

The effect of Core Stability Exercises (CSE) on trunk sagittal acceleration

A thesis submitted for the degree of Doctor of Philosophy

By

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Abstract

Aims

The aim of this study was to investigate Core Stability Exercise (CSE) induced changes in trunk sagittal acceleration as a measure of performance in participants following an acute onset of non-specific low back pain (LBP).

Methodology

A Lumbar Motion Monitor (LMM) was used to measure trunk sagittal acceleration. The LMM was demonstrated to be reliable [Intra-Class Correlation (ICC) for average sagittal acceleration (0.96, 95% CI 0.90-0.98) and peak sagittal acceleration (0.89, 95% CI 0.75-0.96) with a 95% limit of agreement for the repeated measure of between -100.64 and +59.84 Deg/s²]. Pain was measured using the Visual Analogue Scale (VAS) and disability was measured with the Roland Morris Disability Questionnaire (RMDQ).

Results

Differences in mean trunk sagittal acceleration between control and experimental groups at time points were assessed using a regression analysis (ratio of geometric means [95%CI]) and demonstrated to be not statistically significant (3 weeks (20%) 1.2 [0.9 to 1.6], $p=0.2$; 6 weeks (10%) 1.1 [0.8 to 1.5], $p=0.7$; 3 months (20%) 1.2 [0.8 to 1.9], $p=0.9$). Similarly, differences in mean pain score (3 weeks (30%) 1.3 [0.8-2.2], $p=0.3$); 6 weeks (20%) 1.2 [0.7-2.0], $p=0.6$; 3 months (0%) 1.0 [0.5-1.9], $p=1.0$) and difference in mean disability score (6 weeks (0%) 1.0 [0.7-1.5], $p=1.0$, 3 months (30%) 1.3 [0.8-1.9], $p=0.3$) between groups were also not statistically significant.

Conclusions

This work does not infer that CSE are definitively effective in reducing pain, improving subjective disability and improving trunk performance after an onset acute of non-specific LBP. However, there is a suggestion of clinical importance and a possible mechanism by which they may work. Further investigation into this mechanism may provide future effective management strategies for intervention of acute non-specific low back pain with optimistic cost implications for healthcare delivery in general and Physiotherapy in particular.

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Chapter 1

Introduction

1.1 Summary

This chapter introduces the complexity of LBP as a condition in general and acute non-specific low back pain specifically. Acute non-specific low back pain in this instance is low back pain with a period of less than 6 weeks duration and not attributable to any specific underlying pathology (NICE, 2009). It explores the characteristics and behaviour of trunk movement in response to axial loading and also explores current diagnostic tools, considering their advantages and disadvantages.

1.2 Study Background

Low Back Pain (LBP) is a health burden (Koes et al., 2006) and a twentieth century health care enigma (Sieben et al., 2005). The incidence and prevalence of LBP has been widely documented (Croft et al., 1998; Campbell and Muncer 2005; Carragee et al., 2006; Cayea et al., 2006; Carreon et al., 2007; BackCare, 2007) and the reality of the impact is demonstrated by musculoskeletal data and the number of referrals to both primary and secondary care. A number of studies have investigated different aspects of LBP. These include the underlying belief systems (Fullen et al., 2008), resultant muscle pain and its affect on muscle activity and coordination during an onset of LBP (Graven-Nielson et al., 1997), the effects of manipulation as a treatment for LBP (Assendelft et al., 2003; Bronfort et al. 2004; Ernst, 2007), the effect of loading on the spine and the mechanism by which it precedes an onset of LBP (Callaghan et al., 1998), the effect posture on spinal

loading (Cholewicki et al., 2000), the use of stabilisation exercises as treatment (Ferriera et al., 2006) and the general management of the onset of LBP (Hagen et al., 2002, Hagen et al., 2005; Gullick, 2008). However advances in knowledge have not made an impact on its prevalence nor suggested a gold standard of intervention.

Effective treatment is dependent upon the understanding of the mechanisms of onset of LBP. An understanding of trunk behaviour during functional tasks is therefore important within this process. Chapter 1 explores what is already known of the anatomy of the lumbar spine and attempts to put that knowledge into a functional context. The chapter also discusses current diagnostic tools and their merits highlighting the major flaw within their design; the inability to provide definitive causal relationships between what is reported and LBP experienced during functional activity. The diagnostic tools are therefore arguably of limited use to Physiotherapy because it is change in relative functional movement of the trunk structure that effectiveness and efficiency of intervention is measured by. The quality and quantity of lumbar movement is therefore an important part of a Physiotherapy assessment (Petty, 2006).

Objective measures of function are less likely to be susceptible to bias and trunk higher order kinematics (acceleration and velocity) are the most reliable objective measures as outcomes for the quantification of LBP (Kroemer et al., 1990). Chapter 2 therefore explores the current knowledge of trunk performance in this context and discusses the underlying principles by which trunk performance may be more beneficial to a clinician. The chapter also discusses the increasing popularity of Core stability exercises (CSE) as a method of treatment and explores

the possible mechanism by which they may work, especially in the context of improving trunk performance following and onset of LBP. Although CSE are increasingly being used to improve and provide trunk stability (Willardson, 2007b; Willardson, 2007a), the clinical value for this concept remains controversial (May, 2008). The ambiguity in the effectiveness of CSE is because it is difficult to clinically demonstrate (Teyhen et al., 2007) even though the concept of instability (Panjabi, 2003) has in the main been accepted.

Finally the chapter describes the 3 hypotheses of this study and the method by which they were tested.

Because the study is unique, the method needed to be developed. Chapter 3 sets out how this was done. A pilot study evaluated the primary outcome tool and a second study explored trunk behaviour in order that an attempt to interpret the results of the study could be made. The Lumbar Motion Monitor (LMM) (Marras and Wongsam, 1986; Ferguson et al., 2003; Ferguson and Marras, 2004) was identified as the most appropriate equipment to measure trunk performance. This was because the LMM is arguably the most practical for use in the clinical environment because of its portability with minimal setup/labour time and its ability to provide valid and reliable measures for the quantification of LBP (Marras and Wongsam, 1986; Marras et al., 1990; Marras, 1996). Previous studies have provided evidence of the validity and reliability of the other outcomes of pain (Crossley et al., 2004) and disability (Roland and Morris 1983). Further reliability and validity tests were therefore not considered with respect to this study.

Chapter 4 describes the method derived from the previous chapter used to test the hypotheses of the study and the results are presented in the penultimate

chapter 5. The last chapter discusses the results and attempts to make logical interpretation of those results and considering the limitations of the study and exploring possible future work which would enhance our existing knowledge of the effects of CSE on acute LBP.

1.3. Aetiology of low back pain

The incidence and prevalence of LBP suggests that LBP may be “a twentieth century health care enigma” (Sieben et al., 2005). In the United Kingdom 14,754 occurrences of musculoskeletal were reported during a one year period between July 2005 and June 2006 accounting for 23.5% of all reported occurrences of injury (Appendix 1). Incidence and prevalence are descriptive epidemiological terms with the incident rate described as the total number of events within a population at risk of that event over a specified period of time (Guillemin, 2005). Prevalence is described as the state of the population as affected by the condition at a given specified time (Guillemin, 2005). It is therefore perceivable that both the incidence and prevalence of LBP may vary according to the population being studied and the period of time for which the data is collected (Guillemin, 2005). It is suggested that both the number of episodes recorded and the total population considered being at risk should come from the same data source (Guillemin, 2005).

The aetiology of Low Back Pain (LBP) is usually referred to in terms of either its incidence or prevalence with much variation. More recent informed opinion suggests that there is an annual prevalence equating to a third of adults being affected by the condition (Macfarlane et al., 2006), however, other previous studies suggest 40% (Papageorgiou et al., 1996), 15-20% (Wong and Deyo 2001), 7% (Stanley et al., 2000), 60% (Jackson, 2001) and 80% (Haas et al., 2004).

1.4 Impact of low back pain

Lumbar spine disorders have a negative effect on physical health, functioning and bodily pain as measured by the SF-36 health survey (Pahl et al., 2006) and a better understanding of LBP will provide a means of developing strategies to manage the condition.

The total cost of Low Back Pain (LBP) to the United Kingdom is between 1 and 2% of gross domestic product (GDP) (BackCare, 2007) and it is the second largest reason for long term sickness with an estimated 7% of acute episodes of LBP becoming chronic (BackCare, 2007). Although it is not possible to suggest that an incorrect diagnosis may have an impact on these figures a correct management strategy for LBP remains important because there is still ambiguity about the mechanism by which LBP develops and what and how intervention works.

