

**Evaluation of flexion-relaxation in the thoracic erector spinae
and superficial lumbar multifidus during standing flexion and
slumped sitting**

Jesse Armstrong

**A research thesis submitted in partial fulfilment of the requirements of the
degree of Master of Osteopathy**

2013



Declaration

Name of candidate: Jesse Armstrong

This Thesis/Dissertation/Research Project entitled: **Evaluation of flexion-relaxation in the thoracic erector spinae and superficial lumbar multifidus during standing flexion and slumped sitting** is submitted in partial fulfilment of the requirements of the degree of Master of Osteopathy.

Candidate's declaration

I confirm that:

- This Thesis/Dissertation/Research Project represents my own work;
- The contribution of supervisors and others to this work was consistent with the Unitec Regulations and Policies.
- Research for this work has been conducted in accordance with the Unitec Research Ethics Committee Policy and Procedures, and has fulfilled any requirements set for this project by the Unitec Research Ethics Committee.

Research Ethics Committee Approval Number: **2011-1240**

Candidate Signature: Date: 12/03/2013

(Jesse Armstrong)

Student number: 1188556

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Abstract

Introduction: Low back pain is a highly prevalent and costly condition which is often difficult to diagnose. Evaluation of the flexion-relaxation response has been used to objectively assess the neuromuscular adaptation associated with low back pain, and has attracted much clinical interest due its impressive ability to distinguish between low back pain patients and pain-free controls. Numerous methods have been used to quantify flexion-relaxation, yet it remains uncertain which method is most appropriate to quantify the response. Furthermore, flexion-relaxation has been evaluated at different muscle sites and during different flexion tasks; however, the influence of muscle site and flexion task on flexion-relaxation remains unclear.

Aim: The aim of the present study was to i) compare different methods of analysis used to evaluate flexion-relaxation (FR) including dichotomous criteria and quantitative methods; and ii) to investigate the influence of surface electrode site (thoracic and lumbar), and flexion task (standing flexion and slumped sitting) in pain-free participants.

Design: A normative, single-group observational study was conducted.

Participants: 20 healthy, pain-free volunteers (n=12 males, 8 females; mean age \pm SD = 27.9 \pm 7.7y), were recruited from a university population.

Methods: Surface electromyography was used to measure activity in the thoracic erector spinae (TES) and superficial lumbar multifidus (SLM) bilaterally while participants performed standing flexion and slumped sitting tasks. The presence of FR was determined by using six criteria previously defined in the literature and a comparison of these criteria was undertaken. Flexion-relaxation ratios (FRR) and extension-relaxation ratios (ERR) were also calculated for each of the conditions.

Results: There was a large variation in the presence of FR based on the criteria examined. Depending on which criterion was applied, between 7.5% (3/40) and 95% (38/40) of TES sites; and between 27.5% (11/40) and 100% (40/40) of SLM sites were considered to have reached FR during standing flexion. During slumped sitting, between 35% (15/40) and 95% (38/40) of TES sites; and between 17.5% (7/40) and 75% (30/40) of SLM sites were considered to have reached FR. The majority of criteria identified FR more frequently in the TES during slumped sitting compared with standing flexion, and more frequently in the SLM during standing flexion compared with slumped sitting. The ERR was significantly greater (p

< 0.001) than the FRR in the SLM during standing flexion. The FRR and ERR were both significantly greater ($p < 0.001$) in the SLM during standing flexion compared with slumped sitting.

Conclusion: The findings of this study indicate that there is substantial variation in determining the presence of FR dependent on the criteria examined when evaluating the TES and SLM during standing flexion and slumped sitting. The flexion task performed can facilitate or hinder FR depending on the muscle being evaluated. There is a need for consensus within the research community as to which method is most appropriate to evaluate FR. The findings suggest that quantitative methods which measure the extent of FR may be more suitable to evaluate the response.

Keywords: Electromyography; Muscle, Skeletal; Musculoskeletal Physiology, Low Back

Introduction to thesis structure

This thesis is comprised of three main sections

1. Review of Literature

The review of relevant literature provides the theoretical basis and rationale for the study reported in the manuscript.

2. Manuscript

The manuscript is in the format specified for submission to the *Journal of Electromyography and Kinesiology*.

3. Appendices

The appendices provide ethics documentation and other important documents.

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List of Abbreviations

CES	Cervical Erector Spinae
ERR	Extension Relaxation Ratio
FR	Flexion Relaxation
FRR	Flexion Relaxation Ratio
LES	Lumbar Erector Spinae
MVIC	Maximal Voluntary Isometric Contraction
RMS	Root Mean Square
SEMG	Surface Electromyography
SLM	Superficial Lumbar Multifidus
TES	Thoracic Erector Spinae

Section 1: Review of Literature

1.0 Overview of Low Back Pain

1.1 Basic epidemiology of low back pain

Low back pain (LBP) is a very common condition with lifetime prevalence estimated at 80-85% (G. B. J. Andersson, 1999; Cassidy, Carroll, & Côté, 1998; O'Sullivan, 2005; Walker, 2000), and point prevalence estimated at 25-30% (Cassidy 1998, Walker 2004). Low back pain has been reported to be the most common cause of activity limitation in people under 45 years of age (G. B. J. Andersson, 1999) and one of the most common symptom-related reasons for visits to the physician, second only to upper respiratory infections (G. B. J. Andersson, 1999; Deyo & Weinstein, 2001). The peak age group for people reporting LBP is between 35-55 years (G. B. J. Andersson, 1999); however, it remains an issue for all ages and all sectors of society, as prevalence in adolescents has been shown to be similar to that in adults (K. D. Watson et al., 2003). The prevalence of LBP in workers is not dissimilar to that of non-workers (Burton et al., 2006; Nachemson, 1999).

1.2 Cost of low back pain

Due to its high prevalence in all sectors of society, LBP represents a large economic and social burden. There are major costs suffered by both society and the back pain sufferers themselves. The costs involved are not only financial, but also social and psychological and include: medical costs, loss of productivity, time off work, compensation and psychological stress to name a few. In New Zealand from July 2011 to June 2012 back/spinal injuries accounted for 6.95% of the total claims compensated by the Accident Compensation Corporation (ACC, 2012). The cost attributed to back/spinal injuries in that year alone was \$312,469,742 (ACC, 2012). Of considerable note is the number of on-going claims (approximately 5% of back/spinal injuries) which represent chronic conditions.

1.3 Classification of low back pain according to duration of symptoms

Low back pain is often classified according to duration of symptoms. Acute LBP is defined as LBP lasting less than 6 weeks and accounts for 90% of cases (Burton et al., 2006). Between 2-7% of people who experience an episode of LBP go on to develop chronic LBP, defined as LBP persisting for 12 weeks or more (Burton et al., 2006). Although only a small

number of LBP cases become chronic, it is the chronic cases which represent a major burden for society (Croft, Macfarlane, Papageorgiou, Thomas, & Silman, 1998; Engel, Von Korff, & Katon, 1996; Spengler et al., 1986). It has been reported that 70-80% of the healthcare and social costs attributable to LBP are for the small portion of chronic cases (Abenhaim & Suissa, 1987; Nachemson, 1999). It is, therefore, understandable that a copious amount of research has been devoted to understanding and addressing this highly prevalent and costly ailment.

1.4 Anatomical sources of low back pain

There are various local tissues within the low back which are innervated with nociceptive fibres and, therefore, have the potential to be pain generating structures for patients with LBP. Early studies have shown that experimental noxious stimulation of back muscles (Kellgren, 1938), intervertebral disks (Kuslich, Ulstrom, & Michael, 1991), interspinous ligaments (Feinstein, Langton, Jameson, & Schiller, 1954; Kellgren, 1939), dura matter (El Mahdi, Abdel Latif, & Janko, 1981), zygapophyseal joints (Mooney & Robertson, 1976), and the sacroiliac joint (Fortin, Dwyer, West, & Pier, 1994) can produce local and referred pain similar to that reported by people with LBP. Although these structures have been identified as potential sources of pain, much clinical uncertainty still remains regarding the actual source of pain in any given presentation.

1.5 Challenges with clinical diagnosis

The traditional medical approach to LBP has been from a patho-anatomical perspective, attempting to identify a pain causing structure. The clinical diagnosis of LBP has conventionally been made through subjective (palpation and physical examination) and objective means (medical imaging). While pain often has a connected physical cause, it is a subjective experience, and may be reported in the absence of tissue damage or any likely pathological cause (Merskey & Bogduk, 1994). It is a commonly held belief that in up to 85% of back pain cases a precise patho-anatomical diagnosis cannot be made despite thorough medical examination (Burton et al., 2006; Deyo & Weinstein, 2001; O'Sullivan, 2005). Such cases have been termed "non-specific low back pain" (Balagué, Mannion, Pellisé, & Cedraschi, 2012). Moreover, many of the 'abnormal' findings during physical examination

and imaging are also commonly observed in pain-free people. It has been reported that a substantial percentage of people without LBP have had abnormal findings identified in myelograms (23%), computerised tomography scans (36%), discograms (37%) and magnetic resonance imaging (30%) (Boden, Davis, Dina, Patronas, & Wiesel, 1990). An asymptomatic person, therefore, has more than a one in four chance of being identified as presenting with abnormal findings with current imaging. Consequently the presence of an abnormality on imaging is not of great diagnostic value in determining the cause of pain (Nachemson, 1999). This highlights the limitations of some of the current diagnostic techniques used to assess LBP.

In summary it appears that the lack of a definitive aetiology in many cases has been one of the major dilemmas faced by practitioners when diagnosing and treating LBP. This also causes frustration for the patient as a precise mechanism for their condition is often elusive, and they can be left without a clear reason for their pain. Imaging methods are often employed to identify pain generating structures or tissues. However, it is clear that these structural changes may not necessarily be correlated with pain. Improved diagnostic tools are required to objectively assess LBP.

2.0 Changes in neuromuscular function in people with low back pain

2.1 Introduction

Considering LBP from a functional perspective may help to shed some light on the mechanisms underlying the condition of non-specific LBP, and help researchers and clinicians to understand some of the factors which differentiate people with and without LBP. It is known that LBP patients display altered activity of the trunk muscles; however, it remains uncertain whether these functional responses are employed in an adaptive manner in order to support recovery, or if they are detrimental responses and contribute to the development of chronic pain. The modification in trunk muscle activity in patients with LBP has received much interest, and different mechanisms have been proposed to explain the changes in neuromuscular control.

2.2 Pain-Spasm-Pain and Pain-Adaptation models

The 'Pain-Spasm-Pain' model of muscle pain, proposed by Travel, Rinzler and Herman (1942), postulates that pain results in increased muscle activity, which in turn will cause pain. In contrast, the 'Pain-Adaptation' model proposed by Lund et al., (1991) postulates that pain reduces activation of agonists, and increases activation of antagonists in order to reduce movement velocity and range of motion, and prevent pain provocation and further damage of tissues. While receiving much interest in the past, these somewhat simplistic early models have largely fallen out of favour as neither model unequivocally supports findings in studies of LBP (Van Dieën, Selen, & Cholewicki, 2003), and the adaptation that takes place appears to be much more complex than what is proposed by these models. The changes in muscle activity have been found to be task-dependent and related to the individual problem. Changes in muscle activity associated with pain are, therefore, highly variable between and within individuals. Van Dieën, Selen, & Cholewicki (2003) suggested an alternative model, after finding that neither of the two previous models adequately predicted the effects of back pain on trunk muscle activation. From an analysis of literature on trunk muscle activity in LBP patients, Van Dieën et al., (2003) suggest that changes observed due to pain were in order to enhance spinal stability and avoid tensile stresses on injured structures.

2.3 Reduced modulation depth

'Reduced modulation depth' (Zedka, Prochazka, Knight, Gillard, & Gauthier, 1999) is an attractive model explaining the neuromuscular adaptation to pain which is in fitting with the idea of a protective mechanism proposed by Van Dieen et al., (2003). Reduced modulation depth can be described as an increase in baseline activity and a reduction in maximal activity, in effect limiting the amplitude range of the muscle. It is believed that this supplies the injured contractile tissue with increased stability during rest while preventing further injury during activity (Zedka et al., 1999). This reconciles some of the previous conflicting evidence of both hyper and hypo-activity observed in muscles of LBP populations (Geisser et al., 2005). Zedka et al., (1999) found that experimental muscle pain produced greater lumbar muscular activity at full trunk flexion and decreased activity during extension, even when the angle and velocity were controlled. This pattern is supported by other reports evaluating muscle activity in the low back during flexion-extension tasks (Sihvonen, Partanen, Hanninen, & Soimakallio, 1991; P. J. Watson, Booker, Main, & Chen, 1997), as well as in the painful temporomandibular joint (Bodéré, Téa, Giroux-Metges, & Woda, 2005; Stohler, Ashton-Miller, & Carlson, 1988; Svensson, Houe, & Arendt-Nielsen, 1997) and shoulder (Kofler et al., 1998).

