THE ASSOCIATION BETWEEN PRIMITIVE REFLEX SYMPTOMS AND CHRONIC LOW BACK PAIN

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The Association Between Primitive Reflex Symptoms and Chronic Low Back Pain

By

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Abstract

Individuals with chronic low back pain (CLBP) have altered activations patterns of the anterior trunk musculature when performing the hollowing maneuver. Clinically it has been reported that there is a subgroup of individuals with CLBP who demonstrate primitive reflexes (PR). The main objective of this study was to determine if orienting the head and extremities to positions which mimic PR patterns would alter the activation patterns of the anterior trunk musculature during the performance of the hollowing maneuver. This question was investigated by comparing electromyographical (EMG) activity of bilateral rectus abdominis (RA), external oblique (EO), and the lower abdominal stabilizers (LAS) of 11 individuals with CLBP and present PR to a group of 9 healthy individuals during the execution of the hollowing maneuver in 7 different positions. Using magnitude based inferences it is likely (>75%) that the control group had a higher ratio of left LAS: left RA activation in the following positions: supine, Asymptomatic Tonic Neck Reflex (ATNR) left and right, cervical rotation to the right and cervical extension positions. A higher ratio of right LAS: right RA was detected in the supine and ATNR right position. It was also clinically likely (>75%) that the CLBP group had higher activation of the left RA in the supine, ATNR left and right, cervical rotation to the right and cervical flexion positions as well as in the supine and cervical flexion position for the right RA. When the data from both groups were compiled the LAS illustrated significantly ($p<0.05$) less activation when in the contralateral ATNR position compared to all other positions except cervical rotation to the right on the left LAS. Right EO activation was significantly higher ($p<0.05$) in the left ATNR position compared to the supine ATNR right and cervical flexion position. The results indicate that individuals with CLBP and present PR have altered activation patterns during the hollowing maneuver compared to a healthy control group and that altering body position can diminish the differences between groups. It is also indicated that position change alone can change the activation levels of the LAS and EO in both groups.

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Workman J.C., Docherty D., Parfrey K.C., Behm D.G. Influence of pelvis position on the activation of abdominal and hip flexor muscles. Journal of Strength and Conditioning Research 22(5): 1563-1569, 2008.

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List of Abbreviations

ASIS – Anterior superior iliac spine

ATNR – Asymmetric tonic neck reflex

EMG - Electromyographic

CLBP - Chronic low back pain - Classified in this study as having Low back pain for greater than 12 weeks and scoring higher than a 12 on the Roland Morris Disabilities questionnaire

CNS – Central nervous system

EO - External oblique

HIV - human immunodeficiency virus

IAP – Internal abdominal pressure

IO - Internal oblique

LAS – Lower abdominal stabilizers- This is a superficial muscle site used in this study that encompasses both the internal oblique and transverse abdominis

LEO - Site in this study, which records information from the left side of the external oblique

LLAS- Site in this study, which records information from the left internal oblique and transverse abdominis

LRA –Site in this study, which records information from the left side of the rectus abdominis

LSE – Lumbar stabilization exercise

OCD – Obsessive compulsive disorder

PR – Primitive reflexes

RA – Rectus abdominis

REO - Site in this study, which records information from the right side of the external oblique

RLAS - Site in this study, which records information from the right internal oblique and transverse abdominis

RMDQ – Rolland Morris Disabilities Questionnaire

RRA – Site in this study, which records information from the right side of the rectus abdominis

SI – Sacroiliac joint

TrA - Transverse abdominis

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Appendix A: Electrode Placement and Exercise Position

Appendix B: Figures and Tables

Appendix C: Rolland Morris Disability Questionnaire

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Purpose

This study was designed to determine if individuals with Chronic Low Back Pain (CLBP) have altered activation patterns of the anterior trunk musculature compared to a pain free control group during the performance of the hollowing maneuver and if altering cervical and extremity orientation affects the activation pattern. The secondary purpose is to address the controversy of whether the transverse abdominis (TrA) has a bilateral symmetrical or side specific activation pattern.

The results of this study will add to the knowledge on the activation pattern of the TrA in both a CLBP and pain free populations. These results may then help with the introduction of new therapeutic exercise protocols for the treatment of CLBP.

Abstract for the Review of Literature

It has been identified that individuals with chronic low back pain (CLBP) have altered patterns of abdominal muscle recruitment when attempting to perform the abdominal hollowing maneuver. The abdominal hollowing maneuver is an exercise designed to specifically activate the transverse abdominis (TrA) and the internal oblique (IO), and is utilized as a treatment for CLBP. Specifically, individuals with CLBP are unable to selectively activate the TrA/IO and must utilize the rectus abdominis and external oblique when attempting to control the lordotic curve of the spine. Likewise, individuals with CLBP have difficulty learning how to perform the abdominal hollowing maneuver. Recent research has illustrated that individuals with CLBP have alterations to the motor cortex, which were related to alterations in abdominal muscle activation, and a decrease in cerebral gray matter volume and density. Clinically, it has been seen that a sub group of individuals with CLBP have presented primitive reflex (PR) symptoms. PR are brainstem mediated movements present in full term infants which are inhibited by six months of age as the central nervous system (CNS) matures. The presence of PR have been associated with learning difficulties, resurface in adults as the CNS declines and are present in individuals with Alzheimer's, dementia, and the elderly. As CLBP has been associated with CNS alterations and atrophy, it is speculated that these changes will lead to a resurfacing of PR. If the presence of PR is indicative of, or affect muscular activation and motor learning, then new treatment protocols should be used to treat this clinical group. It is theorised that if individuals perform the abdominal hollowing technique in positions that mimic PR the activation patterns of rectus abdominis (RA), external obliques (EO), and TrA/IO will be similar to a healthy control sample.

CHAPTER1

LITERATURE REVIEW

1.1 Introduction

Proper control of the trunk muscles ensures a stable lumbar spine, which is responsible for the support of the upper body during movement and transmitting the compressive and shearing forces to the lower body (Cholewicki & McGill, 1996). These functions are essential in both technical sport movements and everyday activities. The stability of the lumbar spine is provided by bone, disk, ligaments, and muscle restraints (McGill, 2007). It has been shown that the most important factor in the maintenance of lumbar spinal stability under a variety of conditions is the muscles of the trunk area (Ebenbichler, Oddsson, Kollmitzer, & Erim, 2001). These muscles are controlled and coordinated through pre-programmed motor activation patterns, coactivation, afferent activation/inhibition and direct voluntary activation controlled by the cerebellum (Ebenbichler et al., 2001).

Serious musculoskeletal problems can occur when one or more of these control mechanisms malfunction. In vitro, without support of the muscular system, the thoracolumbar spine buckles under compressive loads which exceed 20 N, and the lumbar spine becomes mechanically unstable in loads, which exceed 90 N (Arokoski, Valta, Kankaanpaa, & Airaksinen, 2004; Cholewicki & McGill, 1996). This resistance is far less than the mass of the average upper body. During everyday lifting activities the spine may experience compressive loads of up to 6000N and up 18 000 N in the performance of Olympic lifts. Spinal stability is then ensured by the muscular system and has been compared to guy wires spanning a bending mass (Cholewicki & McGill, 1996). It is also suggested that intra abdominal pressure (IAP) plays a key role in spinal stability. IAP is controlled by the diaphragm and a variety of trunk and pelvic floor muscles (O'Sullivan et al., 2002) which are controlled by the neural system. Without well developed co-ordinated abdominal muscles the spine is then in danger of injury during movement. This injury could arise from a disc protrusion, spondylolysis or spondylolisthesis. Once this initial injury occurs the anatomical stability of the spine will be compromised and the chance of re-injury and a chronic pain state will be increased (O'Sullivan, Twomey, & Allison, 1998). With chronic low back pain (CLBP) it has been illustrated that the motor control of the trunk stabilizing muscles is altered in both activation level (O'Sullivan et al. 1998) and reaction time (Hodges, 1999). Alteration in trunk muscle reaction times in a CLBP group have been shown to correlate with supraspinal alterations to the motor cortex (Tsao, Galea, & Hodges, 2008. Therefore, retraining the activation patterns of the anterior trunk muscles may be indicated for this population. Further, based on clinical experience, it is postulated that there is a sub group of individuals with CLBP who illustrate primitive reflexes (PR) and that these individuals will require a more specific intervention strategy to retrain the activation patterns of the trunk musculature.

In healthy individuals it is unclear on which exercises are best at activating specific trunk muscles, and how all the muscles of the trunk respond to these exercises. While there may be a variety of commercialized products designed to target these specific muscles the most commonly prescribed abdominal exercise would be a variation of the sit or curl-up technique. There is controversy regarding which sit up variation induces the highest general activation of the abdominal muscles. There are conflicting studies in which it is stated that the "crunch" has greater abdominal activation than the sit up (Escamilla et al., 2006; Escamilla, McTaggart et al., 2006; Warden, Wajswelner, & Bennell, 1999) and conversely that the sit up displays grater abdominal activation than the "crunch" (Konrad, Schmitz, & Denner, 2001). The activation levels of the hip flexor muscle group should also be recorded because an over development of this area could lead to an anterior tilted pelvis which would cause an increased lordosis of the spine. This increased lordotic curve will lead to higher shearing and compressive forces placed directly on the lumbar spine, which could lead to injury (Norris, 1993).

In individuals with chronic low back pain (CLBP) these exercises may contraindicate and aggravate a previous injury or cause an increase in pain. For individuals with CLBP it is believed that they have an imbalance or dysfunction in certain trunk muscles. Without proper control of these muscles there is an inability to alter IAP and in turn stabilize the spine during movement (O`Sullivan et al., 2002). Therefore it is advised that CLBP patients should pursue a lower intensity training program that emphasizes the activation of the proper muscles and at the desirable activity levels. Based on clinical experience the sub group of CLBP patients who have retained PR are unable to learn how to activate the deep abdominal muscles through conventional exercise programs. It is therefore recommended that a more specific rehabilitation program be designed to meet their specific pathological condition.

In spite of growing knowledge of spinal anatomy and function as well as an increase in intervention strategies, CLBP remains as one of the most widespread public health problems in the industrialized nations (Demoulin, Distree, Tomasella, Crielaard, & Vanderthommen, 2007). This health problem shows a need to have a higher understanding on how to properly develop the trunk muscles so to avoid spinal instability and or treat CLBP. For healthy individuals, sit up variations are known to cause sufficient activation to cause a training effect in the abdominal muscles (Andersson, Nilsson, Ma, & Thorstensson, 1997; Konrad et al., 2001). However, it is not known which sit or curl up variation results in the highest activation levels in each abdominal muscle while minimizing hip flexor muscle activation. In individuals with CLBP and retained PR it is shown that sit up type exercises should be avoided, because of the spinal compressive forces associated with the exercise (Arokoski, Valta, Kankaanpaa, & Airaksinen, 2002). It is also shown that individuals with CLBP have difficulty learning how to perform a hollowing technique (Hodges, 1999), which has been shown to remedy previously dysfunctional muscles (Hodges, 1999). It is proposed that a sub group of CLBP patients have retained PR, which have been related to learning difficulties and deficits in motor control (McPhillips & Sheehy, 2004), and that this specific group have difficulty learning how to perform the hollowing technique. It is hypothesized that if this sub group of CLBP patients are placed in body positions, which simulate PR it will enhance their ability to learn and perform the hollowing manoeuvre and increase their chance of successful treatment.

1.2 Anatomy of the trunk

The trunk area consists of a variety of different structures which all play important specific roles. These structures consist of specific vertebrae, the ligaments which support the vertebrae, the intervertebral discs which reduce friction between the vertebrae and the muscular system that surrounds the area (McGill, 2007) with the muscular system playing the largest role in maintaining spinal stability (Ebenbichler et al., 2001). The muscles surrounding the spine play specific functional roles and have different anatomical characteristics. One classification system that is generally accepted is Rood's concept of stabilizer and mobilizer muscles (Comerford & Mottram, 2001). Stabilizers have a postural role, which involves eccentric deceleration or resisting momentum, and can also control excessive ranges of motion. Mobilizers are responsible for movement production usually achieved through concentric acceleration of body segments (Comerford & Mottram, 2001). The difference in anatomy between the two classifications is not as straight forward in the spine as it is with other areas of the body. In the spine both stabilizers and mobilizers will cross many different segments and joints within the trunk region. In other parts of the body stabilizers usually involve one joint where as mobilizers involve two or more joints (Comerford & Mottram, 2001). The multifidus is as example of a stabilizer trunk muscle that is multisegmental yet still has attachments to ever vertebrae it crosses. Mobilizer muscles in the trunk cross many segments as well however they only have attachments at their origin and insertion (i.e. rectus abdominis) (Ebenbichler et al., 2001).

Another clinically useful classification system is that of global and local muscles (Bergmark, 1989). Bergmark (1989) used this system to describe the control of load transfer across the lumbar spine. The local muscles are responsible for the maintenance of mechanical stiffness in the spine and intersegmental control while the global muscles help transfer load between the thoracic cage and the pelvis and also have a primary mobility role (Comerford & Mottram, 2001). This muscle classification system is based functional properties and not restricted by anatomical make up.

The multifidus has vertebrae to vertebrae attachments and is proposed to be very important for precise adjustments in the adjacent vertebrae during movement (Stevens et al., 2007). The transverse abdominis (TrA) and the inferior fibres of the internal oblique (IO) have connections throughout the thoracolumbar fascia and directly to the lumbar vertebrae which allows these muscles to have direct control on the positioning of the lumbar spine (Stevens et al., 2007). These three muscles would be considered local muscles because of their intersegmental attachments and because of their specific functions.

The global muscles do not have direct attachments to the spine and are responsible for general trunk stability and torque production (Stevens et al., 2007). The trunk's global muscle system is comprises the rectus abdominis (RA), the external oblique (EO), the gluteus maximus, the latissimus dorsi and the thoracic part of the iliocostalis lumborum muscles (Stevens et al., 2007).

The trunk muscles all play specific roles. While back muscles are essential for trunk extension the abdominal muscles are used for trunk flexion and rotation. As this review examines trunk flexors, only the role of the abdominal muscles will be discussed. The RA primarily works in one plane and is the predominant trunk flexor (McGill, 2007). The RA is the main muscle targeted when performing any variation of the sit up. The crunch is an exercise described as lifting the torso until the scapula raise of the ground (Willett, Hyde, Uhrlaub, Wendel, & Karst, 2001). There has been conflicting results in the literature as it has been shown that a crunch produces higher levels of RA activity than a sit up (Escamilla et al., 2006; Escamilla, McTaggart et al., 2006; Warden et al., 1999) and conversely a sit up has been shown to have higher activation levels of the RA than a crunch (Konrad et al., 2001). RA activity has also been shown to be influence by pelvic position (Workman, Docherty, Parfrey, & Behm, 2008). Workman et al. (2008) compared abdominal activation of three different pelvic positions during the performance of a double straight leg-lowering test. It was shown that during an anterior pelvic tilt there was significantly less ($p < 0.05$) RA activity that there was during a neutral pelvis and a posterior pelvic tilt. This difference in pelvic position illustrates that pelvic positioning should be taken into account when performing abdominal exercises and that an anterior tilt should be avoided.

The oblique muscles, internal (IO) and external (EO), aid in flexion but have a primary role of trunk rotation and lateral bending; therefore a more isolated training movement for these muscles would involve a twist or bend (McGill, 2007). Specifically the IO is more active when the trunk is rotated in an ipsilateral direction and the EO has greater activation with contralateral trunk rotation (Urquhart & Hodges, 2005). However it has been shown that performing a full sit up compared to a crunch produced higher activity levels in both the IO and EO (Escamilla et al., 2006).

It has been thought that the TrA has a different role than the EO and IO; because of the horizontal placement of its muscle fibers it has little direction specific function (Hodges, 1999). Instead it acts almost like a belt and when activated it decreases the circumference of the abdominal wall. It seems that the major role of the TrA is to increase the tension in the thoracolumbar fascia, which can increase IAP as well as aid in respiration (Hodges, 1999). The IO has shown some similar functions to the TrA however it does have more variable activation levels due to its more direction specific activation pattern (Hodges, 1999). The TrA is located deep in the abdominal cavity and therefore is difficult to analyze accurately with surface EMG. However, because it has similar features with the IO it is possible to predict how the TrA is acting by recording information from the IO.

However recent research on cadavers and separate studies on EMG muscle activation have shown that the TrA may be multisegmental with each area providing different functions. Urquhart et al. (2005) used 26 human cadavers to study attachment and fascicle orientation of the TrA and IO. This study allocated the TrA into three sections: upper, with attachments to the costal cartilage, middle, with attachment to the thoracolumbar fascia, and lower, with attachment to the iliac crest. Each section had altered fascicle orientation and hypothesized function. The upper TrA had the traditional horizontal orientation but because of the costal cartilage attachment its function is to stabilize the ribcage. The fascicle orientation of the TrA goes from horizontal in the upper section to a progressive inferior-medial orientation in the middle and lower sections. In the middle section because of its attachment to the thoracolumbar fascia it will have a direct influence on lumbar stability by tensioning the fascia. The lower section will help with the compression of the sacroiliac joints and support the abdominal contents (Urquhart, Barker, Hodges, Story, & Briggs, 2005). This study also allocated the IO muscle in to upper, middle, and lower sections. The orientation of the upper and middle fascicles was in a superiomedial direction, which would be consistent with its role in rotation and side bending. The lower section switched to a horizontal orientation at the level of the anterior superior iliac spine (ASIS) and then to an inferior-medial orientation 2 cm below the ASIS. This shows that the IO may also assist in the compression of the sacroiliac joints and support of the abdominal contents (Urquhart et al., 2005) again establishing the relationship with the TrA.

It has also recently been shown that in EMG studies that TrA may have a direction specific activation pattern. Crommert and Thornstensson (2009) suggested that the pattern of activation was unaffected by a sagittal plane perturbation (trunk extension/flexion) and that it likely acts as a lumbosacral stabilizer in that plane. However it has been suggested that the TrA may play a role in rotation as the amount of activation was related to the side of rotation (Urquhart & Hodges, 2005). Urquhart and Hodges (2005) showed that there was greater activation of the middle and lower regions of TrA with rotation of the pelvis to the contralateral side while the upper TrA had greater activation with ipsilateral rotation. It is possible that the unilateral activation of TrA illustrates that it aids in torque production for trunk rotation (Urquhart & Hodges, 2005). Allison et al. (2008) also showed direction specific activation with unilateral arm movements. Arm raising activities produced greater and earlier contralateral TrA activation. This was demonstrated with both left and right arm movements and right and left TrA activations, respectively, showing a reflexive response to unilateral upper extremity movement (Allison, Morris, & Lay, 2008). It is also possible that to counter the rotational forces on the trunk with unilateral upper extremity movement there must be a contralateral direction specific activation of TrA and IO.

Urquhart and Hodges (2005) also gave other reasons for this direction specific activation. The activation of the lower and middle TrA may pull on the linea alba and anterior aponeuroses stabilizing against the lateral pull of the contralateral EO, while the upper fibres of the TrA counter the pull of the contralateral IO. The other possibility is the more popular function of ribcage stabilization, sacroiliac joint compression, and tensioning of the thoracolumbar fascia by tensioning the attachments of the TrA (Urquhart & Hodges, 2005).

In a healthy population it has been shown that a sit up produced higher IO activation compared to a crunch (Escamilla et al., 2006). However in a population with CLBP neither of these exercises should be used due to chances of re-injury. Individuals with CLBP also have a dysfunctional TrA, which often doesn't activate when needed (O'Sullivan et al., 1998). The Hollowing Maneuver has been shown to be very effective in activating and retraining the TrA in a CLBP population (Jull & Richardson, 2000) and will be discussed in detail later in the chapter.

It was thought that the psoas muscle may play a role in spinal stabilization due to its attachment on the lower thoracic vertebrae (McGill, 2007). However myoelectric and anatomical evidence suggests that the psoas major role is hip flexion. The action of the iliopsoas, specifically the iliacus, muscle may decrease shearing forces on the spine during hip flexion as the iliacus has a direct attachment to the iliac fossa (McGill, 2007). Conversely, an over developed psoas has also been related to an anterior pelvic tilt which causes an increased lordotic curve of the spine and increase in compressive forces placed on L4-L5 vertebrae which is conducive to low back pain (Escamilla et al., 2006; Norris, 1993). Therefore it is important to minimize psoas activity when performing abdominal exercise. It has been shown that having feet fixated during a sit up give the hip flexors a fulcrum pull through, aiding in the execution of the movement (Norris, 1993). Norris (1993) also stated that having hips and knees flexed during a sit up will reduce the amount of hip flexor activity. This claim has been refuted by McGill (1995) and Juker et al. (1998), who showed that there was no difference in hip flexor activity when a sit up was performed with flexed legs and hips compared to a sit up with legs and hips straight. Parfrey et al. (2008) measured abdominal muscle activity during different sit up variations. Parfrey et al (2008) showed an increase in hip flexor activity when feet were fixated, it was also illustrated that performing a sit up without fixated feet produced higher activity in all abdominal muscles measured. Parfrey et al. (2008) also compared knees bent versus knees extended sit up variations. The results agreed with previous literature, which stated no difference in hip flexor activity when performing a sit up type exercise with knees bent or knees extended. However, while not significant, Parfrey et al. (2008) did show a trend that performing a sit up with bent knees caused 19.4% (p=0.1) greater activation of the lower abdominal stabilizer muscle group, which is a site that shows activity levels of both the IO and TrA.

The dangers of an anterior tilted pelvis are illustrated by Workman et al (2008). In this study participants were asked to perform a double straight leg lowering test in three different pelvis positions: anterior tilt, neutral and posterior tilt. EMG levels of the abdominal and hip flexor muscles were recorded during each exercise. The posterior tilt showed the highest levels of RA activity (not significantly higher than the neutral pelvis) and the lowest rectus femoris activity. Surface EMG recording of rectus femoris has be shown to be a surrogate for psoas activity levels (which illustrates hip flexor activity) (McGill, Juker, & Kropf, 1996). As the pelvis moved to an anterior tilt, the levels of RA activity decreased while the activity levels of the rectus femoris increased. The hip flexors and abdominal muscles are both responsible for hip flexion (McGill, 2007). When performing an exercise which involves hip flexion (i.e. sit up) both muscle groups contribute. Therefore if the exercise is executed in a way which bias hip flexor muscle capabilities, such as with an anterior tilted pelvis, then abdominal muscle activity will likely decrease. If this exercise is consistently performed this way it will lead to an overdeveloped psoas causing a permanent anterior tilt to the pelvis and a weak abdominal area due to its lack of targeted training. This combination is very conducive to low back injury (Escamilla et al., 2006).

The anterior trunk muscles also aid spinal control (Ebenbichler et al., 2001). The trunk muscles protect the spine from shearing forces cause by upper or lower body limb movements. The abdominal muscles are activated prior to limb movement, which provides postural support to counteract the spinal perturbations caused by limb movement (Ebenbichler et al., 2001). The direction specific activation of the abdominal muscles prior to the limb movement suggests a hierarchical mode of coordination. This means that for there to be a contraction of the abdominals prior to limb movement then the knowledge of the movement direction must be known. The central nervous system (CNS) will initiate a postural adjustment causing a specific amount of abdominal activation that will counter the forces placed on the spine due to limb movement (Ebenbichler et al., 2001). While the TrA has a unilateral component of increased activation with contralateral arm movement (Allison et al., 2008) it does have similar activation levels independent of the direction of the limb movement (Hodges & Richardson, 1999). This is also evident with the non-direction specific activation of TrA in reaction to trunk flexion/extension perturbations (Eriksson Crommert & Thorstensson, 2009). This non-direction specific postural adjustment of the TrA suggests that it may have different recruitment patterns than the other abdominal muscles and may be able to be selectively activated (Ebenbichler et al., 2001).

