ethics Committee, and each individual provided a written informed consent before participation.

Statistics

Descriptive and inferential statistics analysis of this study was done by IBM SPSS Statistics® version 20.0 (IBM Corp.®, New York, United States), for Mac OS X (64-bit), with a 95% confidence interval (significance level of 0.05).

In order to check variable's normality, Shapiro-Wilk test was used. When variables' normality during the test was not assumed, the quotient between skewness coefficient and standard deviation was determined, and if the result could be inserted between -1.96 and 1.96, the distribution was considered normal. For every variable was used descriptive statistics: mean and standard deviation (Marôco, 2011).

Inferential analysis was done through ANOVA for repeated measures test. Mauchly's Pos-hoc analysis was done with Bonferroni Test, to make an assessment between pairs of paired samples (Marôco, 2011).

RESULTS

Ipsi and contralateral TrA/IO's onset timing during rapid arm flexion movement (RAFM) of both arms are shown below in Figure 1. Significant differences found between the respective TrA/IO and the respective arm movements are also shown in Figure 1.

Relatively to the ipsi and contralateral TrA/IO's onset timing during RAFM, it was possible to identify significant differences on the ipsi and contralateral TrA/IO onset timing during right and left RFAM (F=291.087; p<0.001).

Ipsilateral TrA/IO's onset timing was higher than the contralateral side during right RAFM (p<0.001), with mean onset timings of 29.15 (±13.15)ms and

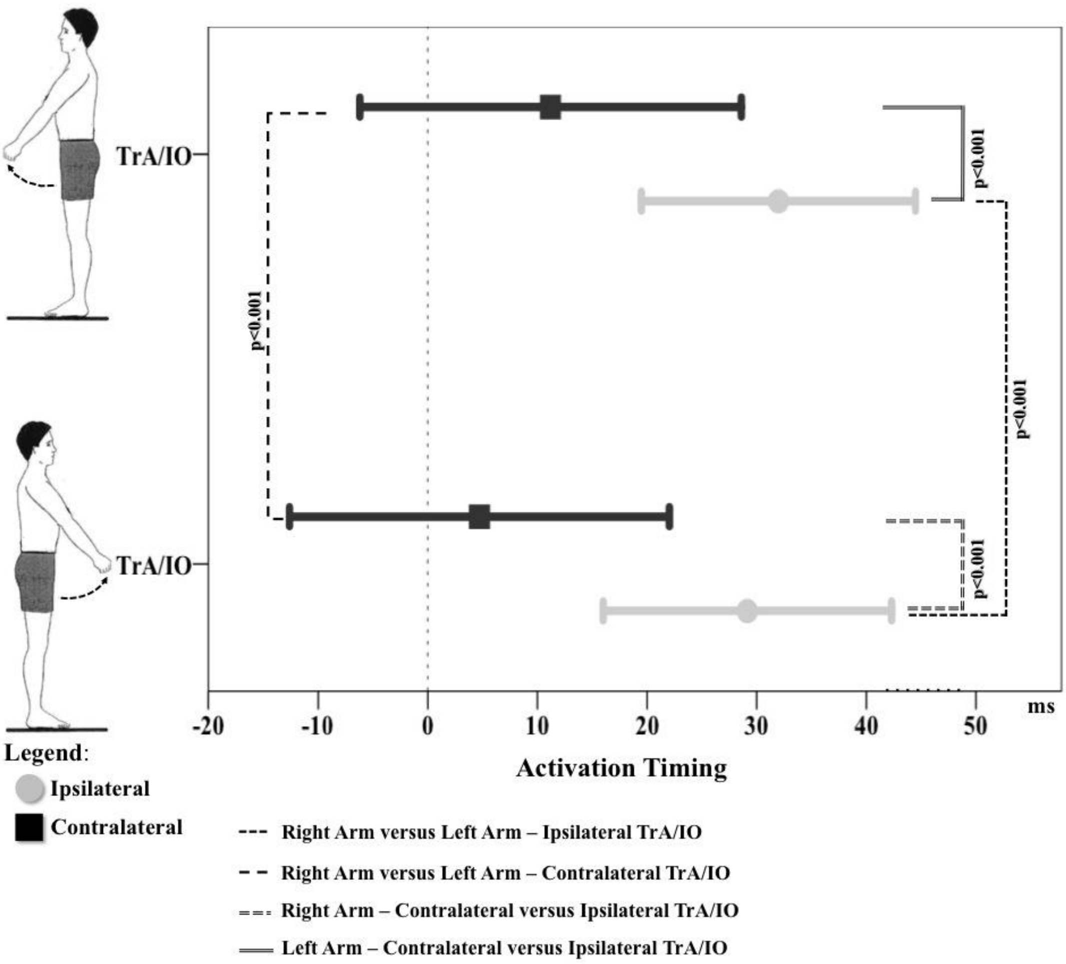

Figure 1. Ipsi and Contralateral TrA/IO's mean onset timings and respective standard deviations during left and right Rapid Arm Flexion Movement.

4.71 (±17.32)ms, respectively. The same happened during left RAFM ($p<0.001$), where contralateral TrA/IO registered a mean onset timing of 12.20 (±17.40)ms while the ipsilateral TrA/IO the mean onset timing was 31.98 (±12.50)ms.

It was also verified that contralateral TrA/IO's onset timing during right RAFM was lower than contralateral TrA/IO's onset timing during left RFAM ($p<0.001$). Ipsilateral TrA/IO had lower onset timing during right RAFM than ipsilateral TrA/IO during left RAFM ($p<0.001$).

DISCUSSION

Hodges & Richardson's (1997) studies showed the existence of some kind of TrA/IO's pre-activation during limb movements, presuming that, once it has its muscle fibers disposed around the waist inserted in the linea alba and thoracolumbar fascia, it would be responsible, through its co-contraction, to act as a "corset" around the lumbar spine prior to movement occurrence, increasing spinal stiffness, protecting and stabilizing it in a segmental way during body movements (Hodges & Richardson, 1997a, 1997b, 1999a, 1999b).

However, more recent studies have demonstrated that TrA/IO onset doesn't occur in a bilateral and symmetrical way, as it was determined in the past. Based on the studies conducted by Morris et al. (2012, 2013), it is known that, during limb movements, TrA/IO has a predominantly unilateral and contralateral feedforward activity, contradicting with the TrA/IO' bilateral activation theory developed by Hodges and Richardson.

Analysing the results of the present study, similar to that of other investigations, it was possible to demonstrate, that TrA/IO's onset timings are not symmetric, being the contralateral TrA/IO muscle to presented, always, a lower onset timing compared to the ipsilateral TrA/IO muscle (G. T. Allison et al., 2008; Morris et al., 2012, 2013). Despite this ipsi and contralateral TrA/IO's onset timings were in the feedforward window, thus acting both TrA/IO muscles for intervertebral motion control (G. T. Allison et al., 2008; Morris et al., 2012, 2013).

The “Corset” hypothesis has a mechanical lumbar spine stabilization theory based on a simultaneous bilateral onset of the TrA/IO muscle, which has already been rebutted by other researches (G. T. Allison et al., 2008; Morris et al., 2012, 2013), as well as this one too, because of the differences found in both TrA/IO’s onset timings during rapid arm flexion movements.

Based on the controversial data, and in a attempt to understand TrA’s onset mechanism, Morris, Lay & Allison (2012) conducted a study where they analysed TrA’s bilateral EMG activity using deep EMG as well as the reaction forces of the trunk during upper limbs movements. The authors demonstrated that, during rapid arm flexion is created an ipsilateral rotational torque, leading to the need of controlling that disturbance, stabilizing the spine. This may explain, why the present investigation and this authors found that contralateral TrA/IO’s onset timing is lower than the ipsilateral one, which may be due a strategy to compensate the rotational trunk torque originated by the arm movement (G. T. Allison et al., 2008; Morris et al., 2012, 2013).

Recent studies, based on the assumption that TrA/IO’s isolated contraction is not enough to grant spinal segmental stability, have been suggesting that, more than a mechanical effect, contralateral TrA/IO muscle may have a predominant neurophysiological importance to motor control development. According to this hypothesis, TrA/IO’s stabilization relevance may be due to the prime-activation of synergic patterns involving other trunk and proximal limb muscles, increasing intra-abdominal pressure and spinal decompressive forces through this synergic activation (G. T. Allison et al., 2008; Morris et al., 2012, 2013; Stokes, Gardner-Morse, & Henry, 2010).

A recent research with asymptomatic participants, mean age 36 (±6.3) years, with bilateral deep and sEMG of TrA, IO, external oblique (EO), erector spinae (ES) and biceps femoris (BF), has shown that contralateral TrA/IO initiates a global muscular synergic relationship and not a local muscular synergic relationship with the homologous TrA/IO to increase spinal stiffness. This global postural synergic pattern seems to be oblique/diagonal way through this order: contralateral TrA/IO, ipsilateral EO, contralateral ES and ipsilateral

BF. However, caution has to be taken because of the low number of participants (n=7) (Morris et al., 2013).

Based on the findings of this study, Morris, Lay & Allison (2013) question about the really need and utility of an increased spinal stiffness done by the bilateral TrA/IO's onset, once the use of a co-contraction pattern leads to a unnecessary energy consumption and also crashing with the pretended precision and selectivity in motor control improvement. For these authors, the mechanism underlying spinal stability must be based on reciprocal innervation rather than in co-contraction, highlighting the importance of the contralateral TrA/IO's early onset, acting as a trigger to this precise motor control mechanism (Morris et al., 2013).

Besides, some other investigations have already shown that non-dominant side of TrA muscle is thicker (higher hypertrophy) that the dominant side (Dorado et al., 2012; Sanchis-Moysi et al., 2013), but no one ever studied if the authors also present differences in the onset timing. For this reason, this is the first study to analyse that topic. Based on the results found in the present study, and knowing that every subject was right-handed, it was possible to demonstrate that side-dominance influences TrA/IO's onset timing, once it was verified that left TrA/IO's onset timing during right RAFM was significantly lower than right TrA/IO during left RAFM.

Another interesting result was that right TrA/IO's onset timing during right RAFM (dominant side) was lower left TrA/IO's onset timing during left RAFM (non-dominant side). This data suggests that when the movement is done with the dominant arm, contra and ipsilateral TrA/IO's onset timing is lower, compared with the non-dominant side. These results can be too explain by the neurophysiology of side-dominance, in other words, the existence of a dominant side and its preferential use leads to mechanical and neurophysiological changes of the skeletal muscles recruited, originating a optimize muscular recruitment sequence when using the dominant limb (Butler, Hubley-Kozey, & Kozey, 2009).

All these findings are really relevant because a great part of lumbopelvic and lower limb rehabilitation and injury prevention methodologies are based on the concepts of TrA/IO's bilateral onset, assuming that they act dependently as a single muscle belly.

CONCLUSION

Through this study it was possible to observe that the onset of right and left TrA/IO muscles is not performed simultaneously, during RAFM, although this occurs within a feedforward window. We observed, also, that the onset of right and left TrA/IO muscles is related with the arm dominance.

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CHAPTER 4

DISCUSSION, CONCLUSION AND FUTURE WORK

4.1. GLOBAL DISCUSSION

The loss of the feedforward muscle activation in the presence of lumbopelvic pain (LPP) is the foundation of the proposal that there is an underlying motor control dysfunction of the deep abdominal muscles in subjects with LPP.

This global discussion will be subdivided into four different parts, namely: (1) methodological aspect of electromyography (EMG); (2) Pain intensity; (3) EMG Onset Timing; and (4) Spine and lumbopelvic stability tests.

4.1.1 METHODOLOGICAL ASPECT OF EMG

Kamen and Gabriel (2009) report that the amplitude of the EMG signal varies according to the muscle electrical activity detected by the electrodes at each moment, providing information on the muscle activation. One of the most commonly used parameters to measure the electromyographic signal amplitude is the root mean square (RMS) (Garry T. Allison et al., 1998; Basmajian & De Luca, 1985; Clancy et al., 2002; Criswell, 2011; Kamen & Gabriel, 2009; Roberto Merletti, 1999; Roberto Merletti & Hermens, 2000).

According to published data, the variation of the electromyographic signal amplitude can arise from several factors, namely the presence of motor points and tendon areas, or the existence of a higher density of subcutaneous tissue between the sensing surface and the muscle, that leads to a lower electromyographic amplitude in the electromyographic curve (Beck et al., 2008; Cescon et al., 2008; Hermens et al., 2000; Hogrel et al., 1998). When we place the electrodes on the centre of the muscle belly or near the motor endplate, it becomes easier to achieve higher EMG signal amplitudes (Basmajian & De Luca, 1985; Criswell, 2011; Hermens et al., 2000; Kamen & Gabriel, 2009).

During the realization of this PhD and regarding the methodological aspects of the use of superficial Electromyography (sEMG), were under study the following parameters: the onset timing and different electrodes location.

Regarding the latter parameter, was performed a comparison between two places (L_1 and L_2 – for more details about the two locations see Study-IV) in Rectus Abdominis (RA) muscle, described previously in the literature.

In respect to the EMG signal amplitude obtained in L_1 and L_2, assessed through RMS the signal was found significant differences between the two locations.

The normalization of the EMG signal in relation to percentage of maximal voluntary isometric contraction, represent the degree (in percentage) in which the muscle is working relatively to its maximum activity, allowing the quantitative comparison of the muscular activity among different subjects, or in the same subject in different days or even between different muscles (Basmajian & De Luca, 1985; Criswell, 2011; Kamen & Gabriel, 2009; Gregory J. Lehman & McGill, 2001).

Studies on the effect of the electrodes' location have been more focused on the EMG signal amplitude, conduction velocity and mean power frequency (Beck et al., 2008; Cescon et al., 2008; Hogrel et al., 1998; Mercer et al., 2006; Mesin et al., 2009). However, no study has mentioned the effect of the electrodes' location after the normalization of the EMG signal to the maximum activity of the muscle.

However, after the normalization of the signal to the maximum voluntary isometric contraction, no significant differences were found between the relative muscle activation values obtained for each location.

Given the results obtained in this PhD study, it should been taken into consideration the reference used in the electrodes' location when comparing studies that intend to withdraw their conclusions from the EMG signal amplitude values.

4.1.2 PAIN INTENSITY

Regarding pain intensity, all group showed a significant reduction. However, since it was found that both intervention groups had significantly lower values then CG it is possible to assume that both motor control exercise approaches improved pain intensity. It was supposed that the dynamic stability improvement of the abdominal muscles with increased lumbopelvic stiffness in both experimental groups decreases nociceptors activity by controlling spine neutral zone (Hodges, 2011). These results were in agreement with a recent meta-analysis of randomized, controlled trials, which reported that motor control exercise reduces pain and disability comparing to other interventions in chronic and recurrent low back pain (Bystrom et al., 2013).