2.4 Introduction to use of SEMG in the study of low back pain

Surface electromyography (SEMG) is a non-invasive measurement tool which has attracted much clinical interest in the study of LBP. SEMG provides a quantitative, reliable and objective means of assessing muscle activity and is one method which has been demonstrated to have the potential use as an objective outcome measure for neuromuscular adaptations associated with LBP. Although SEMG has been deemed by some to be inferior to more precise methods such as intra-muscular electromyography (Haig, Gelblum, Rechten, & Gitter, 1996; Pullman, Goodin, Marquinez, Tabbal, & Rubin, 2000), studies have shown that certain SEMG measures may indeed be useful in the assessment of LBP (Geisser et al., 2005), and possess good clinical utility (Colloca & Hinrichs, 2005). SEMG has several advantages in clinical practice. SEMG is non-invasive, simple to apply, and causes little patient discomfort. SEMG has a broad (non-selective) detection area providing information regarding the overall level of contraction of the muscle group underlying the electrodes, as opposed to only a few muscle fibres observed with intra-muscular electromyography. SEMG

is useful for measuring muscle activity during dynamic tasks. As SEMG measures muscle activity, it can evaluate volitional effort and reflex activity. SEMG is, therefore, able to detect subtle changes in muscle activity owing to various physical and psychological factors such as fear of movement and psychological stress (Flor, Birbaumer, & Turk, 1990; Geisser, Haig, Wallbom, & Wiggert, 2004; P. J. Watson et al., 1997), thus reflecting important parameters that are consistent with the biopsychosocial model of pain (Waddell, 1987).

2.5 Use of SEMG to investigate neuromuscular adaptation

A growing body of literature suggests that there are significant differences in myoelectric activity measured by SEMG between persons with and without LBP. However, the conditions under which SEMG is employed can vary considerably between study designs. SEMG can be measured during static postures, during dynamic movements, and from muscles at different sites. Geisser et al., (2005) performed a systematic review and meta-analysis of published literature on SEMG differences between individuals with LBP and healthy controls. Methodologies and conditions varied greatly between the studies that were analysed. Therefore, in order to summarize the effect sizes the studies were sub-grouped by the position or task SEMG was recorded in. Effect sizes for each study were calculated by subtracting the mean of the normal group from the mean of the LBP group, and dividing by the pooled standard deviation.

2.5.1 SEMG investigation of static postures in people with low back pain compared with asymptomatic controls

Results from the meta-analysis by Geisser et al., (2005) indicated that in a static position some studies showed higher levels of muscle activity in LBP subjects compared with controls (Ambroz, Scott, Ambroz, & Talbott, 2000; Arena, Sherman, Bruno, & Young, 1989, 1991; Hubley-Kozey & Vezina, 2002; Lee, Stokes, Taylor, & Cooper, 1992) while others reported no difference (Ahern, Follick, Council, Laser-Wolston, & Litchman, 1988; Arena, Sherman, Bruno, & Young, 1990; Miller, 1985; P. J. Watson et al., 1997). The static postures assessed in the studies consisted of: standing, unsupported sitting, supported sitting, sitting supported with mental stress, and prone. The mean effect size (d) of all postures was 0.67, with upright standing having the largest effect size ($d=1.14$) out of all of the static postures. Greater

differences were noticed among LBP patients who were disabled (DeGood, Stewart, Adams, & Dale, 1994), or displayed excessive pain behaviour (Lofland, Cassisi, Levin, Palumbo, & Blonsky, 2000). Overall, there was inconsistent evidence to show that SEMG activity differed between LBP patients and pain-free subjects during these static postures.

2.5.2 SEMG investigation of dynamic movement in people with low back pain compared with asymptomatic controls

Some of the most convincing results that demonstrated differences in SEMG activity between LBP patients and pain-free persons were found in studies observing muscle activity during dynamic tasks, in particular those evaluating the phenomenon known as ‘flexion-relaxation’. Four studies included in the analysis examined the differences in flexion-relaxation between low back pain subjects and controls (Ahern et al., 1988; Ambroz et al., 2000; Sihvonen et al., 1991; P. J. Watson et al., 1997). The average effect size from the studies was found to be very large ($d = 1.71$). Based on the average effect size in these studies the amount of non-overlap of flexion-relaxation values between back pain and healthy populations is approximately 76%. Geisser et al., concluded that SEMG measures of flexion-relaxation distinguish LBP subjects from controls with good accuracy, therefore, providing support for evaluation of flexion-relaxation as a useful measure in the study of LBP.

3.0 Flexion-relaxation

3.1 Introduction

Flexion-relaxation (FR) was a term initially coined by Floyd and Silver (1955), to describe the reduction in electrical activity of superficial spinal extensor muscles observed as an individual approaches the end range of lumbo-pelvic flexion. It was initially proposed by Floyd and Silver (1955) that the myo-electrical quiescence observed is caused by a stretch inhibition reflex, as the torque loads from the upper body are transferred from the active elements to the passive spinal elements. It has since been demonstrated that although the superficial muscles are electrically silent, they still provide support through stretching of passive elements (McGill & Kippers, 1994), and some of the deep muscles, namely quadratus lumborum and the deep erector spinae muscles, remain electrically active and, therefore, may assist in the load sharing (E. A. Andersson, Oddsson, Grundström, Nilsson, & Thorstensson, 1996).

Flexion-relaxation (often described as a “phenomenon”) has received much attention in the literature. Although its presence has been observed primarily within a healthy population, it can be influenced by various factors, the most clinically relevant being the presence of LBP. Patients with LBP have been shown to demonstrate a lack of, or diminished, FR response in the lumbar erector spinae muscles. That is, the lumbar erector spinae displays heightened electrical activity during full lumbar flexion. The heightened activity observed in LBP populations during full flexion has been attributed to several possibilities including reduced range of lumbar movement (Ahern et al., 1988), muscle guarding due to pain (Ahern, Hannon, Goreczny, Follick, & Parziale, 1990), altered neuromuscular co-ordination between the trunk and hip (Shirado, Ito, Kaneda, & Strax, 1995), or an effort to enhance spinal stability (Van Dieën et al., 2003). In studies comparing LBP patients and asymptomatic populations, the use of FR evaluation has clearly and consistently discriminated between the two groups (Ahern et al., 1988; Geisser et al., 2005; P. J. Watson et al., 1997). The impressive ability of this measure to differentiate between persons with and without LBP has made it one of the most frequently discussed topics in LBP literature. In this sense, FR measures have the potential to serve as an objective measure of LBP (P. J. Watson et al., 1997), measure progression/resolution of back pain (Haig et al., 1993) and have been correlated with improved clinical outcomes (Mak et al., 2010; Neblett et al., 2003).

Assessment of the FR phenomenon involves the observation of several phases consisting of both dynamic movement and static postures, whilst electrical activity of the selected muscles is recorded. The typical phases observed are as follows:

- Phase 1: Upright (static)
- Phase 2: Active flexion (dynamic)
- Phase 3: Full flexion, where FR is observed to occur (static)
- Phase 4: Re-extension (dynamic)

The myo-electric reduction is observed during phase 3, and has been reported to typically occur from approximately 40-50 degrees of trunk flexion (Ahern et al., 1988; Colloca & Hinrichs, 2005; Solomonow, Baratta, Banks, Freudenberger, & Zhou, 2003).

3.2 Studies evaluating flexion-relaxation

Current literature suggests that FR of the lumbar erector spinae is observed in the majority of a healthy pain-free population (Geisser et al., 2005). However, the literature is not so uniform when other muscle groups are evaluated, or when flexion is performed in a seated position (slumped sitting). To further complicate matters, various methods of evaluating FR have been used by different authors, making it difficult to clearly make comparisons between studies.

The purpose of the current section of the literature review is to highlight some of the inconsistencies and gaps in the current literature where further research might be of benefit.

There are four main studies which have evaluated FR in the thoracic erector spinae and/or the superficial lumbar multifidus. These studies will be referred to in the following sections and compared with regard to evaluation method, muscle group, and flexion task. Extracts from these studies are shown in Table 1.

Table 1. Studies evaluating FR of the thoracic erector spinae (TES) and superficial lumbar multifidus (SLM) in asymptomatic populations.

Author	Electrode Location	Flexion task	Flexion-relaxation Evaluation Method	Results	FR Present in majority of subjects
McGill & Kippers (1994)	TES and LES	Standing flexion (holding 8kg weights)	MVIC normalisation Criterion: Activity during full flexion \leq 3% MVIC	37.5% (n=3/8) of subjects show FR of TES 87.5% (n=7/8) of subjects show FR of LES	TES – No LES – Yes
Callaghan & Dunk (2002)	TES and LES	Standing flexion and Slumped Sitting	MVIC normalisation Criterion: Reduction of at least 1% MVIC from upright to flexed posture	Consistent FR of TES during standing flexion (n=18/22) and slumped sitting (n=21/22). Consistent FR of LES during standing flexion (n=18/22). Inconsistent FR during slumped sitting (n=8/22).	Standing: TES – Yes LES – Yes Sitting: TES – Yes LES – No
O’Sullivan et al., (2002)	TES and SLM	Slumped Sitting	Sub-MVIC normalisation Criterion: Statistically significant reduction from erect to slumped sitting posture	Mean reduction of 84% Sub-MVIC in TES from erect to slumped sitting Mean reduction of 24% Sub-MVIC In SLM from erect to slumped sitting	TES – Yes SLM – Yes
O’Sullivan et al., (2006a)	TES and SLM	Slumped Sitting	MVIC normalisation Criterion: Reduction of at least 3% MVIC from erect to slumped sitting posture	Mean increase of 2% MVIC in TES from erect to slumped sitting Mean reduction of 17% MVIC in SLM from erect to slumped sitting	TES – No SLM – Yes

TES = Thoracic erector spinae; LES = Lumbar erector spinae; SLM = Superficial lumbar multifidus; MVIC = Maximal voluntary isometric contraction; FR = Flexion-relaxation

3.3 Issues with flexion-relaxation evaluation

Comparison of studies evaluating FR can often be difficult because quantification methods and criteria used to define the presence or absence of FR varies considerably between studies.

Numerous methods have been used to evaluate FR including visual interpretation of raw SEMG data, statistical analysis, normalisation methods, and ratio based analyses.

Furthermore, certain studies have dichotomised FR applying specific criteria with cut-off points to determine whether FR is present or absent, while other studies have calculated quantitative values (in the form of ratios of muscle activity between different phases of postural movement and positions) which represent the extent to which FR occurs and have been used to compare pain-free and symptomatic populations. Alongside the variability in evaluation methods, there does not appear to be a clear consensus as to what actually defines FR. It also is not clear whether the same evaluation methods can be appropriately applied when evaluating FR of para-spinal muscles in the different spinal regions (i.e. lumbar, thoracic and cervical), or when flexion is performed in alternate positions (standing flexion and slumped sitting). Burnett et al., (2009) illuminated this issue when they demonstrated the significant variability in results when different methods were used to dichotomise FR in the cervical erector spinae. Asymptomatic subjects (n=20) performed cervical flexion tasks which consisted of 4 phases: erect (phase 1), dynamic flexion (phase 2), full flexion (phase 3) and re-extension (phase 4). The authors employed the use of six different criteria previously defined in the literature to determine the presence or absence of FR in the lumbar muscles.

The criteria were:

1. Decreased muscle activation in Phase 3 compared with Phase 1 determined by visual analysis
2. Significantly less activation in Phase 3 when compared with Phase 1 as determined by statistical analysis
3. Phase 3 muscle activation $\leq 3\%$ of Maximal Voluntary Isometric Contraction (MVIC)
4. Phase 3 muscle activation $\geq 1\%$ of MVIC less than Phase 1 in upright sitting
5. Phase 3 muscle activation $\leq 10\%$ of peak muscle activation during Phase
6. Ratio of phase 3/2 muscle activation (flexion-relaxation ratio) < 1

The presence or absence of FR varied greatly depending on which of the selected criteria were used to define it. FR was deemed to be present in 0-65% of participants depending on

which of the criterion was applied, contrary to similar studies reporting the majority of healthy subjects demonstrating FR in the cervical erector spinae (Airaksinen et al., 2005; Meyer, Berk, & Anderson, 1993; Pialasse, Dubois, Pilon Choquette, Lafond, & Descarreaux, 2009). This highlights the lack of consensus in the previously used criteria for defining FR, and suggests that criteria used to define FR in the lumbar muscles may not be suitable to define FR in the cervical muscles; if in fact FR does exist in this muscle group.

3.4 Methods of flexion-relaxation analysis

3.4.1 Visual analysis

While it is common practise to visually inspect raw traces, dichotomising FR on this information alone has obvious limitations. Visual analysis is time consuming and subjective to the interpreter. O'Sullivan et al., (2006a) evaluated FR by observing the raw traces, and if there was a “clear and sudden reduction in motor activity”, FR was deemed to be present. Visual analysis was also carried out by Burnett et al., (2009) who examined the FR of raw SEMG data between phases 1 and 2 (upright and forward flexion phases), and phase 3 (full flexion). Four investigators came to a consensus in each case to decide if FR had been reached. Although perhaps more thorough with multiple investigators, this method still remains subjective and time consuming. However, results of these studies are similar to those of other studies utilising quantifiable methods, indicating that visual analysis, if employed carefully, may be used to correctly determine the presence/absence of FR. However, to the author's knowledge the intra and inter-examiner reliability and validity of such a method for determining the presence or absence of FR has yet to be explored.