1.5 Causes of low back pain

Low Back Pain is the most common musculoskeletal condition seen in primary care (Wong and Deyo, 2001) and everyone will be affected by it at some stage in their lives (Macfarlane et al., 2006). LBP can be caused by mechanical dysfunction as a result of strains, sprains, spondylosis, herniated intervertebral discs and stenosis of the spine (Jayson, 1996) and by non-mechanical problems associated with conditions such as inflammatory disorders, neoplasms, and metabolic bone disorders (Jayson, 1996). Sometimes LBP has no apparent cause and is termed idiopathic (NHS, 2005; BackCare, 2007). One anecdotal suggestion is that LBP is caused by the disruptive forces affecting the spinal column. Core stability exercises (CSE) are thought to provide a resistance to these forces (Willardson,

2007b). However, it is not clear what effect CSE has on acute LBP. Acute LBP is defined as pain within an initial 6 week period following onset (NHS, 2005; BackCare, 2007).

1.6 Historical management of low back pain

CSE are fast becoming a preferred method of rehabilitation following the onset of LBP (Willardson, 2007a). It is thought that they may reduce the effect of debilitating force generated within the spine during functional movement (Hodges and Richardson, 1996; Hodges and Richardson, 1997; Barr et al., 2005; , Barr et al., 2007).

Traditionally LBP has been seen as a medical problem with a medical approach to management. However, a biopsychosocial model of management may be a more appropriate approach (Waddell et al., 1984). Effective management however, is dependent upon identifying possible ‘red ‘or ‘yellow’ flags which can suggest either serious underlying pathological problems or other factors that may influence the outcome of treatment, respectively (Samanta et al., 2003). Red flags are possible warning signs that the presentation of LBP may be a guise for something more sinister (Table 1.1) (Moffett and McLean, 2006).

Table 1.1: Red flags (Moffett and McLean 2006)

-
- Age of onset <20 or >50 years
 - Violent trauma
 - Constant progressive, non-mechanical pain
 - Thoracic pain
 - Past medical history of malignant tumour
 - Prolonged use of corticosteroids
 - Drug abuse, immunosuppression, HIV
 - Systematically unwell
 - Unexplained weight loss
 - Widespread neurology, including cauda equine
 - Structural deformity
 - Fever
-

Yellow flags (Table 1.2) may influence the mechanism by which an acute onset of LBP can become chronic (Krismer and van Tulder, 2007; Gullick, 2008) but there is no current informed opinion to suggest that these factors may influence an initial onset of LBP.

Table 1.2: Yellow flags (Krismer and van Tulder, 2007; Gullick, 2008)

-
- Belief that pain and activity are harmful
 - Exhibits sickness behaviour
 - Negative moods
 - Effective treatment does not meet best practice
 - Claims and compensation
 - Recurrent claims of low back pain and associated time off work
 - Work issues such as low morale and poor work satisfaction
 - Unsociable working hours and heavy work
 - Overprotective family or lack of support
-

These factors are not considered within this thesis because they will be part of the routine physical assessment used by Physiotherapists as part of the normal treatment process and were part of the exclusion criteria used for recruitment to this study. The red flags indicate that physiotherapy is a contraindication without further investigation and yellow flags indicate caution in treatment.

Most episodes of LBP resolve within 3 months in 90% of cases (Croft et al., 1998) but persistent back pain will resolve by the 6th week following onset (Jayson, 1996; BackCare, 2007) suggesting that although patients are not in distress from the pain for very long periods the effects may never the less be debilitating. Furthermore, it may be that the advice to 'keep mobile' (NICE, 2009) plays an important role in restoring trunk function. It also suggests that any study designed to investigate the effects of an acute onset of non-specific LBP may be difficult because of rapid changes in any intended outcome measure. However, early exercise intervention may not be beneficial because specific back exercises have been demonstrated to increase symptoms in the acute phase of LBP (Atlas and

Deyo, 2001). However, the definition of 'specific exercise' as used by Atlas (2001) is ambiguous and the term 'specific core stability exercise' may be an anomaly because any exercise affecting the 'core' is a core stability exercise (McGill et al., 2003). The 'core' is described as the lumbopelvic region (Willardson, 2007a; Willardson, 2007b).

1.7 Historical beliefs about low back pain

The historical belief is that LBP is caused predominately by structural failure of the spinal column caused by the loading of the spinal column (MacNab and McCulloch, 1990). Spinal stability is important for the prevention and reduction in episodes of acute mechanical LBP (Morgan and King, 1957; Pope and Panjabi, 1985; Panjabi, 1994). The stability mechanism described by Reeves et al. (2007) (section 2.10) may offer an explanation of how the trunk compensates for the effects of axial loading of the spine during functional movement (Reeves et al., 2007). There is increasing inquiry into the efficiency and effectiveness of stability exercises to prevent instability (Koumantakis et al., 2005) in addition to the effects of instability on the changes in kinematics of the spine (Marras and Wongsam, 1986; Kroemer et al., 1990; Marras et al., 1990; Marras, 1996). Unambiguous consensus for the effect of LBP on trunk kinematics is scarce within the current literature.

1.8 Diagnostic imaging

Diagnostic applications may be of use when they can compliment an objective history. There are different diagnostic tools for LBP (Table 1.3) (Patel, 2004). Each tool has its advantages and disadvantages.

Table 1.3: Diagnostic tools for low back pain (from Patel, 2004)

Test	Advantages	Disadvantages	Indications for Use
X-Rays	<ul style="list-style-type: none"> ▪ Simple ▪ Economical ▪ Fast ▪ Efficient 	<ul style="list-style-type: none"> ▪ Outcome measures less reliable ▪ One dimensional ▪ Definitive diagnosis elusive 	<ul style="list-style-type: none"> ▪ Spodylolisthesis ▪ Compression fractures ▪ Spinal alignment and curvature analysis
Computerised Tomography Scan (CT scan)	<ul style="list-style-type: none"> ▪ Can perform Soft tissue analysis ▪ Can perform Fluid analysis (e.g Blood) 	<ul style="list-style-type: none"> ▪ Poor value for the evaluation of post-operative complications ▪ Differentiation of soft tissue planes not clear ▪ Poor evaluation of early degenerative changes 	<ul style="list-style-type: none"> ▪ Spinal canal deficiencies ▪ Neuroforaminal stenosis ▪ Lumbar disc protrusions, extrusions and sequestration ▪ Arthropathies (e.g facet joint dysfunction)
Magnetic Resonance Imaging (MRI)	<ul style="list-style-type: none"> • It provides Clear definition of structures • Very low levels of radiation 	<ul style="list-style-type: none"> • Intimidating environment 	<ul style="list-style-type: none"> • Lumbar Intervertebral Disc deficiencies • Evaluation of neural tissue • Soft tissue differentiation (e.g epidural scar Vs recurrent or residual disc herniation) • Spinal cord compression
Single-Photon Emission Computed Tomography (SPECT)	<ul style="list-style-type: none"> • Can be used effectively when bone abnormality is suspected • High levels of accuracy 	<ul style="list-style-type: none"> • Role within diagnostic imaging still controversial 	<ul style="list-style-type: none"> • Spondylodiscitis • Metastatic lesion • Fractures involving the Vertebrae • Degenerative disease • Spodyllysis • Facet joint osteoarthritis
Discography	<ul style="list-style-type: none"> • Localised • Can provide accurate diagnosis 	<ul style="list-style-type: none"> • Procedure is provocative • Only skilled Physicians can perform test • Can have side effects (Discitis) 	<ul style="list-style-type: none"> • Intervertebral disc dysfunction

X-RAY

Historically the first tool of choice for investigating an onset of LBP is the X-Ray, which can identify problems associated with changes in bone density such as osteoporosis (Fig. 1.1) (Yu, 2001).

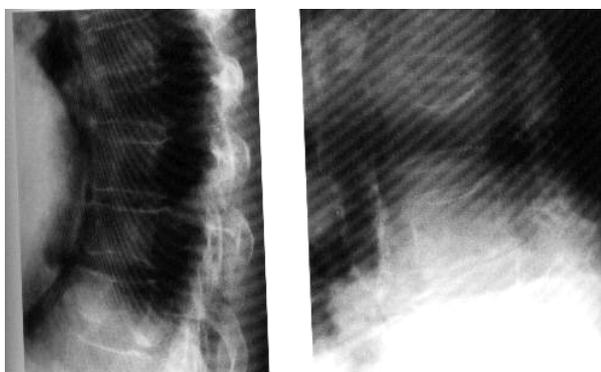


Fig. 1.1: Osteoporosis (from Yu, 2001)

Changes in structural positional relationships may also be investigated (Yu, 2001), for example spondylolisthesis when a vertebral body has migrated forwards in relation to an adjacent vertebral body (Fig. 1.2).