4.1.3 EMG Onset Timing

Lumbopelvic Pain versus Non Lumbopelvic Pain

The typical strategy occurring during limb movements consists of a differential activation of the superficial and deep stabilizing muscles, involving postural adjustments. The impairments found in the muscle recruitment patterns in subjects with lumbopelvic pain (LPP), with loss of the independent activation of superficial and deep stabilizing muscles, may compromise the optimal function of the spine (Hodges, 1999; Hodges & Richardson, 1999b; Richardson et al., 1999, 2004).

The importance of the TrA's activity has been widely studied and it has been questioned if the delay in its activation (in milliseconds), may have significant influence on the vertebral control (Hodges, 1999; Richardson et al., 2004). It is universally accepted that the pre-activation of the TrA is essential when the global stabilizing muscles and mobilizers are not able to provide selective stability to each intervertebral segment and have a limited capacity to provide stability to the sacroiliac joint (Hodges, 1999; Richardson et al., 2004; Richardson et al., 2002). Due to the instability of the spine, particularly in the neutral zone, the impairments in the recruitment patterns expose the vertebral structures to an increased risk of micro-trauma and injury, and seem to be a relevant factor in the recurrence of LPP (Hodges, 1999; Richardson et al., 2004; Richardson et al., 2002).

In this PhD study, the onset timing of the abdominal muscles, associated to the dominant rapid arm flexion, abduction and extension movements, were altered in the subjects with LPP. This change was manifested by the TrA/IO delayed onset in all directions of right upper limb movements analyzed, as well as, the loss of the independent activation between the deep and superficial abdominal stabilizing muscles analyzed.

In the subjects without lumbopelvic pain, the TrA/IO was pre-activated in all directions of dominant upper limb movements analyzed and the muscle recruitment pattern remained independent of the direction of motion. The EO and RA were pre-activated only during the extension movement.

In the present PhD study we observed also that was a consistent sequence of muscle activation between the two groups (with and without lumbopelvic pain), with the exception for the extension movement.

In the subjects with LPP it was found a similar pattern of activation between the superficial and deep muscles of the lumbopelvic region in all directions of movement performed, with the consequent loss of the independent activation between these muscle groups.

These findings agree with previous studies indicating that the TrA has an anticipatory response with the same magnitude, regardless of the movement direction (Hodges & Richardson, 1996, 1997b, 1999a, 1999b).

One of the weaknesses present in the studies-1 and 6 was the absence of bilateral electromyographic evaluation during rapid arm movement, since transversus abdominis response was proven not to be symmetrical. However, during this task, Morris et al. (2013) found a predominant contralateral feedforward activity of the transversus abdominis.

Effect of the Motor Control Exercise on EMG Onset Timing

Motor control exercise programs have been proved to enhance core abdominal function (strength and endurance), increasing lumbopelvic dynamic stability and reducing pain (Hides et al., 2001). However, in subjects with chronic nonspecific lumbopelvic pain, the effect on recruitment pattern and onset timing of the abdominal muscles is still controversial. A systematic review done by A. Y. Wong et al. (2013) highlighted that changes in transversus abdominis activation following conservative treatments tend not to be associated with corresponding changes in clinical outcomes. Nevertheless in the present study both motor control exercise approaches were able to reduce EMG onset timing of the abdominal muscles during postural disturbing (rapid arm movement) together with a pain intensity decrease.

The Richardson_approach significantly decreased TrA/IO EMG onset timing in all rapid arm movements, while the McGill_approach significantly decreased superficial muscles (EO and RA) in rapid arm flexion and abduction movements. When taking into account core abdominal activation techniques (drawing-in and bracing, respectively) and the specificity training principle these results have been expected. In fact, Urquhart et al. (2005) reported a selective activation of transversus abdominis with a drawing-in manoeuvre and a global abdominal activation with bracing. Although both manoeuvres increase lumbopelvic stiffness, it is thought that different core abdominal activation awareness was integrated by the experimental groups in “internal model of body dynamics”. This could generate a specific orientated response of the abdominal muscles according to the training approach, which was local muscle system stabilization for Richardson_approach and global muscle system stabilization for McGill_approach (Richardson et al., 2004).

In the control group, the results observed in this PhD study were expected. The poor motor control due to deep muscles delay (significant increase TrA/IO EMG onset timing in rapid arm flexion movement) was compensated by a decrease in EMG onset timing of the superficial muscles (EO and RA), which is in agreement with the literature (Hodges, 2001a; Hodges & Cholewicki, 2007; Hodges, Moseley, et al., 2003).

4.1.4 SPINE AND LUMBOPELVIC STABILITY TESTS

Active Straight Leg Raising Test

In this PhD study it was identified that active straight leg raising test (ASLR) score could differentiate subjects with and without lumbopelvic pain.

Although this test has already proved useful for differentiating patients with and without lumbopelvic pain (N. G. Lee et al., 2011; Teyhen et al., 2009), no further study compared the effect of 3 stabilization strategies during this task, which were manual pelvic compression, drawing-in manoeuvre and abdominal bracing. Each of these stabilization strategies proved, in the present study, to decrease ASLR score, especially the abdominal bracing who add better results than the others.

Considering that stabilization strategies are often used in lumbopelvic subjects to reduce their pain, this results suggest that an active strategy (drawing-in or abdominal bracing) could have equal to better results, in respect to ASLR difficulty perception, than a passive one (pelvic compression).

Endurance Test

Endurance tests recruit both local as global muscles. In subjects with lumbopelvic pain, pre-activation of erector spinae, internal oblique and transversus abdominis is absent or delayed when a disturb occur (Hodges, 2001b; Hodges et al., 1997; Hodges & Richardson, 1999a; Mannion et al., 2008). These changes in trunk muscle control, in which global muscles have increased activation, can cause increased load on spine elevating injury risk and even pain intensity (Arokoski et al., 2001; Hodges & Richardson, 1999a). In fact, related to the decreased local muscle activation in presence of pain, multifidus, one of the key muscles in lumbar spine intersegmental stabilization, presented less cross-section area and showed evidences of fat and connective tissue infiltration (Key, 2010; Mengiardi et al., 2006; Yanik et al., 2013). Therefore, with less contribution of local stabilization muscles during the endurance tests, more global muscles activation is required. Considering that this muscles are mostly intended for mobility and are composed manly by type II fibres, they are more likely to fatigue and as a result could explain the lower endurance test times in subjects with lumbopelvic pain (Key, 2010)

In this PhD study, it was found that subjects with lumbopelvic pain had lower endurance time of all trunk muscle groups, in comparison with subjects without LPP. Regarding the ratios, all were inferior on the lumbopelvic pain group, including flexors/extensors ratio (0.72±0.16) that differs from the values mentioned by McGill (2007) for this group (higher than 1). This ratio was a consequence of a strong decrease of both trunk flexors and extensors, but in similar proportions. The lateral flexors/extensors ratios for the lumbopelvic pain group also differed from the proposed by McGill (2007), that instead of being less than 0.25 or higher then 1.75, was similar to the non lumbopelvic pain group around 0.5. The other ratios were in agreement with this author, including all ratios for healthy subjects.

Hip Extension Test

In accordance with the objectives of this PhD study relative to the hip extension test, was observed that the subjects, in the LPP group, showed a delay in the onset timing of biceps femoris (BF_Ipsi) and gluteus maximus (GM_Ipsi). It was observed, also, that the “normal” sequence of muscle activation has never been used, however, and despite of some variability observed, the five most frequently used sequences of muscle activation were common in both groups, and each group showed a predominant activation sequence. In both groups, the BF_Ipsi was the muscle that was activated, more times, in first place, and the GM_Ipsi was more frequently the last. Finally, it was observed that individuals, who recruited BF_Ipsi muscle in the first place, had higher anterior pelvic tilt. These results seem to be important in understanding how the muscular system may contribute to lumbopelvic stability. The mechanical muscles properties of this region, gives the ability to the joint structures resist to deformation and its stiffness is changed dynamically by the level of muscle activation (Lederman, 2010). However, changes in motor control may cause an inappropriate recruitment, interfering with the sequences of muscle activation, which compromises the ability to perform, in an automatic way, a proper movement pattern. This change may have an impact on the physiological joint load, changing the direction and magnitude of the imposed forces, originating the onset of lumbopelvic pain (Lewis & Sahrmann, 2009; Sahrmann, 2002; Silfies et al., 2005).

It was observed that the individuals of the LPP group used 9 of the 24 possible sequences of muscle activation, and in the NLPP group, this number was 10 sequences. Despite the minimal difference between the groups, we can considered that the lowest variability in LPP group, may be a protective mechanism, used by the body, to restrict movement patterns available to avoid further damage and consequently lead to an increase of pain intensity (Paul Bruno & Bagust, 2007). The study of Bruno & Bagust (2007), mentioned earlier, found similar results, and was also notorious a greater inconsistency in subjects without lumbopelvic pain.

The literature has proposed that there is a more efficient activation sequence for performing hip extension movement (Paul Bruno & Bagust, 2007; Paul Bruno et al., 2008; G. J. Lehman et al., 2004; Page et al., 2010; Sahrmann, 2002). This theory argues that the GM_Ipsi muscle is the main muscle responsible for this movement and an important functional link between lumbopelvic region and lower limbs, being subsequently aided by the BF_Ipsi muscle. Immediately after contraction of these muscles, there is the activation of the contralateral erector spinae (ES_Contra) and then the ipsilateral erector spinae (ES_Ipsi), to help in the stabilization of the lumbopelvic region (Page et al., 2010; Panayi, 2010).

It is postulated that these changes in muscle activation patterns in the LPP group are an adaptation to the underlying vertebral instability resulting from osteoligamentar laxity, injury and/or muscle dysfunction, as well as inefficient neuromuscular control. To emphasize that, despite the NLPP group not showing symptoms, individuals may have also deficits in motor control (Silfies et al., 2005).

Generally, the analysis of the sequence of muscle activation shown that activation of the muscles BF_Ipsi, ES_Contra and ES_Ipsi tend to become active before the GM_Ipsi, the differences between these three muscles was reduced to the predominance for the activation in first place of BF_Ipsi. The GM_Ipsi muscle, which should be the first to be activated, was the last muscle in most subjects in both groups, residing the exception in a small percentage of individuals of NLPP group. These results are similar to the study of Bruno & Bagust, (2006) which showed that BF_Ipsi was the first to turn up in 34.3% of the 300 repetitions and GM_Ipsi was the last to be activated in 81.3% of these repetitions. More recently, a study carried out by the same authors showed that the BF_Ipsi was the first and GM_Ipsi was the last to turn up, respectively, in 49.7% and 81.3% of 310 repetitions in healthy subjects. In individuals with lumbopelvic pain, the BF_Ipsi was the first to turn up in 61.5% and the GM_Ipsi was the last in 99.0% of the repetitions (Paul Bruno & Bagust, 2007).

Given these findings, it has become pertinent to compare the onset timings of muscle activation in relation to each other's, reinforcing the idea of a significant delay in the activation of GM_Ipsi in the LPP group. The same results were observed in the study performed by Bruno et al. (2008). It can be hypothesized that these muscles are activated early, in order to stabilize the spine before the onset of the GM_Ipsi. If this is the case, then it is possible that a delay in the GM_Ipsi onset, may lead to a compensatory strategy, by the other muscles, such as the activation in the first place but also exhibit an increased activity. This strategy may result in greater load on the lumbar spine due to the increased in tensions and loads transmitted to this region during everyday activities, indicating a possible mechanism underlying the development and/or perpetuation of lumbopelvic pain (Paul Bruno & Bagust, 2007; Lewis & Sahrmann, 2009; Tateuchi et al., 2012).

Given this assumption, it is expected that, only in the individuals with lumbopelvic pain, the GM_Ipsi was the last muscle to be activated, compared with individuals without lumbopelvic pain. However, the findings of this study do not corroborate this assumption, since in the NLPP group, the GM_Ipsi was also mostly the last muscle to be recruited, the great difference resides only in the onset timing, which was lower in this group. Thus, the delay appears to be a normal finding, consisting of a stabilization strategy of the lumbopelvic region, changing the transfer of forces through the pelvis (Arumugam et al., 2012; Guimarães et al., 2010; Hungerford et al., 2003; Tateuchi et al., 2012).

The weakness or inhibition of the GM_Ipsi may be the result of a muscle injury or hyperactivity of an antagonist and/or synergist muscle (Sahrmann, 2002; Ward et al., 2010). Complementing this mechanical weakness or inhibition of GM_Ipsi may be associated with a neurological inhibition due to changes in the sequence of muscle activation. The new sequence is stored in cerebellum, which also contributes to the inhibition of GM_Ipsi (Sahrmann, 2002). In most of the times, this weakness or inhibition is associated with the stiffness of the hip flexors, the lack of motor control and the dominant muscle activity of the ES_Ipsi, ES_Contra and BF_Ipsi, can contribute to the excessive anterior pelvic tilt, during hip extension, and subsequent hyperextension of the lumbar spine (S. Y. Kang et al., 2013; Oh et al., 2007; Page et al., 2010). These changes can cause excessive stresses in the lumbar spine and sacroiliac joint during gait, due to a deficiency in the mechanism of shock absorption (S. Y. Kang et al., 2013; Sahrmann, 2002). This hypothesis was confirmed in this PhD study, since the individuals who activate BF_Ipsi in the first place showed a greater pelvic tilt and consequently a greater pelvic anteversion and an increased of the lumbar lordosis. These results can be explained by the interaction between the dominance of the synergistic muscles which act in force couple, as is the case of GM and BFi, since these two muscles have different characteristics with respect to changes in the muscle lever arm in accordance with the change of the flexion-extension hip angle (S. Y. Kang et al., 2013; Tateuchi et al., 2012). The GM lever arm increases with the increase of the angle of extension of the hip and the opposite is true in BF (Tateuchi et al., 2012). Based on these observations, it appears that the GM has a relative advantage in provide extension force, although both muscles are shortened in the hip extension. Consequently, BF tends to be recruited sooner, increasing pelvic tilt and the extension of the lumbar spine (Hossain & Nokes, 2005; Hungerford et al., 2003; S. Y. Kang et al., 2013; Tateuchi et al., 2012).

The changes in motor control may have a negative impact in lumbopelvic stabilization. This doesn’t suggest, that all individuals with alterations in sequence of muscle activation exhibit the same deficit in motor control, and require the same level of intervention. Therefore, the intervention programs must be compatible with the individual demands and requirements of each patient. The innovation of this PhD study was to investigate the association between the sequence of muscle activation and pelvic tilt, allowing, in this way, verify how the onset timing and their sequence influence the position of the pelvis in the sagittal plane.

However, this finding does not allow support or refute the prevailing theory that a delay in the activation of this muscle during movement is associated with lumbopelvic pain, because it was observed in both groups. However, this delay in the onset timing was higher in the LPP group.

Also, it was observed that the BF_Ipsi muscle was the first to be active, and the individuals who activate this muscle in the first place, have a significantly higher pelvic tilt.