3.4.2 Normalisation

It has been suggested that normalisation of raw SEMG data is desirable due to the inherent variability of the SEMG signal between individuals (Lehman & McGill, 1999). Using an obtained maximal voluntary isometric contraction (MVIC) as a reference value is a common method used to normalise raw SEMG data. This method of normalisation has been employed by several authors examining FR (Burnett et al., 2009; Callaghan & Dunk, 2002; McGill & Kippers, 1994; O'Sullivan et al., 2006a). Despite SEMG measures of MVIC amplitude of the trunk muscles having been shown to be reliable in asymptomatic and symptomatic

populations (Dankaerts, O'Sullivan, Burnett, Straker, & Danneels, 2004), this method has certain limitations. MVIC performance requires genuine maximal effort from the subject and, therefore, can be affected by an individual's motivation and ability to perform the maximal exertions. MVIC values are also likely to be reduced in persons with LBP who may have difficulty executing maximal effort (Geisser et al., 2005; Mayer, Kondraske, Mooney, Carmichael, & Butsch, 1989; O'Sullivan et al., 2002).

McGill and Kippers (1994) normalised SEMG data of several trunk muscles to MVIC and observed muscle activity as subjects performed a bending task while holding an 8kg weight in each hand. The trunk muscles were considered to be electrically silent if they exhibited activity levels $\leq 3\%$ MVIC during full flexion. This criterion was effective in identifying the FR in the lumbar erector spinae for most participants; however, it appears that the threshold of $\leq 3\%$ MVIC may have been too low to detect the relaxation of thoracic erector spinae and abdominal muscles, which demonstrated activity levels between 3% and 26% of MVIC. This highlights the challenge of a defined cut-off point and indicates that this method is specific to the muscles being evaluated.

Callaghan and Dunk (2002) also utilised MVIC to normalise SEMG data when evaluating FR; however, rather than utilising muscle activity only during full-flexion, the authors compared the relative difference in the normalised values during static upright, and fully flexed positions to determine the presence or absence of FR. Using this method the authors set cut-off thresholds to identify the presence of FR. A threshold of activity during full flexion within 1% MVIC of the average activity during upright standing was set for the standard standing FR manoeuvre (i.e. activity that is near a semi-relaxed level). This method and criterion identified 80% of pain free participants to exhibit FR. As with other cut-off methods in other studies, the criteria appear to be specific to the manoeuvre. That is, these authors used a similar method to identify FR during a seated flexion manoeuvre and decided upon a criterion where the activity during the flexed posture needed to be at least 1% MVIC less than the average activity during upright sitting (i.e. a slight decrease in activity). In this context, the criterion successfully identified FR in 21 out of the 22 subjects for the thoracic erector spinae. However, it was not as effective for indicating FR in the lumbar erector spinae (8/22 subjects). Interestingly, in a comparable study O'Sullivan et al., (2006a) employed a similar criterion

but with a 3% decrease and reported findings that appeared more sensitive. It cannot be inferred if the inconsistency between these studies is owing to methodological differences in quantification, in the manoeuvre or simply chance difference in the samples. However, there was a large variation in activity levels between the two studies, with mean activity levels ranging from 15-33% MVIC, compared with 4% MVIC even though both studies observed the same task being performed by healthy subjects. It is possible that the subjects in one study were capable of exerting greater effort, possibly due to the different protocol employed in the study to elicit MVIC. This substantial difference in mean activity levels highlights the potential inconsistency in MVIC normalisation methods. If subjects are not willing or capable of putting forth maximal effort, MVIC normalised values will be much higher than expected. However, rather than utilising the MVIC, these studies compare the relative difference between two phases. With or without the normalisation the relative difference will be the same, so to the use of normalisation here seems redundant. Rather, the MVIC reference was used to set a numerical cut-off limit.

Alternatively to MVIC normalisation, SEMG data can be normalised to a sub-maximal reference value. This method offers the benefit of normalising SEMG data without influence by potential underperformance from pain populations, a quality which may make this method a suitable choice for assessing FR in patients with LBP. Furthermore, measures of sub-maximal contraction have shown better between-day reliability with ICC values (mean ICC = 0.88; range 0.78–0.97) compared with poorer levels of reliability with MVIC (mean ICC = 0.70; range 0.19–0.99) in LBP patients and controls (Dankaerts et al., 2004). A standardised and reliable task which elicits a stable contraction is required in order to normalise data for each individual. This method was successfully employed by O’Sullivan et al., (2002) who utilised normalisation to a sub-maximal contraction to observe SEMG activity of the trunk muscles during commonly adopted postures in a sample of 20 asymptomatic subjects. In order to produce a stable sub-maximal effort, subjects were instructed to lie in a prone position on an examination table, asked to raise their feet 5cm from the table and hold for 5 seconds. Subjects then performed several tasks including erect and slumped sitting. The results from this study are similar to other reports observing FR during slumped sitting, suggesting that this method may be successfully employed as an alternative to MVIC normalisation. However, similarly to previous studies (Callaghan & Dunk, 2002; O’Sullivan et al., 2006a), the authors compared the relative difference between upright and flexed

positions rather than utilising the sub-maximal value, rendering the normalisation somewhat redundant, apart from providing numerical values. Although the method of normalisation to a sub-maximal value appears to be more reliable, and less biased by pain than MVIC normalisation, few researchers have chosen to use it.

3.4.3 Ratio based analysis

The FR phenomenon has also been evaluated in the form of ratios between different phases consisting of dynamic movements and static postures. Two commonly used ratios are the flexion-relaxation ratio (FRR), and extension-relaxation ratio (ERR), which compare the relative difference between active flexion and full flexion (the FRR); and active extension and full flexion (the ERR) respectively. These two particular ratios have been found to be most highly associated with the clinical and musculoskeletal characteristics associated with LBP when compared with several other ratios of different phases of movement or posture (Alschuler, Neblett, Wiggert, Haig, & Geisser, 2009). Many of the methods previously used to evaluate FR have been dichotomous. The FRR and ERR on the other hand provide quantitative values representing FR which can be used effectively to make comparisons between different groups (i.e. pain and asymptomatic populations). The use of the FRR and ERR to quantify FR provides several benefits. Firstly, it eliminates the need for normalisation procedures such as MVIC, which as mentioned earlier can be problematic in pain populations. Secondly this method provides insight into the modulation depth of the muscle, as both active and relaxed states of the muscle are taken into consideration. This may be of greater relevance in a pain population as muscle activity during active and relaxed states have been shown to be altered (Sihvonen et al., 1991; P. J. Watson et al., 1997; Zedka et al., 1999).

3.4.3a Flexion-relaxation ratio

The FRR is calculated by dividing the root mean square (RMS) activity during the active flexion phase by the RMS activity during full flexion (P. J. Watson et al., 1997). A higher ratio, therefore, indicates a greater relative difference between the two phases and presumably less activity during full flexion. Utilising the FRR, several authors have been able to successfully differentiate between LBP patients and pain-free controls (Mak et al., 2010; Paquet, Malouin, & Richards, 1994; P. J. Watson et al., 1997), and also between chronic neck pain patients and controls (Murphy, Marshall, & Taylor, 2010). This measure has been

reported to demonstrate moderate to excellent intra and inter-session reliability (Murphy et al., 2010; P. J. Watson et al., 1997), and has a reported specificity of 75% and sensitivity of 93% for discriminating LBP patients from pain-free participants (P. J. Watson et al., 1997). However, there have been a range of FRR values for symptomatic and asymptomatic populations reported in different studies, which highlights the issue of dichotomising FR using this method. If a consensus cannot be reached on what a 'normal' FRR value should represent, a strict cut-off value to determine the presence or absence of FR will be difficult to define. Paquet et al., (1994) found that a LBP group (n = 10) demonstrated FRRs less than 1, indicating the persistence or an increase in muscle activity during phase 3; full flexion. In contrast, the pain-free group (n=10) showed approximately 50% reduction in muscle activity (FRR = 2) from the active flexion phase to full flexion. Watson et al., (1997) in contrast reported much higher FRRs in asymptomatic subjects (mean FRR = 13.6) and LBP patients (mean FRR = 2.9). Although the LBP patients displayed some reduction in activity during full flexion, it was to a much lesser extent than that of the controls.

Variable utility of the FRR has been demonstrated in more recent studies which have evaluated FR in different flexion positions, and in different muscle groups. Mak et al., (2010) successfully employed this method to discriminate between LBP patients and controls when subjects performed seated flexion (slumped sitting). The authors reported a significant difference in mean (\pm SD) FRR in sitting between pain-free participants (Left: 6.83 ± 3.79 ; Right: 3.45 ± 2.2) and LBP patients (Left: 3.04 ± 2.36 ; Right: 2.02 ± 1.49). The ability of the FRR to also be effectively employed in other muscle groups was demonstrated by Murphy et al., (2010), who found that the FRR in the cervical erector spinae was significantly greater in asymptomatic participants (4.09 ± 1.58) compared with chronic neck pain patients (1.98 ± 0.8), when subjects performed cervical flexion-extension. These results are similar to those reported by Mak et al., (2010), suggesting that utilisation of FRR may be comparable between different muscle sites, and flexion positions.

3.4.3b Extension-relaxation ratio

An extension-relaxation ratio (ERR), calculated by dividing the RMS activity during extension by the RMS activity during full flexion, has also been used to quantify FR, although it has been utilised to a lesser extent in previous literature than the FRR. Similarly to

the FRR, studies have found the ERR effectively differentiates between LBP and pain-free control groups (Ambroz et al., 2000; Sihvonen et al., 1991). The ERR has also been used to effectively evaluate FR in the cervical muscles (Pialasse et al., 2009). In addition, some authors have set specific cut-off values of ERR in order to dichotomise FR.

An ERR greater than 1.66, was used by Pialasse et al., (2009) to define FR in the cervical erector spinae. This criterion successfully identified FR in at least one trial in 95% of subjects (n=18/19). This cut off value is comparable to other studies reporting ERR values in the lumbar muscles of asymptomatic, and LBP patients. Sihvonen et al., (1991) reported a mean ERR of 1.8 ± 0.5 in a group of n=87 LBP patients, which was significantly lower than the mean ERR of pain-free controls (3.2 ± 0.8). Ambroz et al., (2000) also reported comparable results in a group of n=30 LBP patients who had a mean ERR of 1.35 ± 0.41 which was significantly lower than a group of n=30 pain-free controls (2.59 ± 1.04). This tight cluster of results suggests that the criterion established by Pialasse et al., (2009) may have successfully differentiated between the two populations in the other studies. The results also suggest that this method of analysis may possess the advantage of being applied successfully to identify FR in different spinal regions using a similar criterion.

Mathieu and Fortin (2000) used a method similar to the ERR to evaluate FR. Rather than utilizing the RMS value, however, the authors chose to use the peak activity observed during extension. Subjects were deemed to have reached a state of relaxation during full flexion if the muscle activity was < 10% of the peak value observed during the re-extension movement. Based on this criterion FR was observed in 53% of trials. However, this finding was confounded by the fact that subjects performed flexion-extension tasks at different cadences (natural, 3s, 2.25s, and 1.5s). The highest occurrences of FR were in the 3s and 2.25s task, and the lowest occurrence in the 1.5s task. This finding highlights the importance of standardising flexion cadence during data collection.

Alschuler et al., (2009) compared five different measures used to evaluate FR in a sample of n=76 LBP patients relative to clinical status and musculoskeletal abnormalities. The authors found that the FRR and ERR were more highly associated with several clinical measures

(including perceived disability, pain-related fear, range of motion during flexion, and elicitation of pain during straight leg raise) than other measures that contrast SEMG during active flexion with SEMG during active extension, SEMG during upright with SEMG during full flexion, or SEMG during full flexion alone. The ERR was associated with the clinical measures at a higher magnitude than the FRR, and was additionally associated with a measure of clinical pain, suggesting the use of the ERR may be the preferred option of the two ratios.

From the studies that have been mentioned, it is clear that there have been a number of methods used to quantify the FR response in the paraspinal muscle. Numerous criteria have also been proposed by various authors to define the existence of FR, some methods appear to require near electromyographic silence to meet the criteria, while others only require a noticeable reduction. However, there does not appear to be a clear consensus within the literature as to a definitive criterion that satisfies the presence or absence of FR. To date, it appears that no studies have used ratio based methods of analysis to evaluate FR of the thoracic erector spinae or superficial lumbar multifidus.