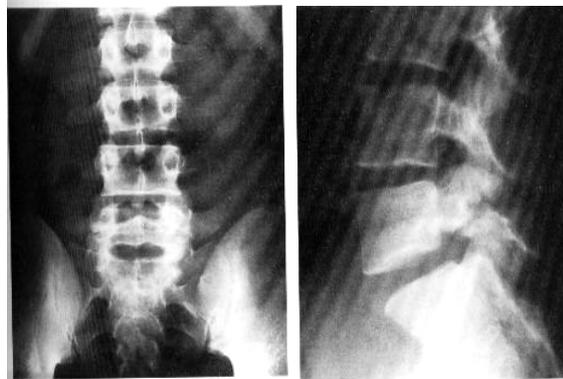


Fig. 1.2: Spondylolisthesis (from Yu, 2001)

The usefulness of this diagnostic tool is unclear because of the relationship between the subjective psychological wellbeing of the patient and any subsequent request for imaging (Lurie, 2005); the greater the discomfort the greater the possibility for an X-ray request. But although there is evidence to suggest high levels of satisfaction within this group of patients there is prolonged care and greater reported disability three months after the initial onset (Lurie, 2005). Inappropriate X-ray requests may also result in increased risk radiation induced side effects (van den Bosch et al., 2004). 66% of the over 55 year olds will demonstrate degenerative change, the use of X-rays is therefore often unjustified (van den Bosch et al., 2004). The use of X-ray imaging for acute non-specific LBP as described later in section 1.9 may therefore be debatable.

Computerised Tomography Scan (CT scan)

CT scans provide much more detail than X-rays by analysing soft tissue as well as bone mass (Semelka et al., 2007). It is however the largest contributor of man-made radiation doses (Semelka et al., 2007) but its use to identify the

effectiveness of posterolateral fusion of the spine demonstrated its effectiveness in predicting the presence of any non-union of this aspect of the spine (Carreon et al., 2007). The CT scan can therefore be advantageous when an episode of LBP may be suspected to involve an inflammatory process.

Magnetic Resonance Imaging (MRI)

The MRI is considered to be the gold standard diagnostic tool because of the low levels of radiation emitted and the ability to distinguish both soft tissue and bone mass (Patel, 2004). However the MRI has limitations (Carragee et al., 2006). The MRI cannot provide evidence to suggest that observed changes are responsible for reported symptoms and a scan before 12 weeks post onset is unreliable because no structural changes can be observed before that time frame (Carragee et al., 2006).

1.9 Differential diagnosis

Effective clinical diagnosis is dependent upon an understanding of the 24 hour pattern of pain as part of the assessment process (Petty, 2006). Different underlying problems may generate similar symptoms (Lurie, 2005). The common various differential diagnoses are illustrated below (Table 1.4),

Table 1.4: Low back pain differential diagnosis (from Lurie, 2005)

Regional Mechanical LBP	Non- Specific (Sprain, strain etc) Degenerative changes (Intervertebral discs, facet joints) Fractures (Osteoporosis, trauma) Deformity (Scoliosis, Kyphosis) Symptomatic Spondylolisthesis
Mechanical LBP with neurogenic leg pain	Prolapsed Intervertebral disc Spinal stenosis Spinal stenosis resulting from spondylolisthesis
Non-mechanical LBP	Neoplasia (Metastases, lymphoid tumours, spinal cord tumours) Infection (Infective spondylitis, epidural abscess, endocarditis, herpes zoster, Lyme disease) Seronegative spondyloarthritides (Ankylosing Spondylitis, psoriatic arthritis, reactive arthritis, Reiter's Syndrome, inflammatory bowel disease)
Visceral disease	Pelvic problems (Prostatitis, endometriosis, pelvic inflammatory disease) Renal problems (Nephrolithiasis, pyelonephritis, renal papillary necrosis) Aortic aneurysm Gastrointestinal problems (Pancreatitis, cholecystitis, peptic ulcer disease)
Miscellaneous	Parathyroid disease Hemoglobinopathies

1.10 Non-specific low back pain

Response to LBP differs according to ethnicity (Campbell and Muncer, 2005) and patients who are unyielding for the need to 'cure' their pain present with numerous secondary issues associated with acute LBP (Campbell and Muncer, 2005). Similarly anecdotal evidence suggests that this subgroup along with colleagues in the medical professions with an episode of LBP make the worst patients as they appear to be sceptical of intervention and the outcome.

Low Back Pain can be classified in terms of its association with a specific disorder or not, that is, whether it is organic or inorganic (Waddell et al., 1984; Waddell, 1987). In the absence of underlying organic abnormality LBP is referred to as being non-specific (Waddell et al., 1984; Waddell, 1987).

1.11 Factors influencing the onset of non-specific low back pain

Non-specific LBP is the most common type of LBP seen in primary care, accounting for almost 95% of all reported cases (Gullick, 2008).

The prognosis for non-specific LBP is poor because of a lack of consistent outcome measures for its treatment (Gullick, 2008). Previous work evaluating trunk movement suggests that this problem may be overcome by using trunk kinematics rather than strength as an outcome measure (Koumantakis et al., 2005; Marras and Wongsam, 1986).

Logic suggests that there is a causal relationship between trunk structural failure and the onset of pain. The direct relationship between movement and force production (Ogrodnik, 1997c) suggests that specific exercises designed to improve the integrity of trunk movement will reduce the effects of the force produced. Furthermore reoccurrence may be due to a failure to restore this capability following an episode of LBP. This is relevant because it is not possible to predict the reoccurrence of onset of LBP from an earlier prognosis (Kent and Keating, 2004).

1.12 Assessment of non-specific low back pain

Management of LBP requires a good clinical assessment however this process may vary according to the experience of the clinician (Doody and McAteer, 2002). The reliability of some of the tests used for objective assessment, for example, the straight leg raise (SLR) in testing nerve root compromise is not reliable (Gullick, 2008). However both the subjective and objective history as part of the assessment is inextricably linked (van den Hoogen et al. 1995; Gullick, 2008; van Tulder et al., 2008). But it is suggested that tests that do not provide reproducible diagnostic value ought to be abandoned (Lurie, 2005). Poor outcome measures for intervention however may be a net result of poor definition of subgroups for LBP (Borkan et al., 1998).

1.13 Functional anatomy of the lumbar spine

The smallest functional part of the spine is the movement segment (Alam, 2002). Each movement segment consists of two adjacent vertebra connected by two facet joints posteriorly and the intervertebral discs (IVD) anteriorly (Alam, 2002). The body of the vertebra is designed to carry load and in adults has an epiphysial ring (a layer of cortical bone) that acts as a growth zone in the young but becomes a point of attachment for the intervertebral disc in adulthood (MacNab and McCulloch, 1990). A layer of hyaline cartilage lies within this epiphysial ring and together these two structures form the end plate (MacNab and McCulloch, 1990).

The spine of each vertebra provides a location for the attachment of the interspinous ligament and the articulating surfaces of each vertebra are found at the end of the articular pillar, the end of which forms the facet joints. Transverse processes protrude from the articular pillar to provide a location for muscular attachment (Fig 1.3) (Martini et al., 1995).

Each end plate (Upper or lower) has a characteristic curvature which is concave in humans and has an important role in load distribution (Langrana et al., 2006). The location for the maximum warp of the curvature is dependent upon the stress distribution on the vertebrae (Langrana et al., 2006).

The Transversus Abdominis and Multifidus muscles play an active role in maintaining with trunk stability (Hodges and Richardson 1996; Hodges and Richardson, 1997) (Figs. 1.4 and 1.5)

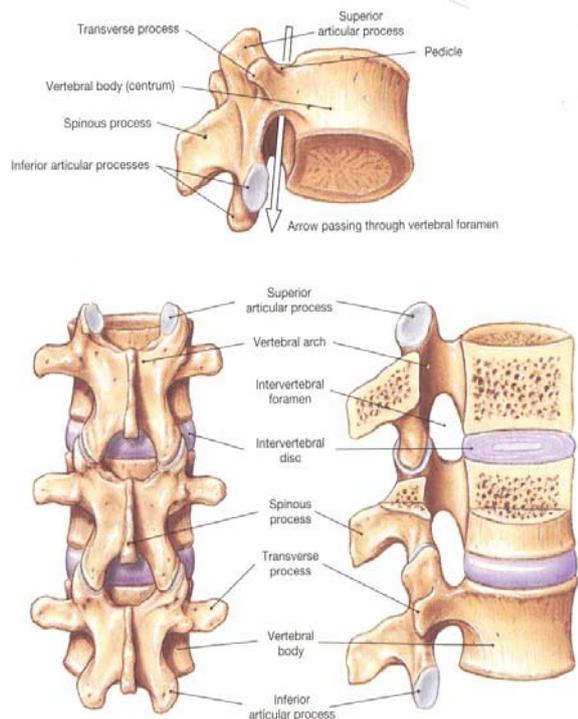


Fig. 1.3: Description of the lumbar spine (from Martini et al., 1995)