Bilateral EMG Onset Timing of the Transversus Abdominis/Internal Oblique

Hodges & Richardson's (1997) studies showed the existence of TrA/IO's pre-activation during limb movements, presuming that, once it has its muscle fibers disposed around the waist inserted in the linea alba and thoracolumbar fascia, it would be responsible, through its co-contraction, to act as a "corset" around the lumbar spine prior to movement occurrence, increasing spinal stiffness, protecting and stabilizing it in a segmental way during body movements (Hodges & Richardson, 1997a, 1997b, 1999a, 1999b).

However, more recent studies have demonstrated that TrA/IO onset doesn't occur in a bilateral and symmetrical way, as it was determined in the past. Based on the studies conducted by Morris et al. (2012, 2013), it is known that, during limb movements, TrA/IO has a predominantly unilateral and contralateral feedforward activity, contradicting with the TrA/IO' bilateral activation theory developed by Hodges and Richardson.

Analysing the results of this PhD study, similar to that of other investigations, it was possible to demonstrate, that TrA/IO's onset timings are not symmetric, being the contralateral TrA/IO muscle to presented, always, a lower onset timing compared to the ipsilateral TrA/IO muscle (G. T. Allison et al., 2008; Morris et al., 2012, 2013). Despite this ipsi and contralateral TrA/IO's onset timings were in the feedforward window, thus acting both TrA/IO muscles for intervertebral motion control (G. T. Allison et al., 2008; Morris et al., 2012, 2013).

The "Corset" hypothesis has a mechanical lumbar spine stabilization theory based on a simultaneous bilateral onset of the TrA/IO muscle, which has already been rebutted by other researches (G. T. Allison et al., 2008; Morris et al., 2012, 2013), as well as this one too, because of the differences found in both TrA/IO's onset timings during rapid arm flexion movements.

Morris, Lay & Allison (2012) demonstrated that, during rapid arm flexion is created an ipsilateral rotational torque, leading to the need of controlling that disturbance, stabilizing the spine. This may explain, why the present investigation and this authors found that contralateral TrA/IO's onset timing is lower than the ipsilateral one, which may be due a strategy to compensate the rotational trunk torque originated by the arm movement (G. T. Allison et al., 2008; Morris et al., 2012, 2013).

Recent studies, based on the assumption that TrA/IO's isolated contraction is not enough to assure spinal segmental stability, have been suggesting that, more than a mechanical effect, contralateral TrA/IO muscle may have a predominant neurophysiological importance to motor control development. According to this hypothesis, TrA/IO's stabilization relevance may be due to the prime-activation of synergic patterns involving other trunk and proximal limb muscles, increasing intra-abdominal pressure and spinal decompressive forces through this synergic activation (G. T. Allison et al., 2008; Morris et al., 2012, 2013; Stokes et al., 2010).

A recent research with asymptomatic participants, mean age 36 (±6.3) years, with bilateral deep and sEMG of TrA, IO, external oblique (EO), erector spinae (ES) and biceps femoris (BF), has shown that contralateral TrA/IO initiates a global muscular synergic relationship and not a local muscular synergic relationship with the homologous TrA/IO to increase spinal stiffness. This global postural synergic pattern seems to be oblique/diagonal way through this order: contralateral TrA/IO, ipsilateral EO, contralateral ES and ipsilateral BF. However, caution has to be taken because of the low number of participants (n=7) (Morris et al., 2013).

For Morris, Lay & Allison (2013) the mechanism underlying spinal stability must be based on reciprocal innervation rather than in co-contraction, highlighting the importance of the contralateral TrA/IO's early onset, acting as a trigger to this precise motor control mechanism (Morris et al., 2013).

There are some studies that have already shown that non-dominant side of TrA muscle is thicker (higher hypertrophy) than the dominant side (Dorado et al., 2012; Sanchis-Moysi et al., 2013), but no one ever studied the differences in the onset timing. For this reason, this is the first study to analyse that topic. Based on the results found in the present study, and knowing that every subject was right-handed, it was possible to demonstrate that side-dominance influences TrA/IO's onset timing, once it was verified that left TrA/IO's onset timing during right RAFM was significantly lower than right TrA/IO during left RAFM. Another interesting result was that right TrA/IO's onset timing during right RAFM (dominant side) was lower left TrA/IO's onset timing during left RAFM (non-dominant side). This data suggests that when the movement is done with the dominant arm, contra and ipsilateral TrA/IO's onset timing is lower, compared with the non-dominant side. These results can be too explain by the neurophysiology of side-dominance, in other words, the existence of a dominant side and its preferential use leads to mechanical and neurophysiological changes of the skeletal muscles recruited, originating a optimize muscular recruitment sequence when using the dominant limb (Butler et al., 2009).

All these findings are really relevant because a great part of lumbopelvic and lower limb rehabilitation and injury prevention methodologies are based on the concepts of TrA/IO's bilateral onset, assuming that they act dependently as a single muscle belly.

Through this PhD study it was possible to observe that the onset of right and left TrA/IO muscles is not performed simultaneously, during RAFM, although this occurs within a feedforward window.

4.2. CONCLUSIONS

One of the most interesting findings of the continuous interaction between the scientific and clinical development is the potential to improve the clinical approach based on the scientific evidence and the development of scientific ideas, based on the clinical findings. This should result in better health care delivery and, eventually, for the control and prevention of lumbopelvic pain.

The uniqueness of the specific exercises described in this PhD study is that they target pain relief and the onset timing of abdominal muscles directly. There are many approaches, presented in the literature, to motor control training and they share many common features, with variation in: (1) the emphasis on individual issues; (2) the assessment methods used to define the nature of the problem; and (3) the specific techniques used to reeducate the patient.

As discussed throughout this PhD thesis, and despite these areas of divergence, the basic underlying philosophies are surprisingly similar and there is a considerable evidence for many aspects of the both approaches, yet there are many questions remaining and it is hoped that it provides a small contribute for ongoing research to test the efficacy and physiological rationale for both, and to refine the implementation of motor control training for lumbopelvic pain. In time the research and clinicians will tell us which approaches are more effective.

Perhaps, in the future, the best “vehicle” for both clinicians and researchers is to increase their personal knowledge and sharing, so that we are all better equipped to take this journey together.

4.3. FUTURE WORK

This thesis results allows the reinforcement of addressing subjects with chronic nonspecific lumbopelvic pain to perform motor control exercise as way of reducing

In spite of the recent breakthroughs, more research is needed, namely:

- Perform a follow up of 12 months in a group of subjects with lumbopelvic pain to verify if the changes extend through time and how far it they occur.
- Establish a link between the trunk deep/local muscles (re-)training and its influence on the respiratory patterns, once the trunk deep/local muscles, the diaphragm and breathing patterns, and the pelvic floor muscles offers another areas of unexplained questions in muscle function and re-education alternatives.
- Understand which approach of motor control exercise will be most effective in the increasing of trunk muscles endurance.
- Verify if there are differences in outcomes between the different ways of determining the onset timing.

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APPENDICES

APPENDIX I - EMG OF THE TRANSVERSE ABDOMINUS AND MULTIFIDUS DURING PILATES EXERCISES

Carvalho, P., Pereira, A., Santos, R. & Vilas Boas, J.P. (2011). EMG of the transverse abdominus and multifidus during Pilates exercises. In: Vilas-Boas, JP, Machado, L, Wangdo, K. Veloso, AP (eds.) Biomechanics in Sports 29, Portuguese Journal of Sport Sciences, 11 (Suppl. 2): 727-730.

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EMG OF THE TRANSVERSE ABDOMINUS AND MULTIFIDUS DURING PILATES EXERCISES

Paulo de Carvalho[1], Ana Pereira[1], Rubim Santos[1] and João Paulo Vilas Boas[2,3]

School of Allied Health Sciences, Porto Polytechnic Institute, Porto, Portugal[1]
Porto Biomechanics Laboratory (LABIOMEP), University of Porto, Portugal [2]
CIFI2D, Faculty of Sport, University of Porto, Porto, Portugal[3]

The purpose of this research study was to evaluate the intensity of muscle activation of Transverse Abdominus /Oblique Internal (TrA/OI) and Multifidus (Mu) during the performance of four Pilates exercises (and variations), compared, in order to understand the importance of these exercises in the lumbopelvic stability in healthy subjects. The sample consisted of 8 individuals. Using the surface electromyography (EMG), it was found that there are differences in the intensity of muscle activation in the analyzed exercises and, therefore, "Shoulder bridge" and "ShoulderBridge_extension (right and left legs)" are the more appropriate exercises for co-activation between TrA/OI and Mu muscles for the reeducation of lumbopelvic stability.

KEY WORDS: Core, Electromyography, Lumbopelvic Stability, Pilates Method.

INTRODUCTION: To the group of muscles that control movement and stabilize the lumbar spine and pelvis is given the name of "core". The stabilization of the core represents the complex interaction of passive subsystems (joints and ligaments of the spine) and active (muscle and nerve) (Willardson 2007). Anatomically, the core is the musculature surrounding the lumbar-pelvic region. The core muscles and the thoracolumbar fascia play a role in the stability of the lumbar-pelvic region (Bliss & Teeple 2005). The increased dynamic stabilization of this region is achieved through the training of local and global systems. The local system is based on the muscle consisting of slow twitch fibers, shorter in length and deep, which have direct connection to the spine that control inter-segment movement between adjacent vertebrae or act by increasing intra-abdominal pressure. These muscles are the TrA/OI (inferior fibers) and Mu. These muscles have short lever arms due to the proximity to the spine and must be activated before the global muscles with the purpose of stabilizing the lumbopelvic region (Hodges 1999; Hodges & Richardson 1999; Richardson et al. 2004; Ekstrom et al. 2007; Willardson 2007; Akuthota et al. 2008). The Pilates Method develops muscle strength of the body center, focusing on the contraction of muscles TrA/OI and Mu and thus contributes to lumbopelvic stability (Smith & Smith 2005; Smith & Smith 2005a; Bernardo 2007; Endleman et al. 2008; Queiroz et al. 2010). The purpose of this study was to evaluate the intensity of the TrA/OI and Mu muscle activation during the performance of four Pilates exercises (and variations), in order to realize the importance of these exercises in the lumbopelvic stability in healthy subjects.

METHODS: The research model of this study was quantitative and the study design was observational cross sectional. The sample consisted of 8 healthy women volunteers (with 2 years of minimum experience in Pilates, average age – 24 years old, average height 1.64 m and average mass – 54.7 kg) which performed four exercises included in this method and their respective progressions (Queiroz et al., 2010). Surface active differential electromyography (EMG) was used (wireless bioPLUXresearch system, Plux active electrodes, sampling – 1000 Hz, Filter – 10-450 Hz), in order to measure the muscle activity of muscles TrA/OI and Mu. Synchronized video records (Sony DCR-SR15 camera, 50 Hz) were used to relate EMG signal with motor events. Each subject performed three repetitions of each exercise, which allowed calculating the average intensity of muscle activation of each muscle in each exercise. Subsequently, we calculated the level of muscle EMG normalized to the maximal voluntary contraction (Allison et al. 1998; Marshal & Murphy 2003; Arokoski et al. 2001). The *Shapiro-Wilk* test was used to verify the normality of variables' distributions.

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When the sample met the requirements of normal distribution we used the t test for paired samples, while in other cases we used nonparametric Willcoxon test. The confidence interval used was 95% with a significance level of 0,05. All participants were informed about the content of the study and its procedures by signing the informed consent considering the "Helsinki Declaration" of the World Health Organization.

RESULTS AND DISCUSSION: The data analysis showed that between the exercises, compared two by two, there is evidence to support that some exercises are different with regard to the intensity of muscle activation in both muscles TrA/OI and Mu.
For training the local muscles it was observed that, for the TrA/OI muscles, the best exercises are "LegCircle (counter clockwise)", "ShoulderBridge_extension right leg" and "ShoulderBridge_extension left leg". In these exercises were found significant differences between "LegCircle (counter clockwise)" and "Scissors_1" (p=0.015); "LegCircle (counter clockwise)" and "RollUp" (p=0.016); "ShoulderBridge_extension right leg" and "Scissors_1" (p=0.005); "ShoulderBridge_extension right leg" and "RollUp" (p=0.024); "ShoulderBridge_extension left leg" and "Scissors_1" (p=0.022); "ShoulderBridge_extension left leg" and "RollUp" (p=0.012).
For the Mu muscle, there were significant differences in the intensity of activation between "LegCircle (clockwise)" and all the exercises, "LegCircle (counter clockwise)" and all the exercises, "ShoulderBridge" and all the exercises, "ShoulderBridge_extension right leg"and all the exercises and "ShoulderBridge_extension left leg" and all the exercises. The best exercises for the training of the Mu were "ShoulderBridge", "ShoulderBridge_extension right leg" and "ShoulderBridge_extension left leg". These exercises seem to be adequate in reeducation of the lumbopelvic stability (Richardson et al. 2004; Urquhart et al. 2005; Stevens et al. 2007), based on the activation ratio of both muscles (see table 1).

Table 1
Mean and Standard Deviation for the muscle TrA/OI and Mu in the different exercises

Exercises	TrA/OI		Multifidus	
	Mean %	Sta. Deviation	Mean %	Sta. Deviation
LegCircle (clockwise)	17.28	7.34	14.89	4.62
LegCircle (counter clockwise)	20.15	5.75	10.94	5.33
RollUp	14.36	6.18	7.56	2.62
ShoulderBridge	16.98*	5.21	24.46*	9.4
ShoulderBridge_extension right leg	22.4*	7.94	31.37*	13.49
ShoulderBridge_extension left leg	21.03*	13.78	33.71*	8.46
Scissors_Right	18.3	7.64	4.75	1.61
Scissors_Left	17.69	3.52	4.14	1.25
Scissors	17.92	7.55	5.86	1.81
Scissors_1	15.59	6.93	6.65	1.77
Scissors_2	18.13	5.90	6.35	2.08

Legend: Values marked with an asterisk (*) indicate best exercises for co-activation of the TrA/OI and Mu muscles.

CONCLUSION: The Pilates method develops proper muscle activity of the core muscles, contributing to lumbopelvic stability. Based on the relative intensity of muscle activation, it was concluded from this study that, for a co-activation of TrA/OI and Mu muscle for the re-education of lumbopelvic stability, the exercises "ShoulderBridge", "ShoulderBridge_extension right leg" and "ShoulderBridge_extension left leg", are the most effective.

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EMG of the TRANSVERSE ABDOMINUS and MULTIFIDUS during PILATES EXERCISES

Paulo de Carvalho[1], Ana Pereira[1], Rubim Santos[1] and João Paulo Vilas Boas[2]

[1] School of Allied Health Sciences, Porto Polytechnic Institute, Vila Nova de Gaia, Portugal

[2] Porto Biomechanics Laboratory, CIFI2D, Faculty of Sport, University of Porto, Porto, Portugal

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The purpose of this research study was to evaluate the intensity of muscle activation of Transverse Abdominus/Internal Oblique (TrA/IO) and Multifidus (Mu) during the performance of four Pilates exercises, compared, in order to understand the importance of these exercises in the lumbopelvic stability in healthy subjects. The sample consisted of 8 subjects. Using the surface electromyography (sEMG), it was found that there are differences in the intensity of muscle activation in the analyzed exercises and, therefore, *Shoulder bridge* and *ShoulderBridge_extension* (*right* and *left legs*) are the more appropriate exercises for co-activation between TrA/IO and Mu muscles for the reeducation of lumbopelvic stability.