With each muscle having different functions and anatomical alignment it is impossible to find a single exercise that has optimal activation levels of all the different groups (Axler & McGill, 1997). However a well developed methodology would allow comparison of a variety of different exercises and a variety of different abdominal muscles to observe the exercise with the best general abdominal activation. At the same time it can be determined which exercises have the lowest psoas activity and which exercises have the highest psoas activity and should therefore be avoided.

1.3 Chronic Pain Theories

While it has been shown that performing a sit up provides high activation levels of the abdominal muscles it may not be the best exercise to use when training or treating CLBP patients. It has been suggested that

CLBP patients avoid trunk flexion exercises because these exercises cause a sufficient amount of spinal loading that could cause further structural damage to the spine and surrounding tissue (McGill, 1998). It has also been shown that CLBP patients have a deficiency in their ability to properly control their local stabilizing muscles (mainly the TrA and IO) and that this should be the targeted area in exercise prescription (Hodges, 1999; O'Sullivan, Twomey, Allison, Sinclair, & Miller, 1997; O'Sullivan et al., 1998; O'Sullivan et al., 2002; Stanton & Kawchuk, 2008; van Dieen, Cholewicki, & Radebold, 2003). This inability to properly control certain muscles of the abdominals show a deficiency in the motor control strategies used to properly stabilize the spine. These dysfunctions can either be caused by or the reason for an initial injury that could lead to chronic low back pain. Chronic low back pain patients are associated with submaximal muscle function, reduced strength, reduced muscular endurance and alterations in muscle size (Mannion, Dvorak, Taimela, & Muntener, 2001). While these factors could be the cause of the CLBP it is more widely accepted that these dysfunctions are considered to be a consequence of the pain because of the increased amount of disuse associated with it.

The sensation of acute pain occurs when there is sufficient stimulus to threaten or damage tissue; this stimulus will activate the nociceptive pathways. The nociceptive withdrawal reflex is a protective mechanism to withdraw from the stimulus and to create an unpleasant memory so that there will be a behavioural adaptation to avoid the stimulus in the future (Latremoliere & Woolf, 2009). Likewise a common adaptation to low back pain is to decrease the amount of agonistic muscle activity to reduce torque and increase antagonistic activity to hopefully limit the back flexion/extension which would reduce the chance of re-injury or pain stimulus (Mannion et al., 2001). This however is an inefficient coping strategy because the eccentric activations of the antagonistic muscle places much higher forces on individual fibers, which will increase chance of re-injury (Ebenbichler et al., 2001).

Another pain theory stated that after the initial injury to soft tissue (muscle) there is a release of substances (i.e. bradykinin) that are very strong activators of the group III and IV afferents nerve endings that signal pain to the CNS through chemosensitve afferent pathways (Johansson & Sojka, 1991). These group III and IV afferents can also stimulate the gamma motor neurons, which can influence stretch sensitivity and thus the discharge of muscle spindles, which in turn enhances muscle stiffness. The increased stiffness almost acts as a static activation, which will release certain metabolites (i.e. histamine) that are known to stimulate the chemosenstitve afferent pathway and thus an induction of pain through supraspinal pathways. This becomes a loop of increased muscle stiffness and increased afferent firing of both muscle spindles and chemosensitive nerve endings. This will cause disturbances in both proprioception and motor control due to the increased firing of the gamma motor neuron pool and a chronic state of pain due to the increased firing of the chemosensitive afferents (Ebenbichler et al., 2001).

However this theory was challenged with EMG activation levels of painful muscles (Simons & Mense, 1998). While the Johansson and Sojka (1991) theory on chronic pain is logical and has a very good physiological description it has not been scientifically demonstrated. In fact Simons and Mense (1998) refuted the Johansson and Sojka theory by stating that increased EMG activity and pain have not been shown to coincide. Therefore even though the area of pain may feel like the muscle is tight it is not due to increased muscle activation or a static contraction. To further refute this theory it was also shown that muscle pain will inhibit rather than stimulate reflexive muscular contractions such as muscle spindle activity (Mense, 1993).

Chronic pain may actually be related to the plasticity of the CNS. Peripheral nerve sensitization commonly occurs with tissue damage to avoid further injury. When tissue is damaged the peripheral nociceptive nerves reduce their threshold for activation so pain will be felt with less stimuli. This is a common phenomenon and usually only lasts a brief period of time (Latremoliere & Woolf, 2009). Central sensitization involves alterations in pathways to the somatosensory cortex. Neurons within the dorsal horn of the spinal cord (sensory neurons) that have undergone central sensitization will have some of the following responses; increase in spontaneous activation, reduction in threshold for activation from peripheral stimuli, increase response to suprathreshold stimuli and an enlargement of their receptive fields. These alterations will turn a nociceptive specific neuron into a neuron that can be activated by non-noxious and noxious stimuli alike (Latremoliere & Woolf, 2009). It has also been suggested that central sensitization will adapt large low threshold myelinated fibres usually used for mechanosensory information to transmit nociceptive stimuli (Latremoliere & Woolf, 2009). If this is the case then movements at the spinal level or even the feeling of a muscle stretching, which would normally not stimulate the nociceptive pathway, may give the feeling of pain.

Unfortunately the cause of chronic pain is not well understood. It is likely that the majority of chronic pain cases are different and that each one has a different combination of physiological and psychological reasons. Physiological reasons could be an ongoing stimulation of nociceptors in the area of tissue damage or decrease in activation threshold for these same, or there could be some central adaptation to the pain pathway. CLBP syndromes have also correlated with changes in the peripheral and CNS, such as sensitization changes in peripheral neurons or increased activity of damaged neurons (Loeser & Melzack, 1999).CLBP doesn't limit itself to physiological symptoms only. CLBP sufferers have shown altered moods and personality, depression and a decrease in overall physical function (Ebenbichler et al., 2001). Therefore, it is possible that a chronic state of pain may not only be caused by some morphological change in the area of pain but also could be attributed to underlying psychological problems.

1.4 Chronic Low Back Pain and Motor Control

Likewise the symptoms of CLBP are individualistic and the causes of these deficiencies are not clearly defined and probably the reason why CLBP does not have a single all encompassing treatment protocol. These symptoms could be altered motor control, a decrease in muscle recruitment and reflex inhibition. The alteration of motor control due to CLBP comes in two forms. One alteration is decreased synergistic activation and the other is latency in the activation of the abdominal muscles. However, it should be noted that the early onset of TrA to an external perturbation or upper extremity movement is situation specific.

When standing, upper extremity movement has been shown to initiate activation of TrA before all other abdominal and upper extremity muscles (Hodges & Richardson, 1997). However, it has been illustrated that in a side lying position activation of TrA happens after or simultaneous to that of the rectus abdominis and EO in response to an external perturbation or voluntary upper extremity movement (Eriksson Crommert & Thorstensson, 2008; Eriksson Crommert & Thorstensson, 2009). This illustrates that the early activation of TrA may only occur when there is a postural demand placed on the individual, and thus when comparing results of conflicting research, the methodology used must be considered.

It has been shown in a number of studies that there is a link between abnormal patterns of muscle recruitment and pain (Bullock-Saxton, Janda, & Bullock, 1994; Kankaanpaa, Taimela, Laaksonen, Hanninen, & Airaksinen, 1998; O`Sullivan et al., 1997; O`Sullivan et al., 1998; O`Sullivan et al., 2002). These studies have suggested that an imbalance in trunk muscle strength is a major risk factor for CLBP. The imbalance in trunk muscle strength is usually some kind of dysfunction with the internal stabilizer muscles (e.g. TrA). Edgerton et al. (1996) described how weakened muscles caused by CLBP allow an opportunity for larger synergistic muscle groups to take over. These larger muscles will then be responsible for generating the force that was previously provided by the weakened muscles. However sometimes the synergistic muscles may not be able to perform the specific functions that the weaken muscles should. This is called muscle substitution and is demonstrated in EMG studies where CLBP patients are unable to activate their IO without also activating their RA (O`Sullivan et al., 1997; O`Sullivan et al., 1998). Muscle substitution may reflect a neurological change. This change has altered the motor pattern in which the abdominal muscles are activated and may be one of the reasons for the presence of CLBP (O`Sullivan et al., 1997; O`Sullivan et al., 1998).

O' Sullivan et al. (2002) later showed another synergistic muscle substitution associated with CLBP. This study showed how CLBP patients have altered patterns of motor control when increasing intra-abdominal pressure (IAP). The TrA, IO, diaphragm and pelvic floor are the boundaries of the abdominal cavity and are also responsible for regulating IAP. These same muscles are thought to have roles in both pelvic stability and respiration. O' Sullivan et al. (2002) showed that when performing an active straight leg movement, a valid and reliable test used to assess the quality of load transfer through the lumbo-pelvic region, CLBP patients had an altered diaphragmatic function when compared to a control group. CLBP patients seemed to slow or stop the motion of the diaphragm when performing the active straight leg test. This break in diaphragmatic motion came in conjunction with an increase in IAP. With a decrease in motion of the diaphragm it would be assumed that there would be a corresponding decline in minute ventilation. However, there was an increase in minute ventilation. If there was increased minute ventilation in conjunction with a decrease in diaphragmatic motion it would seem that the CLBP group not only had altered motor patterns for stabilizing the lumbo-pelvic region but also had an altered motor pattern for respiration. It was proposed by the authors that CLBP patients had to compensate for an inability of the deep abdominal and pelvic musculature to attain the IAP needed to properly perform the active straight leg raise test (O'Sullivan et al., 2002). This compensation came from an altered motor pattern, which allowed the diaphragm to play a larger role in maintaining IAP and thus lumbo-pelvic stability.

As mentioned earlier the TrA will activate prior to the RA, IO, EO and anterior deltoid during arm movement in a variety of directions (Hodges & Richardson, 1997), likewise the TrA is also the first muscle to activate in response to sudden loading in a trunk flexion or extension direction (Cresswell, Oddsson, & Thorstensson, 1994). In the study by Hodges and Richardson (1997) it was shown that the time difference between TrA activation and initiation of arm movement did not vary under different conditions of reaction time and direction indicating that this anticipatory activation is part of a hierarchal motor program, designed to stabilize the spine when the body's center of mass is altered due to unilateral limb movement, and not a reflex mediated response. In CLBP populations the activation of TrA has been shown to occur after that of the anterior deltoid (Hodges & Richardson, 1999; Hodges, 2001; Tsao & Hodges, 2007) indicating a disruption in either the motor planning of the movement or in the transmission of the descending drive to the motor neuron (Hodges, 2001). It has also been shown that TrA activity was not only delayed but also direction specific and more phasic in CLBP patients. For the control group TrA was not direction specific and had a tonic contraction during movements such as walking (Hodges, 1999).

An increase in phasic activity of the TrA may in fact lead to chronic pain as well. Studies have shown a relation between pain and a reduction in cervical kinaesthetic sense and repositioning ability of the lumbo-pelvic area (see review Comerford and Mottram 2001). Kinaesthetic sense depends on afferent input from muscle spindles. These spindles synapse to interneurons that act as inhibitors of nocioceptor transmission to higher centers of the central nervous system (see review Comerford and Mottram 2001). Inefficient tonic contraction of the TrA, as seen with CLBP patients, results in a large decrease in muscle spindle afferent activity. Therefore there is also a large increase in nocioception transmission and could be a reason for chronic pain.

1.5 Chronic Low Back Pain and Supraspinal Alterations

With advances in and increased accessibility to cerebral imaging and stimulating technology, recent research has illustrated a relation between CLBP and changes at the supraspinal level. It has been reported that CLBP can affect CNS drive for muscle recruitment (Hodges, 2001; Strutton, Theodorou, Catley, McGregor, & Davey, 2005) the activation pattern of the motor cortex (Tsao, Galea, & Hodges, 2008; Tsao, Galea, & Hodges, 2010), and even the structure/density of the cerebrum (Apkarian et al., 2004). Hodges (2001) showed that it was unlikely for the CNS drive or transmission of the drive to be altered as reaction times of TrA did not alter under a variety of conditions. Conversely Strutton et al. (2005) illustrated that the threshold required to evoke facilitation or inhibition of the erector spinae via transcranial magnetic stimulation (TMS) of the motor cortex was increased in a CLBP group. Tsao et al. (2008) illustrated that compared to a healthy control group; individuals with CLBP had a reorganization of the motor cortex. Through TMS the authors were able to show that the CLBP subjects had a greater volume of the motor cortex devoted to activation of TrA (deemed motor cortical map). Likewise, the center of gravity (a valid and reliable measurement of motor cortical representation) (Tsao et al. 2008), which is the center of the motor cortical map, was positioned in a more posterior and lateral position. This suggests that the electrico-physical makeup of the motor cortex is altered in individuals with CLBP. Interestingly the volume of the motor cortical map and the center of gravity was related to timing of TrA EMG onset during functional tasks. The larger the map and a more posterior and lateral center of gravity illustrated greater latency in TrA activation. The authors were also able to show that the threshold for ipsilateral responses to TMS was reduced on the less excitable side in the CLBP group.

Apkarian et al. (2004) utilized magnetic resonance imaging (MRI) brain scan data to contrast brain morphology of a CLBP population and a matched healthy population. Apkarian et al. (2004) indicated that the CLBP group had decreased total gray matter volume as well as decreased gray matter density in the dorsolateral prefrontal cortex (DLPFC) and the anterior thalamus compared to the matched control group. While Apkarian et al. (2004) focused on the reason for this decrease as well as the implications in pain perception, these areas also play a role in movement and muscular activation. The DLPFC plays a role in working memory, planning and decision making (Purves et al., 2008). However, the area highlighted in the digital brain model provided by Apkarian et al. (2004) shows that the premotor cortex may be affected as well. The premotor cortex does not have direct a pathway to alpha motor neurons but does influence activity in the primary motor cortex via inhibitory and facilatory synaptic connections. Similarly while the thalamus has a major role in sensation and proprioception, it is also the connection between the basal ganglia and the motor cortex. The basal ganglia are a major component in developing and executing movement patterns (Purves et al., 2008). The basal ganglia perform its function via GABAergic neurons (Purves et al., 2008). These neurons will always have an inhibitory affect on the neurons, to which they synapse. In other words, the basal ganglia allow the motor cortex to execute movement patterns by inhibiting unwanted movements. However the area of the thalamus associated with the basal ganglia is the ventral anterior and ventral lateral nuclei located in the dorsal aspect of the thalamus. These nuclei may not be affected by grey matter atrophy associated with CLBP as Apkarian et al. (2004) showed the anterior portion, not the dorsal aspect, to be the main area of grey matter atrophy in the thalamus. If decreased grey matter is the cause for the altered activation patterns seen with CLBP it is more likely due to the affected premotor cortex, however the thalamus should not be excluded as it is also involved in muscle activation.

In the spinal cord, evidence suggests that mainly GABAergic inhibitory interneurons undergo apoptosis in rats with neuropathic pain (Whiteside & Munglani, 2001). Apkarian et al. (2004) used this evidence to extrapolate that it was mainly GABAergic inhibitory interneurons involved in the decrease in grey matter associated with CLBP. If CLBP causes a decrease in the number of inhibitory interneurons then the altered motor program may be due to over activity of the CNS. A decrease in inhibition could help explain why motor cortical maps increase in volume with CLBP shown by Tsao et al. (2008, 2010) as there will now be less inhibitory interneurons synapsing on neurons that were previously outside the motor cortical map for TrA.

To date it has not been shown that CLBP patients have any large changes in muscle architecture such as length. What is consistently shown is that these muscles have an altered pattern of motor control regulation. This altered pattern leads to a dysfunctional movement pattern of the lumbo-pelvic region and causes instability in both functional and dynamic movements. This is why it is suggested by physiotherapists and clinical practitioners that a main treatment protocol for CLBP patients be exercises that help retrain these specific dysfunctional muscles. The theory lies that by training these muscles the CNS will adapt and retrain its motor control patterns to a more functional and stable muscle activation pattern that will reduce pain and increase functional ability. One of the most common exercise techniques used to retrain these muscles is the hollowing maneuver

1.6 The Hollowing Maneuver

Many clinicians attempt to overcome the altered motor activation pattern seen in individuals with CLBP by trying to retrain the internal muscles responsible for spinal stabilization such as the IO and specifically the TrA. Motor activation pattern retraining is achieved by teaching patients to selectively activate the internal stabilizers without activating the mobilizers (RA). One of the more popular exercises used is the abdominal hollowing technique. The hollowing maneuver performed by drawing in the lower abdominal area toward the spine while minimizing movement of the upper abdominal area. The hollowing maneuver is achieved by activating and contracting the TrA and to a lesser extent the IO while minimizing activity from the RA and the EO (Mannion, Pulkovski, Toma, & Sprott, 2008; Stanton & Kawchuk, 2008). The hollowing technique has been shown to activate the deep abdominal muscles with minimal activity from the RA (O'Sullivan et al., 1998). It is believed that by isolating the specific muscle, even if not at high intensities, they receive a training effect even if only neurological.

More recently the hollowing technique has been compared to other exercises to examine which exercise has the best ability to selectively activate the TrA. Urquhart et al. (2005) used fine wire and surface electrodes to assess the activation levels of the TrA, IO, and RA. The participants performed the hollowing technique, full belly in maneuver, bracing and posterior pelvic tilting. The results suggested that the hollowing technique was the best at selectively activating TrA alone. Teyhen et al. (2008) used ultrasound imaging to assess thickness changes in TrA, IO and EO muscles during the performance of six stabilization exercises one of which was the hollowing technique. While thickness changes do not indicate absolute activation levels it is accepted that increases in activation (up to 20% maximum voluntary contraction) are associated with increases in muscle thickness during static isometric contraction (Teyhen et al., 2008). This study once again showed the hollowing technique to be the best at selectively activating the TrA.

There have also been EMG studies that test the validity of a specific muscle intervention programs ability to increase activity of the TrA (Ebenbichler et al., 2001; Mannion et al., 2001; O`Sullivan et al., 1998; Standaert, Weinstein, & Rumpeltes, 2008; Stevens et al., 2006; van Dieen et al., 2003). O'Sullivan (1998) showed that over four months of treatment, which involved using the hollowing technique, subjects were able to activate their IO with minimal contribution from their RA. The interesting finding that O'Sullivan (1998) illustrated was that these subjects also increased IO activity when performing a normalization exercise. The normalization exercise was not meant to increase IO activity but because of the treatment protocol there was an increase in activity. This post intervention increase in IO activity during the normalization exercise illustrated that the treatment program not only helped teach the patient to voluntarily activate their internal stabilizing muscles but also helped restore an automatic activation pattern. The restoration of IO autonomic activation would probably relate to the anticipatory activation of the TrA that come with limb movements in hope of stabilizing the spine. This study also showed that with the increase in internal abdominal motor control came a decrease in pain and increase in functional mobility in the CLBP patients (O`Sullivan et al., 1998).

Standaert et al. (2008) reviewed three studies which highlighted the effectiveness of what they called lumbar stabilization exercises (LSEs). These LSEs are exercises which focus on improving the neuromuscular control of the internal stabilizing muscles. An example of an LSE would be the hollowing maneuver. In the first study (Cairns, Foster, & Wright, 2006) it was shown that the LSEs caused a meaningful improvement in pain function and quality of life. However there was no difference in effectiveness when compared to a group who received standard physical therapy treatment. In the second article reviewed (Goldby, Moore, Doust, & Trew, 2006) three different treatment protocols for CLBP were compared; a manual therapy group, a minimal care group and a spinal stabilization group. The spinal stabilization group were given exercises to perform which were meant to retrain the proper motor control pathways for the TrA and multifidus specifically. In this study the authors concluded that the spinal stabilization exercises were more effective than both manual therapy and minimal care. The third study (Ferreira et al., 2007) compared general exercise, motor control (stabilization) exercises and spinal manipulative therapy as treatment for CLBP. Both the spinal manipulative therapy and motor control exercises had better outcomes than the general exercise groups after 6 and 12 weeks but there were no differences between groups after 8 months of treatment. Outcome scores were determined through a patient-Specific Functional Scale, global perceived effect, pain (visual analog scale), and the Roland Morris Disability Questionnaire (RMDQ). The authors determined that the LSEs were most effective for improving short term function and perception of effect than long term treatment.

Other studies have shown the effectiveness of LSEs helping increase functionality with CLBP patients. Van Dieen et al. (2003) showed LSEs increasing recruitment levels of the multifidus with LSE training, which correlated with spinal stiffness; this was also shown by Mannion et al. (2001). It has been shown that specific rehabilitation for chronic low back pain can improve reaction times of the trunk muscles after two weeks of training (Wilder et al., 1996), as well as after only a single session (Tsao & Hodges, 2007). In a review article by Comerford and Mottram (2001) it was shown that LSEs helped retrain the anticipatory activation of the abdominal muscles with movement in CLBP patients. It was also shown that specific muscle training helped increase anticipatory recruitment of local stabilizing muscles in the shoulder girdle (Comerford & Mottram, 2001).

While this type of treatment has been shown to work on CLBP patients some patients are unable to perform the hollowing maneuver and have difficulty learning it (see review article Hodges 1999). It is hypothesized that there is a sub group of CLBP patients who have retained primitive reflexes (PR). The PR have either been retained since childhood or have resurfaced due to the severity of the chronic pain. Retained PR are automatic movement patterns and are associated with learning difficulties (McPhillips & Sheehy, 2004). If PR are responsible for the inability to learn the hollowing maneuver and thus retrain the proper activation patterns of the internal stabilizing abdominal muscles then a different treatment protocol must be used to treat this sub group of CLBP patient.

1.7 Primitive Reflexes

Primitive reflexes are brain stem-mediated, complex automatic movement patterns that commence as early as the twenty-fifth week of gestation, and are fully present in term infants (Zafeiriou, 2004). These movement patterns are stimulated by touch or body position and are critical for the survival of the newborn infant, ensuring the baby can breathe and feed (i.e. the suckling and rooting reflexes) (McPhillips, Hepper, & Mulhern, 2000; McPhillips & Sheehy, 2004). Primitive reflexes (PR) are naturally occurring patterns that happen in all individuals as the central nervous system (CNS) develops and are used by neurologists and pediatricians as a simple screening tool to determine CNS integrity (Zafeiriou, 2004).

As the CNS matures these PR start to disappear or transform around the age of six months (McPhillips et al., 2000). This is around the same age as when voluntary action and cortical inhibition develops (Zafeiriou, 2004). The specific areas of the CNS associated with the disappearance of PR are the maturation of neural networks that are specifically associated with frontal brain regions (van Boxtel, Bosma, Jolles, & Vreeling, 2006). In early neonatal life the Ia afferents, responsible for reflexes and excitatory corticospinal activity synapse into many segmental motor neurone and interneurone pools, including direct connections to antagonistic muscles. During development there is a reorganization and specification of these synaptic inputs. One such example would be corticospinal input becoming selective to synergistic muscles only (Dick, 2003).

If PR are persistent beyond their average lifespan they may begin to interfere with proper CNS development and could indicate neurological impairment (McPhillips et al., 2000). Pediatricians perform screening for PR because persistence of PR could indicate many developmental problems later in or throughout life. Mild to moderate PR presence could indicate reading disorders and learning difficulties while a strong persistence could indicate developmental retardation or Cerebral Palsy (McPhillips & Sheehy, 2004). PR in adults have been associated with neurological disorders such as Alzheimer's and dementia (Teixeira et al., 1995; van Boxtel et al., 2006). It is also theorized that the recurrence of PR in adults may be an inherent consequence of usual aging (van Boxtel et al., 2006).