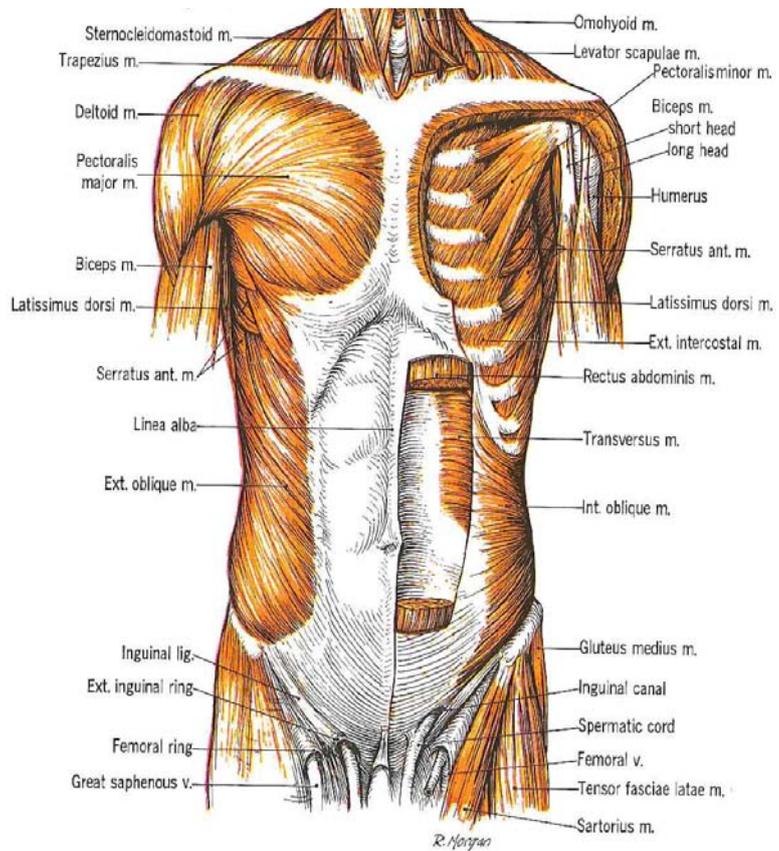


Fig. 1.4: Transversus Abdominis (From Basmajian, 1976)

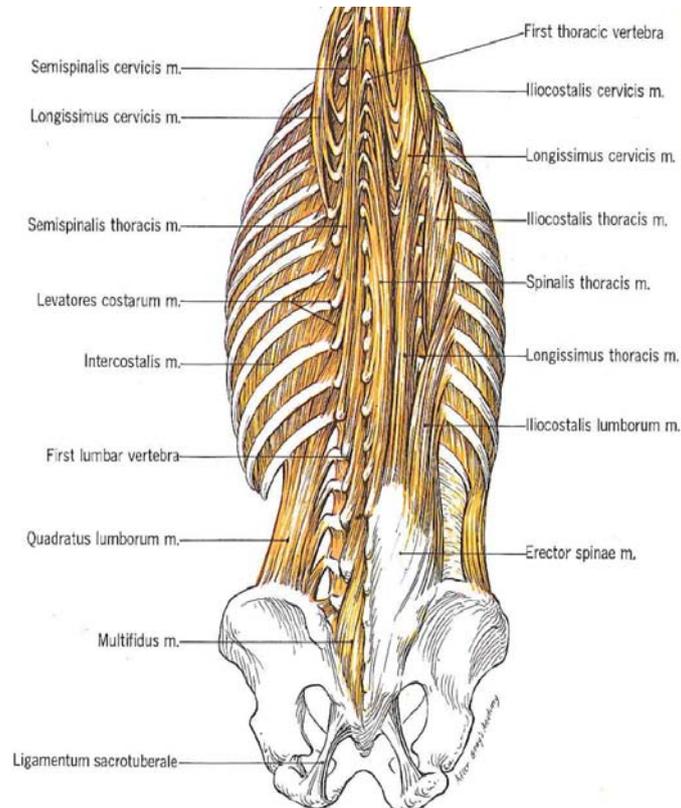


Fig. 1.5 Multifidus muscles (From Basmajian, 1976)

A study of vertebral segment movement demonstrated that posterior-anterior pressure (PA), the ‘Maitland’ concept (Grieve, 1984; Petty, 2006), on the spine of vertebrae in the lumbar region produces most movement at L1/2 in asymptomatic individuals in contrast with symptomatic individuals who demonstrated most movement at L2/3 (Kulig et al., 2007). The least amount of movement occurred in both asymptomatic and symptomatic subjects at L4/5 (Kulig et al., 2007). Active repetitive movements designed to produce centralisation of pain based upon the ‘McKenzie’ concept (Moffett and McLean, 2006) produces most movement at L5/S1 and L4/5 in the asymptomatic and symptomatic subjects respectively with the least movement occurring at L1/2 in both groups of subjects (Kulig et al., 2007). The ‘McKenzie’ concept may therefore be more relevant and effective when dealing with LBP associated with hypo-mobility involving L5/S1, however, the overall success of the technique may be limited by symptoms (Kulig et

al., 2007). There is paucity of literature to adequately demonstrate vertebral segment movement during trunk flexion activity.

1.14 Facet joints

Facet joints are part of the stabilising structures during flexion movements of the spine (Alam, 2002). This stability is achieved by using a ‘hook’ mechanism derived from the angle at which the adjacent surfaces of the joint lie (Alam, 2002). Each joint within the trunk inclines at 90 degrees above the horizontal plane and deviates 45 degrees behind the frontal plane (Whiting and Zernicke, 1998b). The joint surface allows a gliding/sliding movement with the outermost fibres of the annulus fibrosus of the intervertebral discs playing a part in the overall control of the amount of movement produced (Whiting and Zernicke, 1998b). Faults within this mechanism predispose the lumbar spine to instability during functional movement (MacNab and McCulloch 1990). The distinct orientation of the surfaces of the facet joints limit rotation about a vertical axis (Watkins, 1999) and an understanding of the implications of this alignment is useful when evaluating episodes of LBP associated with facet joint dysfunction. However, the relationship between objective findings suggesting facet joint dysfunction and reported symptoms remains unclear (Atlas and Deyo 2001).

The intervertebral discs (IVD) are protected from strain by reducing excessive functional rotation through the ability of the upper lumbar facet joints to cope with axial displacements (Boyling and Jull, 2004). However, the lower down the spine the facet joint is located within the lumbar spine, its orientation alters making those lower facets more susceptible to damage compared to the facet

joints located higher up (Fig 1.6) (Boyling and Jull, 2004). This change in orientation may follow the change in the natural curvatures of the spine in an erect posture.

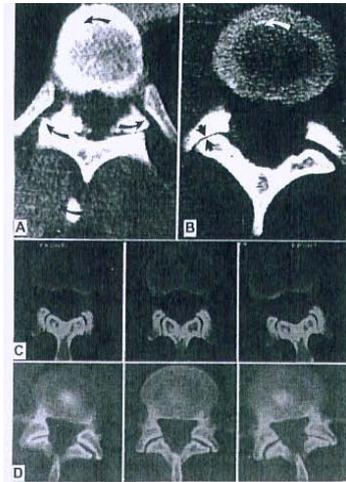


Fig. 1.6: Facet joint orientation comparing Thoracic and Lumbar spine (from Boyling and Jull, 2004)

Rotational movements of the lumbar spine (Fig. 1.6 B) produce less facet joint displacement compared to the thoracic spine (Fig. 1.6 A). The upper regions of the lumbar vertebrae (L1-4), (Fig 1.6 C) demonstrate less compression and separation when compared to L4/5 segment (Fig 1.6 D). The variation in joint orientation may therefore influence effectiveness of physiotherapy treatment when objective signs suggest a problem in either the upper or lower parts of the lumbar spine.

Flexion and extension can either reduce or increase compression forces on the facet joints, respectively, with corresponding reduction or increases in the load on the articular pillar (Watkins, 1999). Long periods of standing can produce low back pain because of trunk lordotic position with L4 and L5 making an angle of 15 and 25 degrees respectively, to the horizontal (Watkins, 1999).

Repeated micro trauma such as an impingement associated with excessive loading and consequential stress on the articular pillar can result in spondylosis (Yu,

2001). Spondylosis increases with age and commonly affects L4 and L5 in 5% of the general population (Yu, 2001). Anecdotal evidence suggests that this is the main cause of LBP of insidious onset in an age group within which natural degenerative change is occurring.

During trunk flexion movements in a cadaveric spine caudal facet joints experience the most moment force and horizontal strain caused by displacement and this strain is more than the vertical strain at the same levels (Ianuzzi et al., 2004). During extension however, there is more vertical strain (mainly at L5/S1) than horizontal strain (Ianuzzi et al., 2004). The intervertebral angle (IVA) is greatest at L5/S1 during flexion/extension but it is greatest at L3/4 during side bending (Ianuzzi et al., 2004). Such research evidence is informative, but limited, as it has been obtained from experiments on cadavers. These movement characteristics however differ from the left to the right side (Ianuzzi et al., 2004). There is paucity of literature demonstrating similar trunk movement characteristics in vivo. However, it has been demonstrated that during flexion, deformation of the lower intervertebral discs occurs before that of the upper discs but during extension from flexion there is little evidence to suggest that deformation occurs at all (Kanayama et al., 1995). However, during extension from the neutral position deformation is mainly at L5/S1 (Kanayama et al., 1995).