KEY WORDS Core – Electromyography – Lumbopelvic Stability – Pilates Method

INTRODUCTION

The stabilization of the core represents the complex interaction of emotions, passive, active and control systems (Willardson 2007). The core muscles and the thoracolumbar fascia play a role in the stability of the lumbar-pelvic region (Bliss & Teeple 2005). The increased dynamic stabilization of this region is achieved through the training of local and global systems. In the local system we have the TrA/IO (inferior fibers) and Mu. They have short lever arms due to the proximity to the spine and must be activated before the global muscles (External Oblique, Rectus Abdominus) with the purpose of stabilizing the lumbopelvic region (Hodges 1999; Hodges & Richardson 1999; Richardson et al. 2004; Ekstrom et al. 2007; Willardson 2007; Akuthota et al. 2008). The Pilates method develops muscle strength of the body center, focusing on the contraction of muscles TrA/IO and Mu and thus contributes to lumbopelvic stability (Smith & Smith 2005; Smith & Smith 2005a; Bernardo 2007; Endleman et al. 2008; Queiroz et al. 2010).

AIM

Evaluate the *intensity* of the **TrA/IO** and **Mu** *muscle activation* during the performance of four **Pilates exercises** (and variations), in order to realize the *importance* of these ***exercises*** in the **lumbopelvic stability** in *healthy subjects*.

METHODS

Participants

8 volunteer subjects♀

TABLE 1	Mean	SD
Age (y)	24	3,1
HEIGHT (cm)	164	4,6
Weight (Kg)	54,7	5,4
Body Mass Index (kg/m²)	20,4	1,8
Years of Practicing Pilates (y)	3,3	0,5

Procedures

Surface active differential electromyography was used in order to measure the muscle activity of muscles TrA/IO and Mu. Synchronized video records (Sony DCR-SR15 camera, 50 Hz) were used to relate EMG signal with motor events. Each subject performed three repetitions of each exercise, which allowed calculating the average intensity of activation of each muscle in each exercise. Subsequently, we calculated the level of muscle EMG normalized to the maximal voluntary contraction (Allison et al. 1998; Marshal & Murphy 2003; Arokoski et al. 2001).

Instruments

plux wireless bioPLUX research system

emgPlux

Filter – 10-450 Hz

Sony DCR-SR15 camera

Statistics

SPSS 16.0 for Windows

Normality of variables' distribution ⇨ ***Shapiro-Wilk*** Test
Normal distribution ⇨ **t test for paired samples**
Other cases ⇨ nonparametric **Willcoxon test**
Significance level ⇨ **0,05**

Ethics

All participants were informed about the content of the study and its procedures by signing the informed consent considering the Helsinki Declaration of the World Health Organization.

RESULTS

EXERCISES	TrA/IO		Multifidus	
	Mean %	Sta. Deviation	Mean %	Sta. Deviation
Shoulder Bridge_extension right leg	22.4*	7.94	31.37*	13.49
Shoulder Bridge_extension left leg	21.03*	13.78	33.71*	8.46
Shoulder Bridge	16.98*	5.21	24.46*	9.4

Values marked with an *asterisk* (*) indicate *best exercises* for **co-activation** of the **TrA/IO** and **Mu muscles**.

These exercises seem to be adequate in **reeducation** of the **lumbopelvic stability** (Richardson et al. 2004; Urquhart et al. 2005; Stevens et al. 2007), based on the **activation ratio** of both muscles.

EXERCISES	TrA/IO		Multifidus	
	Mean %	Sta. Deviation	Mean %	Sta. Deviation
Leg Circle (clockwise)	17.28	7.34	14.89	4.62
Leg Circle (counter clockwise)	20.15	5.75	10.94	5.33
Roll_Up	14.36	6.18	7.56	2.62

EXERCISES	TrA/IO		Multifidus	
	Mean %	Sta. Deviation	Mean %	Sta. Deviation
Scissors_Right	18.3	7.64	4.75	1.61
Scissors_Left	17.69	3.52	4.14	1.25
Scissors	17.92	7.55	5.86	1.81
Scissors_1	15.59	6.93	6.65	1.77
Scissors_2	18.13	5.90	6.35	2.08

CONCLUSION

The **Pilates method** develops proper *muscle activity of the core muscles, contributing* to **lumbopelvic stability**. Based on the *relative intensity of muscle activation*, it was concluded from this study that, for a **co-activation** of **TrA/IO** and **Mu** *muscles* for the **re-education** of **lumbopelvic stability**, the *exercises* **ShoulderBridge, ShoulderBridge_extension right leg** and **ShoulderBridge_extension left leg**, are the most effective.

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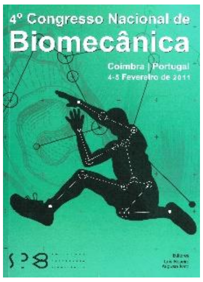
APPENDIX II - ALTERAÇÕES NO RECRUTAMENTO DOS MÚSCULOS ABDOMINAIS EM INDIVÍDUOS COM HISTÓRIA DE DOR LOMBOPÉLVICA EM MOVIMENTOS DO MEMBRO SUPERIOR.



Carvalho, P., Moreira, C., Santos, R. & Vilas-Boas, J.P. **(2011).** Alterações no recrutamento dos músculos abdominais em indivíduos com história de dor lombopélvica em movimentos do membro superior. *Comunicação apresentada no 4º Congresso Nacional de Biomecânica*. ISBN: 978-989-97161-0-0, Coimbra, Portugal, Sociedade Portuguesa de Biomecânica, 4 e 5 de Fevereiro de 2011. pp: 137-144.

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ALTERAÇÕES NO RECRUTAMENTO DOS MÚSCULOS ABDOMINAIS EM INDIVÍDUOS COM HISTÓRIA DE DOR LOMBOPÉLVICA EM MOVIMENTOS DO MEMBRO SUPERIOR

***Paulo Carvalho* [1], *Camilo Moreira* [2], *Rubim Santos* [3] *e João Paulo Vilas Boas* [4]**

[1] *Centro de Estudos do Movimento e Actividade Humana – ESTSP/IPP; pmc@estsp.ipp.pt*

[2] *Centro de Estudos do Movimento e Actividade Humana – ESTSP/IPP; can@estsp.ipp.pt*

[3] *Centro de Estudos do Movimento e Actividade Humana – ESTSP/IPP; rss@estsp.ipp.pt*

[4] *Centro de Investigação, Formação, Inovação e Intervenção em Desporto, FADEUP; jpvb@fade.up.pt*

PALAVRAS CHAVE: *Dor Lombopélvica, Controlo motor, Feedforward, Electromiografia de superfície*

RESUMO: ***Objectivo****: Verificar se existem alterações no padrão de recrutamento do transverso do abdómen/oblíquo interno, recto abdominal e oblíquo externo em indivíduos com história de dor lombopélvica.*

Métodos*: Foi realizado um estudo cuja amostra consistiu num grupo de 15 indivíduos que nunca tiveram dor lombopélvica e por outro de 14 indivíduos do sexo feminino que tiveram pelo menos um episódio de dor lombopélvica nos últimos 6 meses. Foi utilizado o sistema MP150WSW da Biopac, e o respectivo software de aquisição e análise Acqknowledge® , versão 3.9 na recolha e avaliação através de electromiografia de superfície a actividade dos músculos acima referenciados e do deltóide, durante os movimentos rápidos de flexão, abdução e extensão do ombro, tendo sido analisados e comparados nos dois grupos o padrão de recrutamento dos músculos abdominais, tendo sido definido como "onset", o ponto onde a média de 50 frames consecutivas excediam a actividade de base por 3 desvios padrão. A actividade de base foi definida no periodo de 500 ms antes do comando verbal para o inicio do movimento.O teste de Mann-Whitney foi utilizado para comparar a média do tempo de activação muscular entre os dois grupos. O teste de Friedman foi efectuado para comparar o tempo de activação entre os músculos avaliados em cada direcção de movimento (com nível de significância de 5%).*

Resultados: *Registou-se um atraso no tempo de activação do transverso do abdómen no movimento de flexão (p=0,007) e abdução (p=0,015) do ombro e ainda perda da activação independente entre os músculos superficiais e profundos estudados, nos sujeitos com dor lombopélvica.*

Conclusão: *O padrão de recrutamento dos músculos abdominais associado ao movimento do ombro encontra-se alterado em indivíduos com história de dor lombopélvica.*

Appendix III - Motor Control Exercise – McGill Approach – Intervention Manual

Exercise Program – McGill Approach

In the Stuart McGill concept, spine stability should be the primary focus. To achieve stability, McGill argues three fundamental principles: maintaining neutral spine, breath coordination with abdominal activity and abdominal bracing. The abdominal bracing is dependent upon the other two, consisting of a sustained contraction of the muscles of the abdominal wall during the breath two phases, to ensure stability of the spine, not to hold their breath or maintaining superficial breathing (Liebenson, 2008a, 2008b, 2008c; McGill, 2007a, 2007b).

To optimize the training of lumbopelvic stability, McGill has developed five steps in the rehabilitation process of the core muscles, being the first three steps related to the corrective exercise and trunk endurance and stability, in order to aid in prevention of spinal injury, while the last two (strength, speed and agility) are more related to enhancing the performance of athletes (McGill, 2007a, 2007b, 2009).

According to McGill (2007a, 2007b) endurance is achieved through repetitions, advocating the use of an inverted pyramid for the resistance training without inducing fatigue, by reducing repetitions in each set, so that the workout starts without fatigue. Therefore McGill (2007a, 2007b), in order to optimize the muscle activity while minimizing the compressive forces imposed on the spine, created a set of exercises that allow an increase in endurance of the abdominal wall and improve neuromuscular pre-activation and control of the three layers of abdominal wall.

This concept includes three basic exercises: curl-up, front plank/side bridge and cross-crawl (McGill, 2007a, 2007b; McGill & Karpowicz, 2009).

The subjects were advised not to perform any exercise that causes pain (McGill, 2007a, 2007b; McGill & Karpowicz, 2009).

Regarding the exercise program sessions of motor control exercise_McGill approach, they had duration of 45 minutes and were performed three times a week (McGill, 2007a, 2007b; McGill & Karpowicz, 2009).

The principal characteristics of the motor control exercise_McGill approach is described in the Table 1 (McGill, 2007a, 2007b; McGill & Karpowicz, 2009).

Table 1. Characteristics of the motor control exercise_McGill approach.

	Sets	Repetitions	Holding time (seconds)	Rest between sets (minutes)
1st Week	3x	1x – 5 rep 1x – 4 rep 1x – 3 rep	8-10	2
2nd Week	3x	1x – 5 rep 1x – 4 rep 1x – 3 rep	8-10	2
3rd Week	3x	1x – 6 rep 1x – 5 rep 1x – 4 rep	8-10	2
4th Week	3x	1x – 7 rep 1x – 6 rep 1x – 5 rep	8-10	2
5th Week	3x	1x – 9 rep 1x – 8 rep 1x – 7 rep	10	2
6th Week	3x	1x – 11 rep 1x – 10 rep 1x – 9 rep	10	2
7th Week	3x	1x – 13 rep 1x – 12 rep 1x – 11 rep	10	2
8th Week	3x	1x – 15 rep 1x – 14 rep 1x – 13 rep	10	2

PROGRAM EXERCISE

Curl-Up

Description

Subjects were in supine position with both hands placed under the lumbar spine providing neutral curve feedback. They were instructed to rotate around the sternum and lift the scapulae off the mat while maintaining a neutral head/neck position for 5 seconds (see Figure 1) (McGill, 2007a, 2007b, 2009; McGill & Karpowicz, 2009).

Progression

Elevate the elbows from the mat, pre-bracing (stiffening) the abdominal wall, and deep breathing during the exercise. The instruction for bracing was the same in all exercises (see Figure 1) (McGill, 2007a, 2007b, 2009; McGill & Karpowicz, 2009).

Bracing facilitation

The clinician rakes the fascia to stimulate the oblique's muscles, carefully to not encroach on the rectus, with the ends of the fingers so that the subjects contract the abdominal wall, neither drawing-in nor pushing out (see Figure 2) (McGill, 2007a, 2007b, 2009; McGill & Karpowicz, 2009).

Figure 1. Curl-Up. A–with elbows on the mat, and curl up. B–with elbows off the mat, and curl-up. Removed from McGill & Karpowicz (2009) Archives of Physical Medicine and Rehabilitation; 90:118-126.

Figure 2. Raking the fascia to stimulate the oblique's muscles. Removed from McGill & Karpowicz (2009) Archives of Physical Medicine and Rehabilitation; 90:118-126.

In this way of performing the curl-up, very little movement occurs in an effort to protect the disks from damage or pain exacerbation. A progression in abdominal challenge started with a curl-up just to elevate the head/neck/shoulders slightly while the elbows were on the mat. The progression continued with raising the elbows from the mat. This caused a tendency to increase the rectus abdominis (RA) activity while decreasing the upper erector spinae activity, demonstrating a greater flexor torque challenge (McGill, 2007a, 2007b, 2009; McGill & Karpowicz, 2009). According to McGill & Karpowicz (2009) stiffening the trunk with an abdominal bracing increased the activation of both external and internal oblique, with the internal oblique approaching 30% of the Maximal Voluntary Contraction (MVC) during bracing (McGill & Karpowicz, 2009).

Dead Bug

Description

Subjects were in supine position with the right hand placed under the lumbar spine. They started with the hips, knees, and shoulders flexed to 90° and slowly extended the right hip and knee and left shoulder until both were completely extended level to horizontal but slightly elevated from the mat (see Figure 3A). This posture was held for 5 seconds. After, the subjects returned to the starting position (McGill, 2007a, 2007b; McGill & Karpowicz, 2009).

Progression

From the extension position mentioned above the subjects flexed the left/right shoulder and right/left hip. First with slow and small amplitude movement (10º-20º), progressing to movements of greater amplitude (50º-60º in the lower limbs / 80º-90º in the upper limbs) and then to faster movements (this progression was initiated in the 2nd week of the exercise program) (see Figure 3B and 3C). The intention was to first stiffen the trunk and then ballistically contracted in such a way that movement occurs only in the shoulder and hip, and not in the trunk (McGill, 2007a, 2007b, 2009; McGill & Karpowicz, 2009).