3.5 Electrode position

There is strong evidence supporting the existence of FR in the lumbar muscles of a pain-free population, and an absence of FR in patients with LBP. However, there does not appear to be a clear consensus on whether FR occurs consistently in the thoracic erector spinae muscles. The precise location of electrode placement for SEMG is important as it determines which muscles will be examined. It is desirable to obtain a representative signal of the chosen muscle, while avoiding cross-talk from neighbouring muscles and artifact. Specific guidelines have been established to standardise SEMG electrode placement for specific muscles using palpation of bony anatomical landmarks (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). Although these guidelines may assist researchers in specific placement, identification of bony landmarks by individuals is often unreliable (Chakraverty, Pynsent, & Isaacs, 2007; Furness, Reilly, & Kuchi, 2002). Several different muscle groups that act as extensors of the spine have been examined in previous studies evaluating FR. These include the lumbar erector spinae (LES), thoracic erector spinae (TES), superficial lumbar multifidus (SLM), and cervical erector spinae (CES). Studies have demonstrated that these different muscle groups display varied muscle activity patterns while performing the flexion-extension tasks.

3.5.1 Erector spinae

The erector spinae is a large muscle group aligned longitudinally to the spine from the sacrum to the occiput (Bogduk, 2005). The muscles act bilaterally to extend the spine, and unilaterally to laterally flex the spine to the same side (Middleditch & Oliver, 2005). The erector spinae group can be divided into 3 columns namely (from lateral to medial) iliocostalis, longissimus, and spinalis. Each column has 3 different branches as follows (from inferior to superior):

Iliocostalis:

- Iliocostalis lumborum
- Iliocostalis thoracis
- Iliocostalis cervicis

Longissimus:

- Longissimus thoracis
- Longissimus cervicis
- Longissimus capitis

Spinalis:

- Spinalis thoracis
- Spinalis cervicis
- Spinalis capitis

3.5.1a Lumbar erector spinae

The majority of research evaluating FR in LBP populations has been focussed on the LES muscle group. The LES consists of two muscles from the erector spinae group: Iliocostalis lumborum and longissimus thoracis. Furthermore each of these muscles has a lumbar (pars lumborum) and thoracic (pars thoracis) component (Bogduk, 2005). The lumbar components of the Iliocostalis lumborum and longissimus thoracis are typically observed when evaluating FR of the LES.

To record activity of the LES muscles, electrodes are commonly placed approximately 3cm lateral to the spinous process of the lumbar vertebra, with the vertical application sites ranging between levels L1 and L5 spinous processes (Ahern et al., 1988; Callaghan & Dunk, 2002; Mak et al., 2010; Mathieu & Fortin, 2000; McGill & Kippers, 1994; P. J. Watson et al., 1997).

3.5.1b Thoracic erector spinae

The TES muscle group is made up of the thoracic components of the longissimus thoracis and iliocostalis lumborum. The electrode position for observing TES muscle activity has generally been accepted as 5cm lateral to the T9 spinous process. Few studies have evaluated FR of the TES in an asymptomatic population (Callaghan & Dunk, 2002; McGill & Kippers,

1994; O'Sullivan et al., 2006a; O'Sullivan et al., 2002; Toussaint et al., 1995). The studies that have evaluated the FR response in this muscle group have produced varied results with some reporting consistent FR (Callaghan & Dunk, 2002; O'Sullivan et al., 2002), and others reporting a lack of FR (McGill & Kippers, 1994; O'Sullivan et al., 2006a; Toussaint et al., 1995).

Callaghan and Dunk (2002) reported that FR occurred in the TES consistently in a sample of n=22 pain-free subjects while performing both standing flexion (18/22 subjects) and seated flexion tasks (21/22 subjects). Similarly O'Sullivan et al., (2002) found that there was a significant decrease in muscle activity of the TES in slumped sitting when compared with erect sitting in a study of n=20 pain-free subjects. In contrast to these studies, a more recent study by O'Sullivan et al., (2006a) reported that FR was not consistently observed in the TES in a sample of n=24 subjects when moving from an upright to slumped sitting position, with only 58% of subjects (n=14/24) displaying overall FR. Varied patterns of muscle activity were observed in this study which the authors attributed to the fact that the TES is a large torque producing muscle group with attachments at the pelvis and thorax and, therefore, has a greater potential for variability in motor patterning. McGill and Kippers (1994) similarly reported that few subjects (3/8) exhibited FR in TES while performing standing flexion, with only one subject demonstrating near myoelectric silence. However, in these studies subjects were only excluded if they were experiencing LBP at the time of the study, or had done so in the past 1-2 years. There was no exclusion criteria associated with thoracic/upper back pain. There is no evidence to state so far that pain in the thoracic region of the spine influences FR of the TES; however, based on the resounding reports of LBP and neck pain patients demonstrating a lack of FR in the LES and CES respectively, it is plausible to consider that a similar response may exist in the thoracic region of the spine in individuals with upper/mid back pain.

Toussaint et al., (1995) also examined FR in the TES of n=6 participants during lifting tasks. In this study the authors found that TES activity increased when LES displayed FR. The authors suggested that an intricate co-ordinating mechanism between the lumbar and thoracic muscle groups was involved in balancing the torque load at L5/S1 joint, as the torque provided by lumbar level taken up by TES. The thoracic fibres are attached through the

erector spinae aponeurosis to the lumbar and sacral spinous processes (McGill & Norman, 1987) and may, therefore, be capable of providing an extension torque at the L5-S1 articulation independent from the LES fibres. This suggests that the TES muscles may be an important factor to consider in LBP. This is supported by a study by Sung, Lammers and Danial (2009), who found that patients with LBP demonstrated increased fatigability of TES compared with LES, and suggested that this region of the erector spinae muscle group be considered in LBP rehabilitation.

No studies have been found which have evaluated FR of the TES in a symptomatic population (LBP or upper back pain) and correlated with a control population. However, before such comparisons are made, it would be useful to clarify the extent to which FR is observed in an asymptomatic population and how it may be evaluated appropriately, as currently the reports are inconsistent. Due to expansive influence of the TES muscle group on movement at the thorax and pelvis, the muscle group may be important to consider in the study of upper/thoracic back pain. FR in the TES muscle group still appears questionable and further investigation is warranted as to why.

3.5.1c Cervical erector spinae

It has been found that the CES muscles display a FR response similar to low back muscles in an asymptomatic population (Burnett et al., 2009; Pialasse et al., 2009). In a study of n=19 healthy subjects with no neck pain, FR was observed at least unilaterally in n=16/19 (13/19 bilaterally) participants when the subjects performed cervical flexion in a neutral seated position (Pialasse et al., 2009). This increased to n=17/19 unilaterally (15/19 bilaterally) when the same cervical flexion task was performed in a 45° forward leaning position. Burnett et al., (2009) found that FR occurred in the CES of an asymptomatic sample, however, this depends largely on the criteria used to define the phenomenon. Anywhere between 0% - 65% of participants demonstrated FR of the CES during cervical flexion depending on which criterion was used.

A significant difference has also been found between people with chronic neck pain and pain-free controls during cervical flexion. Murphy et al., (2010) compared FR measures of 14

subjects with chronic neck pain and 14 pain-free controls. The FRR was significantly different between neck pain patients (1.98 ± 0.8) and controls (4.09 ± 1.58 ; $P < 0.001$). These measures were additionally found to be highly reproducible (correlation coefficient $r = 0.92$) after 4 weeks.

3.5.2 Lumbar multifidus

The lumbar multifidus muscles are of interest in the study of LBP, as they are considered to be important segmental stabilizers of the lumbar spine (Wilke, Wolf, Claes, Arand, & Wiesend, 1995). Instability of the spine has been identified as an important factor in LBP (Panjabi, 2003), it has, therefore, been suggested that the lumbar multifidus may be of greater clinical significance than the larger fibres of the LES (O'Sullivan et al., 2006a). It has been demonstrated that different parts of the lumbar multifidus have different roles with superficial fibres contributing to the control of spinal orientation, and that the deep fibres play a role in controlling inter-segmental motion (Moseley, Hodges, & Gandevia, 2002). One limitation of SEMG is that it is limited to recording activity of the superficial lumbar multifidus (SLM) (O'Sullivan et al., 2006a). Although this is the case, SEMG appears to provide more information about the muscle activation than their indwelling needle electrode counterparts (Sihvonen et al., 1991). Many studies have evaluated FR in the lumbar muscles; however, few have evaluated the phenomenon in the SLM.

Flexion-relaxation has been observed in the SLM during slumped sitting. O'Sullivan et al., (2006a) found that FR was observed consistently in an asymptomatic population during slumped sitting in the SLM, reporting a mean reduction in muscle activity of 17% MVIC compared with upright sitting. These findings corroborate with an earlier study by O'Sullivan et al., (2002) who also showed that SLM displayed reduced myoelectric activity in a slumped seated position when muscle activity was normalised to a sub-maximal contraction. A mean reduction of 24% of the sub-maximal contraction was reported. These observations contrast with the LES activity observed by Callaghan and Dunk (2002) who reported findings of inconsistent FR during slumped sitting in an asymptomatic population. This suggests that the different muscle groups in the lumbar region; the larger LES group, and the SLM, play different roles during lumbo-pelvic flexion. Although the muscles work closely together, it has been proposed that FR of the SLM may occur in the absence of LES relaxation

(O'Sullivan et al., 2006a). This is supported by studies demonstrating the functional differences of these muscles (Ng, Richardson, & Jull, 1997).

3.6 Posture and flexion-relaxation

Flexion-relaxation has traditionally been evaluated during standing flexion-extension tasks. The majority of research collectively agrees that FR is a normal response observed in the lumbar muscles during standing flexion, although the presence of FR in the thoracic muscles remains uncertain. Recent studies have alternatively evaluated FR in a sitting position, which has resulted in some discrepancy of findings (Callaghan & Dunk, 2002; Mak et al., 2010; O'Sullivan et al., 2006a; O'Sullivan et al., 2002). Slumped sitting postures are commonly adopted in computer and desk work occupations and prolonged sitting postures have been frequently associated with aggravation of LBP (G. B. J. Andersson, 1999). Identification of the cause of pain associated with these postures has been difficult. With an increasing number of occupational roles requiring extended periods of sitting, it is becoming increasingly important to advance our knowledge of the function of spinal muscles during the adoption of flexed sitting postures. Doing so, may help to identify the extent to which active or passive elements are bearing the torque of the spine during a sustained flexed sitting posture, possibly becoming pain generating structures. There have been recent reports suggesting that changes in FR in sitting are correlated with improvement in clinical outcomes (Mak et al., 2010). Therefore, improving our awareness of spinal muscle activity during slumped sitting could prove valuable in understanding the relationship between LBP and slumped sitting, and help direct future studies and intervention.

Several studies evaluating FR during seated flexion (i.e. when subjects move from an upright sitting position, to a slumped sitting position) have reported conflicting results. In the thoracic spine, Callaghan and Dunk (2002) reported that the majority of participants ($n = 21/22$) displayed FR in the TES during slumped sitting. O'Sullivan et al., (2002) similarly reported a significant reduction in TES activity from upright sitting to slumped sitting (reduction of sub-MVIC = 84%; $p = 0.003$) in a sample of $n=20$ subjects without LBP. In contrast, a subsequent study by O'Sullivan et al., (2006a) found that the TES muscle group displayed

varied patterns of activity when subjects moved from upright sitting to slumped sitting, with only 9 out of 24 subjects meeting the criterion for FR.

In the lumbar spine, there have also been mixed results reported in previous studies evaluating FR during seated flexion. Two studies by O'Sullivan et al., (O'Sullivan et al., 2006a; O'Sullivan et al., 2002) observed consistent FR in the SLM during slumped sitting. In contrast Callaghan and Dunk (2002) reported that activation levels of the LES remained relatively constant, with very few participants ($n=8/22$ subjects) demonstrating FR during slumped sitting, suggesting the SLM and LES muscle groups of the lumbar spine exhibit different activity patterns during this movement. Andersson et al., (1996) similarly found that the quadratus lumborum, the deep erector spinae and the superficial erector spinae all displayed comparably low levels of activity in the upright and flexed seated positions, suggesting that these muscles show minimal, if any, difference in activity between erect and flexed sitting postures.

The conflicting results of the studies of FR in sitting may be due to the lack of standardisation of the sitting postures. It has been previously reported that different upright sitting postures can result in activation of different trunk muscles to varying degrees (O'Sullivan et al., 2006b). The lack of standardisation of the upright position may, therefore, contribute to the discrepancy between the two studies. Another possible reason for the discrepancy is that O'Sullivan et al., (2006a) only excluded subjects with LBP. It may be plausible that the presence of upper/thoracic back pain was not accounted for in some subjects, which may have influenced the FR response of the thoracic muscles similar to the way LBP influences FR of the lumbar muscles. However, such an inference would be premature, as a correlation between thoracic pain and an altered FR of the thoracic muscles has not yet been established.