Facet joints are important for both the quality and quantity of trunk movement because removal of the posterior elements of a movement segment decreases the resistance to rotation by 40-60% (Boyling and Jull, 2004).

15-40% of chronic LBP is associated with facet joint pathology but the routine method of extension-rotation to test facet joint integrity has only 12% specificity

even though it does have a 100% sensitivity rating (Laslett et al., 2006). The reliability of the traditional method of palpation is also poor because the reliability between examiners of locating facet joints is low (Najm et al., 2003).

Each facet joint derives its nerve innervation from the medial branches the dorsal ramus of the adjacent spinal nerve (Boyling and Jull 2004). Some localised acute back pain may originate because the intra-articular synovial folds and joint capsule share the same innervation and may offer an explanation as to why these types of back pain respond to manipulation (Boyling and Jull, 2004).

1.15 Intervertebral discs (IVD)

Lumbar intervertebral discs (IVD) (Fig. 1.7) are between 7-10mm thick with an anterior –posterior diameter of approximately 4cm (Urban and Roberts, 2003). Each IVD has an outer annulus fibrosus (AF) and an inner nucleus pulposus (NP); the boundaries of which are distinct in the young but degeneration occurs specifically compared with other soft tissue of the musculoskeletal system (Urban and Roberts, 2003). Although the degenerative process can be asymptomatic, it is linked to the onset of LBP (Urban and Roberts, 2003).

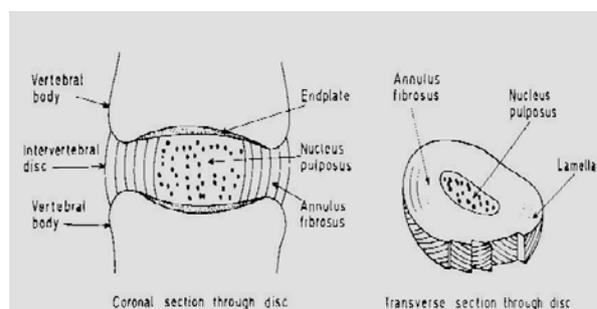


Fig.1.7: The Intervertebral disc (IVD) (from Holm, 1996)

The nucleus pulposus is a proteoglycan matrix with high water content (Giles and Singer, 1997; Boyling and Jull, 2004) but collagen content increases with

maturity (Giles and Singer, 1997). The NP occupies approximately 75% of the disc space and is surrounded by the AF consisting of collagen fibres or lamellae, arranged at an angle of approximately 65° to the vertical and arranged in alternate directions (Boyling and Jull, 2004). This arrangement provides an ideal mechanism to resist rotational forces (Boyling and Jull, 2004). The thickness of the lamellae vary depending upon their position with the thicker fibres found in the anterior and lateral aspects (Boyling and Jull, 2004). Posterior fibres are more closely packed together than other areas of the disc with 50% in the posterolateral aspect appearing as incomplete rings (Boyling and Jull 2004).

There are two layers of lamellae, each with a specific role in the overall biomechanics of the IVD; an outer layer links adjacent vertebrae, limiting movement between them and an inner layer that links adjacent end-plates, providing a capsule for the NP (Boyling and Jull, 2004).

The integrity of the IVD can become compromised by either of two ways (Fig. 1.8).

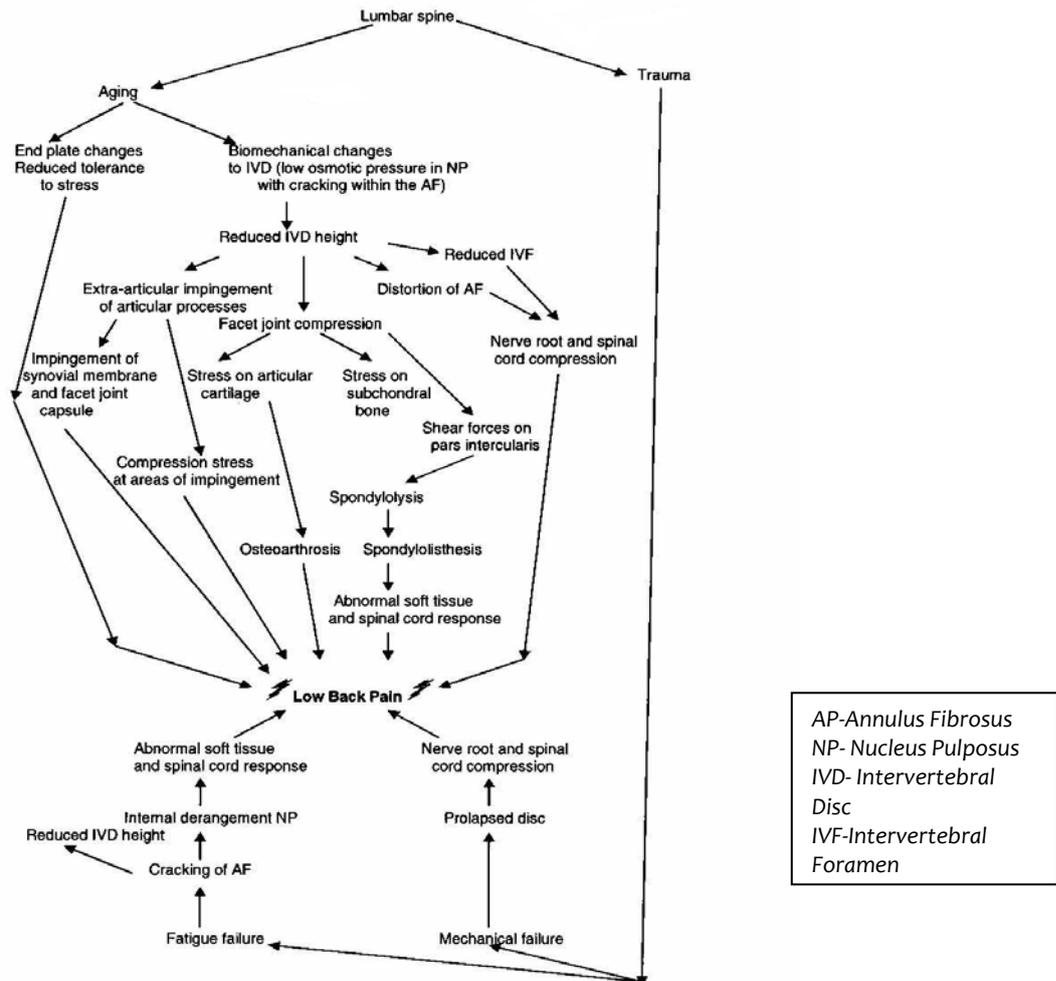


Fig. 1.8: Loss of IVD integrity (from Watkins, 1999)

The IVD can be compromised because of the relationship between loss of structural integrity of the IVD and crystal deposits found within the disc (Gruber et al., 2007). The resulting loss of disc height may alter trunk movement characteristics and influence an onset of symptoms of LBP. This is because as the disc loses height, the articular surfaces experience greater compression and stress as discussed earlier within this chapter (Gruber et al., 2007).

1.16 Finite-element modelling

Finite-element modelling developed by and for engineers in the mid 1950's as a method of simulating structural behaviour allows the investigation of tissue response to external forces (Whiting and Zernicke, 1998a). Complex mathematical

calculations can be used to predict structural deformation caused by stress and strains as a result of loading on the spine but finite element modelling can also provide volumetric representation of the spine under stress/strain (Liebschner et al., 2003). The technique has been used to demonstrate the response of facet joints and the behaviour of the motion segment to compression forces (Gardner-Morse and Stokes, 2004). It was shown that the load-displacement behaviour of facet joints depends upon the axial compressive pre-load to maintain movement segment stiffness during antero-posterior shear (Gardner-Morse and Stokes, 2004). The behaviour of the movement segment to compression does not change when the posterior articulating parts (including the facet joints) were removed suggesting that the response is solely due to the intervertebral disc (Gardner-Morse and Stokes, 2004).

Finite-element modelling has been used to provide evidence for how facet joints play a role in the stability of the spine (Panjabi, 1994) demonstrating that the centre of rotation of these joints migrate in response to forces applied to the segment (Schmidt et al., 2008). The centre of rotation migrates outside the intervertebral disc when the force is at its maximum (Schmidt et al., 2008).

During axial loading of the spine a vertebral body is damaged before an intervertebral disc will be damaged (MacNab and McCulloch, 1990). Finite-element modelling has been used to demonstrate this response in a healthy spine (Tabor et al., 2005) (Fig 1.8). The resilience of the spine during activities such as lifting or carrying a heavy load is demonstrated below with the accompanying scale suggesting that the greatest loading occurs at the lower region of the spine (L5) (Fig 1.9) (Tabor et al., 2005).