McPhillips and Sheehy (2004) evaluated the presence of persistent PR problems in an ordinary school population. They hypothesized that children who had learning difficulties (illustrated as low level reading ability) would have a high prevalence of persistent PR. They also attempted to answer the question posed by Morrison (1985) who criticized the assumed relationship between persistent PR and learning difficulties. Morrison (1985) believed that the percentage of children with persistent PR would be consistent across all education levels and not just those with learning difficulties. By assessing the presence of PR within the average and overachieving school age population as well as the low level readers it should show if there is an association between PR and reading ability. The specific PR studied was the asymmetric tonic neck reflex (ATNR) because it is the most frequently observed persistent PR in infants with neurological legions (McPhillips & Sheehy, 2004). Level of reading ability was determined by taking scores from the WORD (Basic Reading) test. The low level readers were children who scored in the bottom 10% on the test, while the middle level and high level readers scored in the middle and top 10% respectively. McPhillips & Sheehy (2004) found that the low level readers had a significantly higher prevalence of the ATNR present when compared to the middle and high level readers. To refute Morrison (1985), McPhillips & Sheehy (2004) also showed that the middle and high level readers had very similar low prevalence of the ANTR: 66% of the high and middle level readers showed no evidence of the ATNR compared to 24% of the low level readers. Conversely, 17% of the low level readers showed the highest level of ATNR persistence while the middle and high level readers did not show any presence of the ATNR.

McPhillips & Sheehy (2004) also assessed motor control capabilities of their subjects using a standardized test of motor impairment (the Movement ABC test). A bivariate correlation coefficient between the ATNR persistence and motor difficulties showed a significant correlation ($p < 0.001$) suggesting that children with persistent PR had decreased ability to control motor function.

The reoccurrence of PR indicate reduced higher cortical area control over lower brain centres (van Boxtel et al., 2006; Vreeling, Jolles, Verhey, & Houx, 1993) or damage of corticospinal pathways (Tremont-Lukats, Teixeira, & Hernandez, 1999). This may be related to damage to dedicated neural networks, such as cerebral degeneration or other mechanisms of ischemic damage. The basic idea is that as cerebral inhibition decreases with age or disease PR are no longer inhibited and thus return. Therefore the presence of PR is a physical symptom which indicates disruption or degradation of the CNS.

It is also thought that the reoccurrence of PR may also be an inherent consequence of normal aging. Prefrontal networks are crucial to behavioural actions such as planning and the execution of tasks that require memory. These brain areas are sensitive to aging, and it is possible that age related cognitive decline and the reappearance of PR are related and brought out by the same neurodegenerative process (van Boxtel et al., 2006).

Van Boxtel et al. (2006) assessed 470 healthy adult volunteers at baseline, and after 3 and 6 years of the baseline assessment. This study attempted to relate PR reappearance with cognitive decline. However the presence of one or the combination of multiple PR did not explain differences in cognitive performance between ages, or predict changes over a 3-6 year period. It may be possible that adults with PR may have altered motor control and/or other neurological disabilities. The research on the topic of PR presence in an adult population is sparse. However this research is necessary to understand the relationship between PR and neurodegenerative diseases/CNS function.

PR and cognitive decline were shown to be related in subjects who had advanced human immunodeficiency virus type 1 (HIV) (Tremont-Lukats et al., 1999). Thirty-six percent of subjects in this study had both a cognitive impairment (Mini mental state examination) and PR presence (standardized neurological examination). Though no formal motor control capabilities test was done it was assumed that it was affected. The result of this study suggested that PR could be used as the onset and evolution mark for motor/cognitive disorders that are associated with advanced HIV (Tremont-Lukats et al., 1999).

Teixeira et al. (1995) studied 12 subjects with Alzheimer's disease to see if a simple neurological exam could be used to diagnose Alzheimer's related dementia without having to use the aid of a brain biopsy. It is widely known that Alzheimer's is related to memory loss as well as a decrease in cognitive function. This study also showed that four PR were present in all the Alzheimer's patients. Along with this there was also a visible loss in motor function. When performing coordination tests the Alzheimer's patients executed these tasks at a very slow pace. However, it is not known whether or not the reduction of speed when performing a coordination test was caused by the neurodegenerative effects of Alzheimer's or by the natural neurodegenerative decline caused by regular aging.

Obsessive compulsive disorder (OCD) was classically viewed as a functional neurosis and classified as an anxiety disorder. However, it has recently been seen as a neurological motor disorder (Bolton et al., 1998). Bolton et al. (1999) put 51 OCD subjects through a battery of neurological tests (Cambridge Neurological Inventory) to assess "soft signs" of the neurological disease. OCD was associated with a decrease in motor control capability, sensory integration and showed an increase in PR presence. Unfortunately this paper did not describe the kinds of motor control deficits. However they did give possible motor deficits that could be implicated with OCD, such as a decrease in motor speed, coordination and sequencing. This study also implicated specific areas of the brain that could be affected by OCD. Bolton et al. (1999) believed that the area responsible was the frontal-subcortical-area. Bolton et al. (1999) also reference previous neuro-imaging and neuropsychological research that suggested involvement of the basal ganglia with connections to the orbital frontal cortex.

It would make sense that improper connections between the basal ganglia and the orbital frontal cortex could lead to a decrease in motor function. The basal ganglia have been described as the area of the brain which is involved with the planning and the coordination of movement (Behm, 1995). It has also been stated that the connections between the various units in the basal ganglia are critical (Cotterill, 2001). If the connection between this area and others was faulty in any way it could lead to poorly planned coordinated and executed movements. Cotterill (2001) described the linkages between the motor area and the basal ganglia as short cuts to performing a skill. These linkages are essentially records of the system's discovery of unfavourable and favourable sensory-motor scenarios. Having an improper connection between these areas may also be the reason for the presence of PR. Pain and dyslexia studies have also shown altered brain activity when performing movement or reading tasks (Temple, Deutsch, Poldrack, Miller, Tallal, Merzenich, & Gabrieli 2003; Tsao et al. 2008).

Temple et al. (2003) studied the brain function of children with dyslexia when performing a rhyming task. While this study never tested for a prevalence of PR it has been shown that children with dyslexia have persistent PR (McPhillips et al., 2000). MRI records showed that when rhyming, children with dyslexia showed little activity in the left hemisphere language area. Temple et al. (2003) also showed that after going through behavioural remediation the dyslexic children were able to increase the amount of brain activity in the left hemisphere language areas. This increase in brain activity was related to the amount of improvement in oral language skills.

It is hypothesized by Gibbons (unpublished **personal communication**) that healthy adult individuals who have persistent PR will be at a higher risk of CLBP than individuals who have lost all PR. It is believed that because of these PR the ability to control the transverse abdominis is minimal. Likewise, in the presence of CLBP there may be structural (Apkarian et al. 2004) and electro-physical (Tsoa et al. 2008) changes to the brain which may reduce both the ability to properly control the TrA and inhibit PR.

The transverse abdominis is thought to play a specific role in maintaining spinal control (Moseley, 2005). However this muscle seems to be dysfunctional in patients with chronic low back pain. The ability to contract this muscle without contracting the superficial abdominal muscles is considered by many clinicians to be the first step in regaining spinal and trunk control (Moseley, 2005). In a single patient, with CLBP, case study Moseley (2005) tested how pain physiology education may alter brain activity.

Altered pain beliefs have been shown to alter movement performance with CLBP (Moseley, 2005). Pain physiology education also marked an obvious reduction in cortical activity when performing the abdominal draw in task, which is supposed to singularly activate the transverse abdominis. Before the pain physiology education, when performing the task, the patient would show brain activity in the cingulate cortex, the insular cortex, and the frontal cortex. All of these areas are associated with the so called "pain matrix" (Moseley, 2005). After the pain physiology education it was shown that these areas were not activated when performing the task even though the subject did not practice it.

The PR may not be a direct cause for the inability to properly control their trunk muscles. This may be due to a decreased ability to inhibit certain movements, or improper cortical patterns (i.e. wrong connections with the basal ganglia to other cortical areas, or increased activity of the brain stem) of motor control. PR, thus improper motor control, may have returned due to lesions in the brain caused by cerebral ischemia, as seen in neurodegenerative diseases such as Alzheimer's or HIV. However, the reappearance of PR may also be due to the gradual neurodegenerative process that comes with the normal ordinary aging process (van Boxtel, 2006).

Perhaps more important than knowing the reason for persistent PR in adults is knowing whether in adults who experience chronic pain and have PR is it possible to learn how to inhibit these PR. Inturn will the inhibition of the PR coincide with a reduction in pain or increase in function. It is still undetermined whether or not PR inhibition due to CNS maturation is determined entirely by internal mechanisms or if external environmental factors that can interact with this process (McPhillips et al., 2000). McPhillips et al. (2000) examined the effect that a specific movement programme, which mimics stereotypical movements by an infant, had on inhibiting PR in children aged 8-11.

The movement programme involved movement patterns that are similar to that of an infant because it is believed that the developmental movements an infant goes through have reciprocal effects on the underlying structures which are involved with CNS structure and function. Therefore repetition and rehearsal of these movements may play a large role in the process of inhibiting PR (McPhillips et al., 2000). McPhillips et al. (2000) showed that this type of movement programme is also successful at inhibiting persistent PR in children, age 8-11, who should have already naturally inhibited their PR. While there was no testing of motor control capabilities in this study the experimenters did study cognitive function. The group, which learned to inhibit their PR, also had significant improvement in reading abilities.

As a result of previous research (McPhillips et al., 2000; Moseley, 2005; Temple et al., 2003) it seems plausible that CLBP should be able to enhance their motor control capabilities and learn how to inhibit PR. The programme should involve some sort of PR physiology education and be coupled with a repetition/rehearsal specific movement programme that would mimic the stages of movement an infant goes through. While the process is not known exactly, it may come from a combination of learning to use areas of the brain that were previously underused (Temple et al., 2003), learning how to use specific areas while decreasing activity in other areas of the brain (Moseley, 2005), or some other combination that is similar to the process an infant goes through during CNS maturation (McPhillips et al., 2000).

By assessing muscle activity levels, through EMG analysis, in different abdominal muscles it is plausible to determine the activation pattern of different individuals when performing certain tasks. By having CLBP subjects perform the hollowing maneuver in a variety of different positions that mimic movements caused by PR it is possible to see if these different positions alter the amount a specific muscle group will contribute to a successful execution of the hollowing maneuver. If this is compared to a group of controls without PR it can be shown whether or not altering body position affects only the CLBP/PR group or if altering body position affects activity levels in all people. It is hypothesized that altering the body positions will increase the amount of TrA and IO activity levels and decrease the amount of RA and EO activity levels needed to successfully perform the hollowing maneuver when compared to a supine position. If the results reject the null hypothesis then it is possible that a new treatment protocol for CLBP patient with retained PR could be developed which has greater chance of success.

Co-Authorship Statement

Kevin Parfrey was the primary individual for the development of the idea for this thesis, collection and analysis/interpretation of the data, and writing of the paper. Sean Gibbons helped with the generation of the idea, data collection, participant recruitment and assessed the CLBP group for PR symptoms. Dr. David Behm helped with the idea generation, analysis/interpretation of the data and writing revisions.

Effect of Head and Limb Orientation on Trunk muscle Activation with Chronic Low back Pain

Kevin Parfrey

Running Title: Trunk Muscle Activation with Chronic Low Back Pain

CHAPTER 2

INTRODUCTION

Over 80% of chronic low back pain (CLBP) occurrences are of unknown origin and reason. Many different treatment protocols have been created and used by clinicians and physiotherapists (Beith, Synnott, & Newman, 2001). It is thought by many that one underlying reason for the chronicity of low back pain is that specific local spinal stabilizing muscles such as the transverse abdominis (TrA) and internal oblique (IO) have altered activation patterns (Comerford & Mottram, 2001; Ebenbichler et al., 2001; Hall, Tsao, MacDonald, Coppieters, & Hodges, 2009; Hodges & Richardson, 1996; Hodges, 1999; Mannion et al., 2001; O'Sullivan et al., 1998; O'Sullivan et al., 2002; van Dieen et al., 2003). One treatment protocol for CLBP has been performing specific specific activation exercise of the local spinal stabilizing muscles (O'Sullivan et al., 1998). However, it has been shown that individuals with CLBP have difficulties in learning how to perform these specific spinal stabilizing exercises (Hodges, 1999). It has been postulated, based on clinical experience, that a sub group of individuals with CLBP display primitive reflexes (PR), and have difficulty with selectively activating the local spinal stabilizing muscles. The presence of PR within a CLBP population may indicate a deficiency in the supraspinal control of the anterior trunk muscles.

Altered activation patterns are illustrated by a delayed onset of activation of the stabilizing muscles (Hodges & Richardson, 1996), as well as decreased amount of activation of the stabilizing muscles (O'Sullivan et al., 1998). Conversely, in a CLBP population, the level of activation of the larger global muscles such as the rectus abdominis (RA) are increased (O'Sullivan et al., 1998; O'Sullivan et al., 2002). The RA and external oblique (EO) muscles are global muscles and are responsible for gross movements of the trunk. The RA is the major trunk flexor while the EO are more responsible for lateral flexion and rotation (McGill, 2007). It is theorized that the global muscles are substituting for the decreased amount of force, which the stabilizing muscles no longer supply (O'Sullivan et al., 1998;

O`Sullivan et al., 2002). It has been reported that individuals with CLBP also have a more phasic type of contraction of the TrA compared to a more tonic contraction in a healthy population in exercises such as walking (Comerford & Mottram, 2001).

The IO and the TrA are deeper muscles and are more responsible for pelvic and spinal stabilization (Urquhart et al., 2005). Traditionally the TrA was thought to aid in spinal stabilization by tensioning the thoracolumbar fascia and increasing intra abdominal pressure (Hodges, 1999). However recent research on cadavers have shown alterations in fiber orientation in both the IO and TrA, going from supra medial to infra medial orientation with a superior to inferior direction (Urquhart et al., 2005). This anatomical alteration has been insinuated to have functional implications; specifically the upper and middle section of the IO and TrA will have a respective role in trunk rotation and thoracolumbar fascia tensioning while the lower section of both will have a role in sacroiliac joint compression (Urquhart et al., 2005). It has also been suggested that the TrA may also have a direction specific function with the lower section being more active with contralateral rotation and the upper with ipsilateral rotation (Allison et al., 2008; Urquhart & Hodges, 2005).

It is thought that if a specific exercise program is administered, which revolves around retraining the proper activation patterns of these local spinal stabilizing muscles, that the altered function can be corrected (O`Sullivan et al., 1998; Standaert et al., 2008). Standaert et al. (2008) reviewed three "high quality" articles in which the validity of using these lumbar stabilization exercises was assessed. The final conclusion was that the treatment both enhanced function and decreased reported pain. However it was concluded that these exercises work better short term (6 weeks) than long term (12 weeks). It was shown that both general exercise programs and manual therapy had similar results after 12 weeks of participation.

The specific exercise used in these studies (O`Sullivan et al., 1998; O`Sullivan et al., 2002) and one of the more popular exercises used clinically by physiotherapists is the hollowing maneuver. This exercise was devised by Richardson and Jull (Richardson & Jull, 1995) to target the local spinal stabilizing muscles, in particular the TrA. This maneuver is performed by selectively activating the TrA and to a lesser extent IO without coactivating RA and EO (Mannion et al., 2008; Stanton & Kawchuk, 2008).Urquhart et al. (2005c) compared a variety of core exercises and compared the electromyography of the abdominal musculature via fine wire electrodes. It was shown that the hollowing maneuver was the best exercise for selectively activating the TrA. The goal of this intervention is not to increase the strength of TrA and IO but to retrain the pathological motor pattern of the trunk musculature associated with CLBP.

While this type of treatment has been shown to be effective in treating CLBP patients by increasing function and decreasing pain levels (O'Sullivan et al., 1998), some patients have difficulty learning how to perform the hollowing maneuver (see review article Hodges 1999). O'Sullivan et al. (1997) reported that some individuals with CLBP took 4-5 weeks to properly learn and perform the hollowing maneuver.

Based on clinical experience it seems that there is a sub group of CLBP patients who have retained PR. The PR have either been retained since childhood or have resurfaced due to the severity of the chronic pain. A literature review could not produce any research, which identified a sub group of CLBP with present PR, thus it is unknown how PR presence may indicate alterations in muscle recruitment.

PR are brain stem mediated complex automatic movement patterns which are evoked through touch or changes in body position (McPhillips et al., 2000; McPhillips & Sheehy, 2004). PR are fully present in healthy term infants and start to disappear or turn to postural reactions around the age of six months (McPhillips et al., 2000). The disappearance of PR are a sign of central nervous system (CNS) development as it indicates cortical inhibition, which is necessary for voluntary movement (Zafeiriou, 2004). If PR are present beyond associated developmental milestones it indicates a disruption in the proper maturation of the CNS and may indicate neurological impairment (McPhillips et al., 2000). The presence of PR in adults have been associated with neurological disorders such as Alzheimer's and dementia (Teixeira et al., 1995; van Boxtel et al., 2006). It is also theorized that the recurrence of PR in adults may be an inherent consequence of usual aging (van Boxtel et al., 2006).

While there has been no previously published research on PR presence and CLBP, recent research has indicated alterations to the CNS in individuals with CLBP. Tsao et al. (2008) illustrated alterations of the motor cortex in individuals with CLBP, which was also related to a delay in TrA activation (Tsao et al., 2008). As CLBP has been associated with atrophy of CNS gray matter, and specifically GABAergic inhibitory interneurons (Apkarian et al., 2004), then PR may resurface due to a decrease level of inhibition on the brainstem neurons responsible for the autonomic movement patterns.

It may be possible that CLBP has lead to alterations in the CNS and that the presence of PR is an indication of this change. Likewise this presence may explain why some individuals with CLBP have difficulty learning how to perform the hollowing maneuver. If this is the case then an altered treatment protocol must be created which addresses this problem and allows for a greater chance of successful rehabilitation. McPhillips and Sheehy (2000) developed a movement program for children with retained PR between the ages of 8-11 years that mimicked the movements associated with stimulated PR. This program was both successful in inhibiting the retained PR as well as an improvement in reading ability.

The objectives of this study were to examine if (1) there was a difference between the abdominal activation patterns of a CLBP group with apparent PR and a matched healthy control group when performing the hollowing maneuver; (2) by altering the position of the head and limbs to mimic that of a PR the CLBP group would have a similar activation pattern to the control; (3) there is a side specific activation pattern of the TrA in either the CLBP group or the control group.

2.1 Hypotheses

1) When performing the abdominal hollowing maneuver in a crook lying position, the CLBP group would have a different activation pattern of the anterior trunk muscles than the control; with the CLBP have higher respective activation levels of the RA and EO and lower levels of LAS activation.

2) When performing the hollowing maneuver in positions that mimic PR it was hypothesized that the activation patterns of the anterior trunk muscles will be similar between the two groups.

3) There would be a side specific response of the LAS with the greatest activation levels occurring when in the ipsilateral asymmetric tonic neck reflex position.

CHAPTER 3

METHODS

3.1 Subjects

A randomized controlled sample of twenty participants (9 control and 11 CLBP) completed the experiment. Participants were split into a CLBP with prevalent PR group (Height: 163.6 ± 9.1 cm, Weight: 79.6 ± 19 kg, Age: 45.6 ± 9.9 years) or a control group without a history of CLBP (Height: 163.3 ± 9.9 cm, Weight: 78.8 ± 15.3 kg, Age: 42.3 ± 8 years). The control group was age, gender and mass matched to eliminate differences associated with different demographics and morphology. All subjects were explained the procedures of the study, given an opportunity to ask questions for clarification and made aware that they could stop the study at any point. All subjects were required to read and sign a consent form before participation. The Memorial Universities Human Investigation Committee approved the study.

Inclusion for the CLBP group was identified by a score of over 12 on the Rolland Morris Disability Questionnaire (RMDQ) (Appendix C) and suffering from low back pain for greater than12 weeks. Subjects were excluded from the CLBP group if there was a presence of a severe postural abnormality, any neuromuscular or metabolic disorder, a previous diagnosis based on radiographical evidence (specifically spondylolisthesis or spodylolysis) or if the subject was currently taking antidepressant or opiate medication. A certified physiotherapist assessed the presence of PR. Exclusion criteria for the control group were any report of low back pain in the previous 6 months or any signs of retained PR.

PR presence was based on a 0-4 rating scale from absent to the full pattern present (unpublished presentation). For assessment of the asymmetric tonic neck reflex (ATNR), the individual is placed in the supine position. The ATNR is deemed present if active cervical rotation is accompanied by ipsilateral shoulder girdle elevation and/or the contralateral leg appears to shorten. For the secondary assessment of the ATNR the individual stand with feet shoulder width apart. The ATNR is deemed present if active cervical rotation is followed by a weight shift to the side of rotation or ipsilateral shoulder girdle movement. For assessment of the stage 1 phase of the Morrow Reflex the individual was placed in the supine position. The reflex was deemed present if cervical extension to 30° was followed by lumbar spine, hip or shoulder extension, another indicator is if the individual takes a deep breath with cervical extension. Stage 2 of the Morrow reflex is deemed present if cervical flexion is accompanied with trunk, knee, shoulder or elbow flexion, another indicator is fist clenching with cervical flexion.

3.2 Design

This experimental and descriptive study was designed to examine if a change in body position would alter the activation patterns of the anterior trunk muscles during the performance of the hollowing maneuver. This study was also designed to observe if a change in body position would illustrate different effects in individuals with CLBP and PR compared to a pain free population. This will be achieved by comparing the EMG data collected on the two groups during the performance of the hollowing maneuver in 7 different body positions.

3.3 Procedures

The subjects were instructed to lie flat on a horizontal bench and were fitted bilaterally with surface electrodes on the RA, EO, and a site deemed as the lower abdominal stabilizers (Anderson & Behm, 2005; Behm & Anderson, 2006; Hamlyn, Behm, & Young, 2007; Parfrey, Docherty, Workman, & Behm, 2008; Workman et al., 2008). Once the set up was complete the subject was asked to perform a double leg raise exercise, which would be used for normalization of the data. After the normalization procedure was completed the subject was instructed on how to successfully perform the hollowing maneuver in a supine position. Successful performance of the hollowing maneuver was indicated by changing pressure in a biofeedback pressure cuff ™ from 40 mmHg to 50 mmHg. The cuff was placed under the lordotic curve of the participant's spine, specifically between vertebrae S1 and L1. When the subject could successfully complete the hollowing maneuver and hold it for ten seconds three different times the experiment continued. Next the subject would perform the hollowing maneuver in six different randomized body positions three times each for ten seconds. If the investigator noticed any problems in the execution of either the double leg raise exercise or the hollowing maneuver the subject was asked to stop given a break of thirty seconds and asked to retry the exercise. Electromyographic (EMG) data were taken throughout all of the exercises. When the experimenter saw that the participants had changed the pressure from 40 to 50 mmHg it was marked as the starting point to which EMG would be analyzed for comparison. The first three seconds of successful performance were used unless, it was noticed by the experimenter that there was a pressure change at some point in the ten second activation, in which case it was noted that a different starting point should be used for the three second EMG analysis.

3.4 Electromyography

All surface electrodes (Meditrace 130 ECG Conductive Adhesive Ag/AgCl Electrodes, Tyco Healthcare Group LP, Mansfield, MA) were placed bilaterally on six different abdominal muscle sites. To reduce resistance of the signal, all sites for electrode placement were shaved, scrubbed with sand paper and rubbed with an alcohol-soaked paper towel. This process removed body hair, dead skin cells, and oils. All electrodes were placed parallel to the muscle fibres, with an interelectrode difference of 2 cm. The bilateral sites were the rectus abdominis (RA), which was defined as five centimetres below the xiphoid process and three centimetres lateral to the midline. The external oblique (EO) electrodes were placed five cm superior to the anterior superior iliac spine (ASIS) while the lower abdominal stabilizers (LAS: an area that encompasses stabilizing muscles such as the TrA and IO) were placed immediately medial to the ASIS (Figure 1). All the described EMG sites have been used in a number of previous studies published from this laboratory (Anderson & Behm, 2005; Behm & Anderson, 2006; Hamlyn et al., 2007; Parfrey et al., 2008; Workman et al., 2008). A ground electrode for each of the six sites was placed over the iliac crest.