Although there is contention over the presence or absence of FR in the spinal muscles during seated flexion, the clinical utility of FR in sitting has been demonstrated in a recent study by Mak et al., (2010). The authors calculated FRRs of people with LBP ($n = 20$) and pain-free subjects ($n = 25$) during seated flexion. They found that the mean FRRs of pain-free subjects were significantly higher (Left: $p < 0.001$; Right: $p < 0.05$) than those of the LBP group.

Furthermore, there was a significant increase (Left: $p < 0.05$; Right: $p < 0.001$) in the mean FRR of the LBP group following rehabilitation, which was correlated with a significant improvement ($p < 0.05$) in several clinical outcomes (subjective tolerance in sitting and standing, abdominal and back muscle endurance, lifting capacity, and range of motion). Most LBP research of FR has been undertaken with subjects performing standing flexion. This study suggests that the FR measure may additionally be applied in a seated position, and may also be capable of monitoring progression of some clinical outcomes.

During sitting, authors have been able to identify FR of the SLM (O'Sullivan et al., 2006a; O'Sullivan et al., 2002) and TES (Callaghan & Dunk, 2002; O'Sullivan et al., 2002). However, results are not conclusive as some authors have failed to identify FR in the majority of subjects in certain muscle groups (Callaghan & Dunk, 2002; O'Sullivan et al., 2006a). This highlights the challenges with evaluation, yet also indicates that the posture can be effective in evoking the relaxation and perhaps more research is needed to identify the best way of quantifying this. Reports of FR have been identified more consistently in the TES during slumped sitting, in contrast to the lumbar muscles which have been identified as displaying FR more consistently during standing flexion. This indicates that the selection of flexion tasks may play an important role in the identification of FR in a particular muscle group. Comparison of FR during standing and seated flexion tasks in different muscle groups will help to clarify whether flexion position has an influence on determining the presence or absence of FR in these muscle groups.

4.0 Conclusion and rationale for further investigation

The FR phenomenon has the potential to be used to objectively assess individuals with LBP and monitor progression and resolution of symptoms. However, there are inconsistencies in the literature which should be addressed. Flexion-relaxation has been quantified using various methods (visual analysis, normalisation, ratio based analysis), assessed in different muscle groups (LES, TES, SLM, CES) and during different flexion tasks (standing flexion, sitting flexion). The presence of FR in some muscle groups still remains questionable, and there is conflicting evidence of FR during seated flexion. In light of the inconsistencies of previous studies, the aim of the present study is to examine the FR response of an asymptomatic population in the TES and SLM during standing flexion and slumped sitting. As there are many existing criteria for determining the presence or absence of FR, the present study will use several selected criteria from previous literature to define FR with the aim of determining which method most appropriately quantifies the response in the given situation. The primary objective of this research is to compare different methods used to evaluate FR including dichotomous criteria and quantitative methods, and to investigate the influence of electrode site, and flexion task on evaluation of the phenomenon. This may provide further insight into the activity patterns of these muscles during flexion tasks. It may also help to distinguish which evaluation method or methods are most appropriate to quantify the FR in these muscles for the given task.

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Section 2: Manuscript

This manuscript is written in the style described in the guide for authors for the *Journal of Electromyography and Kinesiology* (see Appendix F). For the purposes of completion of this thesis some guidelines from have not been followed. Tables have been placed throughout the body of the document (rather than on a separate document) for ease of examination. The *Journal of Electromyography and Kinesiology* requires a limit of 5000 words which has been exceeded here to allow full and evaluative discussion of the results in this thesis.

**Evaluation of flexion-relaxation in the thoracic erector
spinae and superficial lumbar multifidus during standing
flexion and slumped sitting**

Abstract

The aim of the present study was to i) compare different methods of analysis used to evaluate flexion-relaxation (FR) including dichotomous criteria and quantitative methods; and ii) to investigate the influence of surface electrode site (thoracic and lumbar), and flexion task (standing flexion and slumped sitting) in pain-free participants. 20 healthy, pain-free volunteers (n=12 males, 8 females; mean age \pm SD = 27.9 \pm 7.7y), were recruited from a university population. Surface electromyography was used to measure activity in the thoracic erector spinae (TES) and superficial lumbar multifidus (SLM) bilaterally while participants performed standing flexion and slumped sitting tasks. The presence of FR was determined by using six criteria previously defined in the literature and a comparison of these criteria was undertaken. Flexion-relaxation ratios (FRR) and extension-relaxation ratios (ERR) were also calculated for each of the conditions. There was a large variation in the presence of FR based on the criteria examined. Depending on which criterion was applied, between 7.5% (3/40) and 95% (38/40) of TES sites; and between 27.5% (11/40) and 100% (40/40) of SLM sites were considered to have reached FR during standing flexion. During slumped sitting, between 35% (15/40) and 95% (38/40) of TES sites; and between 17.5% (7/40) and 75% (30/40) of SLM sites were considered to have reached FR. The majority of criteria identified FR more frequently in the TES during slumped sitting compared with standing flexion, and more frequently in the SLM during standing flexion compared with slumped sitting. The ERR was significantly greater ($p < 0.001$) than the FRR in the SLM during standing flexion. The FRR and ERR were both significantly greater ($p < 0.001$) in the SLM during standing flexion compared with slumped sitting. The findings of this study indicate that there is substantial variation in determining the presence of FR dependent on the criteria examined when evaluating the TES and SLM during standing flexion and slumped sitting. The flexion task performed can facilitate or hinder FR depending on the muscle being evaluated. There is a need for consensus within the research community as to which method is most appropriate to evaluate FR. The findings suggest that quantitative methods which measure the extent of FR may be more suitable to evaluate the response.

Keywords: Electromyography; Muscle, Skeletal; Musculoskeletal Physiology, Low Back

1. Introduction

Low back pain (LBP) is a common complaint with approximately 85% of people experiencing at least one episode of LBP in their lifetime (G. B. J. Andersson, 1999). Along with the high prevalence comes a large economic burden, with back injury costing New Zealand \$312,469,742 in claims covered by the Accident Compensation Corporation from June 2011 to July 2012 (ACC, 2012). Much research has, therefore, been devoted to understanding the factors involved in the development and progression of LBP. Surface electromyography (SEMG) is a non-invasive tool which may be useful in the assessment of neuromuscular dysfunction associated with LBP. In previous studies investigating neuromuscular dysfunction one of the most consistent findings that differentiates people with LBP from asymptomatic controls is the absence of the flexion-relaxation response in those with LBP (Geisser et al., 2005). Flexion-relaxation (FR) is a term initially coined by Floyd and Silver (1955), to describe the reduction in myoelectric activity of the paraspinal muscles as an individual approaches the end range of lumbo-pelvic flexion. The myoelectric quiescence of the paraspinal muscles is thought to be caused by a stretch inhibition reflex as the torque loads are transferred from the active spinal elements (eg muscle) to the passive elements (eg ligament) (Floyd & Silver, 1955). A study by McGill and Kippers (1994) investigating the transfer of loads between lumbar tissues during FR found that although the muscles were electrically silent, they continued to generate a substantial force through passive stretching which aided in supporting torque loads. Researchers have also found that some of the deeper spinal muscles remained active during end range flexion and may, therefore, contribute to some of the load sharing (E. A. Andersson, Oddsson, Grundström, Nilsson, & Thorstensson, 1996). The lack of FR in LBP populations has been attributed variously to reduced range of lumbar movement (Ahern, Follick, Council, Laser-Wolston, & Litchman, 1988), muscle guarding due to pain (Ahern, Hannon, Goreczny, Follick, & Parziale, 1990), altered neuromuscular co-ordination between the trunk and hip (Shirado, Ito, Kaneda, & Strax, 1995), or an effort to enhance spinal stability (Van Dieën, Selen, & Cholewicki, 2003).

Numerous studies have evaluated FR in the paraspinal muscles; however, it is difficult to compare studies because different methods are often used to quantify FR. Previous methods used to quantify FR include visual analysis of raw SEMG data, SEMG amplitude

normalisation methods, and various ratio analyses based on distinct movement phases. Additionally, some authors have set cut-off limits in order to define the presence or absence of FR. There appears to be a lack of consensus between some of the dichotomous criteria used to define FR. Burnett et al. (2009) compared six different criteria used to define FR when evaluating myoelectric activity of the cervical erector spinae muscles during cervical flexion and extension. The authors reported a significant variation in the criteria examined, with a wide range in the number of participants (0% - 65%) displaying FR depending on which criterion was applied. As an alternative to dichotomisation, FR has been evaluated using quantitative methods such as the flexion-relaxation ratio (FRR) (Watson, Booker, Main, & Chen, 1997) and extension-relaxation ratio (ERR) (Sihvonen, Partanen, Hanninen, & Soimakallio, 1991). These measures provide a value of the extent of FR rather than simple presence/absence. It remains uncertain which method is most appropriate to evaluate FR, and if there is an effect of site and task on FR.

FR has been evaluated in different spinal muscle groups (lumbar, thoracic and cervical) and during different flexion tasks such as standing flexion and slumped sitting. The presence of FR of the lumbar paraspinal muscles in pain-free populations during standing flexion has been widely documented (Floyd & Silver, 1955; Geisser et al., 2005; McGill & Kippers, 1994; Solomonow, Baratta, Banks, Freudenberger, & Zhou, 2003). Fewer studies have evaluated FR in the thoracic paraspinal muscles, and the studies that exist report conflicting findings (Callaghan & Dunk, 2002; McGill & Kippers, 1994; O'Sullivan et al., 2006a; O'Sullivan et al., 2002; Toussaint et al., 1995). Overall, the presence of FR in the TES remains questionable. Previous studies have reported observing FR during slumped sitting (Callaghan & Dunk, 2002; Mak et al., 2010; O'Sullivan et al., 2006a); however, few studies have compared standing flexion with slumped sitting (Callaghan & Dunk, 2002). Callaghan and Dunk (2002) evaluated FR of the thoracic erector spinae (TES) and lumbar erector spinae (LES) during standing flexion and seated flexion tasks in an asymptomatic population. The authors found that FR occurred consistently in both TES and LES muscle groups during standing flexion; however, during slumped sitting FR was observed consistently in the TES but not in the LES. In contrast, O'Sullivan et al. (2006a) reported that FR occurred consistently in the superficial lumbar multifidus (SLM) during slumped sitting; however the TES displayed varied patterns of muscle activity. Again, the discrepancy in FR criteria and electrode sites between studies makes comparisons and generalisation impractical.

In light of these inconsistencies, the primary aim of the current study was to compare some of the different criteria used to define FR when applied to the thoracic and lumbar paraspinal muscles. Secondly, quantitative measures of FR in the form of FRR and ERR were evaluated and compared. Thirdly, the influence of muscle site and flexion task on each method of analysis was examined by measuring activity of the TES and SLM during standing flexion and slumped sitting.

2.0 Methods

2.1 Participants

Twenty healthy individuals (n=12 males, 8 females; range 21 to 50y), were recruited from a tertiary institution using electronic notices and word of mouth. The mean±SD age, height, weight and body mass index (BMI) of the participants were 27.9±7.7y, 1.76±0.1m, 74.3±11.9kg, and 23.8±2.3kg.m⁻² respectively. All participants were briefed about all procedures involved in the study and written informed consent was gained prior to data collection. Ethical approval for the study was obtained from the Unitec Research Ethics Committee, Unitec New Zealand (UREC 2011:1240). Participants were excluded if they were: experiencing any upper or lower back pain at the time of the study; reported upper or lower back pain in the past year which required consultation with a medical professional, medication, or time off work; had any known or suspected spinal or muscular disorders; had a BMI ≥30 kg.m⁻²; suspected or known to be pregnant, or had given birth in the past 6-months.

2.2 Skin preparation and electrode placement

The participant's skin was abraded using abrasive tape (Red Dot, Trace Prep, 3M Corp., MN) and then cleansed with alcohol wipes. To ensure correct electrode placement, the bony landmarks were palpated and an ink marker was used to identify the levels of the ninth thoracic (T9) vertebrae and the fifth lumbar (L5) vertebra. Pre-gelled disposable Ag-AgCl surface electrodes (Medi-Trace, 3M Corp., MN) with a circular conductive surface of 1cm diameter were then applied to the skin in pairs bi-laterally over the thoracic erector spinae (5cm lateral to the T9 spinous process) and superficial lumbar multifidus (lateral to L5 spinous process, parallel to a line between the posterior superior iliac spine and the L1-2 interspace) with an inter-electrode distance of 2cm. Electrodes were applied to the participants in semi-flexed position to ensure adhesion with skin movement during the procedures. Impedance was measured using a multimeter and a value below 5kΩ was considered acceptable. A common ground electrode was placed over the left olecranon process. All electrodes were secured to the skin with hypoallergenic medical tape (Micropore, 3M Corp., MN), and snap leads were attached to the electrodes.