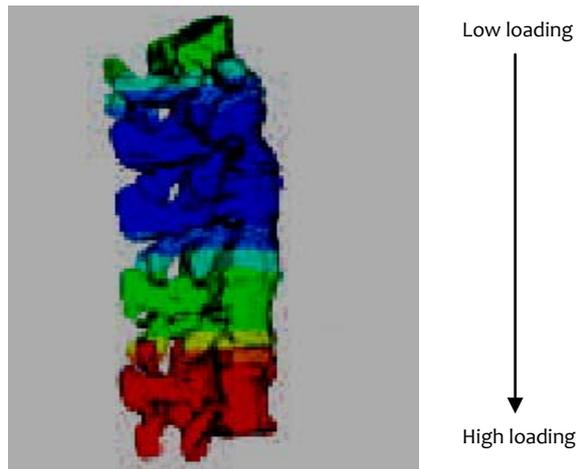


Fig. 1.9: Finite-element imaging of the loaded spine (from Tabor et al., 2005)

1.17 Skeletal muscle physiology

Actin and myosin are the main two proteins responsible for the contractile properties of skeletal muscle and is approximately 80% of all protein found within it (Jones and Round, 1990). A longitudinal section of the smallest contractile unit (the myofibril) demonstrates an arrangement of light and dark bands (Fig 1.10).

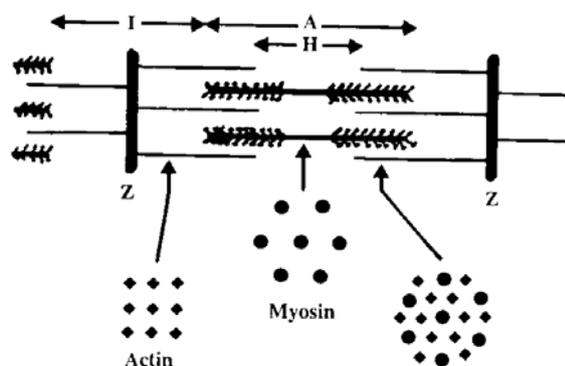


Fig. 1.10: Section of skeletal muscle (from Jones and Round, 1990)

During muscle contraction polymerisation of the actin gives it a double helix appearance. During polymerisation adenosine tri-phosphate (ATP) splits and binding with adenosine bi-phosphate (ADP) occurs (Jones and Round, 1990).

Tropomyosin which is also a double helix structure is found across every 7 subunits of actin and has a main function of preventing contact between the actin and myosin until movement brings them into close proximity when calcium binds with troponin C a constituent of three smaller proteins (troponin I, C and T) also found within muscle (Jones and Round, 1990).

Actin filaments join together to form the z- line and the distance between z- lines is the sarcomere, the length of which changes during muscle contraction (Jones and Round, 1990). The process of actin and myosin binding involves the actin filaments sliding between the myosin filaments. This mechanism is known as the 'sliding theory' of muscle contraction (Jones and Round, 1990).

The functional unit of skeletal muscle is the motor unit (Jones and Round, 1990; Watkins, 1999). Each motor unit is made up of a motor neurone, its axon and all its branches and the muscle fibres that are attached to them (Fig 1.11). The branches may be from either an A α or an A β motor neuron. A contraction is precipitated when an action potential (AP) elicited by the motor neuron is transmitted along the axon and its branches to reach the neuromuscular junction or end plate to produce a muscle response (Jones and Round, 1990; Watkins 1999).

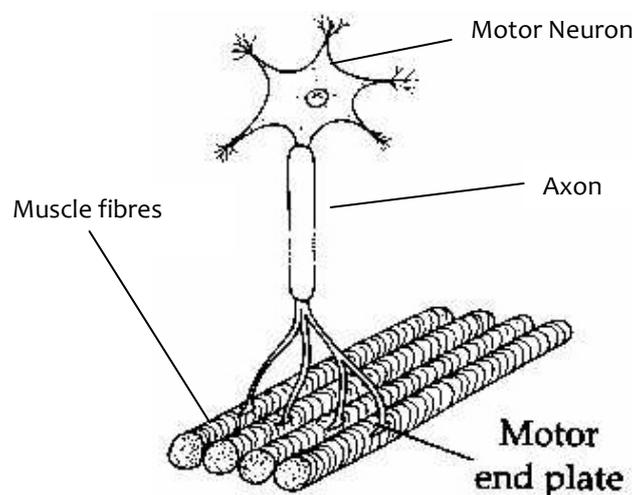


Fig. 1.11: The motor unit (from Watkins, 1999)

If the AP is large enough and/or prolonged enough individual twitches combine to form a contraction (Watkins, 1999). There are three types of motor units each with unique properties that can be activated by stimuli (Table 1.5) (Watkins, 1999).

Table 1.5: Motor unit characteristics adapted from Watkins (1999)

	Slow twitch	Fast twitch (Fatigue Resistant)	Fast twitch (Fatigable)
Activation threshold	Low	Moderate	High
Contraction time (ms)	100-120	40-45	40-45
Innervation ratio of motor units	Low	Moderate	High
Type of muscle fibres	1	2a	2b
Type of Axon	A β	A α	A α
Speed (m/s)	40-80	65-120	65-120
Duration and size of force	Prolonged Low force	Prolonged Relatively high force	Intermittent High force

There are equal proportions of both slow and fast twitch motor units in each muscle however the ratio may vary according to the action of the muscle (Jones and Round, 1990; Watkins, 1999). Muscles used for fast responses possess a greater number of fast twitch than slow twitch motor units and in muscles responsible for posture and prolonged activity there are greater number of slow twitch motor units (Jones and Round, 1990; Watkins, 1999).

The innervation ratio of motor units is the ratio between the numbers of muscle fibres per axon and the greater the ratio the greater the force produced by its activation (Watkins, 1999). Trunk muscle group activation and the sequence of activation is ambiguous (Barr et al., 2007). It is suggested that the Transversus Abdominis (TA) and Multifidus (MF) are activated first to maintain stability of the spine during movement of the extremities but the TA is activated before the MF (Barr et al., 2005). However, trunk stability is achieved through a tripartite arrangement involving three sub-systems; the passive (bones, IVD and ligaments),

the active (muscles) and the neural (sensory receptors, cortical and sub-cortical controls) (Panjabi, 1994). A 20lb load is sufficient to cause the collapse of the spine if the muscles are removed (Crisco, 1989). Muscle response to pain is by either a 'pain-spasm-pain' or 'pain adaptation' model (van Dieen et al., 2003).

1.18 The pain-spasm-pain model

Pain causes a muscular response which creates further pain and discomfort (van Dieen et al., 2003). This model is elicited by either of two ways (Fig. 1.12).

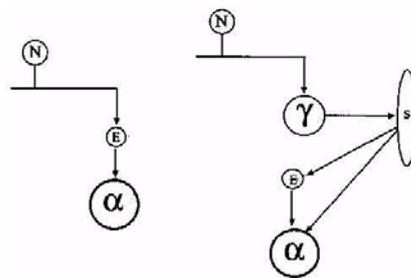


Fig. 1.12: The pain-spasm-pain model (from van Dieen et al., 2003)

Nociceptor activity (N) via the posterior horn influences the brain through the neural pathway simultaneously increasing muscle activity by causing excitation (E) of the α -neurons at the level of the segment of the spine which they supply (Johansson and Sojka, 1991). Alternatively the nociceptors (N) increase muscle spindle (S) activity via γ -afferents. This hyperactivity proceeds to excite the α -neurons (Johansson and Sojka, 1991).

1.19 The pain-adaptation model

The excitation of both inhibitory (I) and excitatory (E) interneurons results in a process where pain reduces agonist muscle group activity simultaneously increasing antagonist muscle group activity (van Dieen et al., 2003). This process is controlled by the central nervous system through motor command (Fig. 1.13) (van Dieen et al., 2003).

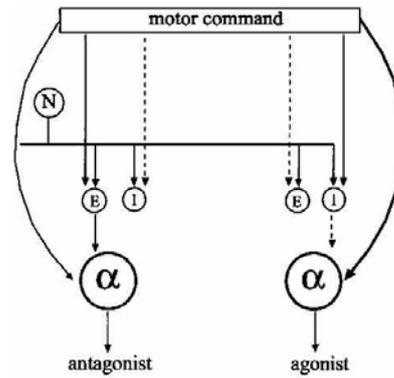


Fig. 1.13: The Pain adaptation model (from van Dieen et al., 2003)

It is not clear as to how this model may fit in with the complex nature of the synergy demonstrated by trunk muscles because studies suggesting this model have only used large muscles such as the gastrocnemius (Graven-Nielson et al., 1997). However this model may result in a reduction in movement velocity in the spine (van Tulder et al., 2000).