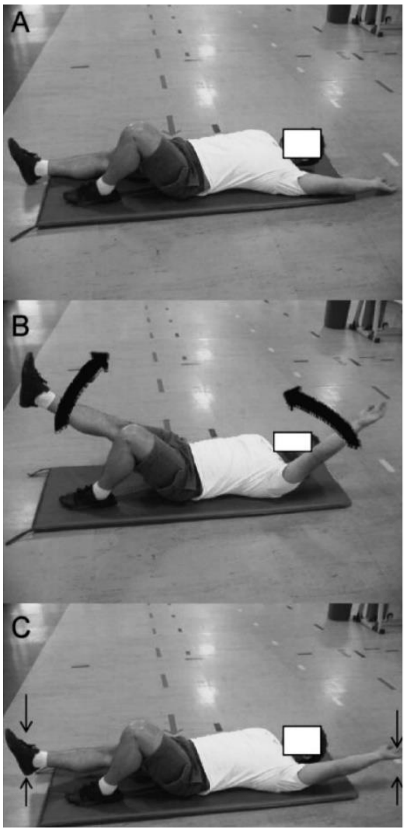

Figure 3. Dead Bug. A–Initial phase. B–Great amplitude in slow motion movement. C–Short amplitude and faster movement. Removed from McGill & Karpowicz (2009) Archives of Physical Medicine and Rehabilitation; 90:118-126.

Side-Bridge

Description

The easiest way to perform this exercise was using the knees support (shorter lever arm): subject lying on the right/left side supported by the right/left hip and elbow/forearm (flexed to 90°) (see Figure 4A). Performed extension of the hips, as if they perform a squat, and at the same time lift the hips from the mat, getting supported by the distal half of the thigh, right/left knee and right/left elbow/forearm (see Figure 4A and 4B). The left/right hand was positioned over the right/left shoulder and the arm drawn across the chest to stabilize the shoulder (McGill, 2007a, 2007b; McGill & Karpowicz, 2009).

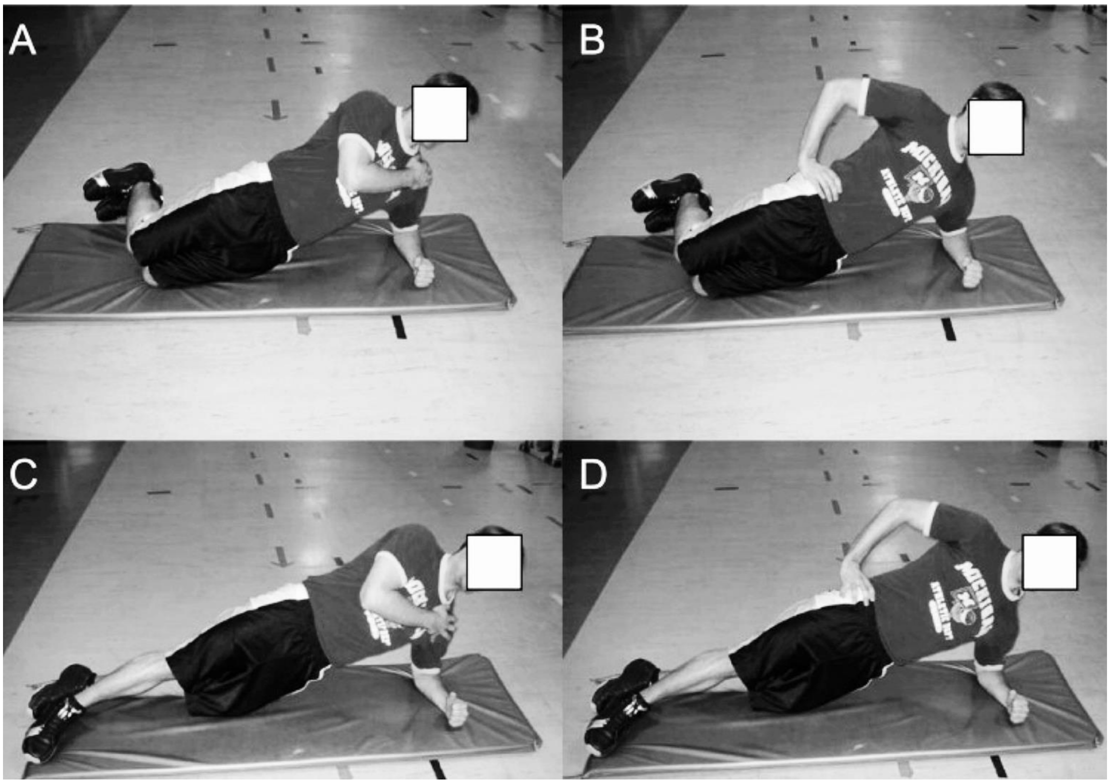

Figure 4. Side-bridge variations. A-Side-bridge with knees on the ground and the hand on shoulder. B-Side-bridge with the hand on the pelvis. C-Side-bridge with feet on the ground and the hand on the shoulder. D-Side-bridge with the hand on pelvis. Important to note the alignment between the ribcage and pelvis so that the spine was in a neutral position. Removed from McGill & Karpowicz (2009) Archives of Physical Medicine and Rehabilitation; 90:118-126.

Progression

Subjects progressed by removing the hand from the shoulder and placing the left/right arm over the trunk and the hand on the pelvis (see Figure 4B and 4D). In the full side-bridge, the legs were extended, and the top leg foot was placed in front of the lower leg foot for support. Subjects support themselves on the right/left elbow/forearm and on their feet while lifting their hips off the mat to create a straight line over the length of their body (see Figure 4C and 4D) The right/left hand was placed first on the opposite shoulder and after on the pelvis. They started the full side-bridge exercise in the 5th week of the exercise program (McGill, 2007a, 2007b; McGill & Karpowicz, 2009).

In the final progression (7th week), subjects were instructed to roll from the left/right side-bridge into the plank position (prone, supported on elbows and feet toes), and out of the plank into a right/left side-bridge (see Figure 5A, 5B and 5C). Corrections and feedback was given to eliminate the twisting between the ribcage and pelvis (see Figure 6) (McGill, 2007a, 2007b; McGill & Karpowicz, 2009).

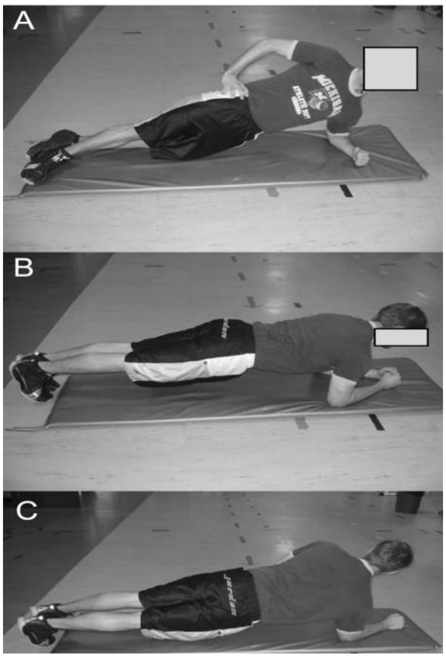

Figure 5. A - left side-bridge; B - roll to plank position; C - roll from the plank position to right side-bridge (the movement is not yet complete). In this movement is important to lock the ribcage to the pelvis so that result in minimal spine twist. Removed from McGill & Karpowicz (2009) Archives of Physical Medicine and Rehabilitation; 90:118-126.

Figure 6. An incorrect transition to right side-bridge from the plank position, and we can observed a spine twist. Removed from McGill & Karpowicz (2009) Archives of Physical Medicine and Rehabilitation; 90:118-126.

According to McGill & Karpowicz (2009) the side-bridge performed using the knees support caused the lowest trunk muscle challenge. In the full side-bridge, with the feet elevated, increased the activity in all muscles, making it a more challenging exercise. Rolling into a plank position, pausing, and continuing to the other side for a side-bridge was the most demanding, with activity approaching 50% of the MVC in the RA and the oblique muscles (McGill & Karpowicz, 2009).

Birddog

Description

Subjects initiate this exercise in a quadruped position (see Figure 7A). Initially, participants lifted only the left/right arm, and then progressed to the right/left leg only. Next, the left/right arm and right/left leg were lifted simultaneously with an abdominal bracing (McGill, 2007a, 2007b; McGill & Karpowicz, 2009).

Progression

According to McGill & Karpowicz (2009) the increased activity of the abdominal muscles progresses as follows: just arm elevation, just leg elevation, both arm and leg (full birddog), in all this variations the subjects performed conscious abdominal bracing, and finally the drawing circles and squares with the hand and foot, creating shoulder and hip motion. These final movements increased the upper back extensors from 23% to 35% of the MVC (McGill & Karpowicz, 2009).

In this exercise progression the subjects drawing circles first and than squares with the hand and foot, restricting motion to the shoulder and hip joints (see Figure 7B) (McGill, 2007a, 2007b; McGill & Karpowicz, 2009).

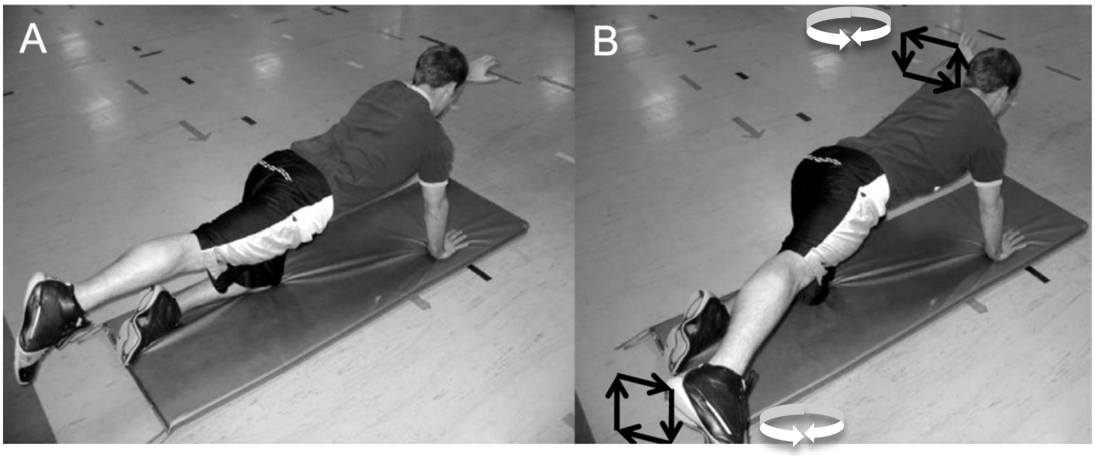

Figure 7. A-Birddog; B- Birddog with the hand and foot drawing circles and squares, Is important to refer that all motion occurred at the shoulder and hip joints and no motion occurs in the spine. Removed from McGill & Karpowicz (2009) Archives of Physical Medicine and Rehabilitation; 90:118-126.

All the components of progression were introduced only when the subjects had apprehended the competences of the exercise that was being performed (McGill, 2007a, 2007b; McGill & Karpowicz, 2009).

Expert Correction - appears to make some subtle changes. For example, when performing the curl-up while breathing, raking of the fascia overlying the oblique causes less rectus abdominis activity (34% to 17% MVC on average) and more activity in the internal oblique (36% to 50% MVC). The amount of spine flexion decreased from 9° to 2°, indicating a more neutral spine. The corrected technique during the side-bridge with the rolling action emphasized locking the ribcage to the pelvis to eliminate spine twist. This correction significantly increased activity in both oblique's. Torso twisting was reduced from 11° to 4°

with corrected instruction. Expert instruction during the birddog, in which the hand and foot drew squares, significantly increased activity in the left internal oblique. The correction also resulted in a more neutral spine (spine flexion decreasing from 16° to 0° with expert correction) (McGill & Karpowicz, 2009).

APPENDIX IV - MOTOR CONTROL EXERCISE_RICHARDSON APPROACH – INTERVENTION MANUAL

EXERCISE PROGRAM – RICHARDSON APPROACH

The program goals were to:

1. Retraining the motor control and ability of the deep muscles of the lumbopelvic region (specifically transversus abdominis (TrA), inferior fibers of the internal oblique (IO) multifidus (MU), Diaphragm (D) and the pelvic floor muscles (PFM));
2. Re-educate motor control of the superficial muscles of the lumbopelvic region (specifically external oblique (EO), rectus abdominis (RA), Erector Spinae (ES));
3. Encourage postures and patterns of movement that reduce pain;
4. Retraining coordination between deep and superficial muscles of the lumbopelvic region during static and dynamic tasks;
5. Retraining of breath control with trunk motor control strategies;
6. Progress training for function.

Exercise Progression

Motor control retraining involves a series of sequences and progressions, from the initial identification and retrain of the motor patterns to the functional retrain. The patient progress through the phases is indicated in the middle column of Figure 1. In both sides of this column are the issues that were considered throughout the progression of exercise program. The basic treatment process involved the initial identification and correction of deficits in control of the trunk muscles (both deep/local and superficial/global), progressing to the coordination training of the trunk muscles in function. Reeducation of dynamic motor control of the spine and pelvis was guided by the assessment (Costa et al., 2009).

PHASE-I

Identification and correction of muscle activation strategies and movement patterns

The goal in this phase is to assess the muscle activation strategies and movement patterns, and then based on the findings, correct any aspects of muscle activation and movement that are inappropriate or pain provocative (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

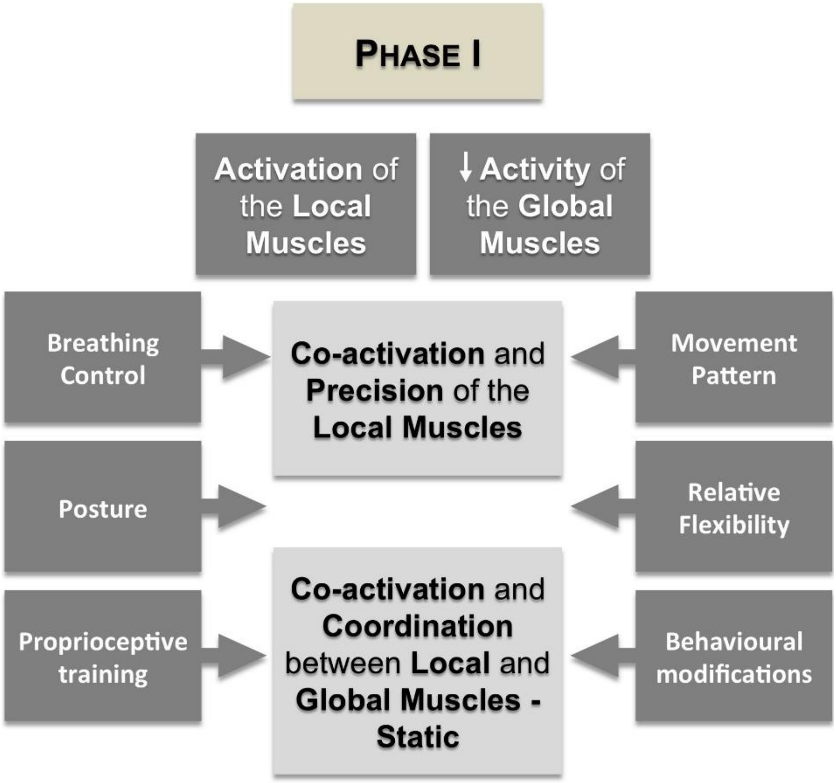

Figure 1. Progression and characteristics of the motor control exercise program used in this study during Phase I.