2.3 SEMG Recording

Myoelectric activity was sampled at 2000Hz using an Octal Bio Amp (ML138) and PowerLab® (ML785) system (ADInstruments Pty Ltd., NSW.) with a common mode rejection ratio >85dB typical (1-60Hz). Data were collected and processed using LabChart 7® software (ADInstruments Pty Ltd., NSW). Finite Infinite Response (FIR) filters were used on the raw SEMG data. Data was band-pass filtered between 30Hz (high-pass FIR filter with a half-amplitude frequency of 30Hz and transition width of 23Hz) and 500Hz (low-pass FIR filter with a half-amplitude frequency of 500Hz and transition width of 100Hz). A higher than usual high-pass filter was selected to reduce electrocardiographic artefact at the recording sites of the thoracic muscles (Drake & Callaghan, 2006). Visual spectrum analysis (1-sec epoch FFT), revealed a consistent spike at 50Hz uncharacteristic of muscle activity, therefore, a 50Hz second-order notch filter with 32 dB attenuation was employed to filter noise artefact.

2.4 Experimental protocol

The data collection protocol consisted of two flexion-extension tasks: standing flexion and slumped sitting. Both tasks consisted of four phases, with each phase lasting 4s. Each task was performed three times with the mean value of the three trials used for analysis of each phase. The timing for each phase was kept using a digital metronome (Mobile Metronome version 1.2.4) set at a cadence of 60 beats.min⁻¹, and verbal cues were provided by the investigator to indicate the beginning of each phase. Participants were given practice trials in order to familiarise themselves with the movements and the timing of the phases, and to ensure they fully understood the instructions.

The standing flexion task began with participants in an erect standing position, feet positioned shoulder width apart, with ankles hips and shoulders in approximately the same vertical plane, as visually determined by the investigator. This posture was maintained for 4s (Phase 1). Participants were then instructed to “tuck their chin to their chest and bend forward as if to touch their toes” (Phase 2) and given 4s to reach full flexion. Participants were instructed “to bend as far forward as they could comfortably go”. The fully flexed position

was then held for 4s (Phase 3). Participants then re-extended to the starting position reaching erect standing in a period of 4s (Phase 4).

To perform the slumped sitting task participants were instructed to sit on a height adjustable stool with no back or arm rests. The height was adjusted so that the participant's feet were flat on the ground, and hips and knees at approximately 90deg as visually determined by the investigator. The participants were instructed to maintain an upright head position and keep their arms relaxed at the side of their body for the duration of the procedure. To begin the task they were instructed to sit upright, in order to achieve a neutral pelvic tilt, a neutral lordosis of the lumbar spine and neutral thoracic kyphosis, as employed in previous studies (O'Sullivan et al., 2006a; O'Sullivan et al., 2002). This position was maintained for 4s (Phase 1). They then moved to a slumped sitting posture by relaxing the thoracolumbar spine and letting the pelvis rotate posteriorly (Phase 2). The slumped position was held for 4s (Phase 3). Participants then returned to the erect sitting position in 4s (Phase 4).

2.5 Normalisation

A maximal voluntary isometric contraction (MVIC) was performed for the purpose of SEMG data normalisation. This task was performed after the experimental protocols so that any fatigue induced by the tasks did not influence results from the experimental procedures. To generate MVIC for the TES and SLM, participants were instructed to lie in a prone position on the examination table with the legs straight. A pillow was placed behind the participants knees which were then secured to the table by a webbing strap. Participants were instructed to "interlace their fingers behind the neck and raise the head, shoulders and elbows off the examination table with maximal effort" whilst equal manual resistance was provided by the investigator to the scapular region to ensure an isometric contraction. Verbal encouragement was given to the participants to perform a maximal contraction. Three MVIC trials were performed with a rest period of 1min between trials in order to avoid the effects of fatigue. The mean value of the three trials was used as the MVIC value for each site.

2.6 Data processing

Raw SEMG data from each movement phase was imported into Microsoft Excel for processing. Data was rectified and averaged using a moving 1s window Root Mean Square (RMS) calculation, where each window included 2000 raw data points and each successive window incremented by a single data point until the entire movement phase, or MVIC, had been processed. The greatest RMS value from each phase was used for analysis. The percentage of MVIC was calculated for each of the phases. An FRR was calculated by dividing the RMS activity during active flexion (phase 2) with the activity during full flexion (phase 3). An ERR was also calculated by dividing the activity during extension (phase 4) with the activity during full flexion (phase 3). Left and right sides were averaged for each of these calculations to provide representative data of each muscle pair.

2.7 Identification of flexion-relaxation

A number of methods have been described to determine the presence or absence of FR in the spinal extensor muscles. FR was evaluated for the TES and SLM during standing flexion and slumped sitting using six criteria defined in previous studies. These consisted of:

- I) RMS activity at phase 3 below 3% MVIC RMS (McGill & Kippers, 1994)
- II) Reduction of RMS activity from phase 1 to phase 3 greater than 1% MVIC RMS (Callaghan & Dunk, 2002)
- III) Reduction of RMS activity from phase 1 to phase 3 greater than 3% MVIC RMS (O'Sullivan et al., 2006a)
- IV) Phase 3 RMS activity \leq 10% peak SEMG activity during phase 4 (Mathieu & Fortin, 2000)
- V) Ratio of phase 3: phase 2 $<$ 1 (Paquet, Malouin, & Richards, 1994)
- VI) Phase 3 activity $<$ 40% Phase 4 (Pialasse, Dubois, Pilon Choquette, Lafond, & Descarreaux, 2009)

2.8 Statistical analyses

A comparison of criteria I to VI was undertaken for each electrode location and flexion task. One-way ANOVA was used to compare muscle activity during the four phases of the experimental trials, and to compare FRR and ERR. Bonferroni's post hoc multiple comparisons were used to identify where significant differences existed between phases, muscle groups and tasks. Statistical analysis was performed using the IBM SPSS Statistics (v20 IBM Corp., NY).

3.0 Results

3.1 Comparison of criteria

Depending on which criterion was used to define FR there was between 7.5% (3/40) and 95% (38/40) of TES sites demonstrating FR during standing flexion, and between 35% (15/40) and 95% (38/40) of TES sites demonstrating FR during slumped sitting (Table 1). FR was considered to be present in between 27.5% (11/40) and 100% (40/40) of SLM sites during standing flexion and between 17.5% (7/40) and 75% (30/40) of SLM sites during slumped sitting. The majority of criteria (I,II,III,IV and VI) were more sensitive to detecting FR in the TES during slumped sitting compared with standing flexion. In contrast, the majority of the criteria (II – VI) were more sensitive to detecting FR in the SLM during standing flexion compared with slumped sitting.

Table 1. The number of electrode sites (pooled out of 40) demonstrating flexion-relaxation during standing flexion and slumped sitting tasks according to each criterion

Electrode Site		Standing Flexion						Slumped Sitting					
		Criterion						Criterion					
		I	II	III	IV	V	VI	I	II	III	IV	V	VI
Thoracic Erector Spinae	Left	5	9	0	12	19	12	8	14	10	14	19	16
	Right	4	6	3	10	19	14	7	17	11	14	19	16
	Pooled	9	15	3	22	38	26	15	31	21	28	38	32
Superficial Lumbar Multifidus	Left	3	11	6	19	20	19	6	6	4	11	14	14
	Right	8	12	9	18	20	19	8	8	3	13	16	17
	Pooled	11	23	15	37	40	38	14	14	7	24	30	31

Criteria to define flexion-relaxation:

- I) RMS activity at phase 3 below 3% MVIC RMS
- II) Reduction of RMS activity from phase 1 to phase 3 greater than 1% MVIC RMS
- III) Reduction of RMS activity from phase 1 to phase 3 greater than 3% MVIC RMS
- IV) Phase 3 RMS activity \leq 10% peak activity during phase 4
- V) Ratio of phase 3: phase 2 $<$ 1
- VI) Phase 3 activity $<$ 40% Phase 4

3.2 Statistical analysis of MVIC

Statistical analysis revealed that there was a significant difference between phase 4 and all other phases in the TES and SLM during both standing flexion and slumped sitting tasks (Table 2). Additionally a significant difference was found between phase 1 and phase 2 ($p < 0.001$); and between phase 2 and phase 3 ($p < 0.001$) in the SLM activity during the standing flexion task. When conditions were compared within phase, SLM activity during standing flexion was significantly greater than all other sites and tasks during phases 2 ($p < 0.001$) and 4 ($p < 0.001$). There were no other significant difference between site and task within phase.

Table 2. Muscle activation (mean left and right RMS) of Thoracic Erector Spinae (TES) and Superficial Lumbar Multifidus (SLM) during all phases of movement.

Task	Site		Phase 1	Phase 2	Phase 3	Phase 4	<i>F</i> -value	<i>p</i> -value
Standing	TES	Mean (%MVIC)	5.6	11.1	6.8	16.8*	10.916	< 0.001
		SD	2.7	5.3	4.2	10.8		
	SLM	Mean (%MVIC)	9.1 ^a	30.3 ^{ab}	8.1 ^b	56.9*	39.33	< 0.001
		SD	6.4	13.4	10.9	22.2		
Sitting	TES	Mean (%MVIC)	8.6	8.0	5.3	13.8*	6.126	0.002
		SD	4.9	4.5	3.4	9.2		
	SLM	Mean (%MVIC)	7.1	7.2	6.0	16.5*	6.14	0.001
		SD	4.9	5.1	5.2	9.7		

* Statistically significant difference ($p < 0.05$) between phase 4 and all other phases

^a Significant difference between phase 1 and phase 2 (SLM during standing flexion)

^b Significant difference between phase 2 and phase 3 (SLM during standing flexion)

RMS = Root Mean Square, MVIC = Maximal Voluntary Isometric Contraction

3.3 Comparison of ratios and flexion task

Both ratios (FRR and ERR) for the SLM were significantly different between standing flexion and slumped sitting with standing showing higher values (Table 3). ERR was significantly greater than FRR for the SLM during standing flexion ($p < 0.001$), but not during slumped sitting ($p = 0.15$) (Table 4). The TES showed no significant difference between ratios (FRR and ERR), or flexion task (standing and sitting).

Table 3. Comparison of standing flexion and slumped sitting tasks for FRR and ERR

Ratio	Site	Task	Mean	SD	Mean Difference	95% CI of Difference	<i>p</i> -value
FRR	TES	Standing	2.04	1.08	0.19	-2.83 to 3.21	1
		Sitting	1.85	0.55			
	SLM	Standing	6.76	3.89	5.27	2.25 to 8.29	< 0.001*
		Sitting	1.49	0.99			
ERR	TES	Standing	3.20	1.71	0.01	-3.01 to 3.03	1
		Sitting	3.19	1.49			
	SLM	Standing	12.97	6.44	8.8	5.77 to 11.82	< 0.001*
		Sitting	4.18	2.83			

* Statistically significant difference ($p < 0.05$)
 FRR = Flexion-relaxation ratio, ERR = Extension-relaxation ratio, TES = Thoracic erector spinae, SLM = Superficial lumbar multifidus

Table 4. Comparison of FRR and ERR for standing flexion and slumped sitting tasks

Task	Site	Ratio	Mean	SD	Mean Difference	95% CI of Difference	<i>p</i> -value
Standing	TES	FRR	2.04	1.08	-1.16	-4.18 to 1.86	1
		ERR	3.20	1.71			
	SLM	FRR	6.76	3.89	-6.21	-9.24 to -3.19	<0.001*
		ERR	12.97	6.44			
Sitting	TES	FRR	1.85	0.55	-1.34	-4.36 to 1.68	1
		ERR	3.19	1.49			
	SLM	FRR	1.49	0.99	-2.69	-5.71 to 0.34	0.15
		ERR	4.18	2.83			

* Statistically significant difference ($p < 0.05$)
 FRR = Flexion-relaxation ratio, ERR = Extension-relaxation ratio, TES = Thoracic erector spinae, SLM = Superficial lumbar multifidus

4. Discussion

4.1 Overview

The current study sought to compare different methods of FR evaluation, including dichotomous criteria and quantitative methods. Additionally, the influence of flexion task (standing flexion or slumped sitting) on FR in different muscles (TES and SLM) was examined. There was considerable variation between the results of the dichotomous criteria applied, suggesting a lack of versatility and comparability with such criteria. Quantitative ratio based methods appear to be more informative and have more versatility when used to evaluate FR, with the ERR potentially offering a more sensitive measure.