All EMG signals were collected over a 20 second period, sampled at 2000 Hz with a Blackman -61 band-pass filter between 10-500 Hz, and amplified (500X) (Biopac Systems MEC bi-polar differential 100 amplifier, Santa Barbara CA., input impedance = 2M, common mode rejection ratio > 110db min (50/60Hz), noise > 5 UV). EMG activity was then directed through a 12 bit analog-to-digital converter (Biopac MP 100) and stored on a computer (Sona, St John's, Newfoundland, Canada). The data were later transferred to a personal computer for further analysis. EMG activity was analyzed over a 3 second period corresponding to the change in the biofeedback pressure monitor from 40-50 mmHg. The signal was band passed filtered (10-500Hz), rectified and integrated. Each site at each position had two successful trials which were rectified and integrated, these two trials were averaged. The average integral of each muscle and exercise was normalized to the rectified integral of the same muscle during the double straight leg raise test.

3.5 Exercises Performed

Double leg raise exercise

Subjects were asked to lie supine on a bench with their hips flexed to 45°. On the investigators mark the subject would raise both feet 1 cm off a plinth and hold the position for ten seconds. This exercise was then used to normalize the exercise EMG data. While it was a submaximal isometric contraction it was better than using a maximal contraction for normalization since maximal contractions are known to be unreliable in a CLBP population (Beimborn & Morrissey, 1988). The double leg raise exercise was selected because it has been shown to activate all the abdominal muscles of interest to stabilize the pelvis during the maneuver (O'Sullivan et al., 1998).

Abdominal hollowing maneuver

The abdominal hollowing maneuver was executed as described by Jull and Richardson (2000). Subjects would lie supine with a pressure biofeedback monitor placed under the lordotic curve of the spine between S1 and L1. The pressure was set to 40 mmHg. Subjects were asked to draw in their lower abdominal cavity by activating their deep abdominal muscles. They were instructed to do this by attempting to pull their ASIS together. The head and trunk were to remain stable and subjects were told to not flex forward or push through their feet. By pushing through their feet people are able to alter the pressure on the biofeedback cuff without properly performing the hollowing maneuver by putting a posterior tilt in their pelvis, therefore this was considered unsuccessful performance. It was determined if the subjects pushed through their feet by placing weight scales ™ under their feet. When the pattern of execution was satisfactory as determined by the physiotherapist, the subject was then asked to perform the hollowing maneuver until they were able to change the pressure in the biofeedback cuff at a steady state from 40 to 50 mmHg. The subjects would then hold this isometric activation and keep the pressure at 50 mmHg for at least ten seconds.

The abdominal hollowing maneuver was chosen because it has been shown to preferentially activate the deep abdominal stabilizing muscles in a pain free population (Urquhart, Hodges, Allen, & Story, 2005). However, in a CLBP population there is a decreased ability to selectively activate these muscles when performing the hollowing maneuver (P. Hodges, Richardson, & Jull, 1996). The hollowing maneuver is also a clinical test of evaluating and training the function of the deep abdominal stabilizing muscles used by physiotherapists (Mew, 2009; P. O`Sullivan et al., 1997).

3.6 Simulated Primitive Reflexes

The six body positions used in the experiment were positions that mimic the orietation of the body if a specific PR was stimulated. The ATNR was chosen because it was described by McPhillips & Sheehy

(2004) as the most frequently observed retained PR in infants with neurological lesions. The ATNR is stimulated by rotating the head at least 15° in either direction. The reflex causes the limbs to which the head is pointing to extend and the contralateral limbs to flex (McPhillips & Sheehy, 2004). Therefore in this experiment two positions used were cervical rotation to either the left or right with the arm (side to which head is pointed) extended straight out and perpendicular to the torso and the leg (side to which head is pointed) extended. The arm on the opposite side to which the head pointed was flexed with the hand laid on the chest and the leg of the same side was flexed 45° at both the hip and knee (Figure 3 and 4). Another two positions were simple cervical rotation to the left or right with their arms crossed on their chest and legs/hips flexed at 45° (Figure 5 and 6). These positions were used to determine if cervical rotation alone was enough to stimulate the ATNR.

Another PR that was simulated was the Moro reflex. This reflex is stimulated by cervical extension in the supine position and has two stages (Allen & Capute, 1986). Stage one occurs immediately after cervical extension, which elicit extension and abduction of the upper extremities, stage two is the return to fetal position and involves cervical flexion along with upper extremity flexion and adduction (Allen & Capute, 1986). Both stages of the Morro were mimicked in this study. Stage one was simulated by having the subject extend at the cervical spine as far as possible without causing pain and arms abducted to approximately 60° resting on the plinth (Figure 7). Stage two was simulated by having the subject flex at the cervical spine as far as possible without causing pain as well as having the arms resting on the subject's chest (Figure 8). When the end point of cervical flexion was achieved a triangular pad was placed under the head so it could rest at that position. If end range flexion exceeded that of the pad the subject was asked to bring their head back until it was resting on the pad, which was placed to hold the maximum amount of flexion. Hips and knees were flexed to 45 ° for both stages.

3.7 Statistical Analysis

Descriptive statistics include means and standard deviations (SD). All data were analyzed with repeated measures 2 way ANOVAS. The two levels included the subject groups (controls and CLBP/PR) and the exercises (double straight leg raise test, supine hollow, ATNR to the right hollow, ATNR to the left hollow, cervical rotation to the right hollow, cervical rotation to the left hollow, Morrow hollow, and abdominal hollow). If significant differences ($p \leq 0.05$) were identified in the main effects, a Bonferroni Dunn's post hoc was utilized.

Magnitude based inferences for clinical significance were calculated based on effect sizes. Cohen's guidelines for the qualitative interpretation of effect sizes are 0.2, 0.5 and 0.8 for a respective small, moderate, and large effect (Drinkwater, Pritchett, & Behm, 2007). Of interested was the practical difference in abdominal muscle activation patterns between a CLBP group and a matched control in different body positions when performing the hollowing maneuver. Similarly, it was of interest to see if there was a clinical difference in the activation patterns between a male and female population. Therefore, the smallest worthwhile difference (clinically significant) was based on a small effect size (0.2) (Cohen, 1988). This was calculated via a previously constructed spread sheet (Hopkins, 2007) and was interpreted as a percentage of there being a likely difference. Briefly, < 1% was deemed almost certainly not; < 5% very unlikely, < 25% unlikely, 25-75% possible, > 75% likely, > 95% very likely, and > 99% almost certain. As the sample size in the present study is suboptimal it is suggested that a percentage greater than 75% is deemed clinically significant (Liow & Hopkins, 2003). This analysis was performed on the normalized data as well as a ratio of LAS:RA. The LAS:RA ratio has been shown to be the best representation of hollowing maneuver performance in previous research (O'Sullivan 1997, 1998) as the goal of the exercise is to activate TrA/IO without activating RA.

CHAPTER 4

RESULTS

4.1 Differences between the CLBP and Control Group.

Between group differences for LAS:RA ratio

No significant differences were found between groups with the ANOVA. Using magnitude based inferences, for the LLAS:LRA ratio the control group would, clinically, be more likely to have a greater ratio in the supine, ATNR left and right, cervical rotation to the right and cervical extension positions (respectively 77%, 76%, 90%, 75,77%) than the CLBP group (Figure 9). Similarly on the contralateral side it was likely that the control group would have a greater RLAS:RRA ratio than the CLBP group in the supine and ATNR left positions (respectively 80% and 90%) (Figure 10).

Between group differences for normalized site specific activation levels

Analysis of confidence limits and effect sizes illustrated no clinical difference between the two groups in any position for the LAS or EO sites (Table 2). There was however clinical and statistical difference between groups for the RA. For the LRA it was likely that the CLBP group would have greater activation than the control in the supine (96%, p=0.02), ATNR left (91%) and right (96%, p=0.04), cervical rotation to the right (87%) and flexion (90%) positions (Figure 11). For the RRA it was likely that the CLBP group would have greater activation than the control in the supine (93%, p=0.05) and cervical flexion position (80%) (Figure 12).

4.2 Compiled Data

Effect of altering body position on Right (RLAS) and Left (LLAS) Lower Abdominal Stabilizer Activation

The ATNR left position produced significantly less activity ($p<0.0001$) in the RLAS site compared to all other positions, with the supine, ATNR right, cervical rotation to the left and right, cervical extension, and cervical flexion producing respectively 5.6%, 87.5%, 22.8%, 26.2%, 15.1%, and 6.8% greater levels of activity. (Figure 13)

The lowest amount of activity for the LLAS was shown in the ATNR right position ($p=0.0008$) showing 11.3%, 50.3%, 10.6%, 9.5%, and 2.5% lower activity levels than the supine, ATNR left, cervical rotation to the right, cervical extension, and cervical flexion positions respectively. (Figure 14)

Effect of altering body position on Left (LEO) and Right (REO)External Oblique Activation

There was a trend ($p=0.065$) shown for alteration of body position affecting activation of the LEO with the ATNR left position producing the highest level of activation and positions cervical rotation to the right and cervical flexion producing the lowest activation. These positions illustrated a 78% difference in activation (Table 3).

The greatest level of REO activation ($p=0.01$) was shown in the ATNR left position producing 25.1%, 22.2%, and 60% greater activation than supine, ATNR right, and cervical flexion positions respectively. (Figure 15).

Effect of altering body position on Right (RRA) and Left (LRA) Rectus Abdominis Activation

There was no significance found in alteration of RRA and LRA muscle activation levels caused by changing body position at this site (Table 3).

4.3 Gender Differences

Effect of Gender on LAS:RA ratio

Using magnitude based inferences, the female population, clinically demonstrated a higher RLAS:RRA ratio in the supine, right ATNR, cervical rotation to the right and left, cervical flexion and cervical extension (respectively 89%,87%, 88%, 81%, 92%, 86%) compared to the male population (Figure 16). For the LLAS:LRA ratio only the cervical extension (75%) position illustrated a clinical difference with the female population to likely have a greater ratio than the male population (Figure 17).

Effect of gender on specific muscular activation

Magnitude based inferences illustrated gender based differences, with men having higher activation levels for all sites. Clinically the men were likely and very likely to have higher activation of the LRA in the supine (94%), left ATNR (76%), right ATNR (81%), cervical rotation to the left (95%) and right (93%), cervical extension (97%) and cervical flexion (79%) (Figure 18). For RRA the men were likely, very likely and almost certain to have higher activation in the supine (99%), ATNR left (98), ATNR right (88%), cervical rotation to the left (99%) and right (99%), cervical extension (99%) and cervical flexion (95%) than the women (Figure 19). For the LLAS it was likely for the men to have higher activation than the women in the supine (78%), ATNR left (91%), ATNR right (80%), cervical rotation to the left (88%) and right (79%) (Figure 20). For the RLAS it was likely for the men to have higher activation in the ATNR left (94%), cervical rotation to the left (91%) and right (79%) compared to the women (Figure 21).

REO illustrated the men being likely to have higher activation than the women in the supine (86%), ATNR left (92%), ATNR right (85%), cervical rotation to the left (95%) and right (91%) and the cervical extension positions (88%) (Figure 22). LEO showed a difference between genders in only the ATNR left (75%) position with men being likely to have greater activation than women (Figure 23).

CHAPTER 5

DISCUSSION

The results of this paper indicate that during the performance of the hollowing maneuver there was a clinical and statistical difference in muscle activation levels of RA and LAS:RA ratios between the CLBP and matched control groups. However, this difference was minimized when cervical orientation was altered. This result indicates a spinal or supraspinal response to cervical orientation altered the activation patterns of the anterior trunk musculature. When the data of both groups are combined it was shown that changes in body position affected activation levels of different muscles, specifically the EO and LAS sites. In this case, alteration of extremity position affected activation levels of the trunk musculature more so than cervical orientation. This could indicate changes in muscle fiber orientation or length, or a proprioceptive response to extremity position as an explanation of altered activation levels. The results of this study may enhance the clinician's ability to instruct individuals with CLBP and PR to selectively activate TrA and IO.

5.1 Chronic Low Back Pain vs. Healthy Control

Muscle substitution

It is accepted that there are different activation patterns of the abdominal musculature between CLBP patients and the healthy population (Hodges & Richardson, 1996; Hodges, 1999; O'Sullivan et al., 1997; O'Sullivan et al., 1998). These alterations are considered to be deficiencies in the coordination and control of the abdominal musculature and result in a less stable spine during movement (McGill, 2007) and in response to a perturbation (Hodges, 1999). While there may be multiple differences between the two groups the most recurring themes in the literature are muscle substitution and a delay in the anticipatory activation of the deep abdominal musculature, specifically the TrA. However, it has been illustrated that in the absence of postural demand the presence of anticipatory activations diminishes

(Eriksson Crommert & Thorstensson, 2008; Eriksson Crommert & Thorstensson, 2009). As the supine position used in this study eliminated any postural demand onset times of the anterior trunk muscles were not recorded.

In the present study an initial statistical analysis with an ANOVA did not illustrate any significant difference between the two groups for any position at any site when performing the hollowing maneuver. However, the main objective of the hollowing maneuver is to selectively activate the TrA, and to a lesser extent the IO (LAS), while minimally activating the RA (O`Sullivan et al., 1997). For this reason previous research has used a ratio of LAS:RA when comparing performance of the hollowing maneuver with a higher ratio illustrating better performance (O`Sullivan et al., 1997; O`Sullivan et al., 1998; Vera-Garcia, Elvira, Brown, & McGill, 2007). In the present study when ratio based comparisons were made via multiple t-tests, statistical and clinical significant differences were found. Significant difference was shown with the RLAS:RRA ratio in the ATNR left position, with the controls having a higher ratio (better performance). This difference illustrates that when performing the hollowing technique in this position the CLBP group must activate the RA to a greater extent than the controls. It is thought that muscle substitution occurs because the RA attempts to compensate for the deficient TrA/IO in the CLBP group (O`Sullivan et al., 1997). Muscle substitution has been shown in previous research in this population (O`Sullivan et al., 1997). However, there is no research demonstrating that an alteration of body position changes the ratio of LAS:RA during the hollowing maneuver. While not statistically significant there was a trend ($p=0.08$) for the LLAS:LRA ratio to be higher in controls when in the ATNR right position, again illustrating how a change in body position can alter the ability to activate the LAS and RA. These findings disprove the hypothesis that placing a subject in the ATNR position will lead to a similar activation patterns for both groups, as it was in this position that the two groups seemed to have the largest discrepancy.

Clinically, it was likely that the control group had a higher ratio of the LLAS:LRA (better performance for the abdominal stabilizers) in the supine, ATNR left and right, cervical rotation to the right and cervical extension positions than the CLBP group. Similarly on the contralateral side it is likely that the control group would have a greater RLAS:RRA ratio than the CLBP group in the supine and ATNR left positions. These results are in agreement with O'Sullivan et al. (1997, 1998). The present study illustrates muscle substitution of the RA over LAS (TrA/IO) in a CLBP group during the abdominal drawing in maneuver. The novel finding in the present study was that activation levels were affected by altered body position of the subjects. This implies that in certain body positions CLBP patients illustrated a pathological motor pattern when attempting to selectively activate their LAS (TrA/IO) and in other body positions had a motor pattern that resembled the healthy population. For the LLAS:LRA ratio the CLBP group had a similar ratio with cervical rotation to the left and cervical flexion positions compared to controls. Similarly the CLBP group had similar activation levels of the LRA with the cervical rotation to the left and extension positions. Interestingly, these activation levels were altered by changes of cervical orientation and not the extremities. This indicates that the changes in activation are not due to structural changes in the position of the muscle itself but more likely at the spinal and/or supraspinal level.

CNS Alterations

CLBP has been shown to alter numerous areas of the CNS. It has been reported that CLBP can affect CNS drive for muscle recruitment (Hodges, 2001; Strutton et al., 2005) the activation pattern of the motor cortex (Tsao et al., 2008; Tsao et al., 2010),and even the structure/density of the cerebrum (Apkarian et al., 2004). Evidence via neuropathic pain studies on rats indicates that cell apoptosis occurs in the CNS and that it is mainly GABAergic inhibitory interneurons which are lost (Whiteside & Munglani, 2001). Apkarian et al. (2004) used this evidence to extrapolate that it was mainly GABAergic inhibitory interneurons involved in the decrease in grey matter associated with CLBP. Therefore, it seems that

CLBP may be associated with an overall reduction of CNS inhibition. This could have a profound effect on many systems including motor coordination.

If CLBP causes a decrease in the number of inhibitory interneurons then the altered activation pattern of the anterior trunk muscles of the CLBP group during the hollowing maneuver compared to the control may be due to over activity of the CNS. A decrease in inhibition could help explain why motor cortical maps increase in volume with CLBP shown by Tsao et al. (2008, 2010) as there will now be less inhibitory interneurons synapsing on neurons that were previously outside the motor cortical map for TrA. In terms of muscle substitution, it is generally thought that the RA increases its activation level to make up for a deficient ability to activate TrA/IO (O'Sullivan et al., 1997). While theoretically and functionally this makes sense, recent research on CLBP and brain morphology/activity poses an alternate explanation. With a decrease in gray matter volume and density it is mainly a loss of inhibition that results (extrapolated from Apkarian et al. 2004). Therefore the increased activation levels of RA may be due to an inability to inhibit this activation when attempting to selectively activate TrA/IO. This explanation would support the results in the present study as the CLBP patients exhibited higher normalized levels of both left and right RA compared to a matched control in a variety of different positions but had similar levels of TrA/IO activation. This indicates that while both groups were able to activate LAS (TrA/IO) to the same extent the control group was better at activating LAS in isolation (inhibiting RA).

While reduced inhibition helps explain muscle substitution it does not clarify why the present study showed that altering cervical orientation can affect RA activation and LAS:RA ratio. The novel approach to this study was that an inclusion criterion for the CLBP group was the presence of at least one PR. While there has been no published research on PR presence in a CLBP, clinically the presence of PR have been seen in patients with CLBP. PR typically start to be inhibited at six months (McPhillips et al., 2000) and their presence is used to assess CNS integrity by physicians (Zafeiriou, 2004). While it is unknown whether the PR in this current population has resurfaced, as it does with normal advanced aging, or if they have been present throughout the subjects life it can possibly indicate CNS disruption. Age is an unlikely reason for the resurfaced PR as the population employed had an average age of 45 and PR remergence is usually not seen until the sixth decade (Odenheimer et al., 1994). It should be noted that the decreased gray matter seen in the CLBP patients in the Apkarian et al. study (2004) was reported to be equivalent to an extra 10-20 years of aging. Similarly if PR are resurfacing it would agree with the theories that there is an overall reduction in inhibition associated with reduced grey matter and CLBP. These results may help with the classification of CLBP patients and help clarify the cause of the persistent pain. If PR are present in an individual with CLBP it may be possible that this pain is due to a reduction in supraspinal inhibition.

Cervical orientation and abdominal muscle activation

It was hypothesized that the muscle activation patterns of the CLBP group would be more similar to the control during performance of the hollowing maneuver when placed in a position mimicking either ATNR or the Morrow reflex. Placing the CLBP patients in the ATNR position with altered position of the extremities did not affect performance compared to controls. However, cervical rotation to the left with the hollowing maneuver by CLBP, indicated by LLAS:LRA ratio, had activation of LRA similar to controls. Cervical extension and flexion also affected activation patterns of RA and LAS:RA ratio. Cervical flexion showed a similar ratio between groups but indicated that it was likely to increase activation of RA compared to controls. This pattern would not be recommended, as increasing RA activation will only reinforce the faulty motor pattern of this population. Cervical extension illustrated a lower ratio for LLAS:LRA for the CLBP group (altered motor pattern) but similar levels of RA activation.

How cervical orientation affects trunk muscle activation patterns in this study can only be speculative. In infants, and the CLBP group, the ATNR is stimulated by cervical rotation, this is one of the first PR to be inhibited during normal infant development (McPhillips et al., 2000). Likewise the Morrow reflex is stimulated with cervical extension and is also inhibited within the first two years of life (Allen & Capute, 1986). PR are brainstem mediated movement patterns which are inhibited by areas in the frontal lobe (Sudo, Matsuyama, Goto, Matsumoto, & Tashiro, 2002). If subjects present PR, rotation or extension of the head while keeping the extremities stationary will actively inhibit the PR. Perhaps by inhibiting this reflex it is reopening latent inhibitory synaptic pathways in the frontal lobe. This may in turn facilitate other inhibitory pathways allowing the CLBP patients to activate TrA/IO while also inhibiting activation of RA during the hollowing maneuver. This could happen along two pathways; cortical-cortical or cortico-bulbar. If latent inhibitory synapses are reopened in the cortical-cortical pathway there can be direct inhibition on the premotor or motor cortices which have been shown to affect TrA activation patterns (Tsao et al., 2008; Tsao et al., 2010). However, it has been indicated that motor neurons for postural and axial muscular, RA and TrA/IO, receive a major portion of their excitatory and inhibitory input from the ventral corticospinal tract (Deliagina, Beloozerova, Zelenin, & Orlovsky, 2008). In turn the ventral corticospinal tract receives a large portion of input from the cerebellum and brainstem via reticulospinal and vestibulospinal neurons located in the brainstem (Deliagina et al., 2008). As PR are brainstem mediated movement patterns this may be a more active area in the CNS with CLBP. This increased brain stem activity could cause an increase in tonic sub threshold drive to RA alpha motor neurons via reticulospinal and vestibulospinal pathways. When the command to activate TrA/IO descends the CNS there could also be excitatory inputs to RA at either the cortical or brainstem levels. In a healthy population the excitatory input to RA drive would not be enough to cause depolarization or is inhibited. In a CLBP population, because of the increase in tonic drive, the slight excitatory input to RA could be sufficient to cause depolarization or is not inhibited. Therefore the opening of latent corticobulbar inhibitory interneurons, by actively inhibiting PR, may reduce activity in the brain stem and thus tonic drive to RA when attempting to activate TrA/IO or may open up inhibitory synapses on the RA activation pathway. Either way the end result is sub threshold activity.

5.2 Compiled Data

EO activity with positional changes

With group data combined, the ANOVA illustrated that position change can significantly alter the activation levels of the LAS and EO. It is accepted that the EO is responsible for contralateral rotation and ipsilateral side-flexion of the trunk (Urquhart & Hodges, 2005). Likewise it has been shown that side bridging can produce a significant difference for side to side activation for the EO muscles (Okubo et al., 2010). The present study has intriguing results as it shows that position change alone can cause an increase in side specific activation of the EO even when performing the hollowing maneuver, which is an exercise that is meant to have minimal EO activation. The results indicate that when in the ATNR right position the subjects had significantly greater activation of the right EO compared to that of the supine, ATNR left, and cervical flexion positions. Similarly, on the contralateral side when in the ATNR left position the left EO showed a trend ($p=0.065$) to have greater activation levels than when in the cervical rotation to the right and cervical flexion positions. For position change to have altered activation levels there are three possible explanations; the position change altered the static architecture of the muscle, the position change was sufficient enough to move the skin and surface electrodes thus altering the area in which the data was collected or finally the position change allowed sufficient proprioceptive feedback to alter descending drive to the motor neuron.

As a joint goes through its range of motion the muscles surrounding that joint will undergo length changes. At a microscopic level the individual units of a muscle fiber (sarcomere) also change in length. The length-tension relationship indicates that there is an optimal muscle length to obtain the maximal number of crossbridges (Powers & Howley, 2007). When performing a task in which a set load is to be achieved, such as when performing the hollowing maneuver, a muscle at an optimal length will require less activation (Andersson et al., 1997). This could be used as a possible explanation for the alteration in activation levels seen in this study as the highest levels of activation for both left and right EO are seen when in the ipsilateral ATNR position. This result is significant because only in this position will the subjects have their hip in extension. With hip extension there will be an anterior rotation of the pelvis (Forst, Wheeler, Fortin, & Vilensky, 2006) and as the EO is attached to the iliac crest there could be a change in muscle length. Similarly, it has been shown that orientation of the pelvis can alter recruitment of the abdominal musculature (Urquhart, Hodges, Allen et al., 2005). Posterior pelvic tilting is a common therapeutic exercise and has been shown to alter activation levels of the TrA/IO, EO and RA (Workman et al., 2008), however there is some controversy in regards to which muscle is most affected (Urquhart, Hodges, Allen et al., 2005). While this is a possible explanation for the changes in EO activation it should be noted that this change in length will be small as no other attachment of the EO has been altered. Likewise, the rotation of the pelvis, while not recorded, was likely less than 5^{o}.