Assessment

Subjective assessment

Specific attention was given in the identification of dysfunctions that were problematic and that the patient liked to regain as a result of treatment. This was necessary to guide the development of an appropriate exercise program and the respective progression plan. Specific attention was given to tasks, movements and postures that increase and decrease symptoms in order to help us in the identification of movement patterns and postures.

Assessment of muscle activation patterns

Tables 1 and 2 show us the process for assessment of muscle activation strategies. This involves the assessment of the ability to perform the skill of activation of the deep muscles without the superficial muscles. The associated activation of superficial muscles provides us an indication of the over activity strategy (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

The “ideal” performance would involve clear activity of the deep muscles, minimal activation of the superficial muscles and smooth slow contraction with normal breathing. Assessment of voluntary independent activation involves teaching a patient to activate the muscle. In practice the contraction is taught, the patient is allowed several repetitions to optimize the performance of the contraction and then the assessment is performed. The goal is to hold the contraction for 10 s and repeat the contraction 10 times. The performance was graded as referred in Table 3 (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Table 4 and 5 shows the results of the clinical rating scale used for the assessment of the quality of activation of TrA, for the subjects with (Table 4) and without (Table 5) LPP.

Assessment global/superficial muscle activity

This involved the evaluation of certain number of components including: (1) superficial muscle activity evaluation during deep muscles activation assessment; (2) breath assessment; (3) posture and movement pattern assessment (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Table 1. Assessment parameters of the ability to activate transversus abdomins (TrA) and superficial trunk muscles substitution used in this study.

Transversus Abdominis (TrA)	
Cues	"Relax, breathe in and then breathe out. Without breathing in, slowly and gently draw in the lower abdomen; hold the contraction and breathe; then slowly relax." "Slowly draw in the lower abdomen, away from the elastic of your pants." "Slowly pull your navel up and in toward your backbone." "Slowly pull in your abdomen to gently flatten your stomach below your navel." "Slowly move my fingers together"
Ideal response	Slow, gentle increase in tension under the examiner's fingers No or little activity of the superficial muscles Smooth and sustained action Symmetrical contraction Approximately 10% to 15% effort Able to breathe normally 10 x 10 seconds contractions
Activity confirmation	*Palpation* Examiner's thumbs/fingers were placed slightly inferior and medial to the anterosuperior iliac spine (ASIS), with a gentle but firm pressure into the muscle. During contraction of the transversus abdominis (TrA), a gentle, deep increase in tension should be felt under the fingers. With activation of the internal oblique (IO), a swelling of muscle should occur directly below the fingers. The contraction was evaluated bilaterally to assess for asymmetry. Also, the contraction was assessed with the patient in multiple postures (prone, supine and upright posture). *Ultrasound imaging* A 7MHz ultrasound transducer was placed transversely across the abdomen midway between the iliac crest and the rib cage. The medial edge of the transducer was positioned such that the medial edge of the muscle is visible in the image. During contraction, the TrA should slide laterally and thicken. The adjacent muscles should show minimal change in thickness.
Superficial trunk muscles substitution assessment	*Palpation* Contraction of the EO can be palpated in the anterolateral aspect of the abdominal wall, and at its origin on the lower ribs. The IO was described previously. Activity of the rectus abdominis (RA) is palpated as tensing of the muscle above and below the navel. *Ultrasound imaging* Was used to observe the contraction of TrA, IO, EO and RA muscles. *Observation* Contraction of the RA/EO/IO can be observed as movement of the pelvis (posterior pelvic tilt), flexion of the thoracolumbar junction, flattening of the lower rib cage, inward movement of the upper abdomen, activation during breathing, or an inability to relax the abdominal wall. Inappropriate inward movement of the abdominal wall may also be induced by taking a deep breath and abdominal wall sucking. *Surface electromyography (EMG) Biofeedback* Surface EMG electrodes were placed on the abdominal wall to record the activity of the RA, and EO.

Table 2. Assessment parameters of the ability to activate Multifidus (Mu) and superficial trunk muscles substitution used in this study.

Multifidus (Mu)	
Cues	"Relax, breathe in and then breathe out. Without breathing in, slowly and gently swell the muscle into my fingers; hold the contraction and breathe; then slowly relax". "Think about tilting the pélvis but without really doing”.
Ideal response	Slow, gentle increase in tension under the examiner's fingers No or little activity of the superficial muscles Smooth and sustained action Symmetrical contraction Approximately 10% to 15% effort Able to breathe normally 10 reps x 10 seconds contractions
Activity confirmation	*Palpation* Activity was palpated as a slow gentle increase in tension under the fingers. During Mu contraction the activity of TrA was also palpated in the anterior abdominal wall. The contraction was evaluated bilaterally to assess for asymmetry. Also, the contraction was assessed with the patient in multiple postures (prone, supine and upright posture). *Ultrasound imaging* The contraction of Mu was observed with the ultrasound transducer placed parasagittaly 2-3cm lateral to the mid line. Emphasis was placed on slow gentle increase in thickness, particularly on the muscle deep fibers.
Superficial trunk muscles substitution assessment	*Palpation* If present, the contraction of the long erector spinal muscles can be palpated, particularly lateral to the multifidus and at the thoracolumbar junction. The contraction of the superficial abdominal muscles suggests bracing. *Ultrasound imaging* The contraction of the superficial muscles was often identified by the rapid contraction on ultrasound imaging. Contraction of the long erector spinae is obvious from palpation or surface EMG and ultrasound imaging was not used for that purpose. *Observation* The contraction of the superficial paraspinal muscles was often accompanied by the pelvic anterior tilt and subtle thoracolumbar junction extension. Pelvic posterior tilt was observed sometimes, as an attempt to push the spine up into the fingers during multifidus muscle activation/contraction. *Surface electromyography (EMG) Biofeedback* Surface EMG electrodes was placed on the thoracic erector spinae and superficial abdominal muscles to assess substitutions.

Table 3. Clinical rating scale used for assessing quality of contraction of deep muscles.

Criteria	Score
Quality of Contraction	
No contraction	0
Rapid, superficial contraction	1
Just perceptible contraction	2
Gentle, slow contraction	3
Substitution	
Resting substitution	0
Moderate to strong substitution	1
Subtle perceptible substitution	2
No substitution	3
Symmetry	
Unilateral contraction	0
Bilateral but asymmetrical contraction	1
Symmetrical contraction	2
Breathing	
Inability or difficulty with breatlling during	0
Able to hold contraction while maintaining	1
Holding	
Hold < 10 seconds	0
Hold ≥ 10 seconds	1

Table 4. Results of the clinical rating scale for assessing quality of contraction of transversus abdominis in the subjects with lumbopelvic pain.

ID	Quality of Contraction	Substitution	Symmetry	Breathing	Holding
1	1	1	0	0	0
2	1	1	0	0	0
3	1	1	1	0	0
4	1	1	1	0	0
5	1	1	0	0	0
6	1	1	1	0	0
7	2	1	2	0	0
8	2	1	2	0	0
9	2	1	2	0	0
10	2	1	2	1	0
11	1	1	1	0	0
12	2	1	2	1	0
13	1	1	1	0	0
14	1	1	1	0	0
15	2	2	2	1	1
16	1	1	1	0	0
17	1	1	1	0	0
18	1	1	1	0	0
19	1	1	1	0	0
20	1	1	1	0	0
21	1	1	1	0	0
22	1	1	1	0	0
23	1	1	1	0	0
24	1	1	0	0	0
25	1	1	0	0	0
26	1	1	1	0	0
27	1	1	0	0	0
28	1	1	0	0	0
29	2	2	2	0	0
30	1	2	1	0	0
31	1	2	2	0	0
32	1	1	0	0	0
33	1	1	1	0	0
34	1	1	0	0	0
35	2	1	2	1	0
36	2	1	2	0	0
37	2	2	2	1	1
38	1	1	1	0	0
39	2	1	2	0	0
40	2	1	2	0	0
41	1	1	1	0	0
42	2	2	2	1	1
43	1	1	1	0	0
44	1	1	2	0	0
45	1	1	2	0	0
46	1	1	1	0	0
47	1	1	1	0	0
48	1	1	1	0	0
49	2	2	2	1	0
50	1	1	1	0	0
51	1	1	1	0	0
52	1	1	0	0	0
53	1	1	1	0	0
54	1	1	1	0	0
55	1	1	1	0	0
56	1	2	2	0	0
57	1	1	1	0	0
58	2	1	2	1	0
59	1	1	1	0	0
Mean	**1,25**	**1,14**	**1,15**	**0,14**	**0,05**
SD	0,439	0,345	0,690	0,345	0,222

Table 5. Results of the clinical rating scale for assessing quality of contraction of transversus abdominis in the subjects without lumbopelvic pain.

ID	Quality of Contraction	Substitution	Symmetry	Breathing	Holding
1	2	2	2	1	1
2	3	3	1	1	1
3	3	3	2	1	1
4	2	2	1	1	1
5	3	3	2	1	1
6	3	3	2	1	1
7	3	2	2	1	1
8	3	3	1	1	1
9	3	3	2	1	1
10	3	2	2	0	0
11	3	3	2	1	1
12	2	2	2	1	1
13	3	3	2	1	1
14	3	3	2	1	1
15	2	2	1	0	0
16	3	3	2	1	1
17	3	3	2	1	1
18	3	2	2	1	1
19	2	2	1	1	1
20	3	3	2	1	1
21	3	3	2	1	1
22	3	2	2	1	1
23	3	3	2	1	1
24	2	2	2	1	1
25	2	2	1	1	1
26	3	2	2	1	1
27	3	3	2	1	1
28	3	2	2	1	1
29	3	3	2	1	1
30	3	2	2	1	1
31	3	2	1	1	1
32	3	2	1	1	1
33	3	3	2	1	1
34	2	2	2	0	0
35	2	2	2	1	1
36	2	2	2	1	1
37	3	3	2	1	1
38	3	2	1	1	1
39	3	2	2	1	1
40	3	2	2	1	1
41	3	3	2	1	1
42	3	2	1	1	1
43	3	3	2	1	1
44	3	2	2	1	1
45	3	2	2	1	1
46	3	3	2	1	1
47	3	2	2	1	1
48	3	3	2	1	1
49	3	2	2	1	1
50	3	3	2	1	1
51	2	2	2	0	0
52	3	2	2	1	1
53	2	2	1	1	1
54	3	2	2	1	1
55	3	2	2	1	1
56	3	2	2	1	1
Mean	**2,79**	**2,41**	**1,80**	**0,93**	**0,93**
SD	0,414	0,496	0,401	0,260	0,260

Assessment of posture and movement pattern

Patient posture was observed in a range of positions (lying, sitting and standing) and during a range of movements (assessment of provocative movements) and functional tasks. Assessment of patient posture involves also the evaluation of the spinal curves and the associated muscle activity (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

In general it is considered that the ideal posture in sitting and standing would involve:

- Neutral pelvic tilt;
- Lumbar lordosis;
- Thoracic kyphosis with transition at around T10-11;
- Cervical lordosis;
- Neutral head tilt;
- Minimal frontal plane curvature;
- Equal weight bearing right and left;
- Minimal activity of the superficial muscles;
- Gentle activity of the deep muscles;
- Normal breathing pattern – even distribution of motion to abdomen, basal rib cage and upper chest.

And those common deviations in posture include:

- Loss of lumbar lordosis or loss of lordosis in a particular region of the lumbar spine (lower lumbar spine);
- Slumped posture with upper cervical extension;
- Thoracolumbar extension;
- Excessive thoracic kyphosis;
- Sway back (pelvis anterior to thorax);
- Excessive activity of long erector spinae;

- Excessive activity of the superficial abdominal muscles (flat upper abdomen).

The assessment in this study included the: (1) start and finish of curves; (2) curves depth; (3) segmental changes; (4) pelvic position; (5) frontal curves; (6) right/left weight bearing; (7) deep and superficial muscles activity (observation / palpation / ultrasound imaging / superficial EMG) and (8) ability to activate deep/local muscles (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

In the assessment of movement pattern there are two components: (1) assessment of provocative movements; (2) evaluate the typical pattern and muscle activation strategies. Basic principles used in the assessment of movement pattern were:

- Provocative movements/postures;
- Asymmetry in spine/pelvic posture, movement and range;
- Protected motions;
- Excessive superficial muscle recruitment during movements (excessive activity of erector spinae muscles during trunk flexion, etc.).

Was performed a range of movements besides those that are normally assessed as part of a physical assessment, as well as functional movements that was identified by the patient as problematic and also specific movements that could highlight movement deficits. Movements that have been useful include was: flexion, extension, rotation and lateral flexion, sit to stand, walking, isolate the movements of the lumbar spine in relation to the thorax (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Assessment of breathing pattern

In most patients it is important to evaluate the breathing pattern in order to identify any abnormal recruitment of the trunk muscles, any features that may complicate the optimal control of the spine and pelvis (excessive superficial abdominal muscle activity, excessive abdominal movement), and any features that would indicate inefficiency in the breathing apparatus (upper chest breathing pattern). Components of the assessment used in this study are presented in Table 6 (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Table 6. Techniques used for breathing assessment.

Parameter	Techniques
Chest wall movements	*Principle* The quiet breathing should involve movement of the abdomen, basal rib cage, and upper chest. No region should be dominant. Basal rib cage movement is greater in positions in which tension in the abdominal wall resists abdominal displacement and therefore causes shortening of the diaphragm to elevate the lower ribs. *Abdomen* We must observe motion in the upper and lower abdomen. Movement should be present in each region and should not be confined to inward movement of the upper abdomen with contraction of the external oblique (EO). *Basal rib cage* Movement should be smooth and symmetrical (the symmetry of movement can be assessed by placing the hands on the lower ribs). *Upper chest* Upper chest movement should be observed, without excessive activity of the sternocleidomastoid.
Respiratory activity of trunk muscles	During quiet breathing in supported positions, minimal activity of the superficial abdominal muscles should occur during expiration. Activity of the transversus abdominis (TrA) should occur. In unsupported positions, slight activity of the external and internal oblique (EO/IO) and/or the rectus abdominis (RA) may be noted to aid the elevation of the diaphragm. The diaphragm should descend smoothly during inspiration.

(Re-) Training

Re-education of dynamic motor control of the spine and pelvis is guided by the assessment. The intervention is specifically targeted to the patient presentation (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Re-education involves a motor learning approach, which requires the acquisition and refinement of movement and coordination that leads to a permanent change in movement performance (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Motor learning provides principles for optimal training of motor function. Motor learning of complex movements can be facilitated by the practice of movement parts (segmentation), before performing the whole movement. Learning can be facilitated by simplification of the task by reduction of load (to make it easier for the patient to perform the task correctly), through feedback (is paramount to ensure learning process) (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Retraining the trunk motor control involved training function components that were found to be problematic in the assessment.