4.2 Dichotomous criteria

The current results demonstrate a lack of agreement between selected dichotomous criteria when applied to evaluate FR. These findings are similar to those of Burnett et al. (2009) who reported a lack of consensus between several predefined criteria when evaluating FR in the cervical erector spinae. While the results in the present study highlight the issue of various dichotomising criteria, there are further limitations when it comes to comparing results between studies even when identical criteria are employed. McGill and Kippers (1994) utilised criterion I, and reported 37.5% (3/8) and 87.5% (7/8) of pain-free participants met this criterion for the right TES and LES respectively during standing flexion. In the current study 20% (4/20) of participants met this criterion in the right TES, however only 40% (8/20) met the criterion in the SLM. Callaghan and Dunk (2002) utilised criterion II to define FR and reported that almost all participants met this criterion for the TES during slumped sitting and the majority met it during standing flexion. In the present study, the majority of participants met criterion II during slumped sitting, however, fewer than half of the participants met the criterion during standing flexion. O'Sullivan et al. (2006a) reported a mean reduction in SLM activity of 17% MVIC and a mean increase in TES activity of 2% MVIC when pain-free participants moved from an upright to a slumped sitting position. In contrast the current study found non-significant mean reductions of 1.1% MVIC and 3.3% MVIC of the SLM and TES respectively. Callaghan and Dunk (2002) similarly reported a negligible change in LES activity and a mean reduction of about 3% MVIC in the TES when pain-free participants moved from upright to slumped sitting positions. The differences in results may be due to several factors including standardisation of testing posture, MVIC

performance, chance difference in the samples, or could be owing to any of the numerous processes involved with recording and processing SEMG data.

The importance of standardisation with FR is highlighted when considering methodological sources of potential variability such as movement posture and position and normalisation using MVIC. It has been demonstrated that different erect sitting postures result in activation of different spinal muscles (O'Sullivan et al., 2006b), which could be a factor in the discrepancy between studies, and highlights the need for standardisation of postures. However, in the current study, the instructions given to participants to assume erect and slumped postures were comparable to those of other studies evaluating FR in these positions (Callaghan & Dunk, 2002; O'Sullivan et al., 2006a). There are also inherent issues with MVIC normalisation which could contribute to the contrasts between studies (Callaghan & Dunk, 2002; O'Sullivan et al., 2006a). MVIC performance can be influenced by various factors including the participant's ability and willingness to execute a maximal effort, previous training, and fatigue. Furthermore, performing maximal exertion can be problematic for LBP populations, as performance is also influenced by pain related anxiety (McCracken, Gross, Sorg, & Edmands, 1993), fear of re-injury (Vlaeyen, Kole-Snijders, Boeren, & van Eek, 1995) and other psychological factors (Foster, Thomas, Bishop, Dunn, & Main, 2010). Consequently LBP patients may underperform in such a task, making this method of analysis inappropriate in detection of FR in LBP patients. Ultimately, the use of MVIC adds a potential source of error which is then reflected throughout the remainder of the method. Due to the added complications with MVIC, methods of FR evaluation that do not require normalisation procedures may be preferable.

The extent of muscle relaxation that occurs for an individual during a flexion task is highly variable, and can range anywhere from near or complete myoelectrical silence, to activity that is barely discernible from that recorded during dynamic trunk movements. A range of criteria have been proposed in previous literature which set cut-off limits along this spectrum in order to appropriately define FR. Some are strict and require considerable muscle relaxation (e.g. criterion I: RMS activity at phase 3 below 3% MVIC RMS (McGill & Kippers, 1994)), some are more liberal and simply require a small reduction in muscle activity (e.g. criterion V: Ratio of phase 3: phase 2 < 1 (Paquet et al., 1994)), and other criteria lie (II, III, IV and VI) at

various levels in between. These arbitrary cut-off points used to dichotomise FR are not sensitive to detect where on the spectrum each individual lies, so small changes in the criteria can have a significant effect on the outcome. Moreover, the diversity of the criteria limits the comparability of the results obtained by the studies. Future researchers should justify their rationale when selecting a specific criterion to define FR. Alternatively, measurement techniques that quantify the extent of muscle activity should be employed to enable comparison between studies.

4.3 Ratio based analysis

The FRR and ERR provide the benefit of quantifying FR without requiring normalisation procedures (Watson et al., 1997). These ratios contrast active phases (phase 2 or 4) with the full flexion phase (phase 3) and offer a more informative and appropriate method to evaluate FR as they provide a measure of the extent of FR. This is supported by a study in which Alschuler, Neblett, Wiggert, Haig, & Geisser (2009) assessed 5 different ratios used to quantify FR in a sample of LBP patients relative to clinical and musculoskeletal abnormalities. The authors found that the FRR and ERR were more strongly associated with several clinical measures (including perceived disability, pain-related fear, range of motion during flexion, and elicitation of pain during straight leg raise) compared with measures that contrast active flexion to active extension, SEMG during upright standing to SEMG during full flexion, or SEMG during full flexion alone. The ERR was associated with these measures at a slightly higher magnitude than the FRR, and was additionally associated with a measure of clinical pain, providing support for this measure as a preferred option. Similarly, in the present study the mean ERR was higher (although not always significantly) than the mean FRR in all muscles and in both flexion tasks. This was an expected observation and can be explained by the concentric contraction of the muscles during extension requiring greater neural drive to extend the torso against gravity, compared with the eccentric contraction lowering the torso during flexion (Nakazawa, Kawakami, Fukunaga, Yano, & Miyashita, 1993; Westing, Cresswell, & Thorstensson, 1991). Similar to the benefit of a large signal to noise ratio observed when recording a raw SEMG trace, the larger ERR values provide a greater contrast between active and relaxed states. Theoretically, this may make the ERR more sensitive to detect differences, and perhaps, in combination with the findings of

Alschuler et al. (2009) lends support for the ERR as the more preferable of the two ratio methods.

The ERR values in the present study are comparable to results in other studies evaluating FR in the lumbar muscles (Ambroz, Scott, Ambroz, & Talbott, 2000; Sihvonen et al., 1991) and cervical muscles (Pialasse et al., 2009). The FRR values reported in the current study are also comparable to those previously reported in the lumbar muscles (Descarreaux, Lafond, Jeffrey-Gauthier, Centomo, & Cantin, 2008) and cervical muscles (Murphy, Marshall, & Taylor, 2010). However, there are exceptions where reported ratios are markedly different (Mak et al., 2010; Watson et al., 1997). Like dichotomous criteria, variation could be affected by posture, chance variation in sample, or variation in recording and processing of SEMG data.

4.4 Influence of electrode location and flexion task

The present study found that FR manifests differently in different muscles (TES and SLM) and during different flexion tasks (standing flexion and slumped sitting). Due to this variation in muscle activity patterns, it seems inappropriate to apply a single criterion to define FR for all muscles and tasks. When dichotomous criteria were applied to evaluate FR, the influence of the flexion task being performed was pronounced. The majority of criteria identified the presence of FR more often in the TES during slumped sitting compared with standing flexion. In the SLM, the converse was true with the majority of criteria identifying the presence of FR more often during standing flexion. When FRR and ERR were evaluated in the current study, neither the flexion task or ratio used had a significant effect on the TES results. In contrast, the flexion task and ratio used both had a significant effect on the SLM. Performing the standing flexion task and applying the ERR helped to facilitate the FR response in the SLM. This finding is similar to that of Callaghan and Dunk (2002), who found that FR was more pronounced in the LES during standing flexion when compared with slumped sitting. The selection of flexion task and ratio is, therefore, important when evaluating FR in the SLM. There is currently insufficient evidence to develop standardised recommendations for all back muscles during all flexion tasks. Until such a time that this evidence exists, researchers must exercise caution and select postures and tasks with just reason.

4.5 Recommendations

In order to effectively compare studies and sample populations, it would be favourable if authors used the same method to evaluate FR. In the present study, the ERR appeared to be the most sensitive measure for the SLM in a standing position, and other, non-significant trends in favour of this method were also observed for other muscle in other postures. Overall, the measures of FRR and ERR appear to be more versatile than dichotomous criteria for evaluating FR and can be used to effectively quantify FR in different muscles and during different flexion tasks. The ERR in particular appears to be most suitable due to the greater contrast between active and relaxed states, making it more sensitive to detect subtle differences.

4.6 Limitations

There are several limitations of the current study which should be considered. Firstly, spinal range of motion was not measured in this study. Many previous studies employ concurrent spinal range of motion measures, however, the current study did not seek to determine the association between range of motion and FR, which has been previously reported (Ahern et al., 1988; Neblett et al., 2003), but sought to evaluate the response when each participant reached their own maximal range of flexion. Shin, Shu, Li, Jiang and Mirka (2004) found that FR occurred when participants reached their own individual threshold, associated with flexibility, rather than a pre-set angle. Measurement of range of motion was, therefore, not considered a necessity. Furthermore, all participants were healthy and pain-free and no obvious limitations in movement were noticed by the researcher. Secondly, it cannot be certain that the SLM recording sites were specific to the SLM muscles. It is possible that there was cross-talk from the larger adjacent muscles such as the LES. Future studies should clarify whether the LES and SLM display different FR responses during standing flexion and slumped sitting. Thirdly, only pain-free participants were included in the current study, which limits the clinical relevance of the findings. This study, however, sought to determine the ability of each criterion to determine the presence of FR, not the ability to correctly distinguish between LBP patients and controls. Future studies should further apply FRR and ERR quantification methods to compare FR in healthy populations and LBP populations in order to provide a confident recommendation for one measure over the other.

5. Conclusion

The findings of this study indicate that there is substantial variation in determining the presence of FR dependent on the criteria examined when evaluating the TES and SLM during standing flexion and slumped sitting. The results also demonstrate that different muscle sites and flexion tasks evoke different FR responses. There is a need for consensus within the research community as to which method is most appropriate to evaluate FR and what criteria best define flexion-relaxation. Quantitative methods of analysis such as the FRR or ERR appear to be more suitable for evaluating FR than dichotomous criteria as they are more versatile and enable comparisons between studies.

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Section 3: Appendices

Appendix A: Table 1

Individual data demonstrating the presence or absence of flexion-relaxation according to each criterion and individual electrode site during standing flexion and slumped sitting tasks.

Participant	Site	Standing Flexion						Slumped Sitting					
		Criterion						Criterion					
		I	II	III	IV	V	VI	I	II	III	IV	V	VI
1	TES L	Y	Y	N	Y	Y	Y	Y	Y	N	Y	Y	Y
	TES R	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	SLM L	N	Y	Y	Y	Y	Y	N	N	N	N	N	N
	SLM R	Y	Y	Y	Y	Y	Y	N	N	N	Y	N	Y
2	TES L	N	N	N	Y	Y	Y	N	Y	Y	Y	Y	Y
	TES R	N	N	N	Y	Y	Y	N	Y	Y	Y	Y	Y
	SLM L	N	N	N	Y	Y	Y	N	N	N	N	N	N
	SLM R	N	N	N	Y	Y	Y	N	N	N	N	Y	N
3	TES L	N	Y	N	Y	Y	Y	N	Y	Y	Y	Y	Y
	TES R	N	N	N	Y	Y	Y	N	Y	Y	Y	Y	Y
	SLM L	N	Y	N	Y	Y	Y	N	N	N	N	Y	N
	SLM R	N	Y	Y	Y	Y	Y	N	N	N	N	Y	Y
4	TES L	N	Y	N	Y	Y	Y	N	Y	Y	Y	Y	Y
	TES R	N	N	N	N	Y	Y	N	Y	Y	Y	Y	Y
	SLM L	N	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y
	SLM R	N	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y
5	TES L	N	N	N	N	Y	N	N	Y	Y	Y	Y	Y
	TES R	N	N	N	N	Y	N	N	Y	Y	Y	Y	Y
	SLM L	N	N	N	N	Y	N	N	N	N	N	Y	N
	SLM R	N	N	N	N	Y	N	N	N	N	N	Y	N
6	TES L	N	N	N	N	N	N	N	N	N	N	N	N
	TES R	N	N	N	N	N	N	N	N	N	N	N	N
	SLM L	N	N	N	Y	Y	Y	Y	Y	N	Y	Y	Y
	SLM R	N	N	N	N	Y	Y	Y	N	N	N	Y	N
7	TES L	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
	TES R	N	N	N	Y	Y	Y	N	Y	Y	Y	Y	Y
	SLM L	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y
	SLM R	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
8	TES L	N	Y	N	Y	Y	Y	N	Y	N	N	Y	Y
	TES R	N	Y	Y	Y	Y	Y	N	Y	N	N	Y	Y
	SLM L	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	SLM R	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
9	TES L	Y	N	N	Y	Y	Y	Y	N	N	N	Y	Y
	TES R	N	N	N	N	Y	N	N	Y	N	N	Y	N
	SLM L	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
	SLM R	N	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y
10	TES L	N	Y	N	Y	Y	Y	N	Y	Y	Y	Y	Y
	TES R	N	Y	N	Y	Y	Y	N	Y	Y	Y	Y	Y
	SLM L	Y	Y	Y	Y	Y	Y	N	N	N	Y	N	Y
	SLM R	Y	N	N	Y	Y	Y	Y	Y	N	Y	Y	Y
11	TES L	Y	Y	N	Y	Y	Y	N	Y	Y	Y	Y	Y
	TES R	N	N	N	Y	Y	Y	Y	Y	N	N	Y	Y
	SLM L	N	Y	N	Y	Y	Y	N	N	N	N	N	Y
	SLM R	N	Y	N	Y	Y	Y	N	N	N	Y	N	Y
12	TES L	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
	TES R	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	SLM L	N	N	N	Y	Y	Y	N	N	N	Y	Y	Y