Similar to changes in the length of a muscle altering activation levels, body position alone may also influence muscular activity. By having the muscle in a lengthened position it is possible that the muscles have sufficient stretch to cause a reflex mediated increase in activity (Urquhart, Hodges, Allen et al., 2005). This however is unlikely to be the reason for the altered EO activity in this study as the EO is not in a position that would cause a stretch great enough to induce this response. It has been shown that an individuals' internal body representation can vary with changes in the relative position of body segments (Urquhart, Hodges, Allen et al., 2005). An internal body representation is fundamental in the performance of any task as it gives an individual a perceived location of their body parts in space (Longo & Haggard, 2010). While this body representation is created via constant afferent signals, sensory information does not provide any insight into body size and shape. Thus sense of position must refer to a stored body model, which includes metric properties of size and shape (Longo & Haggard, 2010). Urquhart et al. (2005c) stated that changes to an individuals' internal body representation may influence movement performance. It is possible that by altering the position of our subjects we altered their internal body representation; this then lead to a different activation pattern of the abdominal musculature when attempting to perform the hollowing maneuver.

Direction specificity of LAS

While alteration in EO activity due to changes in body position is a novel finding it is accepted that EO is a contralateral rotator and ipsilateral side flexor of the trunk therefore showing side to side differences should not be controversial. With the side to side differences of the LAS there is some controversy as the LAS surface EMG electrodes record information from the TrA (as well as the IO) which has been shown to have a non direction specific activation pattern (Eriksson Crommert & Thorstensson, 2009; Hodges & Richardson, 1997) and to have a role in ipsilateral rotation by others (Okubo et al., 2010; Urquhart & Hodges, 2005). The differences in these findings may however be due to methodological differences in these studies.

Early studies performed by Hodges & Richardson (1997, 1999) which examined arm motion and activation of TrA illustrated that the TrA will activate in a similar manner no matter the direction of arm movement. Without a direction specific activation pattern it was deduced that the major functional role of TrA was spinal stabilization. Urquhart et al. (2005a) stated that previous research may not have uncovered the direction specific activation of TrA because single arm rising may not induce a sufficient rotator moment to demand specific activation. Allison et al. (2008) however believe that early research did not show direction specific activation of TrA because bilateral EMG information was not collected nor was the magnitude of EMG compared. Allison et al. (2008) show a side specific activation of TrA with arm rising. While there was bilateral activation, arm rising produced greater activation of the ipsilateral TrA.

Likewise electrode placement may be responsible for the conflicting results. The present study collected EMG information from a site that would represent both lower IO/TrA. Hodges & Richardson (1997, 1999, and 2001) and Urquhart (2005b) both utilized similar intramuscular electrode placement and recorded information from middle TrA. Unfortunately Allison et al. (2008) did not provide electrode placement measurements. While it seems that middle and lower divisions of TrA have a similar morphology and function (Urquhart & Hodges, 2005; Urquhart et al., 2005; Urquhart, Hodges, & Story, 2005; Urquhart, Hodges, Allen et al., 2005) care should be taken when comparing research, which have different EMG collection sites of TrA.

LAS activity with positional changes

The present study illustrated a side specific response to alterations in body position for the LAS. While previous research has shown TrA and IO activation to be affected by changes in body position which alters postural demand (Eriksson Crommert & Thorstensson, 2008; Eriksson Crommert & Thorstensson, 2009; Urquhart, Hodges, & Story, 2005), the present research provides novel information as postural demand does not change, all information is collected during static isometric contractions, and only cervical and extremity position is altered. Therefore, positional changes alone may explain the alteration in activation levels.

The right LAS was significantly less active ($p \leq 0.0001$) in the ATNR left position compared to all other positions. Likewise the left LAS showed significantly less activation ($p \leq 0.0008$) in the ATNR right position compared to all other positions except cervical rotation to the left. While no comparison between side to side magnitude of LAS was made, the contralateral response to position change indicates a selective side specific activation pattern of the LAS site. The alteration in activation levels due to changes in body position could be explained similarly to the EO (muscle length, movement of EMG electrodes, proprioceptive feedback) as well with the effect of body position on sacroiliac (SI) joint closure.

It is unlikely that the changes can be attributed to changes in muscle length or electrode position as the position of the hip when the LAS is at its lowest activation is the same as it is in the 5 other positions. It is possible that proprioceptive feedback could have altered activation levels. When in the ATNR position one hip is flexed to 45° while the other is extended flat on the plinth. This will cause the two innominate to be in different orientations in terms of nutation. Hip flexion posteriorly rotates the innominate into nutation while hip extension anteriorly rotates the innominate into counter nutation (Forst et al., 2006). Similarly, when rotating to the left, the left innominate goes into nutation and the right into counter nutation (Sturesson, Uden, & Vleeming, 2000). Therefore, when in the ATNR right position the hips are in similar orientation as when rotating to the left. Thus, when in the ATNR right position, proprioceptive feedback may be informing the internal body representation that the body is already rotated to the left. The lower region of IO and TrA are both involved in ipsilateral rotation (Urquhart & Hodges, 2005) and when in the ATNR right position the body already feels like it is rotated to the left. Therefore, it is possible that when the hollowing maneuver was performed in the ATNR right position the left side was already in an end range rotational position thus did not require or was unable to produce high activation levels.

Another proposed function for the lower region of TrA/IO is SI stabilization. The SI joint connects the sacrum and the pelvis, due to its anatomical composition it is very stable and has a maximal movement of 2.5 ° (Sturesson, Selvik, & Uden, 1989), and is located just inferior to the posterior superior iliac spine (Forst et al., 2006).The stability of the joint is attributed primarily to the many adjacent ligaments, which cover the joint, however with prolonged upright posture the ligaments creep, become more lax and in turn a greater reliance is placed on the muscular system (Cohen, 2005). The SI joint runs along the coronal plane and is stabilized by muscle fibers that run in a horizontal direction, specifically periformis, gluteus maximus, IO, and TrA (Sturesson et al., 2000). The SI joint is most stable when the two surfaces are in full contact with one another, this can be achieved via the skeletal system and is dubbed form closure or the muscular and ligamentous system dubbed force closure. As stated in the above paragraph hip movements have an effect on innominate orientation, which will in turn affect SI joint closure. Biomechanical models have shown that when standing or when the hips are in extension there is counter nutation (anterior rotation) of the innominate which leads to a form closure of the SI joint (Forst et al., 2006). Similarly, it is shown that when performing the standing hip flexion test, which involves single leg stance on a fully extended leg and 90° flexion of the contralateral hip and knee, both innominate undergo similar movements due to their extensive ligamentous connection (Sturesson et al., 2000). However it must be noted that the standing hip flexion test is performed in weight bearing posture while the ATNR is performed in supine, eliminating the gravitational effect from upright posture, and may have a different effect on innominate orientation. It may be possible that when in the ATNR position both SI joints have undergone form closure due to the extension of one of the hips. Thus when performing the hollowing technique in the ATNR position TrA may not activate to the same extent because one of its major functions, SI joint closure, has already been performed due to skeletal alignment. Increased SI joint closure has been shown to reduce activation of the gluteus maximus (Takasaki, Iizawa, Hall, Nakamura, & Kaneko, 2009) and has been previously suggested (Urquhart, Hodges, & Story, 2005) that SI joint stability could alter the activation patterns of the lower abdominal muscles. Similarly cadaver studies have indicated that the SI joint has afferent innervations of paciniform-encapsulated mechanoreceptors, which would strongly suggest proprioceptive input to higher centers (Forst et al., 2006). Proprioceptive input indicating an already closed SI joints may influence descending drive for TrA activation. Thus, when in the ATNR position SI joint closure could decrease bilateral drive to TrA/IO while rotational proprioceptive feedback may decrease drive to the contralateral TA/IO. This reduction in drive may be sufficient to decrease activation levels of the contralateral LAS site when in the ATNR position as seen in this study.

5.3 Gender Differences

While not one of the major goals of this study, male and female activation patterns were compared. It has been previously demonstrated that TrA takes up a greater portion of the lateral abdominals in females than it does in males (Mannion et al., 2008). This may indicate females would have better neuromuscular control of TrA and in turn be better at selectively activating TrA (Springer, Mielcarek, Nesfield, & Teyhen, 2006). Mannion et al. (2008) illustrated no gender differences for changes in muscle thickness ratios, via ultrasound, during the hollowing maneuver for TrA/ IO or TrA/EO ratios. Conversely, the present study did illustrate sex differences for activation ratios and levels of specific sites. The women were more likely to have a better ratio of RLAS:RRA in all the positions except ATNR left while the men were more likely to have higher levels of activation in all three muscles bilaterally for a variety of positions. This indicated that the women were better at selectively activating TrA/IO, when performing the hollowing maneuver, while the men had greater global activation of the trunk. This may be attributed to two factors; the men required more activation to attain the 10 mmHg of pressure required for a successful performance of the hollowing maneuver or that the men had a different activation pattern when performing the normalization exercise (supine crook lying double leg lift). If there was a gender difference in the activation pattern for the normalization exercise it would alter the results when comparing the activation patterns of men and women during the hollowing maneuver. Anatomically, this could be explained by differences in pelvis size between sexes. Along with TrA having a larger portion of the lateral abdominals (Mannion et al., 2008), women also generally have a wider pelvis (Agur & Dalley, 2009). This could cause the fibers of lower TrA/IO to be more horizontal in orientation. This could mean that female lower TrA/IO would likely have a larger role in SI joint closure and visceral support in standing, and less of a role in ipsilateral rotation. No cadaver studies could be found to illustrate different fiber orientation between sexes. However, it was illustrated in a review by Cohen (2005) that women had SI joint ranges of motion double that of men (1.2^{o} to 2.8^{o}) indicating a need for more support. If the women did have more horizontally oriented fibers they may require less activation of the TrA/IO to successfully perform the hollowing maneuver. Conversely, if the lower fibers of TrA/IO are more oblique in men then it may require more activation to perform the hollowing maneuver correctly. Future cadaver studies should investigate fiber orientation of this muscle to see if there is a difference between sexes. It should also be noted that Mannion et al. (2008) investigated thickness changes with ultrasound. To make ratios with EO, Mannion et al. (2008) needed to make measurements from the middle to upper regions of TrA/IO. The present study utilized EMG information recorded from the lower region of TrA/IO therefore it is difficult to make comparisons between the two, or indicating that only the lower regions of TrA have different sex dependent functions.

5.4 Limitations

This study poses new insight into both muscular activation patterns of CLBP patients as well as how altering body position can affect activation levels in both CLBP patients and a compiled population of healthy and CLBP groups. However, the results must be considered within the limitations of the study. Compared to other studies on TrA activation patterns the major limitation in the present study is that surface EMG electrodes were used to record information of the deep abdominal muscles. With surface EMG at this site it is impossible to selectively record TrA without recording IO as it lies directly over the muscle. However this limitation should not affect the interpretation of the results in this study for three reasons. Anatomically it has been shown that the lower fibers of both IO and TrA have similar orientation and attachments (Urquhart et al 2005a). Likewise it has been proposed that they have similar synergistic functions in ipsilateral rotation and SI joint closure (Urquhart et al. 2005b). Finally it has been shown that the hollowing maneuver is performed by the combined activity of IO and TrA (Monfort-Panego et al. 2009). Because of the similarity in function and anatomy these two muscles have been recorded together (LAS site) in a number of studies (Behm, Cappa, & Power, 2009; Hamlyn et al., 2007; Parfrey et al., 2008; Workman et al., 2008). Any alterations in activation, due to changes in body position, would represent both muscles. In studies where reaction time of TrA is being assessed fine wire electrodes should be used as it has been shown that TrA will activate prior to IO (P. W. Hodges & Richardson, 1997). However these studies utilized middle TrA, it would be interesting to see if reaction times of lower IO were similar to that of lower TrA.

Secondly, the LAS site may have recorded activity from adjacent muscles such as EO and RA, this phenomenon is known as crosstalk. As the EO, IO and TrA run in layers along the anterior trunk surface electrodes have the capacity to pick up information from any of these muscles. It has been shown previously that crosstalk between RA and other abdominal muscles are unlikely (Chanthapetch, Kanlayanaphotporn, Gaogasigam, & Chiradejnant, 2009). As the LAS site was placed just inferior and medial to the ASIS this should prevent crosstalk from the EO as its fibers do not travel below the ASIS (Urquhart et al., 2005). It has been shown in a previous study (Chanthapetch et al., 2009), which utilized a similar site, that crosstalk between EO and TrA/IO is unlikely with careful electrode placement.

It should be noted that during the experiment the patients were instructed on how to perform the hollowing maneuver in the supine position. When a successful performance was performed the data were recorded for analysis. This means that while the other positions were randomized; supine was always first. It has been shown that patients with CLBP have more difficulty when initially attempting to selectively activate the TrA/IO (Hodges & Richardson, 1996). This illustrates that differences between groups in the supine position may not be as valid as the other positions as it was always the first exercise performed and the healthy population may have been better at selectively activating TrA/IO in the initial stages of the experiment. The final limitation is that there is no true control group in which there is a presence of LBP but no presence of PR. It may be ascertained that any individual with LBP is able to alter activation patterns of the abdominal musculature by changing cervical orientation.

5.5 Clinical Applications

Clinically this paper suggests that the re-emergence or continuing presence of PR symptoms can affect CLBP muscle activation. A trained physiotherapist was able to identify the presence of PR symptoms in all the participants of the CLBP group. No previous published paper has indicated that CLBP may be associated with a remergence or resurfacing of PR symptoms. This could open up new assessment protocols for CLBP patients in which PR presence should be determined. If there is a PR present then it can be possible that there is a decrease level of supraspinal inhibition and that the main goal of treatment should not be activation of the TrA/IO but learning to inhibit RA when performing the hollowing maneuver. Likewise clinicians may find it easier to teach individuals how to inhibit RA by changing cervical orientation. It should also be made clear that the hollowing maneuver should not be a technique used to increase spinal stiffness as it has been shown to have little effect on spinal stability (Vera-Garcia et al., 2007) with external perturbations. The hollowing maneuver is used to retrain a proper motor pattern in which the TrA/IO can be activated in isolation of RA.

For the compiled data this research illustrates that the TrA/IO have side specific activation patterns which can be affected by changing of body position. For a healthy individual who is able to selectively activate TrA/IO the hollowing maneuver may not provide any benefit, it is recommended that the exercises and results from Okubo et al. (2010) should be used for exercise prescription of this population when the goal is increasing spinal stability. In this study there was a clinical difference in activation patterns of the anterior trunk muscles between men and women. Clinically, this may not affect treatment as it is unknown whether CLBP has a different effect on muscular activation between males and females. More research is needed on this topic.

CHAPTER 6

SUMMARY

Low back pain causes significant issues in Western industrialized health care, being one of the major reasons for seeking primary care from a physician and second most frequent reason for not returning to work (Ebenbichler et al., 2001). As a large percentage of CLBP cases have an idiopathic onset, there is a large discrepancy in treatment used by physiotherapists and physicians. It has been shown that individuals with CLBP have an altered activation pattern of the trunk musculature in response to an internal perturbation and when performing the hollowing maneuver (Hodges & Richardson, 1996; O`Sullivan et al., 1997). One of the main treatment protocols for CLBP is a program of lumbar stabilization exercises which targets not only strengthening and endurance of the muscles but also retraining motor control and activation patterns (O`Sullivan et al., 1998). It has been shown that individuals with CLBP have difficulty learning how to correctly perform the hollowing maneuver, which is a lumbar stabilization exercise (O`Sullivan et al., 1998). It has been hypothesized (unpublished observation) that there is a sub group of individuals with CLBP who also have retained PR which may interfere with motor learning, and that altering cervical and extremity orientation to mimic PR will allow individuals with CLBP to have similar activation patterns of the trunk musculature compared to a pain free population when performing the hollowing maneuver.

There is also controversy in the role and function of the abdominal musculature in terms of spinal stability, specifically the TrA and IO. It is classically believed that the TrA has a bilateral activation pattern no matter the movement or reaction to perturbation, acting like a corset to stabilize the spine (P. W. Hodges, 1999). Conversely it is believed that the TrA and IO are broken down into sections, which have different roles pending on the angle of muscle fibers and have a side specific activation pattern with movement and postural reactions (Allison et al., 2008; Urquhart & Hodges, 2005; Urquhart et al., 2005).

Key Findings:

- Individuals with CLBP illustrated increased RA activation and decreased LAS:RA ratio compared to a pain free control (Figures 9, 10, 11 and 12).
- Alteration of cervical orientation minimized the between group difference in activation indicating a supraspinal response (Figures 9, 10, 11 and 12).
- When the data were compiled activation levels of the LAS (TrA/IO) and REO were altered by changing body position (Figures13, 14 and 15).
- Extremity orientation illustrated a contralateral decrease in LAS activation indicating a side selective activation pattern of TrA/IO (Figures 12 and 14).

Future Directions

Further research is required to clarify if there is a sub group of individuals with CLBP who have present PR. This project did not use a group of Individuals with CLBP who do not have PR symptoms therefore it is unknown whether the findings are applicable to the total CLBP population or just those with PR symptoms. Additional research comparing these two groups will help clarify that issue. It is also important to see the efficacy of this as a treatment protocol in which it is seen how performing the hollowing maneuver in altered cervical/extremity orientation over a period of weeks compared to in a stationary crook lie or while moving affects motor control, function and perceived level of pain and disability.

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Appendix A

Electrode Placement and Exercise Position

Figure 1: Electrode Placement

From superior to inferior placement bilateral RA, EO and LAS

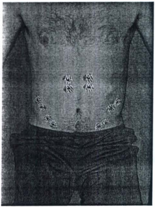


Figure 2: Supine

Figure 3: ATNR Left

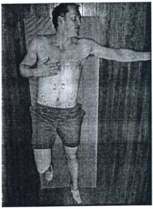


Figure 4: ATNR Right

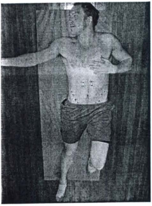


Figure 5: Cervical Rotation to the Left

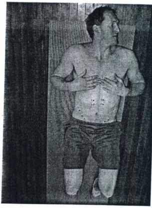


Figure 6: Cervical Rotation to the Right

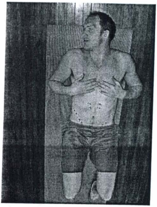


Figure 7: Morrow Stage 1 Defined as Cervical Extension

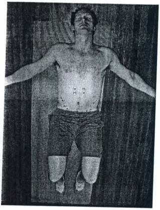
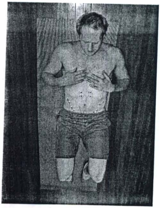


Figure 8: Morrow Stage 2 Defined as Cervical Flexion



Appendix B

Graphs and Tables

Figure 9: LLAS:LRA Mean Ratio Difference of CLBP vs Control with 95% Confidence Limits.

Clinically, it was likely that the control group would have a higher LLAS:LRA ration than the CLBP group in the supine, ATNR left and right, cervical rotation to the right and cervical extension positions (respectively 77%, 76%, 90%, 75,77%).

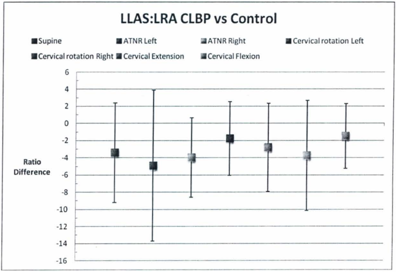


Figure 10: RLAS:RRA Mean Ratio Difference of CLBP vs Control with 95% Confidence Limits.

Clinically, it was likely that the control group would have a higher RLAS:RRA ration than the CLBP group in the supine and ATNR left positions (respectively 80% and 90%).

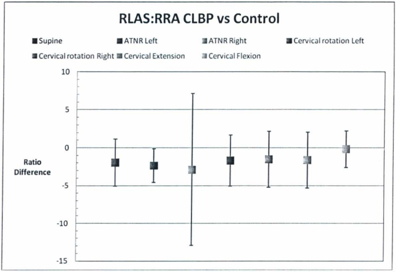


Figure 11: LRA Mean Activation Difference for CLBP vs Control with 95% Confidence Limits.

Clinically it was likely to very likely that the CLBP group would have higher activation levels of the LRA in the supine, ATNR left and right, cervical rotation to the right and flexion positions (Respectively 96%, 91%, 96%, 87%, 90%).

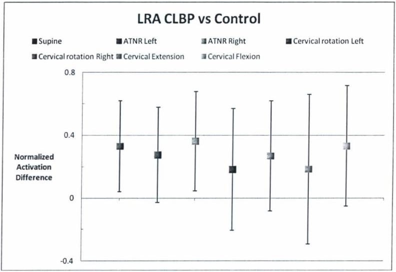


Figure 12: RRA Mean Activation Difference for CLBP vs Control with 95% Confidence Limits.

Clinically it was likely that the CLBP group would have higher activation levels than the control in the supine (93%,) and cervical flexion position (80%).

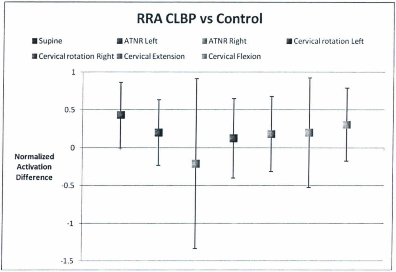


Figure 13: Compiled Data; Effect of Body Position on RLAS Muscle Activation.

The * indicates that the activation of the Right LAS site was significantly less ($p \leq 0.05$) in the ATNR L position than any other position when all subjects data is compiled.

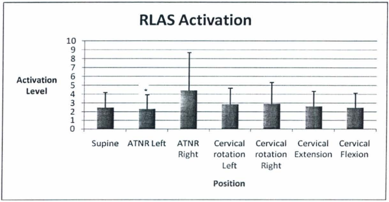


Figure 14: Compiled Data; Effect of Body Position on LLAS Muscle Activation

The * indicates that activation levels of the Left LAS site was significantly less ($p \leq 0.005$) in the ATNR R position than any other position, except cervical rotation to the left, when all subjects data is compiled.

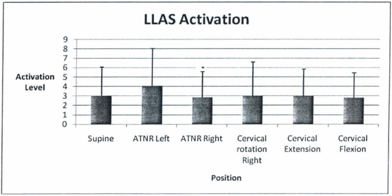


Figure 15: Compiled Data; Effect of Body Position on REO Muscle Activation

The * indicates that the activation levels for the Right EO site are significantly greater ($p \leq 0.05$) in the ATNR R position compared to the supine, ATNR L, and Flex position.

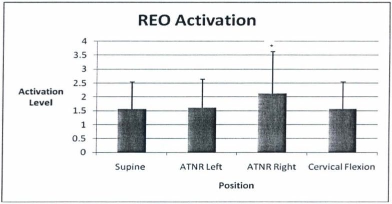


Figure 16: RLAS:RRA Mean Ratio Difference for Women vs Men with 95% Confidence Limits.

Clinically it was likely that the women would have a higher ratio of RLAS:RRA compared to men in the supine, right ATNR, cervical rotation to the left and right, cervical flexion and cervical extension positions (respectively 89%,87%, 88%, 81%, 92%, 86%).

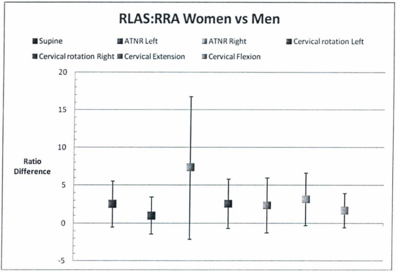


Figure 17: LLAS:LRA Mean Ratio Difference for Women and Men with 95% Confidence Limits.