<u>Spine and pelvis deep muscles activation and reduction superficial muscles over activity</u>

In many patients assessment we identified poor activation of some component(s) of the deep muscle system and evidence of over-activity of one or more of the superficial muscles. Table 7 presents a range of strategies that was used to deal with these issues (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

At the completion of the initial session it is critical to be able to answer three questions. (1) What strategy worked best for the patient? (2) How can you be sure that the patient will practice the correct task at home (strategies for feedback of contraction of the deep and superficial muscles)? (3) What will the home program be (the number of contractions and the duration of hold up to 10 reps x 10s contractions)?

Exercise was progressed by the increased of the number of repetitions, increased holding time, reduction of feedback (gradual weaning) and progression to perform contractions in different positions (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Re-education of breathing pattern

It is essential that patients can breath effectively at all levels of training. In the initial phases of training, breathing can be used as a strategy to help patients to learn effective control strategies (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Later in training the emphasis shifts to ensuring that progression of exercise does not compromise ability to coordinate breathing, stability and movement. In Table 8 are presented a range of issues on breathing control that was assessed along with the strategies used for patient management (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

The progression of the exercises was taken by weaning from techniques to change breathing, to training in different positions, and to incorporate into functional activities (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Table 7. Clinical strategies used to increase the activity of the deep/local muscles and decrease the activity of the global/superficial muscles.

Goal of **Intervention**	**Clinical Strategies**
Techniques to reduce activity of the superficial muscles	*Posture* We used supported postures to help in the reduction of activity of the superficial/global muscles. We used in some patients the following postures: supine, side lying, and prone over a pillow (to relax the paraspinal muscles). We had specific attention to the spinal curvature (even in the supine position), placing the patient in a more neutral position to reduce superficial activity. *Breathing* When tonic activity persists or if activity of the superficial muscles is modulated with breathing, we encourage relaxation by re-education of breathing. We focus on active inspiration, using contraction of the diaphragm (movement of the abdominal wall and basal rib cage) and relaxed expiration. We used the manual contact to encourage basal rib cage expansion. We used biofeedback electromyographic (EMG) on expiratory activity. *Effort* We provide patients encouragement to reduce their effort such that they stop at a level below that at which the superficial muscles become active. *Feedback* We provide feedback (palpation, observation in a mirror, surface EMG biofeedback) of contraction of the superficial muscles to provide greater awareness of activation. *Imagery* We used images to help patients - "get the idea". Examples may include thinking of the sand moving in an hourglass to give the idea of the slowness required.
Techniques to increase activity of the transversus abdominis (TrA)	*Instruction* For us was very important that the patients understand that the task is not aimed at strength; rather, the emphasis is on control. Emphasis is placed on a slow and gentle approach. *Co-activation* In some patients we used the activation of the pelvic floor muscles (PFM) or multifidus (MF) to initiates activity in the TrA (with contractions performed in a slow and controlled manner). For achieved the best TrA activation we use the neutral spine position. *Feedback* We used the following techniques to give feedback to the patients: palpation, observation of inward movement of the lower abdomen, superficial EMG and ultrasound imaging. *Imagery* We use several images used to help the patients to learn the activation of the TrA.

Table 8. Assessment interpretation and strategies used to stimulate breathing pattern.

Problem	Interpretation	Management
Rib cage - limited basal expansion	*Increased activity of EO/RA/IO hindering rib elevation*	• Feedback Techniques to decrease EO/RA/IO activity – EMG, palpation and US; • Stimulate breath control with active inspiration and relaxed expiration; • Techniques to stimulate basal expansion – manual feedback, elastic band around the thorax to improve awareness.
	Stiff/hypomobile thoracic spine and rib cage	• Were used manual techniques and mobility exercises, if basal expansion was restricted by poor flexibility/mobility of the rib cage and thoracic spine.
	Reduced ability of the diaphragm to shortening	Were used techniques to stimulate diaphragm breathing and train rib cage motion.
Excessive Upper Chest Movement	*Increased activity of EO/RA/IO hindering rib elevation movement and displacement of the abdominal wall*	• Encourage basal expansion Feedback Techniques to decrease EO/RA/IO activity – EMG, palpation and US; • Stimulate breath control with active inspiration and relaxed expiration; • Techniques to stimulate basal expansion – manual feedback, elastic band around the thorax to improve awareness.
Inability to maintain contraction of deep/local muscles during breathing	*Inability to hold due to the requirement to use the abdominal wall movement for breathing*	• Encourage basal expansion – as above.
	Inability to maintain contraction during inspiration	• Enhance feedback of contraction with palpation, US observation; • Inspiratory volume training – gradually increase inspiratory volume during successive breaths until the threshold is identified.
	Changes in breathing pattern between superficial or upper chest	• Encourage basal expansion – as above; • Inspiratory volume training – gradually increase inspiratory volume during successive breaths until the threshold is identified.
	Poor posture that hinders normal motion of rib cage with breathing	• Postural correction to stimulate normal basal expansion of the rib cage – neutral spinal posture.

Rehabilitation of Functional posture: *Movement patterns and posture*

Postural correction had the following goals:

- Optimise posture and loading;
- Avoid provocative postures;
- Reduce over activity of superficial/global muscles;
- Help in the activation of deep/local muscles in functional postures;
- Assist with the optimisation of the respiratory pattern;
- Help in the optimisation of control of pelvic floor muscles.

The techniques used in this study to correct posture were dependent on the findings of the assessment. Key areas that often require control are the thoracolumbar junction, lumbar lordosis and pelvis. Table 9 presents a range of factors that we had into consideration and the strategies that was used for retraining program (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Findings in movement patterns assessment give us essential information regarding the provocative movements and relieving postures. This also provides some guidance regarding the components of the muscle system that must be retrained. Treatment target was directed to the retraining muscles, movements and postures that control the provocative movements/postures (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Progression of exercise involved increased speed and movement complexity, progression from sitting to standing, progression from static control to dynamic control of posture and movement during functional activities (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Relative flexibility

The presence of a motion restriction of the adjacent joints needs to be rectified in a way that the spine has a normal function. Evaluation of movement patterns will provide an initial indication of the importance of function of the adjacent joints (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Co-activation of deep/local muscles and improved retraining precision

An initial goal was to stimulate the co-activation of the deep/local muscles system. Generally, patients fall into one of three categories: (1) those who have automatic co-activation of the deep muscles; (2) those who require emphasis placed on the other muscles (feedback of other muscles of the system); and (3) those who require separate exercises for each muscle to be integrated later (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

The next step was to improve the precision and efficiency of the control of the deep/local muscle system. This involves increased holding time, number of contractions, reduced feedback (gradual weaning from feedback) and decrease reliance on special techniques involving position and co-contraction. At the completion of this phase the goal was, for the patient, to have a contraction independent of the superficial muscles (but the deep/local muscles all working together), performed voluntarily, with minimal feedback, minimal effort, held for 10s and should be able to breathe while holding the contraction. When this is achieved the patient can progress to the next phase of training (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Lumbopelvic Positioning

In this phase was teaching the normal movements (see Figure 2) of the spine and pelvis to help develop kinesthesis awareness of pelvic mechanics and its relationship to the lumbar spine and hips, as well as how to maintain stability of the lumbopelvic region with movement of the upper and lower limbs (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004; Smith & Smith, 2005).

The biomechanics demonstrates that the spine is more stable and strongest when in neutral position, so we used this position in this phase and in the closed kinetic chain exercises (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004; Smith & Smith, 2005).

As a progression factor, and according to the individual symptoms, we used all the movements of the lumbopelvic region in this exercise program (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004; Smith & Smith, 2005).

Head and Neck Position

Given the potential of injury and excessive stress to neck muscles, ligaments and discs, we used neutral alignment of cervical spine and head. According with Kendall (2005), this position (normal cervical lordosis) creates balance between cervical neck flexors and extensors. When there are not in balance, the normal recruitment pattern of the deep neck flexors will be altered, leading to tension and/or pain in the head, neck and shoulders (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004; Smith & Smith, 2005).

The general rule used was to nod the head slightly with emphasis on craniocervical flexion (see Figure 3). In the individuals who had excessive thoracic kyphosis we provide support by using a towel to promote neutral starting alignment. Also, the individuals with forward head position we repositioned with a slight craniocervical flexion (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004; Smith & Smith, 2005).

During sitting, standing and quadruped positions the cervical spine was, also, supported in neutral position (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004; Smith & Smith, 2005).

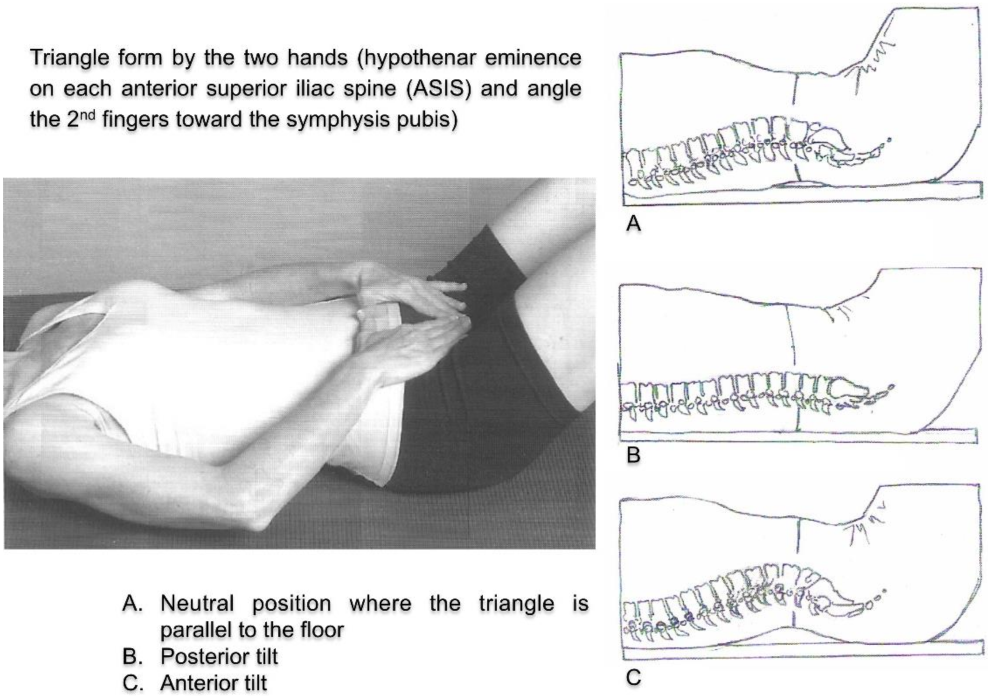

Figure 2. Finding Neutral position of lumbopelvic region – direct method. Adapted from Smith & Smith p.41 and 42.

Figure 3. Neutral position of cervical spine and head. Adapted from Smith & Smith p.50.

Table 9. Techniques used for postural correction.

Factor to be **addressed**	**Cues** and **techniques**
Forward or backward leaning	**Feedback** Hands placed on manubrium and on the anterior aspect of the pelvis.
Asymmetry in weight distribution through ischial tuberosities	**Feedback** Hands placed under the ischial tuberosities can be used to provide feedback of weight symmetry.
Excessive thoracolumbar extension	**Manual handling** With the therapists hand placed on the sternum and thoracolumbar (TL) junction the patient is stimulated to sink and flatten the TL junction. The patient can be allowed to temporarily roll on the pelvis, but should not simply slump. **Feedback** The thumb on the xiphoid and the 5th finger, of the same hand, in the navel was used as this distance reduces with thoracolumbar flexion. **Cues** • "Let your chest sink"; • "Open at the back"; • "Inspire/breathe into the middle back". **Avoid** • Using the scapula protraction to simulate thoracic movement; • Slump the upper thorax; • Upper cervical extension – correct the head position.
Decreased lumbar lordosis or flexion (often in low lumbar spine)	**Manual handling** Hand placed on the superior aspect of the sacrum or in the flexed segments can be used to provide gentle stimulation to move the spine. Subjects that had difficulty in dissociation lumbar and thoracic motion – perform pelvic movements without moving the thorax in a four-point kneeling position. **Feedback** The thumb on the xiphoid and the 5th finger, of the same hand, in the navel was used to monitor and avoid thoracolumbar extension. **Cues** • "Imagine a string attached to your tailbone, and some is gently pulling the string up to the sky"; • "Grow tall from the tailbone"; • "Allow the ball to roll underneath you, and let the pelvis fall forward". **Avoid** • Strong activation of the paraspinal muscles; • Extension at the thoracolumbar junction - motion feedback at this segment with hand placed on the xiphoid and navel (this distance should not change during motion).
Increased thoracic kyphosis	**Manual handling** Hands were used to provide a lengthening sensation - by spreading 2 fingers along spinous processes over the segments to be flattened. **Cues** • "Imagine a spot on the top of your head being gently pulled up to the sky"

Home daily exercises

Exercises were performed daily for a total of 30 min during the first month and a total of 1 hour in the second month. These exercises were performed at the same level, with the same facilitation technique, in the same position as those demonstrated during the treatment session. This was performed 3-4 times per day. Emphasis was given to avoid fatigue and undesired contractions. It was explained to the subjects how important is the performance of the daily exercises for the treatment success (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

As performance improves the subjects was encouraged to incorporate training into their function. For instance, should activate deep/local muscles system while sitting at their desk or other work activities. They was encouraged to link training with some trigger, such as performing a contraction each time they that answer the phone, some specific music on the radio, etc (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

The objectives of Phase I were:

- Confident/Independent/Cognitive contraction of deep/local muscles;
- Minimal feedback;
- Minimal effort;
- Hold 10s;
- Able to maintain optimal relaxed breathing pattern;
- Co-activation of deep muscles;
- Correct posture and movement pattern;
- Correction of relative flexibility.