1.20 Biomechanical properties of the lumbar spine

The restoration of trunk stability using core stability exercises (CSE) is increasing in popularity (Willardson, 2007a; Willardson, 2007b). The effectiveness of CSE is uncertain (Standaert and Herring, 2007; Standaert et al., 2008). However trunk biomechanical characteristics are influenced by non-specific LBP (Barr et al. 2005; Barr et al., 2007).

1.21 Trunk stability

There is no definitive definition of trunk stability. However several studies have described 'Instability' as being a phenomenon resulting from applied loads causing abnormal movement of the movement segment (Panjabi, 1994; Fritz et al., 1998; O'Sullivan, 2000; Alam, 2002). Mechanisms for stability have also been

suggested as the tripartite arrangement described earlier (section 1.15) (Panjabi, 1994; Barr et al., 2005; Barr et al., 2007).

Radiological tests demonstrate that traction spurs, IVD space narrowing, asymmetric collapse of the IVD, mal-alignment of associated vertebrae and abnormal glide and rotational movements of the spine during flexion and extension can be evidence of instability (Alam, 2002). It has been proposed that specific stabilisation exercises were not effective in reducing pain and disability in acute LBP but may be effective in reducing reoccurrence after an episode (Ferriera et al., 2006) however they are more effective than other forms of active intervention for the management of chronic LBP (May and Johnson, 2008).

Trunk stability is dependent upon 3 sub-systems- passive, active and neural control systems (Panjabi, 1994; Fritz et al., 1998) (Fig 1.14).

The passive subsystem consists of the IVD, ligaments and facets (Fig 1.14). The annulus fibrosus of the IVD portrays a unique arrangement of fibres, an orientation of +30 to -30 degrees in adjacent laminae which provides stability to counter axial torque and excessive lateral flexion (Panjabi, 1994). Injuries to the annulus may cause pain and discomfort in a single direction whereas the injury to the nucleus pulposus may be identified by pain and discomfort during multidirectional movements (Panjabi, 1994).

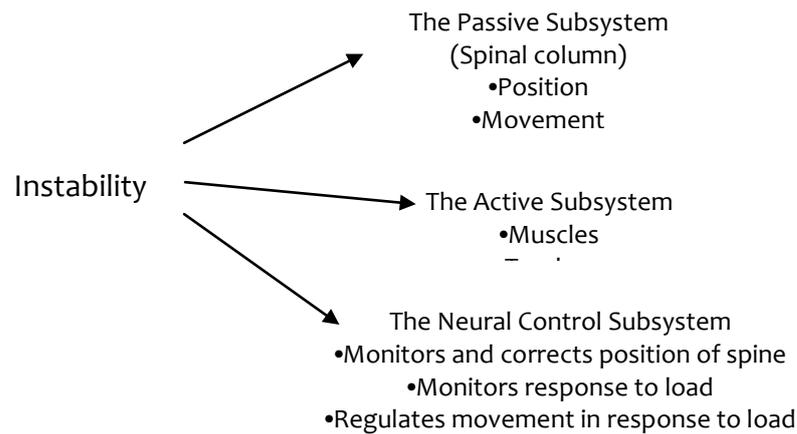


Fig. 1.14: Trunk stability sub-systems

Ligaments provide trunk stability but their efficiency is dependent upon the size of the ligament in terms of its length and cross sectional area, its location from the centre of movement of the segment and the direction of movement it is supposed to regulate (Panjabi, 1994). Facet joint hypertrophy as the spine degenerates through a natural ageing process is also considered to be a cause of LBP (Panjabi, 1994) and it has been demonstrated that the removal of just one facet joint within a segment exposes the segment to significant to multidirectional instability (Abumi et al., 1990).

Muscles are important for trunk stability (Fig 1.15) (Panjabi, 1994). The ratio of tolerable physiological load to critical load that will result in the spinal column collapse is approximately 17:1 when in the flexed position of 20 degrees (Nachemson and Morris, 1964; Crisco, 1989). This is prevented by muscles exhibiting similar characteristics to guy wires (Panjabi, 1994). These characteristics are assisted by the large cross sectional area of the muscles around the low back region and their large lever arms (Panjabi, 1994). Trunk muscles either produce movement or inhibit it, a process that provides spinal control (Norris, 1995). Muscles are grouped as either global muscles responsible for gross movement of the spine or deep local

muscles responsible for segmental adjustments required to maintain local stability (Barr et al., 2005). However, specific exercise is not beneficial as a treatment for LBP in the absence of any clinical signs suggesting instability (Koumantakis et al., 2005; Ferriera et al., 2006).

Exercise for the management of LBP using the large muscles with large lever arms, such as back extension exercises in the prone position can cause an exacerbation of symptoms in some patients (Callaghan et al., 1998). They may therefore not be appropriate if the source of the LBP involves a nucleus pulposus which does not tolerate multidirectional movement (Kanayama et al., 1995). The aforementioned exercise also increases the stress on the facet joints (Callaghan et al., 1998).

Tendons are an integral part of the muscle system operating across the lumbar spine and are inaccessible by non-invasive techniques. They contain similar structural composition as other soft tissue and as such exhibit similar viscoelastic properties of stress, strain and fatigue etc. (Watkins, 1999).

The neural control subsystem is responsible for the control and regulation of the other two sub-systems (Fritz et al., 1998). Neural input is provided by both the lower centre of the spinal cord through reflex loops and from the brain that has the capacity to override instruction from the spinal cord (Fritz et al., 1998). Poor neuromuscular control can result in recurrent episodes of LBP but there is no current evidence to suggest that poor neuromuscular control pre-empts a first episode of LBP (Fritz et al., 1998). However, it is suggested that inadequacies in this subsystem can reduce the ability of the spine to anticipate the effect of applied load as demonstrated by Multifidus and Transversus Abdominis activity preceding active

limb movements in the absence of LBP (Hodges and Richardson, 1996; Hodges and Richardson, 1997) but alterations to this sequence of events are evident in chronic LBP (Barr et al., 2007). It is therefore possible to differentiate pain and disability associated with either psychosomatic pain or somatopsychic pain because the latter will demonstrate alterations in activation of either or both the Transversus Abdominis and Multifidus muscle groups (Hodges and Richardson, 1996; Hodges and Richardson, 1997).

A load-displacement curve for trunk flexion-extension movements (Fig 1.15) demonstrates trunk biomechanical characteristics in response to load.

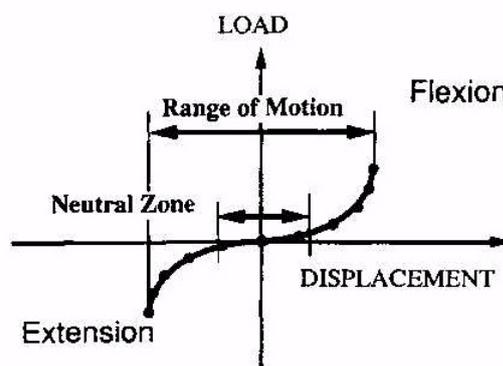


Fig. 1.15: Load-displacement curve (from Panjabi, 1994)

The spine is flexible enough to low loads but stiffens to high load (Panjabi, 1994). This is demonstrated by a non-linear curve which suggests two distinct areas of a neutral zone where the segment is providing very little resistance and an actual range of movement zone (Fig. 1.15). If the neutral zone is greater than the actual range of movement zone instability results with the likelihood of accompanying pain (Panjabi, 1994).

1.22 Effects of force on the spine

When the spine is subjected to loading the activity of all the components of the spinal column compliment each other (Cripton et al., 2000). Their response

however, varies according to tissue type and the amount of force applied (Cripton et al., 2000). The stability of the spinal movement segment is dependent upon the IVD (Cripton et al., 2000) and the nucleus pulposus has a major role within this mechanism (Nachemson, 1981).

The pressure within the nucleus pulposus is expressed in mathematical terms as;

$$P_{(\text{nucleus pulposus})} = K (F_{(\text{disc})} / A_{(\text{disc})}) \text{ (Nachemson, 1981)}$$

($F_{(\text{disc})}$ - vertical force applied to the IVD, $A_{(\text{disc})}$ - surface area and K- coefficient [between 1.3 and 1.6])

The intradiscal pressure is greatest during trunk flexion when compared to side flexion or extension (Cripton et al., 2000). This response creates more pain in the early morning compared to the latter parts of the day because of the hydrophilic nature of the disc material (Giles and Singer 1997; Boyling and Jull, 2004) and the gradual loss of fluid caused by the effects of gravity when in an erect position.

Anecdotal evidence suggests that lumbar traction has been used for many years to treat LBP caused by an increase in intradiscal pressure. However the mechanism by which this works remains unsubstantiated because it is thought that the beneficial effect of the technique does not last for longer than 30 minutes following application (Twomey, 1985). The process involves the application of axial load to distract the movement segments. The efficiency and overall affect of the lumbar traction is dependent upon two main factors;

- The position of the patient in order for the load to be applied; either with the hips and knees in 90 degrees of flexion or not. The former is

described as the Fowler position and considered to be the most effective (Lee and Evans, 2001).