Clinically it was likely that the women would have a higher LLAS:LRA ratio than the men for only the cervical extension (75%) position.

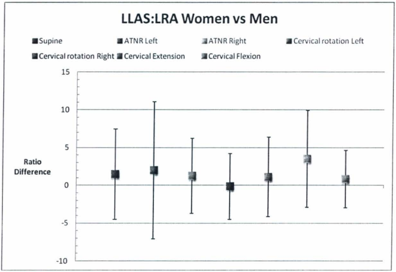


Figure 18: Mean Difference Between Female and Male Activation Levels of LRA with 95% Confidence Limits.

Clinically it was likely to very likely that the women would have lower activation levels of the LRA compared to men in the supine, left ATNR, right ATNR, cervical rotation to the left and right, cervical extension and cervical flexion (Respectively 94%, 76%, 81%, 95%, 93%, 97%, 79%).

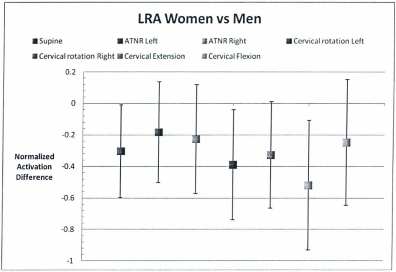


Figure 19: Mean Difference Between Female and Male Activation Levels of RRA with 95% Confidence Limits.

Clinically it was likely very likely and almost certain that the women would have lower activation levels of the RRA compared to men in the supine, ATNR left, ATNR right, cervical rotation to the left and right, cervical extension and cervical flexion than the women (Respectively 99%, 98%, 88%, 99%, 99%, 99%, 95%).

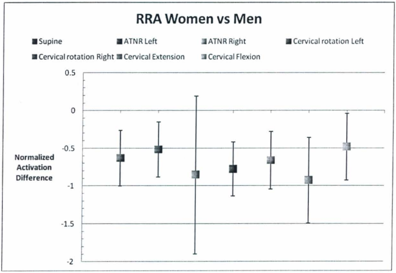


Figure 20: Mean Difference Between Female and Male Activation Levels of LLAS with 95% Confidence Limits.

Clincally it was likely that the women would have lower activation levels of the LLAS in the supine, ATNR left, ATNR right, cervical rotation to the left and right positions (Respectively 78%, 91%, 80%, 88%, 79%).

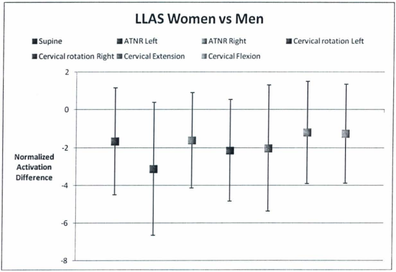


Figure 21: Mean Difference Between Female and Male Activation Levels of RLAS with 95% Confidence Limits.

Clinically it was likely that the women would have lower activation of the RLAS compared to the men in the the ATNR left, cervical rotation to the left and right positions (Respectively 94%, 91%, 79%).

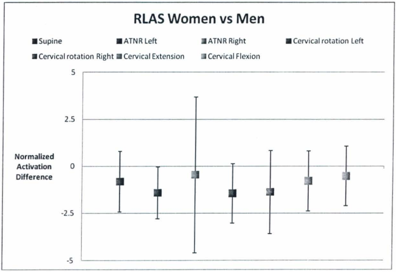


Figure 22: Mean Difference Between Female and Male Activation Levels of REO with 95% Confidence Limits.

Clinically it was likely that the women had lower activation of the REO compared to the men in the supine, ATNR left, ATNR right, cervical rotation to the left and right and the cervical extension positions (Respectively 86%, 92%, 85%, 95%, 91%, 88%).

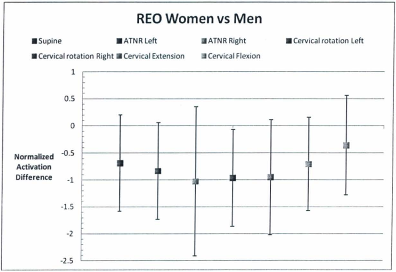


Figure 23: Mean Difference Between Female and Male Activation Levels of LEO with 95% Confidence Limits.

Clinically it was likely that the women had lower level of LEO activation than the men in the ATNR left (75%) position.

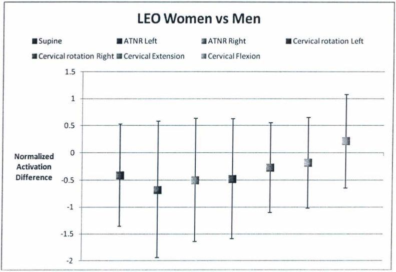


Table 1: Effect Sizes and Likelihoods of Clinically Meaningful Difference When Comparing the LAS:RA Ratio of a Control and CLBP Group.

Ratio and position	p-value	Cohen's d	Likelihood of difference being clinically meaningful (%)
RLAS:RRA – Supine	0.2011702	-0.58	80
RLAS:RRA - ATNR (L)	0.0379177	-0.91	95
RLAS:RRA - ATNR (R)	0.5501253	-0.28	57
RLAS:RRA – Cervical rotation left	0.3103694	-0.47	72
RLAS:RRA – Cervical rotation right	0.400778	-0.39	66
RLAS:RRA – Cervical extension	0.3658144	-0.42	68
RLAS:RRA – Cervical flexion	0.8621262	-0.08	40
LLAS:LRA – Supine	0.2344045	-0.55	78
LLAS:LRA - ATNR (L)	0.2568413	-0.52	76
LLAS:LRA - ATNR (R)	0.0876154	-0.77	90
LLAS:LRA - Cervical rotation left	0.4001613	-0.39	66
LLAS:LRA – Cervical rotation right	0.2672622	-0.51	75
LLAS:LRA - Cervical extension	0.2376006	-0.54	77
LLAS:LRA - Cervical flexion	0.4198933	-0.37	65

Any percentage ≥ 75% is deemed as it being likely, ≥ 95 % as very likely that the control group will have a higher LAS:RA ratio in that position compared to the CLBP group.

Table 2: Effect Sizes and Likelihoods of Clinically Meaningful Difference When Comparing Site Specific Activation Levels in Different Positions of Control and CLBP groups.

Site and Position	p-value	Cohen's d	Likelihood of difference being clinically meaningful (%)
LLAS Supine	0.48	-0.33	61
LLAS ATNR (L)	0.40	-0.39	66
LLAS ATNR (R)	0.44	-0.36	64
LLAS Cervical rotation left	0.34	-0.44	70
LLAS Cervical rotation right	0.39	-0.40	67
LLAS Cervical extension	0.30	-0.48	73
LLAS Cervical flexion	0.38	-0.41	67
RLAS Supine	0.78	0.13	24
RLAS ATNR (L)	0.52	-0.30	59
RATNR (R)	0.65	-0.21	51
RLAS Cervical rotation left	0.80	-0.12	43
RLAS Cervical rotation right	0.80	-0.12	43
RLAS Cervical extension	0.86	-0.08	40
RLAS Cervical flexion	0.98	0.01	32
LRA Supine	0.03	0.97	96
LRA ATNR (L)	0.07	0.80	91

LRA ATNR (R)	0.03	0.97	96
LRA Cervical rotation left	0.33	0.45	70
LRA Cervical rotation right	0.12	0.70	87
LRA Cervical extension	0.43	0.37	64
LRA Cervical flexion	0.09	0.77	90
RRA Supine	0.05	0.87	94
RRA ATNR (L)	0.34	0.44	70
RRA ATNR (R)	0.70	-0.18	21
RRA Cervical rotation left	0.62	0.23	52
RRA Cervical rotation right	0.45	0.35	63
RRA Cervical extension	0.57	0.27	56
RRA Cervical flexion	0.20	0.59	80
LEO Supine	0.90	-0.06	38
LEO ATNR (L)	0.50	-0.31	60
LEO ATNR (R)	0.89	-0.06	39
LEO Cervical rotation left	0.63	-0.23	52
LEO Cervical rotation right	0.58	0.25	17
LEO Cervical extension	0.92	-0.05	37

LEO Cervical flexion	0.55	0.28	16
REO Supine	0.58	0.26	17
REO ATNR (L)	0.60	-0.24	54
REO ATNR (R)	0.72	-0.17	47
REO Cervical rotation left	0.89	-0.06	38
REO Cervical rotation right	0.74	-0.15	46
REO Cervical extension	0.90	-0.06	38
REO Cervical flexion	0.80	0.12	25

Any percentage $\geq$ 75% is deemed as it being likely, $\geq$ 95 % as very likely that there is a difference between two groups. When the Cohen's d effect size is a negative number it indicates that the control group will likely have higher activation levels in that position for that site. When the Cohen's d effect size is positive it indicates that the control group will likely have lower activation levels of that muscle site in that position.

Table 3: Normalized Activation Levels of Compiled Data for Each Site and Position

*indicates that this position produced significantly ($p \leq 0.05$) lower activation levels at the corresponding site than the positions marked ^
**indicates that this position produced significantly ($p \leq 0.05$) higher activation levels at the corresponding site than the positions marked ^

	Supine	ATNR (L)	ATNR(R)	Cervical rotation left	Cervical rotation right	Cervical Extension	Cervical Flexion
LLAS	3.03 (3.02)^	4.09 (3.96)^	2.86 (2.72)*	3.47 (2.97)	3.01 (3.59)^	2.98 (2.85)^	2.79 (2.63)^
RLAS	2.45 (1.71)^	2.33 (1.59)*	4.44 (4.26)^	2.86 (1.79)^	2.93 (2.4)^	2.6 (1.7)^	2.48 (1.66)^
LRA	0.75 (0.34)	0.7 (0.34)	0.74 (0.37)	0.84 (0.41)	0.78 (0.38)	0.85 (0.5)	0.81 (0.43)
RRA	0.85 (.5)	0.84 (0.46)	1.11 (1.16)	0.93 (0.54)	0.86 (0.52)	0.98 (0.75)	0.92 (0.52)
LEO	1.36 (1.0)	1.62 (1.35)	1.41 (1.2)	1.53 (1.17)	1.27 (0.87)	1.31 (0.87)	1.27 (0.89)
REO	1.56 (0.98)^	1.61 (1.02)^	2.12 (1.5)**	1.77 (1.05)	1.71 (1.2)	1.66 (0.96)	1.57 (0.97)^

Table 4: Effect Sizes and Likelihoods of Clinically Meaningful Difference When Comparing the LAS:RA ratio of Women to Men

Ratio and Position	p-value	Cohen's d	Likelihood of difference being clinically meaningful (%)
RLAS:RRA Supine	0.10	0.75	89
RLAS:RRA ATNR (L)	0.40	0.39	66
RLAS:RRA ATNR (R)	0.12	0.70	87
RLAS:RRA Cervical rotation left	0.11	0.72	88
RLAS:RRA Cervical rotation right	0.19	0.60	82
RLAS:RRA Cervical extension	0.07	0.81	92
RLAS:RRA Cervical flexion	0.14	0.68	86
LLAS:LRA Supine	0.61	0.24	53
LLAS:LRA ATNR (L)	0.65	0.21	51
LLAS:LRA ATNR (R)	0.60	0.24	54
LLAS:LRA Cervical rotation left	0.95	-0.03	31
LLAS:LRA Cervical rotation right	0.66	0.21	51
LLAS:LRA Cervical extension	0.27	0.51	75
LLAS:LRA Cervical flexion	0.65	0.21	51

Any percentage ≥ 75% is deemed as it being likely that the women will have a higher LAS:RA ratio in that position compared to the men.

Table 5: Effect Sizes and Likelihoods of Clinically Meaningful Difference When Comparing Site Specific Activation Levels in Different Positions of Men and Women

Site and Position	p-value	Cohen's d	Likelihood of difference being clinically meaningful (%)
LLAS Supine	0.23	-0.55	78
LLAS ATNR (L)	0.08	-0.79	91
LLAS ATNR (R)	0.19	-0.59	81
LLAS Cervical rotation left	0.11	-0.72	88
LLAS Cervical rotation right	0.22	-0.57	79
LLAS Cervical extension	0.36	-0.42	69
LLAS Cervical flexion	0.32	-0.46	71
RLAS Supine	0.30	-0.48	73
RLAS ATNR (L)	0.04	-0.89	95
RLAS ATNR (R)	0.82	-0.11	42
RLAS Cervical rotation left	0.07	-0.81	92
RLAS Cervical rotation right	0.21	-0.57	80
RLAS Cervical extension	0.31	-0.47	72
RLAS Cervical flexion	0.49	-0.32	60

LRA Supine	0.04	-0.89	94
LRA ATNR (L)	0.25	-0.53	77
LRA ATNR (R)	0.19	-0.60	82
LRA Cervical rotation left	0.03	-0.95	96
LRA Cervical rotation right	0.06	-0.85	93
LRA Cervical extension	0.02	-1.04	98
LRA Cervical flexion	0.21	-0.58	80
RRA Supine	0.00	-1.26	>99
RRA ATNR (L)	0.01	-1.12	99
RRA ATNR (R)	0.10	-0.73	89
RRA Cervical rotation left	0.00	-1.43	>99
RRA Cervical rotation right	0.00	-1.28	>99
RRA Cervical extension	0.00	-1.23	99
RRA Cervical flexion	0.04	-0.93	95
LEO Supine	0.37	-0.42	68
LEO ATNR (L)	0.27	-0.51	75
LEO ATNR (R)	0.37	-0.42	68
LEO Cervical rotation left	0.37	-0.41	68
LEO Cervical rotation right	0.50	-0.32	60

LEO Cervical extension	0.65	-0.21	51
LEO Cervical flexion	0.61	0.24	18
REO Supine	0.12	-0.70	87
REO ATNR (L)	0.07	-0.82	92
REO ATNR (R)	0.13	-0.68	86
REO Cervical rotation left	0.04	-0.92	95
REO Cervical rotation right	0.08	-0.79	91
REO Cervical extension	0.10	-0.73	89
REO Cervical flexion	0.42	-0.37	65

Any percentage $\geq$ 75% is deemed as it being likely, $\geq$ 95 % as very likely, and >99 as almost certain that the men will have higher activation levels than the women at that site and position.

Appendix C

The Roland-Morris Disability Questionnaire

When your back hurts, you may find it difficult to do some of the things you normally do.

This list contains sentences that people have used to describe themselves when they have back pain. When you read them, you may find that some stand out because they describe you *today*.

As you read the list, think of yourself *today*. When you read a sentence that describes you today, put a tick against it. If the sentence does not describe you, then leave the space blank and go on to the next one. Remember, only tick the sentence if you are sure it describes you today.

1. I stay at home most of the time because of my back.

2. I change position frequently to try and get my back comfortable.

3. I walk more slowly than usual because of my back.

4. Because of my back I am not doing any of the jobs that I usually do around the house.

5. Because of my back, I use a handrail to get upstairs.

6. Because of my back, I lie down to rest more often.

7. Because of my back, I have to hold on to something to get out of an easy chair.

8. Because of my back, I try to get other people to do things for me.

9. I get dressed more slowly then usual because of my back.

10. I only stand for short periods of time because of my back.

11. Because of my back, I try not to bend or kneel down.

12. I find it difficult to get out of a chair because of my back.

13. My back is painful almost all the time.

14. I find it difficult to turn over in bed because of my back.

15. My appetite is not very good because of my back pain.

16. I have trouble putting on my socks (or stockings) because of the pain in my back.

17. I only walk short distances because of my back.

18. I sleep less well because of my back.

19. Because of my back pain, I get dressed with help from someone else.

20. I sit down for most of the day because of my back.

21. I avoid heavy jobs around the house because of my back.

22. Because of my back pain, I am more irritable and bad tempered with people than usual.

23. Because of my back, I go upstairs more slowly than usual.

24. I stay in bed most of the time because of my back.

Note to users:

This questionnaire is taken from: Roland MO, Morris RW. A study of the natural history of back pain. Part 1: Development of a reliable and sensitive measure of disability in low back pain. Spine 1983; 8: 141-144

The score of the RDQ is the total number of items checked – i.e. from a minimum of 0 to a maximum of 24.

It is acceptable to add boxes to indicate where patients should tick each item.

The questionnaire may be adapted for use on-line or by telephone.

Addendums

The effects of different sit- and curl-up positions on activation of abdominal and hip flexor musculature

Kevin C. Parfrey, David Docherty, R. Chad Workman, and David G. Behm

Abstract: The purpose of this study was to evaluate abdominal muscle activation with variations in trunk flexion (sit or curl up) positions, including the protocol currently used by the Canadian Society of Exercise Physiology (CSEP) Health and Fitness Program. Electromyographic (EMG) data were collected during isometric contractions from the upper rectus abdominis (URA), lower rectus abdominis (LRA), external obliques (EO), lower abdominal stabilizers (LAS), rectus femoris (RF), and the biceps femoris (BF) in 14 subjects. Sit-up positions were varied and randomized through 3 variables: the distance the hand traveled along the floor (5, 10, or 15 cm), bent knee or extended knee, and fixed or non-fixed feet. In regard to the distance the hand traveled along the floor, the 10 cm position produced the highest activation of the LRA (p = 0.02), the 5 cm distance produced the lowest RF activation (p = 0.001), and the 15 cm distance produced the lowest activation of the URA (p = 0.001). There was no significant difference between bent-knee and extended-leg sit-up positions; however, there was a trend (p = 0.1) showing that the bent-knee sit-up position produced higher levels of LAS activation and lower levels of RF activation. Foot fixation resulted in significantly lower activation levels of all abdominal sites and higher levels for the RF ($p < 0.0001$). The technique used for the CSEP Health and Fitness program partial curl- or sit-up test produced the highest or equal activation levels for all abdominal muscle sites.

Key words: electromyography, rectus abdominus, external obliques, rectus femoris, CSEP Health and Fitness Program.

Résumé : Le but de cette étude est d'évaluer l'activation des muscles abdominaux en fonction des positions du tronc, soit en position assise ou repliée, y compris la position utilisée dans le protocole du programme courant de Santé et condition physique de la Société canadienne de physiologie de l'exercice (SCPE). On enregistre chez quatorze sujets l'activité myoélectrique (EMG) de la partie supérieure du grand droit (URA), de sa partie inférieure (LRA), des obliques externes (EO), des stabilisateurs inférieurs de l'abdomen (LAS), du droit antérieur (RF) et du biceps crural (BF). Les diverses postures adoptées au cours des redressements assis sont réparties aléatoirement en fonction de trois variables : la distance parcourue par la main au sol (5, 10 ou 15 cm), le genou fléchi ou étendu et le pied ancré ou non. En ce qui concerne la distance parcourue par la main au sol, c'est la distance de 10 cm qui suscite le plus d'activation chez la LRA (p = 0,02), la distance de 5 cm qui en suscite le moins chez le RF (p = 0,001) et la distance de 15 cm qui en suscite le moins chez l'URA (p = 0,001). On n'observe aucune différence d'activation entre les positions de genou fléchi et de genou étendu, mais on note une tendance (p = 0,1) à une plus grande activation du LAS et une moins grande activation du RF quand le genou est fléchi durant le redressement assis. Quand le pied est fixé, on observe de façon significative les plus faibles niveaux d'activation de toutes les régions de l'abdomen et les plus hauts niveaux d'activation du RF ($p < 0,0001$). La technique utilisée dans le programme Santé et condition physique de la SCPE, soit le redressement assis partiel, suscite le plus ou autant d'activation dans tous les muscles de l'abdomen.

Mots-clés : électromyographie, grand droit, obliques externes, droit antérieur, Programme Santé et condition physique de la SCPE.

[Traduit par la Rédaction]

Introduction

Well-developed abdominal musculature is important in maintaining trunk and spine stability to reduce low back pain and enhance athletic performance (Axler and McGill 1996; Escamilla et al. 2006*b*). A variety of exercises are used to develop and test the abdominal musculature and its contribution to trunk stability. Many modifications are made to sit-up exercises in an attempt to maximize the activation of abdominal muscles considered to contribute to trunk stability and minimize the compressive forces on the lumbar spine. Other modifications to the sit- or curl-up exercise are made in an attempt to decrease the activation of the hip flexors, which increase the risk of lower back injury if they are over developed relative to the abdominal muscles (Andersson et al. 1998; Axler and McGill 1997; Escamilla et al. 2006*a*; Norris 1993). The modifications to the various sit-up techniques include fixed or non-fixed feet, the degree of knee flexion (from full extension to bent at 90°), or the distance the torso travels from the ground (often reflected by the distance the hands are slid along the floor).

Different professional groups and associations recommend

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different sit-up protocols or techniques for developing or testing muscular fitness of the abdominal muscles. The American College of Sport Medicine (ACSM) use a partial sit-up test in which the knees are bent at 90° without foot fixation and the arms are fully extended at the side on the mat with finger tips at the edge of a piece of tape. When the age of the group being tested is over 45 years, the finger tips travel 8 cm, whereas clients less than 45 years of age slide their fingers tips 12 cm (Heyward 2002). Hoffman (2006) recommends a bent-knee, fixed-foot sit-up with the hands held behind the head and the endpoint identified as the elbows touching the knees. The Canadian Society for Exercise Physiology (CSEP) Health and Fitness Program (Gledhill and Jamnik 2003) uses a protocol similar to that of the ACSM, in which a bent-knee partial curl-up is performed with arms extended at the side, finger tips at the edge of a piece of tape, and without foot fixation. The fingertips travel 10 cm along the floor. The test is ended if the feet lose contact with the floor.

Foot fixation has been shown to increase the activation of the hip flexors and hyperextend the lumbar spine during a sit-up (Norris 1993). However, the literature that compares fixed to non-fixed foot position and abdominal muscle activation is quite limited. Andersson et al. (1997) found no difference in abdominal muscle activation between the 2 conditions. However, they compared sit ups involving a dynamic movement, which may have compromised the validity of the surface electromyography (EMG) readings (Deluca 1997).

The relationship between degree of knee flexion and activation of the hip flexors has been equivocal. The degree of knee flexion has been found to have no effect (Juker et al. 1998), as well as decrease (Norris 1993) or increase (Andersson et al. 1997; McGill 1995) activation of the hip flexors.

The "crunch" is an exercise in which the trunk is lifted until the scapulae raise off the ground (Willett et al. 2001) and has been shown to produce less activation of the hip flexors than a full sit-up in which the entire back is lifted off the floor (Andersson et al. 1997, 1998; Escamilla et al. 2006*a*, 2006*b*; Juker et al. 1998; Konrad et al. 2001; Warden et al. 1999). It has also been found that performing a "crunch" produced high levels of activation of the rectus abdominis (Escamilla et al. 2006*a*, 2006*b*), as well as the external obliques (Escamilla et al. 2006*a*, 2006*b*; Konrad et al. 2001).

Previous research examining activation of the abdominal muscles and hip flexors has measured the distance the trunk travels through either a change in hip angle (Andersson et al. 1997, 1998) or by a restraining rod (Piering et al. 1993; Warden et al. 1999). The effect of the distance traveled by the hands sliding along the floor on muscle activation has not been examined despite this being a reliable and easy method to administer and used in the CSEP Health and Fitness Program abdominal endurance test (Gledhill and Jamnik 2003).

The CSEP Health and Fitness program uses this test to assess abdominal endurance, which is compositely used with other tests to indicate the risk of low back pain. Validity for the inclusion of the sit-up test in the CSEP Health and Fitness program test battery has been established by the relationship between the number of partial curl ups performed in a minute (to a maximum of 25) and the occurrence of low back pain (Albert et al. 2001; Payne et al. 2000). However, to our knowledge, there was no inclusion of any studies that used EMG to quantify and identify the activation of specific abdominal musculature and hip flexors.