PHASE-II

Progression of exercise to function

As presented in Figure 4 this can be achieved by progression through exercises of increasing complexity, again specific to the patient's presentation (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Co-activation of deep and superficial muscles - Static

When the patient can perform confident activation of the deep muscles it is then necessary to train coordination between the deep and superficial muscle systems (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

The static control training goals was the: (1) integration training between deep/local and superficial/global muscles; and (2) retraining the control of lumbopelvic orientation/alignment. The key in this phase was to pre-activate the deep/local muscles system, hold this activation tonically, and then use load and resistance to initiate superficial/global muscles activity. The underlying principle is that once load is applied to the limbs or trunk, activation of the global muscles is required to control the alignment (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Co-activation of deep and superficial muscles - Dynamic

More complex than static control, but essential for progression to function, is the requirement to train control of the spine and pelvis in dynamic situations. The key elements are to pre-activate the deep muscles and hold this tonically while the movement is performed. Were used simple tasks with emphasis on posture control and muscle activity during the movement (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

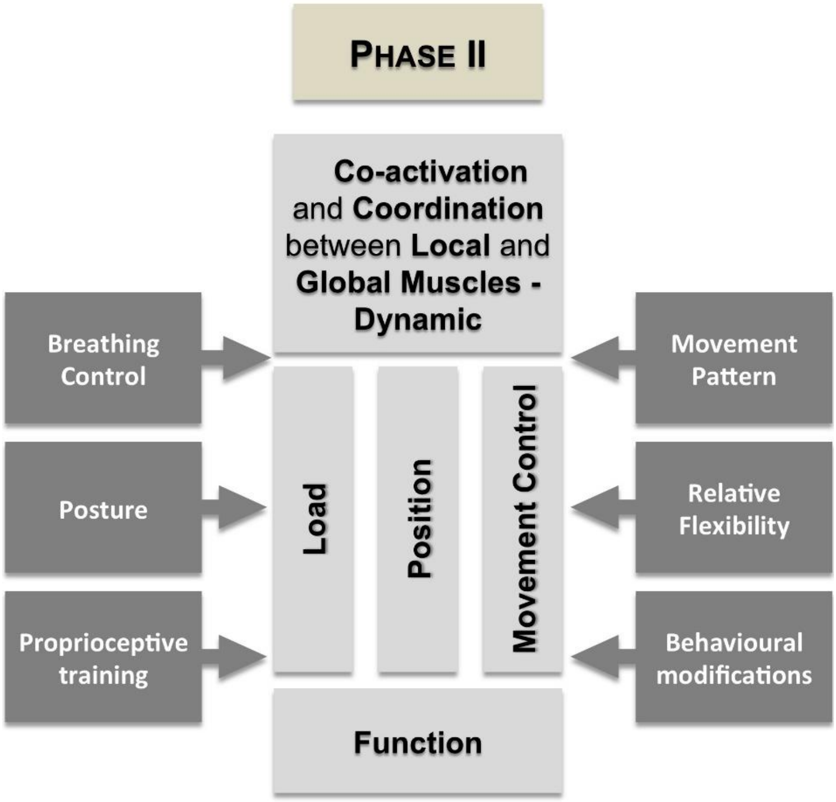

Figure 4. Progression and characteristics of the exercise program during Phase II.

Progression of load, position and dynamics

The exercise program progression was made through load increasing, position and dynamics. It was necessary, for some subjects work, with more load and/or in unstable environments. Specific attention was placed on the control of the deep muscle contractions during the progression, on the specific movement and postural dysfunctions identified in the assessment, and on the ability to maintain correct breathing pattern during the progressions (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Functional rehabilitation

Functional training follows similar principles to the preceding phases but focuses on the training of functional tasks. Again the ideally goal was the automatic activation of the deep muscles or with minimal requirement to activate this muscles. However, was helpful initiate the re-training with the pre-activation to ensure the integration of this component. Also attention to movement, postural faults and breathing pattern was performed. Progression included exercise in more challenging environments to ensure training transfer (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Home daily exercises and instructions

Pre-activation of the deep muscles is encouraged before any functional activities such as walking, bending and carrying loads. Continued attention to correction of the posture and breathing pattern (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

The objectives of Phase II were:

- Appropriate activation of global muscles over local muscles
- Control of lumbopelvic position during limb movements
- Assess and re-train specific deficits in global system
- Automatic activity
- Appropriate control during target functional tasks

EXERCISE PROGRAM

Regarding the exercise program sessions of motor control exercise_Richardson approach, they had duration of 45 minutes and were performed three times a week. In all the exercises were performed 3 series of 6-10 repetitions (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Some examples of the exercises performed:

Leg-loading - the requirements were: (i) keep the pressure as steady as possible (40 mmHg in the digital pressure biofeedback unity) (ii) maintaining the deep muscle corset action (drawing in). The patient was positioned in supine crook lying and the load was applied in a progressive manner by moving the legs in different planes of motion, maintaining the position of the spine and pelvis. The subject watches the pressure dial feedback and draws in the abdominal wall (pressure will increase slightly) keeping the pressure level steady throughout the movement. The load should be increased slowly, and control of the lumbopelvic region monitored using the pressure biofeedback unit. This feedback helps ensure precision in the exercise and guides logical progression. This exercise was graded from very low-load of short lever leg loading (see Figure 5) to higher load tests involving monitoring of lumbopelvic control through a leg-extension task (see Figure 6).

The progression of leg load exercise were: Level 1 - single leg slide, contralateral leg support. (Left) Leg slide with heel support to full extension and return. (Right) supported on exercise surface (see Figure 6 (b)); Level 2 - Single leg slide, contralateral leg unsupported. (Left) Leg slide with heel support to full extension and return. (Right) Unsupported leg slide: the heel is held approximately 5 cm from exercise surface (see Figure 6 (c)) (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

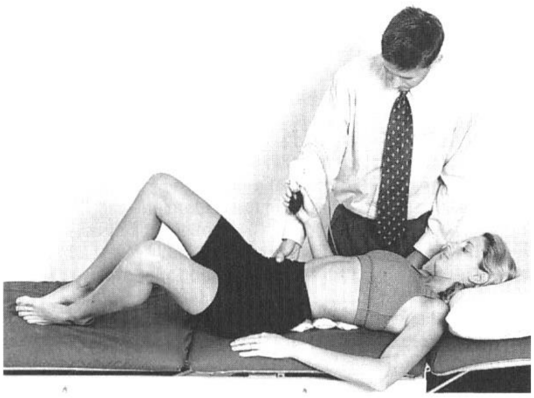

Figure 5. Subject performs abduction and external rotation one hip while the leg remains supported on the exercise surface. Removed from Richardson et al. (1999). Therapeutic exercise for spinal segmental stabilization in low back pain. p.119. Churchill Livingstone, Edinburgh, UK.

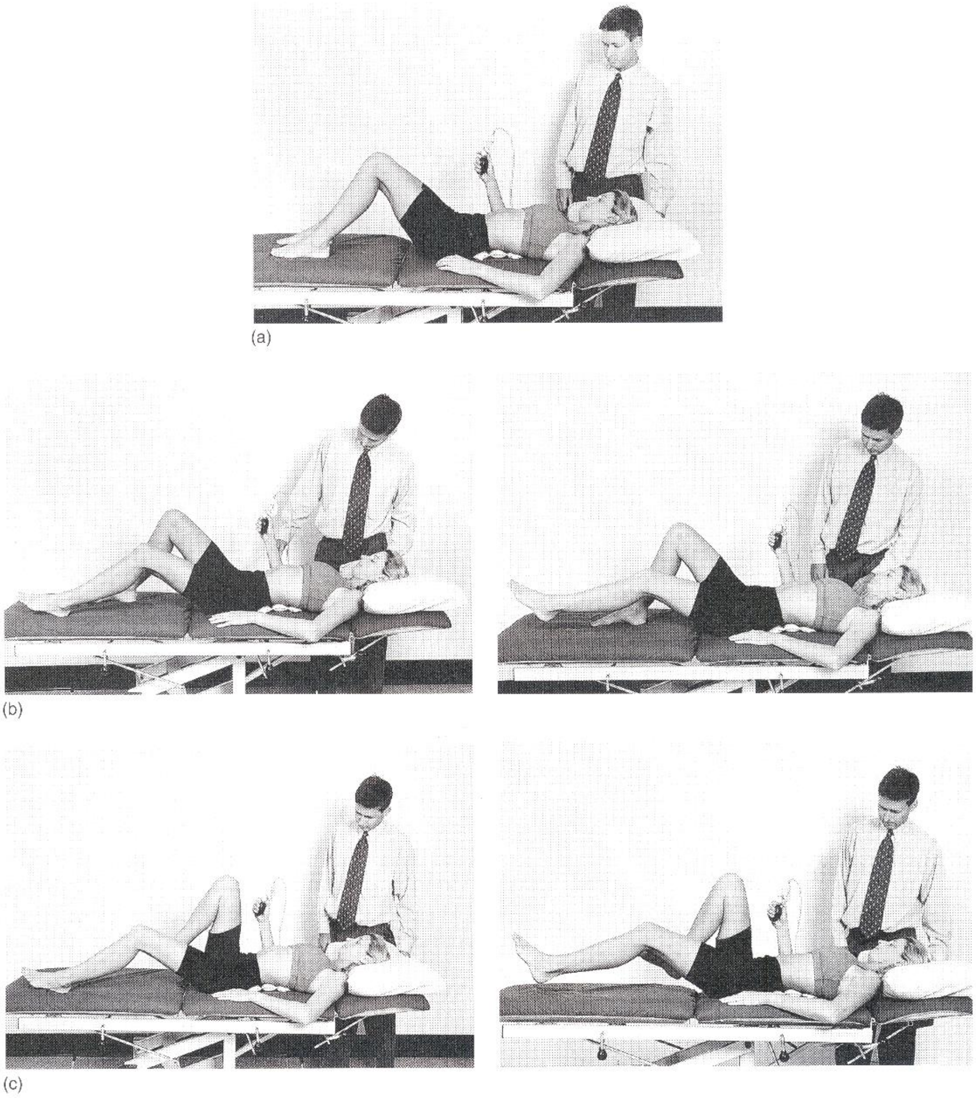

Figure 6. Leg-loading exercise: (a) initial preparation; (b) level 1 progression; (c) Level 2 progression. Removed from Richardson et al. (2004). Therapeutic exercise for lumbopelvic stabilization: a motor control approach for the treatment and prevention of low back pain. p.239. Churchill Livingstone, Edinburgh, UK.

Rhythmic stabilizations (proprioceptive neuromuscular facilitation)

In sitting position with neutral alignment rotary force (low force - 30%) was applied to the shoulders in alternating directions (slowly in the first 4 weeks and than progressive increased). During the direction change, the activation of the superficial muscles alternates over the tonically maintained activation of the deeper muscles (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

Four-point kneeling with arm and leg extension

The patient controls the neutral spinal posture and pelvic position. The subject activates first the deep muscles by drawing in the lower abdominal wall and holding this contraction throughout the exercise. Load is applied first through short levers (bent limbs) and then through longer levers with the limbs straight. The leg is slowly extended, the patient focusing not on lifting the leg but on maintaining the lumbopelvic position (not allowing the pelvis to lift and/or the hip rotation and/or hyperextension). When controlling this position, the arm is raised, with a similar focus on trunk and girdle control. The position was held for up to 5s-10s and the exercise was repeated using the opposite diagonal. The exercise was progressed by challenging trunk stability through the use of unstable surfaces (see Figure 7) (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

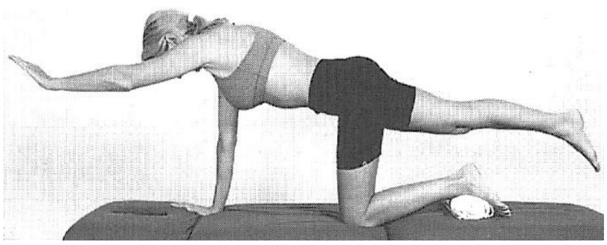

Figure 7. Four-point kneeling with arm and leg extension. The patient controls the neutral spinal posture and pelvic position. Removed from Richardson et al. (1999). Therapeutic exercise for spinal segmental stabilization in low back pain. p.152. Churchill Livingstone, Edinburgh, UK.

Bridging - from the crook lying position was used as a basic exercise

Prior to the bridge, the deep muscle co-contraction was performed and the subject focusing on lifting the pelvis and extending the hips with a gluteal contraction, keeping the spine and pelvis in a neutral position and being held for 5s-10s (see Figure 8) (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

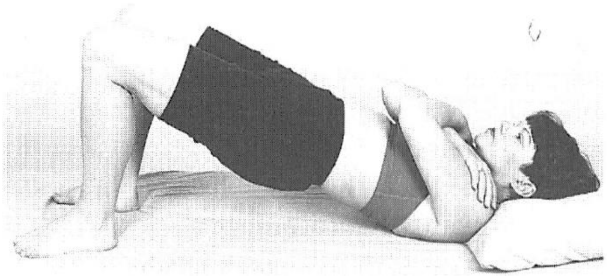

Figure 8. Bridging exercise, while holding the spine in neutral position. Removed from Richardson et al. (1999). Therapeutic exercise for spinal segmental stabilization in low back pain. p.152. Churchill Livingstone, Edinburgh, UK.

The bridging exercise progression was made by the reduction of the base of support through a single leg extension, with the emphasis on maintaining the spine and pelvis in a neutral position and being held for 5s. In the 7th week the progression was performed through the increase of speed, which challenges the global muscles to be working phasically while the deep muscles hold their isometric contraction. The subject focuses on keeping the abdomen flat and the lumbopelvic in neutral while rhythmically extending alternate legs. This was done slowly at first; as the subject gains control, the speed was increased gradually (see Figure 9) (Costa et al., 2009; P.W. Hodges et al., 2009; Richardson et al., 1999, 2004).

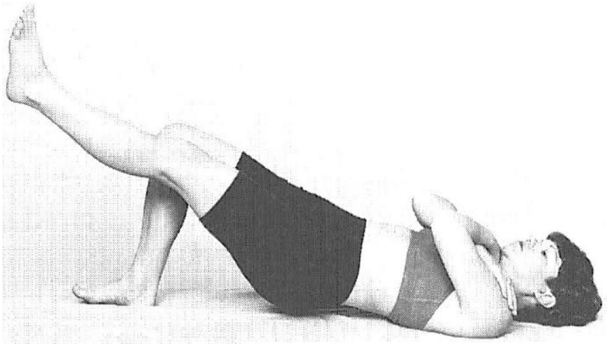

Figure 9. Bridging exercise with single leg extension. Removed from Richardson et al. (1999). Therapeutic exercise for spinal segmental stabilization in low back pain. p.152. Churchill Livingstone, Edinburgh, UK.

Some **Clinical Pilates** exercises was also performed: (i) the hundred – started in table top position with the neutral spine and head alignment, the hips and knee flexed at 90º, arms along the body, with the hands down on the mat. Prior to the flexion the cervical to mid-thoracic spine, reaching the arms off the mat in line with the shoulders. Hold this flexed position for 5s; (ii) swimming – started in prone position with the arms overhead, the legs in extension, ankles in plantar flexion and the spine and pelvis in neutral position. Lift the right upper limb/left lower limb off the mat, maintaining neutral spine and pelvis, with scapular stabilization, hold this position for 5s and than lift the opposite upper and lower limb; (iii) one-leg circle – started in the supine position with the spine and pelvis in neutral position, one lower limb extended in the air and the other with hip and knee flexed to 90º and the foot on the mat; arms along the side with the hands on the mat. Maintain neutral pelvis, was made a circle to dissociate the hip from the pelvis and spine; (iv) push-ups - first 5 weeks with the knees down on the mat and than in the plank position (Smith & Smith, 2005).