	SLM R	Y	Y	N	Y	Y	Y	Y	N	N	Y	Y	Y
13	TES L	N	N	N	N	Y	N	N	N	N	Y	Y	N
	TES R	N	N	N	N	Y	Y	N	Y	N	Y	Y	Y
	SLM L	N	Y	N	Y	Y	Y	N	Y	N	Y	Y	Y
	SLM R	N	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y
14	TES L	N	Y	N	Y	Y	Y	N	Y	Y	Y	Y	Y
	TES R	Y	Y	N	Y	Y	Y	N	Y	Y	Y	Y	Y
	SLM L	N	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y
	SLM R	N	Y	Y	Y	Y	Y	N	Y	N	Y	Y	Y
15	TES L	N	N	N	N	Y	N	Y	N	N	Y	Y	Y
	TES R	N	N	N	N	Y	N	Y	Y	N	Y	Y	Y
	SLM L	N	N	N	Y	Y	Y	Y	N	N	Y	N	Y
	SLM R	Y	N	N	Y	Y	Y	Y	N	N	Y	Y	Y
16	TES L	N	N	N	N	Y	N	N	N	N	N	Y	N
	TES R	N	N	N	N	Y	N	N	N	N	N	Y	N
	SLM L	N	N	N	Y	Y	Y	Y	N	N	Y	Y	Y
	SLM R	Y	N	N	Y	Y	Y	Y	Y	N	Y	Y	Y
17	TES L	N	N	N	N	Y	N	Y	Y	Y	Y	Y	Y
	TES R	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y
	SLM L	N	N	N	Y	Y	Y	N	N	N	N	Y	N
	SLM R	N	N	N	Y	Y	Y	N	N	N	N	N	Y
18	TES L	N	N	N	N	Y	N	Y	Y	N	N	Y	Y
	TES R	N	N	N	N	Y	N	Y	Y	N	Y	Y	Y
	SLM L	N	Y	N	Y	Y	Y	N	N	N	N	Y	Y
	SLM R	N	N	N	Y	Y	Y	N	N	N	N	Y	Y
19	TES L	N	N	N	Y	Y	Y	Y	Y	N	Y	Y	Y
	TES R	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
	SLM L	N	Y	N	Y	Y	Y	N	N	N	N	Y	N
	SLM R	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y
20	TES L	N	N	N	N	Y	N	N	N	N	N	Y	N
	TES R	N	N	N	N	Y	Y	N	N	N	N	Y	N
	SLM L	N	N	N	Y	Y	Y	N	N	N	N	N	Y
	SLM R	N	Y	N	Y	Y	Y	N	N	N	N	N	Y
Total	TES L	5	9	0	12	19	12	8	14	10	14	19	16
	TES R	4	6	3	10	19	14	7	17	11	14	19	16
	TES												
	Pooled	9	15	3	22	38	26	15	31	21	28	38	32
	SLM L	3	11	6	19	20	19	6	6	4	11	14	14
	SLM R	8	12	9	18	20	19	8	8	3	13	16	17
SLM													
	Pooled	11	23	15	37	40	38	14	14	7	24	30	31

TES = Thoracic erector spinae, SLM = Superficial lumbar multifidus, L = Left, R = Right. Whether FR was deemed to occur (Y (green) = Yes, N (red) = No) is listed according to criterion.

Criteria to define flexion-relaxation:

- I) RMS activity at phase 3 below 3% MVIC RMS
- II) Reduction of RMS activity from phase 1 to phase 3 greater than 1% MVIC RMS
- III) Reduction of RMS activity from phase 1 to phase 3 greater than 3% MVIC RMS
- IV) Phase 3 RMS activity \leq 10% peak activity during phase 4
- V) Ratio of phase 3: phase 2 < 1
- VI) Phase 3 activity < 40% Phase 4

Appendix B: Participant information sheet



RESEARCH INFORMATION FOR PARTICIPANTS

Evaluation of the flexion-relaxation phenomenon in thoracic and lumbar paraspinal muscles

You are invited to participate in our research investigation. Please read carefully through this information sheet before you make a decision about volunteering.

Researcher

My name is Jesse Armstrong and I am a Master of Osteopathy student at Unitec New Zealand. As part of this programme I am conducting a research project.

Purpose of the study

A relationship between altered muscle activity patterns and low back pain has been observed in previous studies. Flexion-relaxation (FR) is a stereotypical muscle pattern where low back spinal muscles relax at maximal voluntary trunk flexion (e.g. when touching your toes from standing). This is consistently observable in the low back muscles, in most pain free people, and is usually absent in people with low back pain. Observations of this response in muscles of the mid-back however have been variable.

This study aims to evaluate the FR response in a pain-free population, by measuring muscle activity in the mid-back and low back during 2 different flexion procedures (standing and sitting), and to compare the reliability of different methods used to evaluate the response.

What the study involves

If you volunteer to take part in this experiment, your age, height and weight will be recorded initially. You will then be asked to expose your mid back and lower back and to enable application of the recording equipment. We may need to shave (using a single-use disposable razor) a 2-3cm square of skin for each electrode site if there is body hair that would interfere with the electrode placement. Skin overlying the muscles will be lightly abraded with abrasive strips and cleansed with alcohol wipes. 4 pairs of self-adhesive electrodes will then be placed on the skin on either side of the back, and secured with adhesive medical tape. These electrodes connect to a laptop which records information about the tone of the underlying muscle.

Participants will then be directed through several simple movement procedures while muscle activity is recorded. These procedures consist of:

The following two procedures will be performed on an examination table:

- Maximal isometric contraction – participants perform contraction of the back muscles with maximal effort by extending the back from a prone (lying on your front) position against resistance. To be performed 3 times.
- Stable sub-maximal contraction – participants extend the back from a prone position and hold the position for a period of 5 seconds under their own weight (no additional resistance applied).

The following 2 procedures will be performed 3 times each:

- Standing flexion – Standing and bending forward toward toes and re-extending at a set pace.
- Slumped sitting – slumping forward from an upright seated position and re-extending at a set pace.

Taking part in this study will require you to attend 1 session at the Osteopathic Clinic at Unitec Institute of Technology on Carrington road. This session will last approximately 1 hour.

Your voluntary participation

Your participation in this study is entirely voluntary and you may withdraw at any time during the practical procedures. Data collected from your involvement in the study may be withdrawn up until 1 week following data collection.

Who may participate?

You are eligible to participate if you:

- Are aged between 18 and 50 years of age.
- Are willing to give informed written consent.

Unfortunately you are unable to participate if you:

- Are experiencing back pain currently
- Have any known or suspected spinal or muscular pathologies (including spinal stenosis, spinal surgery, neurological symptoms, osteoporosis, lower limb surgery, disc injuries).
- Have experienced back pain in the past 12 months which required: Medication, consultation with a health professional or time off work.
- Are pregnant or have given birth within the last 6 months.
- Have an inability to perform the tasks required for the study.
- Experience any pain while performing the tasks.

Please inform the researcher if any of the above pertains to you.

What we do with the data and results, and how we protect your privacy.

Personal information is collected and stored under the guidelines provided by the Privacy Act 1993 and the Health Information Privacy Code 1994. For information

collection your identity will remain anonymous and you will simply have an identification number. If the information you provide is reported or published, this will be done in a way that does not identify you as its source. All the data recorded will be stored in a password-locked computer and archived in a locked file room and will be stored for a minimum of 5 years. Access to this data will be limited to the principle researcher, the research supervisor, and yourself.

Compensation may be available in the unlikely event of injury of negligence

Should you incur a physical injury as a result of your participation in this study, you may be covered by ACC under the Injury Prevention, Rehabilitation and Compensation Act 2002. You may or may not be entitled to ACC compensation, depending on several factors such as whether or not you are an earner. ACC will usually cover a proportion of income lost due to a physical injury, this does not cover mental injury unless as a direct result from a physical injury. ACC cover may affect your right to sue. Please contact your nearest ACC office for further information (0800 735 566) or visit their website: www.acc.co.nz

You have the right to withdraw your data from this project at any time, until one week after your data collection. This can be done by contacting the researcher below.

A summary of the final report will be available to you if you are interested.

Please contact me if you require further information about the study.

Contact Details

Jesse Armstrong
Phone: 021 1544550
Email: jess.nzed@hotmail.com

Supervisor Details

Rob Moran
Phone: 021 073 9984
Email: rmoran@unitec.ac.nz

This study has been approved by the Unitec Research Ethics Committee from (13-01-2012) to (13-01-2013). If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the UREC Secretary (Ph: 09 815 4321 ext.7254). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

Appendix C: Participant consent form



Evaluation of the flexion-relaxation phenomenon in the thoracic and lumbar paraspinal muscles

Name of Participant:

This form is to ensure that you understand the requirements of your participation and that you are aware of your rights. Please read carefully through the points below. If you are happy and agree with the points then please sign at the bottom of the page. If you have any questions at all please ask the researcher before signing this form.

- I have had the research project explained to me and I have read and understood the information sheet given to me.
- I understand that I don't have to be part of this if I don't want to and I may withdraw myself (or any information I have provided) at any time prior to the completion of the research project.
- I understand that everything I say and the information I provide will be collected in accordance with the Health Information Privacy Code 1994 and kept confidential and in accordance with the Privacy Act 1993. I understand that the only persons who will have access to my information will be the researchers and relevant clinical staff.
- I understand that all the information I give will be stored securely on a computer at Unitec for a period of 5 years.
- I understand that I can see the finished research document.
- I have had time to consider the information provided, to ask questions, and to seek any guidance.
- I give my consent to be a part of this project

Participant Signature: *Date:*

Principal Researcher: *Date:*

This study has been approved by the Unitec Research Ethics Committee from (13-01-2012) to (13-01-2013). If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the UREC Secretary (Ph: 09 815 4321 ext.7254). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

Appendix D: Ethics approval



Jesse Armstrong
151c Ash Street
Avondale
Auckland

26.1.2012

Dear Jesse,

Your file number for this application: **2011-1240**

Title: **Evaluation of the flexion-relaxation phenomenon in the thoracic and lumbar paraspinal muscles.**

Your application for ethics approval has been reviewed by the Unitec Research Ethics Committee (UREC) and has been approved for the following period:

Start date: 13.1.12

Finish date: 13.1.13

Please note that:

- 1. The above dates must be referred to on the information AND consent forms given to all participants.**
- 2. You must inform UREC, in advance, of any ethically-relevant deviation in the project. This may require additional approval.**

You may now commence your research according to the protocols approved by UREC. We wish you every success with your project.

Yours sincerely,

Scott Wilson
Deputy Chair, UREC

cc: Rob Moran
Cynthia Almeida

study@unitec.ac.nz
Tel +64 9 849 4100
Fax +64 9 815 2901
www.unitec.ac.nz

Postal address
Private Bag 52025
Victoria St West
Auckland 1142
New Zealand

Mt Albert campus
139 Carrington Rd
Mt Albert
Auckland 1025
New Zealand

Newmarket campus
277 Broadway
Newmarket
Auckland 1023
New Zealand

Northern campus
10 Rothwell Ave
North Harbour
Auckland 0632
New Zealand

Waitakere campus
5-7 Ratanui St
Henderson
Auckland 0512
New Zealand

Appendix E: Ethics approval for requested changes



Jesse Armstrong
151c Ash Street
Avondale
Auckland

21.6.12

Re: Request for changes

Dear Jesse,

Your file number for this application: **2012-1240**

Project Title: Evaluation of the flexion-relaxation phenomenon in the thoracic and lumbar paraspinal muscles.

Your request for changes to the above application have been reviewed by the Unitec Research Ethics Committee (UREC) and have now been approved. Please note that all other conditions as specified in your original application approval letter apply.

You may now continue your research according to the protocols approved by UREC. We wish you every success with your project.

Yours sincerely,

Scott Wilson
Deputy Chair, UREC

cc: Rob Moran

study@unitec.ac.nz
Tel +64 9 849 4180
Fax +64 9 815 2901

www.unitec.ac.nz

Postal address
Private Bag 92025
Victoria St West
Auckland 1142
New Zealand

Mt Albert campus
159 Cerrington Rd
Mt Albert
Auckland 1025
New Zealand

Newmarket campus
277 Broadway
Newmarket
Auckland 1023
New Zealand

Northern campus
10 Rothwell Ave
North Harbour
Auckland 0632
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5-7 Ratanui St
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Appendix F: Journal of Electromyography & Kinesiology Guide for Authors

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All authors should have made substantial contributions to all of the following: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, (3) final approval of the version to be submitted.

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For the Far East and Australia:

Professor T. Moritani, Laboratory of Applied Physiology, The Graduate School of Environmental Studies, Kyoto University, Sakyo-ku, Kyoto 606, Japan; Tel: 81 75 753 6888, Fax: 81 75 753 6734

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Number tables consecutively throughout the paper (with Arabic numerals) referring to them in the text as Table 1, Table 2 etc. with a caption at the top of each table. Avoid the use of vertical rules. Tables should not duplicate results presented in graphs.

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