The purpose of this study was, therefore, to investigate the effect of several modifications of an exercise commonly used to develop and test trunk stability on the activation of the different abdominal musculature and hip flexors. Of particular interest was the activation of the various abdominal musculature and hip flexors while performing the CSEP Health and Fitness Program curl- or sit-up protocol. To avoid the potential artifact on the EMG signal as a result of movement (Deluca 1997), this study elected to monitor the EMG signal during isometric held positions at different trunk inclinations with the feet fixed or non-fixed and the knees bent at 90° or straight.

Materials and methods

Subjects

A convenience sample of 14 male participants volunteered to participate for the study with a respective mean age, height, and body mass of 24.8 (±7.4) y, 176.9 (±9.0) cm, and 78.9 (±13.0) kg. All participants were either competitive rugby players or recreational athletes with no known or apparent musculoskeletal injuries and able to perform the exercises correctly. All subjects were required to read and sign a consent form before participation. Memorial University's Human Investigation committee approved the study.

Experimental design

Subjects participated in a familiarization session on a separate day prior to the experimental session where they attempted and completed all variations of the sit-up protocol. On the subsequent visit, subjects were instructed to lie flat on a horizontal bench and fitted unilaterally with surface electrodes on the upper rectus abdominis (URA), the lower rectus abdominis (LRA), the external obliques (EO), the lower abdominal stabilizers (LAS), the rectus femoris (RF), and the biceps femoris (BF) muscles.

Once the subject was in the appropriate position (knee angle, extent of foot fixation, and prescribed distance of the finger tips) for the specific sit-up technique, he was then directed to perform the action to the desired position. The subject was permitted 3 s to establish the correct position and hold for at least 2 s, during which time the EMG recording was taken and used for analysis. If the investigator noted that the subject took longer than 3 s to get to a stable isometric position, data collection was delayed until the subject was stable. There were 12 conditions tested: 3 hand positions (5, 10, and 15 cm) × 2 knee positions (bent and extended) × 2 stabilization conditions (feet fixed or not fixed).

As there are various interpretations of sit ups, curl ups, and crunches in the literature, this study offers the following definitions. The "crunch" is an exercise in which the trunk is lifted until the scapulae raise off the ground (Willett et al. 2001), which in this study corresponds to the 5 cm movement of the hands. Sit ups and curl ups are used synonymously in this study to indicate a movement whereby the scapulae and trunk are elevated off the surface with the feet remaining in constant contact with the surface. The sit up involving a 10 cm movement of the hands in the present study corresponds to the CSEP Health and Fitness Program partial curl up (Gledhill and Jamnik 2003), whereas the 15 cm hand movement sit up corresponds to the bent knee sit ups illustrated by Juker et al. (1998).

Electromyography

All surface electrodes (Meditrace 130 ECG Conductive Adhesive Ag–AgCl Electrodes, Tyco Healthcare Group LP, Mansfield, Mass.) were placed on the right side of the body on 6 different muscle sites. To reduce resistance of the signal, all sites for electrode placement were shaved, scrubbed with sand paper, and rubbed with an alcohol-soaked paper towel. This process removed body hair, dead skin cells, and oils. All electrodes were placed parallel to the muscle fibres, with an inter-electrode difference of 2 cm. The URA was identified as the midpoint between the xiphoid process and the umbilicus and 3 cm to the right of the linea alba. The LRA area was identified as 3 cm to the right of the linea alba and perpendicular to the iliac crest. The electrodes for the EO were placed 5 cm superior to the iliac crest and at an oblique angle (~45°). Electrodes for LAS (an area that encompassed the stabilizing muscles of the transversus abdomonis and internal obliques) were placed immediately medial to the anterior superior iliac spine, a site used in previous published studies from this laboratory (Anderson and Behm 2005; Behm et al. 2005, 2006; Hamlyn et al. 2007) The BF electrode location was the mid point between the gluteal fold and the popliteal space and the electrode placement for RF was immediately distal to the anterior superior iliac spine and inferior to the inguinal ligament. The RF site has been shown to provide reliable and valid estimates of the EMG activity of the iliopsoas muscle group (McGill et al. 1996). All ground electrodes were placed on the nearest bony prominence for each pair of active electrodes.

All EMG signals were collected over a 5 s period, sampled at 2000 Hz, with a Blackman –61 band-pass filter between 10–500 Hz, and amplified (500×) (Biopac Systems MEC bi-polar differential 100 amplifier, Santa Barbara, Calif.; input impedance = 2MΩ, common mode rejection ratio > 110 db min (50/60 Hz), noise > 5 UV). EMG activity was then directed through a 12 bit analog-to-digital converter (Biopac MP 100) and stored on a computer (Sona, St. John's, Nfld.). The data were later transferred to a personal computer for further analysis. The EMG signal was rectified and integrated over the final 2 s of the 5 s isometric contraction. An average of the 2 rectified and integrated trials was used for statistical analysis. Because the focus of this study was on changes in activation of individual muscles caused by different exercises, and not between muscles or subjects, normalization of the EMG signal to a maximal voluntary contraction was considered unnecessary. The study was a repeated-measures design that was completed in a single experimental session (no change in electrode position), therefore absolute data were analyzed.

Exercises performed

The study had 3 independent variables: the distance the hand traveled during the trunk position or inclination based on hand positions (5, 10, or 15 cm), holding the sit-up position with the knees bent at 90° or legs fully extended (180°), and holding the sit-up with feet fixed or non-fixed. Each subject performed the 12 different exercise conditions (3 hand conditions × 2 knee positions × 2 stabilization conditions) at least twice. For each sit-up position the participant was instructed to keep both arms extended by their side. The tips of the subject's fingers on their left hand were placed on a ruler. As the subject performed a sit-up the fingers slid along the ruler indicating the distance traveled (extent of trunk flexion). A randomly predetermined distance of 5, 10, or 15 cm was chosen prior to each sit-up and set with a stopping block. On the investigator's command, the subject performed the sit up, stopped, stabilized once he hit the stopping block, and held the position for 5 s.

Prior to each new condition the subject was instructed to either bend his knees to 90° or to fully extend his knees (180°). The angle of the knee was measured with a goniometer. The subject was instructed to keep his heels in contact with the bench during the entire isometric contraction for both conditions. If the subject's heels lifted off the bench the data were discarded and the subject performed another trial.

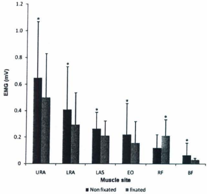
When the condition required foot fixation the feet of the subject were held by one of the investigators. The investigator held the lower legs with the fingers just superior to the lateral maleoli. When the sit up was performed with feet in the fixed condition the subject was allowed to use the resistance provided by the investigators to aid in trunk flexion and obtain the required position. When holding the non-fixed sit-up position the subject was not allowed to lift his heels off the bench.

All subjects were given a verbal and visual demonstration of each sit-up condition and allowed to practice the condition. Incorrect procedures such as excessive shoulder protraction and retraction were monitored by the investigators. Each subject performed 12 different exercise conditions at least twice. A third or fourth sit up was performed if one of the investigators decided the participant performed the sit up incorrectly. The order of sit-ups that were performed was randomized. Thirty seconds rest was allocated between each type of sit up. Subjects unanimously agreed that fatigue was not a factor throughout the testing period.

Statistical analysis

A series of separate 2-way analysis of variance (ANOVA) repeated measures for each muscle site was used to test for differences in activation levels for each condition. When statistical significance was found, the Bonferroni–Dunns post hoc test was used to reveal the differences between conditions. Effect sizes (ES is calculated by dividing the mean change by the standard deviation of the sample scores) were also calculated and reported (Cohen 1988). Qualitative descriptors were allocated for the effect sizes with ratios of 0.35–0.80, 0.80–1.5, and >1.5 indicating small, moderate, and large effects, respectively (Rhea 2004). Descriptive statistics include means ± standard deviation (SD).

Fig. 1. The effect of foot fixation during a sit up on electromyographic (EMG) activity of the upper rectus abdominis (URA), lower rectus abdominis (LRA), lower abdominal stabilizer (LAS), external obliques (EO), rectus femoris (RF), and biceps femoris (BF). Asterisks (*) indicate significant difference ($p \leq 0.05$) between the two conditions at the same muscle site.



Results

Main effect for feet fixed vs non-fixed

Sit-up positions in which the feet were non-fixed compared with fixed resulted in 27.9%, 19.2%, 27.8%, 22.7%, and 55.1% significantly greater EMG activation of the EO ($p = 0.01$; ES = 0.27), LAS ($p < 0.0001$; ES = 0.41), LRA ($p < 0.001$; ES = 0.35), URA ($p = 0.000$; ES = 0.36), and BF ($p = 0.03$; ES = 0.40), respectively (Fig. 1). Only the RF had significantly ($p < 0.0001$; ES = 0.91) less activity (42.1% less) when the feet were non-fixed.

Main effect for sit-up distance

Sliding the hands 10 cm and holding this position resulted in greater activation of the EO and LRA muscle groups. A 10 cm position provided 9.9% (ES = 0.13) and 16.5% (ES = 0.21) significantly ($p = 0.02$) greater LRA activation than the positions in which the hands were slid 5 and 15 cm, respectively. There was a trend ($p = 0.1$) towards greater EO activation with 29.1% (ES = 0.22) higher activation holding the 10 cm position compared with the 5 cm position. The position at 15 cm provided 24.1% (ES = 0.47) and 27% (ES = 053) less EMG activity for the URA compared with the 10 and 5 cm positions, respectively ($p = 0.001$). The RF was 37.8% (ES = 0.47) and 42.7% (ES = 0.59) significantly ($p = 0.001$) less activated at the 5 cm position than at 10 and 15 cm, respectively (Fig. 2).

Main effect for knee position

There were no significant differences in muscle activation in regard to knee position. However, the LAS tended to have a 19.4% (ES = 0.35) higher level of activation when the knees were flexed ($p = 0.1$), whereas the RF showed 21.4% (ES = 0.54) more activity when the knees were extended ($p = 0.1$) (Fig. 3).

Fig. 2. The effect of travelling different distances during a sit up on electromyographic (EMG) activity of the upper rectus abdominis (URA), lower rectus abdominis (LRA), lower abdominal stabilizer (LAS), external obliques (EO), rectus femoris (RF), and biceps femoris (BF). Asterisks (*) indicate significant difference ($p \leq 0.05$) between the 3 conditions at the same muscle site.

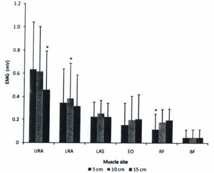
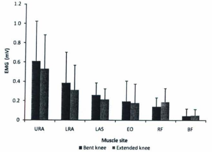


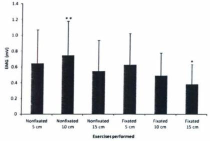
Fig. 3. The effect of alterations in knee position on electromyographic (EMG) of the lower abdominal stabilizers (LAS). URA, upper rectus abdominis; LRA, lower rectus abdominis; EO, external obliques, RF, rectus femoris; BF, biceps femoris.



Feet fixation × distance interaction

The lowest activation of the URA occurred when the position involved fixed feet and the hands slid 15 cm. A 15 cm hand position with fixed feet resulted in 22.2% (ES = 0.43) and 39.2% (ES = 0.97) less activity than when the hands were held at 10 and 5 cm, respectively ($p < 0.0001$). Compared with the non-fixed sit-up position, a fixed 15 cm position resulted in 30.3% (ES = 0.66), 48.8% (ES = 1.44), and 40.9% (ES = 1.04) less URA activity than the non-fixed 15, 10, and 5 cm positions, respectively ($p < 0.0001$). A non-fixed 10 cm position provided the greatest URA activity, 26.6% (ES = 0.45), 15.9% (ES = 0.27), 34.3% (ES = 0.59),

Fig. 4. The effect of foot fixation and distance traveled on electromyographic (EMG) activity of the upper rectus abdominis during a sit up. A single asterisk (*) indicates a significant difference ($p \leq 0.05$) compared with all other conditions. Double asterisks (**) indicate a significant difference compared with all other conditions except the non-fixed feet, 5 cm sit up.



and 48.8% (ES = 0.84) higher than with non-fixed feet at 15 cm and fixed feet at 5, 10, and 15 cm positions, respectively ($p < 0.0001$). There were no significant URA activity differences between non-fixed sit-up position with the hands at 5 or 10 cm (Fig. 4).

Similarly, the least activation of the LRA occurred with the fixed 15 cm sit-up position. The fixed-feet 15 cm sit-up position produced 29.7% (ES = 0.34), 42.2% (ES = 0.48), 70.7% (ES = 0.81), 94.7% (ES = 1.09), and 49.9% (ES = 0.57) less EMG activity than the fixed 10 and 5 cm positions, as well as the non-fixed sit-up positions held at 15, 10, and 5 cm, respectively ($p < 0.0001$). The greatest activation of the LRA also occurred in the non-fixed 10 cm sit-up position. The non-fixed 5 cm and fixed 5, 10, and 15 cm situp positions had 22.9% (ES = 0.30), 26.9% (ES = 0.36), 33.3% (ES = 0.44), and 48.6% (ES = 0.64) less activity than the non-fixed 10 cm sit-up position ($p < 0.0001$). There were no significant LRA activity differences between nonfixed sit-up positions at 10 or 15 cm (Fig. 5).

Feet fixation × knee position interaction

Significantly ($p < 0.0001$) higher activation of the LAS occurred in the non-fixed, flexed- knee, sit-up position. The non-fixed extended knee, fixed flexed knee, and fixed extended knee positions produced 23.1% (ES = 0.37), 22.3% (ES = 0.43), and 38.2% (ES = 0.76) less EMG activity, respectively, than the non-fixed flexed knee sit-up position (Fig. 6).

Non-significant interactions

There were no significant findings for knee position × distance interaction or knee position × foot fixation × distance interaction.

Discussion

This study compared 12 variations of the sit up performed by most healthy people. The most important finding of this study was that the 10 cm, non-fixed, bent-knee sit-up position produced the highest activation levels in 3 of the abdominal muscle sites monitored. Activation of the hip flexors (RF) was lowest in the 5 cm non-fixed position, but this position did not produce high levels of activation of the abdominal muscles and may, therefore, have less effect on stabilizing the trunk.

Fig. 5. The effect of foot fixation and distance traveled on electromyographic (EMG) activity of the lower rectus abdominis during a sit up. A single asterisk (*) indicates a significant difference ($p \leq 0.05$) compared to all other conditions. Double asterisks (**) indicate a significant difference compared to all other conditions except the non-fixed feet, 15 cm sit up.

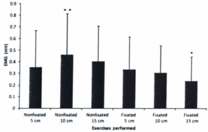
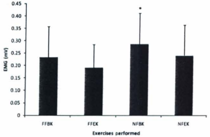


Fig. 6. The effect of alterations in foot fixation and knee position on electromyographic (EMG) activity of the lower abdominal stabilizers. Asterisk (*) indicates a significant difference ($p \leq 0.05$) compared with all other conditions. FFBK, feet fixed with bent knee; FFEK, feet fixed with extended knee; NFBK, non-fixed feet with bent knee; NFEK, non-fixed feet with extended knee.



In agreement with Norris (1993), a sit-up with fixed feet produced significantly higher RF activation levels. McGill et al. (1996) showed that activity of the RF is a valid and reliable indicator of the hip flexor activity, especially the iliopsoas. However, Norris (1993) did not mention how fixed feet affected activation levels of the abdominal muscles compared with non-fixed feet. This study found that a sit-up position with non-fixed feet increased activation levels of the URA, LRA, LAS, and EO. These data conflict with Andersson et al. (1997), who found that foot fixation did not affect abdominal muscle activity; however, Andersson et al. (1997) compared dynamic movements, whereas the current study used isometric contractions. In the present study, the contractions were held at prescribed distances, whereas the increased variability associated with monitoring the EMG of the muscles in which the fibre length is changing, as was the case with Andersson et al. (1997), may explain the differences in the findings. The combination of increased activation levels for the hip flexors and decreased levels for the abdominal muscles may predispose an individual to lower back injuries (Norris 1993). This type of exercise might over-develop the hip flexor muscle group, pulling the pelvis into an anterior tilt increasing lordosis, and placing increased compressional forces on the lumbar spine, particularly at the L4–L5 vertebral levels (Escamilla et al. 2006*a*). Axler and McGill (1997) reported that a curl-up with feet not fixated had the lowest compressional loads on the spine of any abdominal exercise tested in their study, making it a good and practical choice for health and fitness assessment. With a decrease in abdominal activation caused by foot fixation the abdominal musculature might not develop at the same rate as the hip flexors, producing a muscle imbalance and subsequent reduced spine-stabilizing capabilities (Konrad et al. 2001). The increased lordosis coupled with decreased training of the abdominal musculature may increase the possibility of lower back injury.

Bending the knees while performing a sit up is often prescribed to reduce the contribution of the hip flexors during the exercise (Norris 1993). Norris suggests that having the knees flexed to 90° would reduce the tension by 40%–50% of its maximum. One of the few studies examining this assumption found that performing a sit up with the legs straight produced lower levels of hip flexor activity compared with a bent-knee sit up (Andersson et al. 1997). They suggested that the higher activation levels were due to the decreased force-producing capabilities from the shortened length of the hip flexors in the bent-knee position. However, Juker et al. (1998) found no significant difference in the activation levels of the hip flexors between bent-knee and straight-leg conditions. The present study supports the findings of Juker et al. (1998), but did find a trend for the knee-flexed position to produce 21.4% less RF activity than the knee-extended position. Norris (1993) contends that bending the knees during a sit up will shorten the hip flexors, which will decrease the tension in the muscle and its subsequent activation. It appears more research is needed to clarify the activation of the hip flexors as it relates to the position of the legs.

This study showed a trend that the bent-knee sit-up position produced higher activation (19.4%; $p = 0.1$) of the LAS than the straight-leg sit-up position. This trend disagrees with previous research that found no difference in any of abdominal muscle sites when bent-knee and straight-leg sit ups were compared (Andersson et al. 1997; McGill 1995).

McGill (1995) and Andersson et al. (1997) provided 2 reasons why there would be no change in abdominal muscle activation when comparing a bent- and straight-leg sit up. First, bending the knees produces a decrease in hip flexor length and should, therefore, affect only the hip flexors and not the abdominal muscle group (Andersson et al. 1997). McGill (1995) took a biomechanical view and stated that a knee bend had no effect on torso mechanics and, therefore, should not affect levels of activation. However, the present study agreed with Juker et al. (1998) who found a trend ($p = 0.1$) for higher levels of activation for the LAS during the bent-knee sit up compared with the straight-leg sit up. With the knees in a bent position and the trunk raised off the ground, the base of support for the body would be much smaller than if the legs were extended. This decreased base of support would decrease stability and consequently increase the work required by the LAS group.

The final variable examined in this study was the distance covered by the hands as the trunk was elevated during a sit-up procedure. In previous research, the height of the sit up has been determined by hip angle (Andersson et al. 1997, 1998), a restraining rod (Piering et al. 1993; Warden et al. 1999), or the subjects performing the exercise with verbal instructions (Clark et al. 2003; Escamilla et al. 2006*b*; Juker et al. 1998; Konrad et al. 2001; Lehman and McGill 2001; Sarti et al. 1996). No studies have used the distance covered along the floor as a means of controlling the height the trunk is raised off of the floor. This technique was chosen for this study because the testing protocol for the CSEP Health and Fitness program abdominal endurance test uses distance and not angle or a restraining rod to establish how high the trunk is raised. This study used the 5 cm sit-up distance to reflect a "crunch", the 10 cm distance because it is the CSEP Health and Fitness program curl- or sit-up protocol, and the 15 cm position as a "full sit up" for comparative purposes.

The "crunch" has been shown to minimize hip flexor activity when compared with the full sit up (Andersson et al. 1997, 1998; Escamilla et al. 2006*a*, 2006*b*; Juker et al. 1998; Konrad et al. 2001; Warden et al. 1999). However, it has also been found to induce greater levels of URA and LRA (Escamilla et al. 2006*a*, 2006*b*) activity, whereas the full sit up produces more EO activity (Escamilla et al. 2006*a*, 2006*b*; Konrad et al. 2001).

The present study showed a higher activation level for the RF (37.8%) and a trend of higher levels of EO activity ($p = 0.1$) for the 10 cm sit-up position than for the 5 cm "crunch", which is in agreement with previous research (Escamilla et al. 2006*b*; Konrad et al. 2001). However, in contrast to some previous research (Escamilla et al. 2006*a*, 2006*b*), the present study showed no difference for the URA when the 5 cm crunch and 10 cm sit-up positions were compared, but it did show that the LRA produced 9.9% and 16.5% more activity in the 10 cm sit-up position than in the 5 cm crunch and 15 cm sit-up positions, respectively.

The 10 cm sit-up position elicited a significant increase in the LRA, but not in the URA; this suggests that certain exercises may stimulate separate sections of the RF. Such a finding is in agreement with previous research that compared the URA and LRA to examine if it is possible to selectively activate different portions of the rectus abdominis (Sarti et al. 1996; Warden et al. 1999; Willett et al. 2001). Anatomically, there is segmental innervation of the anterolateral abdominal musculature from the ventral rami of the lower 6 or 7 thoracic nerves. In addition, the rectus abdominus is separated into different sections by its tendonous inscriptions, which should increase its ability to segmentally contract (Clark et al. 2003; Sarti et al. 1996). However, from a biomechanical standpoint, this may not be possible. The rectus abdominis is a strap-like muscle. Superiorly, the rectus abdominis is attached to the 5th, 6th, and 7th ribs, as well as to the xiphoid process. Inferiorly, it is attached to the crest of the pubis, the pubic tubercle, and the front of the pubic symphysis. When the rectus abdominis contracts it should, with an equal and balanced force, pull on all insertion points (Clark et al. 2003), thereby making segmental contraction improbable. Clark et al. (2003), Lehman and McGill (2001), and Piering et al. (1993) have all shown that the rectus abdominis lacks the ability to selectively activate its different segments. Although the participants who volunteered for this study were not elite athletes they were a generally well-trained group and may have had an increased ability to selectively activate individual sections of their rectus abdominis (Lehman and McGill 2001).

The lowest levels of activation for URA in this study occurred when the feet were fixated in the 15 cm sit-up position. This sit-up position also provided the highest levels of activation for the RF. This sit up was considered the "full sit-up" and probably had the lowest level of activation because the exercise required holding the torso in a position where the resistive torque of the trunk was at its lowest of the 3 held positions. This finding concurs with Andersson et al. (1997) who found that abdominal activation decreased after the subject reached a hip-to-ground angle of 30°.

In the present study, the highest levels of activation came from the 10 cm sit-up position with non-fixed feet and bent knees. This is the type of sit-up used in the trunk endurance test for the CSEP Health and Fitness program protocol (Gledhill and Jamnik 2003). This study showed that the CSEP Health and Fitness program abdominal strength and endurance test provides high activation of the abdominal musculature with minimal activation of the hip flexors. However, it is acknowledged that the 5 cm position–exercise is possibly a good option for individuals with low back pain, in that it would seem to minimize the compression on the lower back and still provide good activation of the abdominal muscles.

Conclusion

The findings of this study have practical applications when selecting a test of abdominal performance or prescribing an abdominal exercise program. The condition of the individual and health of the individual's back will influence which exercise should be performed. If there is history of low back pain or recovery from lower back injury, the individual should be informed to proceed no farther than 5 cm for this will limit hip flexor activity and increase abdominal stability. If the subject is healthy and seeking a more intense exercise, the individual can implement greater trunk flexion (i.e., equal to a 10 cm movement of the hands along the floor). It should be recommended that the subject not perform a full sit up (i.e., equal to a 15 cm movement of the hands along the floor), because the final stage of this type of sit-up exercise seems to target the hip flexors. Going beyond a 10 cm position of the hands or raising the trunk to an angle greater than 30° may provide a rest period (reduced trunk muscle activation) for the abdominal muscles, but the hip flexors may remain activated. Foot fixation during abdominal exercise should be avoided and other strategies used to increase the strength and endurance of the trunk flexors. Although this study did not find significant effects for knee position on muscle activation, it did find a trend towards greater activation of the abdominal musculature and lower RF activation when the knees were bent. It must be kept in mind that the present study analyzed EMG activity during an isometric contraction, which may not fully represent the responses during a dynamic contraction.

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Influence of Pelvis Position on the Activation of Abdominal and Hip Flexor Muscles

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Abstract

Workman, JC, Docherty, D, Parfrey, KC, and Behm, DG. Influence of pelvis position on the activation of abdominal and hip flexor muscles. *J Strength Cond Res* 22(5):1563–1569, 2008–A pelvic position has been sought that optimizes abdominal muscle activation while diminishing hip flexor activation. Thus, the objective of the study was to investigate the effect of pelvic position and the Janda sit-up on trunk muscle activation. Sixteen male volunteers underwent electromyographic (EMG) testing of their abdominal and hip flexor muscles during a supine isometric double straight leg lift (DSLL) with the feet held approximately 5 cm above a board. The second exercise (Janda sit-up) was a sit-up action where participants simultaneously contracted the hamstrings and the abdominal musculature while holding an approximately 45° angle at the knee. Root mean square surface electromyography was calculated for the Janda sit-up and DSLL under 3 pelvic positions: anterior, neutral, and posterior pelvic tilt. The selected muscles were the upper and lower rectus abdominis (URA, LRA), external obliques, lower abdominal stabilizers (LAS), rectus femoris, and biceps femoris. The Janda sit-up position demonstrated the highest URA and LRA activation and the lowest rectus femoris activation. The Janda sit-up and the posterior tilt were significantly greater ($p < 0.01$ and $p < 0.05$, respectively) than the anterior tilt for the URA and LRA muscles. Activation levels of the URA and LRA in neutral pelvis were significantly ($p < 0.01$ and $p < 0.05$, respectively) less than the Janda sit-up position, but not significantly different from the posterior tilt. No significant differences in EMG activity were found for the external obliques or LAS. No rectus femoris differences were found in the 3 pelvis positions. The results of this study indicate that pelvic position had a significant effect on the activation of selected trunk and hip muscles during isometric exercise, and the activation of the biceps femoris during the Janda sit-up reduced the activation of the rectus femoris while producing high levels of activation of the URA and LRA.

Key Words isometric exercise, muscle activation, electromyography, rectus abdominis, rectus femoris

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Introduction

Therapists, trainers, and coaches have emphasized the importance of abdominal exercises for years. Reasons have included sport performance, injury prevention and rehabilitation (especially low back pain), and aesthetics. Much of the interest has centered on the perceived need to stabilize the "core," which has generated a variety of abdominal exercises designed to target specific muscles. Several studies have examined the interplay between the hip flexors and the abdominal muscles during a variety of exercises (2,3,10,20). The general consensus has been that high levels of hip flexor activity during abdominal strengthening exercises are undesirable. Ways in which the abdominal muscles can be optimally activated while minimizing activation of the hip flexors would seem to have practical importance.

Abdominal muscle activity has been found to be very dependent on the position of the pelvis during the execution of the exercise. In particular, a posterior pelvic tilt has been found to have a marked influence on the activation of abdominal musculature (9,20,23). Shirado and colleagues (21) reported that pelvic alignment could influence the electromyographic (EMG) activity of the trunk flexors and extensors during isometric trunk exercises. Full flexion of the lumbar spine has been reported to be unnecessary for maximum electrical activity of the abdominal muscles, suggesting that it is the position of the pelvis that influences the activation of the trunk muscles (19). Although there are some studies that have examined the effect of a posterior pelvic tilt on activation of the trunk musculature, the effect of an anterior tilt or neutral position of the pelvis has not been clearly elucidated. Many therapists and exercise specialists advocate the maintenance of a neutral spine and pelvis (17,18) during abdominal exercises in order to facilitate carryover into functional activities. In addition, observation of people performing a variety of abdominal exercises reveals that most do not prevent moving from a neutral to an anterior tilt, which potentially changes the purpose of the exercise and may predispose them to a risk of low back problems (13). It would seem important to define more clearly the effect of pelvic position, especially neutral and anterior tilt positions, on the activation of the trunk flexors.

The Janda sit-up (Figure 1), devised by Czech physician Vladimir Janda and also referred to as a heels-press sit-up, has received popularity in part because it is purported to decrease hip flexor activity during the sit-up movement through reciprocal inhibition (10). By actively contracting the hamstrings muscles, an individual will theoretically deactivate the hip flexors (10). However, there is little published evidence to support or refute this theory.

The purpose of this study was to determine the influence of pelvis position on the relative activity of selected abdominal and hip musculature. A second purpose of the study was to compare the relative muscle activity during an isometric hold at approximately 45° of the Janda sit-up to the relative activity of the muscle in the 3 pelvic positions. It was hypothesized that the neutral and posterior pelvic tilt would increase the activation of the anterior trunk muscles and that anterior pelvic tilt would increase the activation of the rectus femoris (reflecting the iliopsoas). In addition, it was hypothesized that the Janda sit-up would produce high levels of activation in the anterior trunk muscles while decreasing the activation of rectus femoris.

METHODS

Experimental Approach to the Problem

Participants assumed a supine position and were fitted unilaterally with surface EMG electrodes on the upper rectus abdominis (URA), lower rectus abdominis (LRA), lower abdominal stabilizers (LAS), external obliques, rectus femoris, and biceps femoris muscles. Participants were asked to perform a Janda sit-up (exercise 1) and hold a position during the sit-up with the trunk at approximately 45° to the bench while contracting the hamstrings. The second exercise involved an isometric double straight leg lift (DSLL) (exercise 2) in each of 3 pelvis positions: anterior tilt, neutral, and posterior tilt. Each contraction was randomly allocated and held for 5 seconds. Two trials of each exercise were performed with a 30-second rest between trials and a 3-minute rest between each different exercise test position. The EMG activity of each muscle was monitored across each condition.

Figure 1. A Janda sit-up with resistance provided to the posterior ankle/heel area so that the participant can contract the hamstrings while attempting to curl the trunk/abdominal region.

Subjects

A convenience sample of 15 subjects was selected to participate in this study. All participants were male, with a mean age of 25.9 ± 8.4 years, mean height of 177.4 ± 9.5 cm, and mean weight of 78.9 ± 11.9 kg. The participants were instructed on the nature of the study and the equipment and apparatus involved and were provided with the opportunity to clarify this information. All subjects were either competitive rugby players ($n = 11$) or recreational athletes (racquet sports, running) ($n = 4$) who presently had no apparent or known musculoskeletal injuries. All participants had extensive experience with resistance training and performing a variety of abdominal exercises throughout their training career. Furthermore, they all scored in the excellent category in the partial curl-up test of the Canadian Physical Activity, Fitness, and Lifestyle appraisal. Fourteen participants were able to complete the exercise movements correctly. One participant was unable to maintain the pelvic tilt position during the isometric portion of the leg raise activity. His data were not included in the statistical analysis. Each subject was required to read and sign a consent form before participation. The Human Investigation Committee, Memorial University of Newfoundland, approved this study.

Surface Electromyography Preparation and Placement

It has been suggested that a valid EMG signal is compromised when the muscles of interest are performing a dynamic contraction (4,8). As the joint moves through a range of motion, the distance between the muscle and the detection surface changes, which results in a change in the EMG amplitude. It is recommended that isometric contractions be used to control for movement during surface EMG testing. Although this detracts from the ecological validity, it does increase the validity and reliability of the EMG signal (8). An effective start for analyzing the effect of pelvis position on trunk muscle activity would be to use quantified and controlled EMG procedures.

The electrode placement sites were prepared by shaving, exfoliating with sandpaper, and wiped with isopropyl alcohol. Participants were placed in a supine position on a plinth, providing support to the entire length and width of the body. Electromyographic surface electrodes (Kendall Medi-trace 100 series; Kendall, Chikopee, MA) were placed in parallel with the muscle fibers with an interelectrode distance of 2 cm. A ground electrode was placed at the nearest bony prominence for each pair of active electrodes. The 6 muscle sites were the URA, LRA, external obliques, LAS (reported to represent activation of the internal obliques and transversus abdominis [1,5,6]), biceps femoris, and rectus femoris. The rectus femoris was used to approximate the activity of the deep hip flexors, namely, the iliopsoas muscle group (14). Landmarking for the URA was achieved by measuring 3 cm lateral to the midline and midway between the xiphoid process and the umbilicus. The LRA was positioned 3 cm lateral to the midline and 2 cm inferior to the umbilicus. Additional electrodes were placed superior to the inguinal ligament and 1 cm medial to the anterior superior iliac spine for the lower abdominals. McGill et al. (14) reported that surface electrodes adequately represent the EMG amplitude of the deep abdominal muscle within a 15% root mean square difference. However, Ng et al. (15) indicated that electrodes placed medial to the anterosuperior iliac spine would receive competing signals from the external obliques and transverse abdominis with the internal obliques. Based on these findings, the EMG signals obtained from this abdominal location are described in the present study as the LAS, which would be assumed to include EMG information from both the transverse abdominis and internal obliques. The external obliques were positioned superior to the anterior superior iliac spine at an oblique angle, at the level of the umbilicus. Biceps femoris electrodes were positioned at the midpoint of the muscle belly of the biceps femoris. Rectus femoris electrodes were positioned at the most proximal aspect of the muscle belly. All muscle sites were measured on the right side of the body only.

Exercise Instruction

The participants were instructed on proper technique to complete a maximal anterior pelvic tilt and maximal posterior pelvic tilt. The anterior pelvic tilt was achieved by asking the participants to tilt the pelvis forward in order to create as much space as possible between the plinth and the lower back area. The posterior pelvic tilt was achieved by asking the participants to flatten their lower back into the plinth. Manual guidance was also provided during the instruction and familiarization period to ensure proper technique and understanding. The neutral position was described as the participants' normal, comfortable resting supine position. One investigator was positioned by the side of each participant to ensure proper pelvic positioning during data collection as well as palpating the anterosuperior iliac spine as a way of monitoring pelvic position. A second investigator was positioned at each participant's feet to ensure proper leg lifting during the exercise. Participants were instructed to keep their head resting on the plinth and to rest their hands by their sides. Participants began in a supine position on the plinth with their legs straight and their feet placed on a stable bench 15 cm in height. For the anterior pelvic tilt position, participants were asked to assume the proper position. A reference mark was placed on the lateral malleolus and the bench supporting the feet. This mark would be used to ensure the same starting position for the second trial of the exercise. The participants were asked to raise their feet off the support 5 cm, hold the position for 5 seconds, and return to the support. A 30-second rest period was provided before a second trial was performed. The same procedure was followed for the neutral and posterior pelvic tilt positions. A 3-minute rest period was provided between the anterior, neutral, and posterior tilt trials. The order of exercises was randomized. If the position was not held properly, then the position and the data acquisition was terminated and attempted again after an appropriate rest period.

The Janda sit-up was performed in a supine, crook-lying position (Figure 1). A padded bar was placed at the back of the lower leg and held in place manually by one of the investigators. This bar provided an object against which each participant was able to contract the hamstring muscles, by attempting to perform bilateral knee flexion. This bar was held manually by an investigator in order to ensure that consistent hamstring contraction occurred throughout the entire exercise trial. The participants were instructed to contract the hamstring muscles, perform the sit-up, and hold for 5 seconds at approximately 45° before returning to the start position. A 30-second rest period was provided before the second trial. The order of pelvic position and the Janda sit-up was randomly assigned.

The isometric BSLL was used in this study to allow us to maintain a relatively constant torso and leg position, while changing only the pelvis position. We do acknowledge that with any change in pelvis rotation there will be changes in the rest of the kinetic chain, both above and below the pelvis. However, this exercise would provide the most consistency in the upper and lower body segments, allowing us to examine the influence of the pelvis on abdominal muscle activity.

Electromyographic Data Collection

Electromyographic data were collected during the concentric and isometric contractions of each exercise. The EMG signals were amplified (MEC 100 amplifier; Biopac Systems Inc., Santa Barbara, CA), monitored, and directed through an analog-digital converter (Biopac MP100) to be stored on the computer (Sona, St. John's, Newfoundland, Canada). The EMG signals were collected over 15 seconds at 2000 Hz and amplified (×500). The EMG activity was sampled at 2000 Hz with a Blackman 61-dB band-pass filter between 10 and 500 Hz, amplified (Biopac Systems MEC bipolar differential 100 amplifier, Biopac Systems, Inc.; input impedance = 2 MΩ common mode rejection ratio >110 dB minimum (50/60 Hz), noise >5 UV) and analog-to-digitally converted (12 bit) and stored on personal computer for further analysis. The

EMG signal was rectified and integrated over the 5-second static (isometric) contraction period of the movement. An average of the 2 trials was obtained, and the mean integrated value used for statistical analysis. Similar to previous published research from this laboratory (6), absolute rather than normalized EMG data were analyzed because it was a repeated-measures design that was completed in a single experimental session (no change in electrode position). Since the focus was on changes in activation of individual muscles and not between muscles or individuals, normalization of the electromyogram was not considered necessary.

Statistical Analyses

A 1-way, repeated measures analysis of variance (GBStat; Dynamic Microsystems, Silver Spring, MD) was performed to detect differences in muscle activation for each muscle, relative to pelvic position and Janda sit-up exercise. When statistical significance was found, the Dunn's (Bonferroni) post hoc test was used to reveal the differences. Descriptive statistics include mean ± SD.

RESULTS

Upper Rectus Abdominis

For the URA site, the Janda sit-up demonstrated the highest EMG activity. Relatively, the anterior pelvic tilt position showed 70.9% less activity in the URA ($p < 0.01$). The EMG activity in the neutral position was 52.1% less than that seen in the Janda sit-up ($p < 0.01$). There was no significant difference between the Janda sit-up and the posterior pelvic tilt position. The anterior position demonstrated 57% less activity than the posterior pelvic tilt position ($p < 0.05$) (Figure 2).

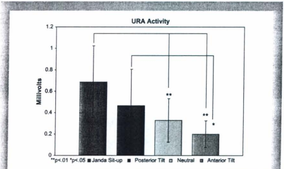

Figure 2. Upper rectus abdominis (URA) electromyographic activity in each pelvis position and the Janda sit-up. Bars and accompanying lines represent mean electromyographic activity and SDs, respectively. *Significant difference at the $p < 0.05$ level; **significance level of $p < 0.01$.

Lower Rectus Abdominis

For the LRA site, the Janda sit-up elicited the highest EMG activity. This was significantly different than the anterior pelvic tilt position ($p < 0.01$), which showed 68.4% less activity, and the neutral position ($p < 0.05$), which showed 46.3% less activity. There was no significant difference between the Janda sit-up and the posterior pelvic tilt position for LRA activity. The anterior pelvic tilt position showed significantly less (56.6%) activity in the LRA than in the posterior pelvic tilt position ($p < 0.05$) (Figure 3).

Rectus Femoris

The rectus femoris site demonstrated the highest activity in the anterior pelvic tilt position. This was significantly different from the Janda sit-up ($p < 0.05$), which showed 38.1% less activity. There were no other significant rectus femoris differences when compared to the other test positions. The Janda sit-up was not significantly different from the posterior pelvic tilt or neutral positions (Figure 4).

Biceps Femoris

In the biceps femoris site, the Janda sit-up provided the highest EMG activity. This was significantly higher than all other test positions ($p < 0.01$). The neutral, anterior, and posterior pelvic tilt positions demonstrated 91.1%, 88.6%, and 87.8% less biceps femoris activity, respectively. There were no other significant differences in biceps femoris activity among the pelvic tilt positions (Figure 5).

External Obliques

There were no statistically significant differences in external obliques EMG activity when comparing the 4 test positions ($p = 0.09$). The Janda sit-up and the neutral pelvis positions showed the greatest difference in EMG activity.

Lower Abdominal Stabilizers

There were no statistically significant differences in LAS EMG activity when comparing the 4 test positions.

DISCUSSION

The major findings of this study show that changing the position of the pelvis significantly changes the pattern of activation of the URA, LRA, and rectus femoris. This is in agreement with a study by Shields and Heiss (20) who found that the double straight leg lowering exercise, while maintaining posterior pelvic tilt, achieved greater abdominal muscle activation compared to a typical

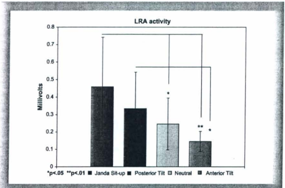

Figure 3. Lower rectus abdominis (LRA) electromyographic activity in each pelvis position and the Janda sit-up. Bars and accompanying lines represent mean electromyographic activity and SDs, respectively. *Significant difference at the $p < 0.05$ level; **significance level of $p < 0.01$.

crunch exercise. Posterior pelvic tilting has also been found to activate the rectus abdominis to a greater degree than in the abdominal hollowing exercise (9). Other studies have identified high levels of rectus abdominis activity during the posterior pelvic tilt maneuver (24) and leg lifting exercise (2). This differs from the results of Urquhart et al. (23) who found the internal oblique muscle more active than the rectus abdominis during a posterior pelvic tilt. In the Urquhart et al. study, participants were asked to gently and slowly rock their pelvis backward. Urquhart et al. (23) describe this as a gentle effort, corresponding to a 2 on the Borg scale. The present methodology differed in that the posterior pelvic tilt was accompanied by the isometric DSLL, a much more demanding task. Our study was in agreement, however, with the authors' conclusion that abdominal muscle activity was dependent on body position, including lumbopelvic motion or position.

There is general agreement that an individual cannot preferentially activate the URA versus LRA (7,12) unless highly trained (19). The results of the present study also found similar activation patterns for the URA and LRA throughout the exercises. Moreover, it has been found that no single exercise is able to optimally recruit all the abdominal musculature simultaneously (3). Therefore, a comprehensive, individualized program is required to sufficiently challenge each of the abdominal muscles (3) in different planes of movement.

The anterior pelvic tilt position provided the highest EMG activity in the rectus femoris and the lowest EMG recordings in both the URA and LRA. The anterior tilt may place the rectus femoris and underlying iliopsoas muscle group in a more optimal length position. This will change the muscle length–tension relationship and produce higher contractile forces. As the rectus femoris is in an optimal position, the LRA and URA will be placed in a relatively lengthened position. For the LRA and URA, the change in length-tension relationship may place the muscles in a disadvantageous position and cause a reduction in

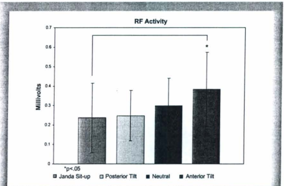

Figure 4. Rectus femoris (RF) electromyographic activity in each pelvis position and the Janda sit-up. Bars and accompanying lines represent mean electromyographic activity and SDs, respectively. *Significant difference at the $p < 0.05$ level.

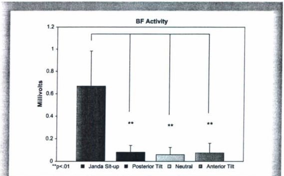

Figure 5. Biceps femoris (BF) electromyographic activity in each pelvis position and the Janda sit-up. Bars and accompanying lines represent mean electromyographic activity and SDs, respectively. **Significance level of $p < 0.05$.

contractile forces. Furthermore, several authors have cautioned against the use of the BSLL because of the risk of low back injury caused by increased shear and compressive forces (3,9). Invariably, individuals may adopt an anterior pelvic tilt position when performing sit-ups or leg raises that can be considered contraindicated considering the increased shear and compressive forces (3,9) placed on the lower back by stronger hip flexors.

A secondary finding showed that the Janda sit-up produced relatively high levels of URA and LRA activity and low levels of rectus femoris activity; however, this was not significantly different from the posterior pelvic tilt. Our results regarding the inability of the Janda sit-up to significantly reduce hip flexor activity in comparison to the posterior pelvic tilt are in agreement with Juker et al. (10) who found no decrease in psoas activity using the "press heels" sit-up. The Janda sit-up is identical to a traditional bent-knee sit-up when considering the trunk flexion component. The difference is in the contraction of the hamstring muscles during the exercise. As this is a sit-up movement, it is typically performed in a posterior pelvic tilt start position (16). Participants were not instructed regarding pelvis position before the Janda sit-up trials. Therefore, pelvis position was not controlled during this exercise. This may account for some of the similarities between the Janda sit-up and the results from the posterior pelvic tilt position. The contraction of the hamstrings during the Janda sit-up purportedly reduces hip flexor activation through reciprocal inhibition (10). Our data cannot conclude whether the low rectus femoris activity can be attributed to reciprocal inhibition through contraction of the hamstring musculature. The Janda sit-up did demonstrate the highest biceps femoris activity as anticipated. However, the rectus femoris activity was not significantly different from the posterior pelvic tilt position.

Differences in the posterior pelvic tilt and Janda sit-up are seen when we examine their relationship to the neutral pelvis position. For both the URA and LRA sites, the Janda sit-up demonstrated significant differences from the neutral position; however, the posterior pelvic tilt position did not. This may be explained by the investigators' definition of neutral pelvis. The participants were asked to maintain their normal, comfortable supine position. The discrepancy of neutral for each participant may have influenced the results. In addition, anatomically, the neutral position may be closer in range of available motion to the posterior tilt than the anterior direction. This may account for the lack of significant difference in muscle activity when comparing the neutral position to the posterior pelvic tilt position.

When we examine the overall trend of muscle site activity, a pattern emerges. As the participant moves from a posterior pelvic tilt position through neutral to the anterior pelvic tilt position, the relative activity of the URA, LRA, and rectus femoris becomes reversed. During the posterior pelvic tilt and Janda sit-up, there are high levels of activity in both the URA and LRA and low activity in the rectus femoris. In the neutral position, the level of activity of the URA and LRA decreases, although this was shown to be only significantly different from the Janda sit-up. The activity of the rectus femoris increased slightly when mean EMG activity was examined; however, the change was not significant. In the anterior pelvic tilt position, the URA and LRA exhibited their lowest activity levels, while the rectus femoris shows the highest level of activity.

There was no significant difference between the exercises in the amount of EMG activity in the LAS or external obliques muscle sites. This differs from Shields and Heiss (20), who found varying levels of oblique muscle activity during their isometric double straight leg lowering exercise. The finding in the present study would suggest that the stabilizing role of the LAS (24) was similar for all pelvic positions as well as the Janda sit-up. As the DSLL is not a trunk flexion exercise, a significant difference in the activity of a trunk flexor such as the external obliques might not be expected. The Janda situp, however, is a trunk flexion exercise, but it did not show significant differences in external obliques activity compared to the 3 different pelvis positions. During these exercises, the external obliques probably also act as a stabilizer (2).

The biceps femoris muscle site was also unaffected by a change in pelvis position. This hip extensor muscle may be expected to have little activation during a hip flexion type of activity. During the Janda sit-up, there was significantly greater biceps femoris activity compared to the other test positions. This is to be expected as the participant is instructed to actively contract the hamstrings while performing the Janda sit-up.

Practical Applications

The results of this study will be of value when instructing persons in correct posture during supine abdominal strengthening activities. There is evidence showing that specific exercise instruction is important for a client to learn and retain the proper technique and form of an exercise (11). Particular attention should be given to individuals with increased lumbar lordosis or very weak abdominal muscles. Several authors have stressed the potential increase in lumbar compression and shear force with some abdominal exercises. The BSLL is not recommended for individuals who have known lumbar pathologies or very weak abdominal musculature (3,10). These individuals may be at risk of moving into an anterior pelvic tilt position due to postural habit or fatigue while exercising (9,22). By changing the rotation of the pelvis, the focus of the strengthening exercise may shift from the abdominals to the hip flexors. These results will add to the existing and emerging scientific literature regarding the relationship between the pelvis, hip, and lumbar spine and the interplay of the supporting musculature.

From these data, we can conclude that a change in pelvis position demonstrates significant differences in URA, LRA and rectus femoris muscle activity, as measured by surface electromyography. When considering pelvis position independently, the highest abdominal muscle activity occurs in the posterior pelvic tilt position. The Janda sit-up also seems to be effective in producing significant activation of the rectus abdominis.

Acknowledgments

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