- The angle at which the load is applied to the spine. For effective coupling of forces this angle is approximately 18 degrees (Colachis and Strohm, 1969).

Lumbar traction is applied in the Fowler position; crook lying with the knees supported in 90 degrees of flexion, to produce an anterior shear with simultaneous flexion of the movement segments to increase the size of the neural foramina (Lee and Evans, 2001). There is also a reduction in tension within the posterior column of the spine including the posterior fibres of the annulus fibrosus (Lee and Evans, 2001).

Lumbar traction also affects facet joints (Ianuzzi et al., 2004). Because of the angle to which they lie and because facet joints are sliding joints there is a tendency for the contact area between the surfaces to be reduced (Ianuzzi et al., 2004). This effect is limited by the capsule and associated ligaments (Ianuzzi et al., 2004) but the force applied can produce shear strain between the surfaces (Ogrodnik, 1997a; Watkins, 1999).

However compressive force causes the spine to shrink as a result of either flexion or to a lesser degree rotation of the vertebrae (Wisleder et al., 2001). There are however only a few instances where true compression actually occurs (Wisleder et al., 2001) but there is usually extension between L2 and L4 and flexion at L5 (Wisleder et al., 2001). There is simultaneous anterior shear at these levels with a corresponding loss of lumbar lordosis (Lee and Evans, 2001). However, the net effect of compression may be exaggerated by torque as demonstrated in a study

using the cervical spine. It was demonstrated that torque grossly affects tissue response to axial loading because the majority of damage occurs at the end plates as the vertebral body with the facet joints remaining relatively unscathed even though the overall stability of the movement segment is jeopardised (Aultman et al., 2004).

Because of the tendency for the segments L2-4 to extend in response to compressive loading (Wisleder et al., 2001), TrA activation timing and the influence of the TrA on lumbar lordosis is important, a process already demonstrated suggesting that the TrA is an 'anticipator' to loading activities (Hodges and Richardson, 1996; Hodges and Richardson, 1997).

1.23 Effects of mechanical stress and strain on the spine

Direct or indirect forces applied to tissue causes tensile stress which is a ratio of the force (F) applied to a cross-sectional area (A) of the surface, to which the load is applied,

$$\text{Stress} = F/A$$

The stress developed within the tissue causes it to change shape or deform. This is achieved by a change in its length. The ratio of the length change to the original length is the strain which the tissue is put under.

$$\text{Strain} = \Delta l/l$$

(Δl - change in length; l - original length before deformation)

The effect of either stress or strain on tissue can be demonstrated in living tissue (Ogrodnik, 1997a; Whiting and Zernicke, 1998b; Watkins, 1999). Living tissue is heterogeneous in nature consisting of both viscous and elastic properties. It is therefore expected that a vertebral body and the IVD will respond in a particular

way to axial loading (Whiting and Zernicke, 1998b; Watkins, 1999). The effect of the axial loading is directly related to the length of time for which the load is applied (Ogrodnik, 1997a) because Hooke's law suggests that the longer the time frame during which it is applied the increasing likelihood of the structure losing its integral elastic property and returning to its normal shape because it would have exceeded its elastic limit (Ogrodnik, 1997a).

Temperature fluctuation influence tissue performance by producing a thermal strain as can be demonstrated in isotropic materials (Ogrodnik, 1997a).

$$\text{Thermal strain} = \text{Thermal Coefficient} \times \Delta T$$

(ΔT - change in temperature)

There is paucity in the literature describing the effects of thermal strain on trunk tissue. However, this maybe a component of an underlying mechanism by which the anecdotal evidence may suggest occurrence of LBP reported by patients in the clinical environment to be worse during the winter months and extremely warm summers.

1.24 Deformation of tissue as a response to loading

The IVD as part of the movement segment experiences the greatest deformation during loading losing approximately 0.16mm in height (Heuer et al., 2007), and when an IVD is subjected to an axial load of 500N for 15 minutes its internal pressure decreases linearly (Heuer et al., 2007). However, loading will initially cause anterior deformation because the whole deformation process is time dependent (Little et al., 2004). The long term effects of the deformation are created postero-laterally where it can be shown to be greatest (Heuer et al., 2007). This suggests that the historic assumption that acute LBP and associated radicular

symptoms reported after an immediate incident may not be caused by direct IVD damage but by the immediate response to facet joint loading, deformation of the IVD and the narrowing of the neural foramina (Little et al., 2004). Asymmetrical deformation in response to load is a viscoelastic property referred to as creep (Watkins 1999).

1.25 Creep

‘Creep’ is a time dependent property demonstrated by continual tissue deformation after the cessation of the application of load applied to it before there is a gradual return to a normal state as seen before the point of tissue failure as caused by prolonged application of the load (Fig 1.16).

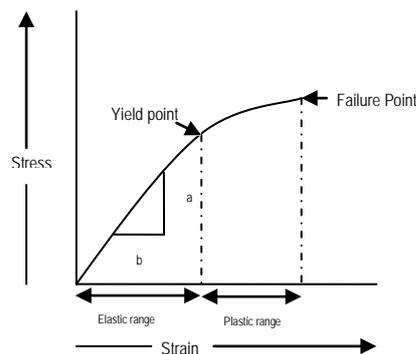


Fig. 1.16: Stress-strain curve (from Whiting and Zernicke, 1998b)

There is a linear relationship between stress and strain (Fig 1.16) and homogenous materials demonstrate characteristics that obey the laws of elasticity or Hooke's law (section 1.21). Observation of the Hookean law suggests that when a load is removed, the material will be restored to its original length. This response is a ratio of the gradient of the stress-strain curve (a/b). Within this range the material has elastic properties. If the load is removed at or beyond the yield point the material will not return to its original length but assumes another shape demonstrating 'plastic or non-elastic' properties (Watkins, 1999). Exceeding the

plastic range when the material will reach its maximum tolerance causes failure (Watkins, 1999) and when if applied to the trunk, acute LBP may ensue.

The enforced change in shape of the tissue is proportional to the load applied; the greater the load the greater the change in shape. When the load is removed and if the strain remained within the elastic range, the deformation will gradually reverse until the normal shape or length is resumed (Watkins, 1999) (Fig 1.17).

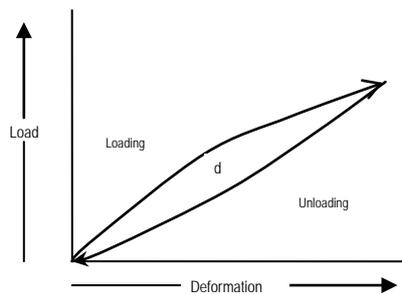


Fig. 1.17: Load - Deformation curve (from Whiting and Zernicke, 1998a)

The 'creep' response demonstrated by the capsule of facet joints is particularly significant after sustained flexion at L5/S1 (Little et al., 2004), suggesting that the spine is very vulnerable after performing tasks when in prolonged flexion. Furthermore it also suggests that such induced LBP will respond effectively to rest in a supine or prone position during which deformation is reversed. It has been suggested that this reversal can take up to 20 minutes (Little et al., 2004).

'Creep' as a characteristic therefore can have a detrimental effect on the stability of the movement segment especially when the muscles responsible for stability during trunk functional activity involving sustained or repeated flexion demonstrate a reduction in reflexive activity (Gedalia et al., 1999, Solomonow et al., 2000; Williams et al., 2000; Claude et al., 2003; Lu et al., 2004). Changes in Multifidus electromyography (EMG) activity when adjacent facet joints are

stimulated with an electric current (Little et al., 2004) demonstrate a possible mechanism for loss of trunk stability.

1.26 Energy absorption

As tissue experiences deformation some energy is absorbed to provide resistance to the load. During the unloading stage this energy is re-released gradually and a natural 3-dimensional shape is regained. The amount of energy released is equal to the area between the curves, 'd' (fig 1.17) (Whiting and Zernicke, 1998a; Watkins, 1999). It may be this energy that is reported as an increase in temperature during LBP and it may not be the same as the increase in temperature and associated erythema observed during an objective assessment with palpation or during an inflammatory process. There is paucity in the literature to support this supposition.

1.27 Conclusions

Low Back Pain continues to be a complicated condition generating concern. Although there are various historical diagnostic tests available to diagnose LBP these tests are only effective when there is an underlying pathology. The diagnostic tests however lack sensitivity to demonstrate effectiveness of intervention for mechanical non-specific back pain. It is therefore justified to explore the possibility of quantifying real time trunk movement characteristics after using interventions such as the increasingly popular core stability exercises. There is also empirical evidence to suggest physiological mechanisms for trunk movement that may underlie CSE (Hodges and Richardson, 1996; Hodges and Richardson, 1997; Barr et al., 2005; Barr et al., 2007).

This study utilises a method of analysis that evaluates changes in trunk acceleration and investigates the relationship between the effectiveness of CSE and the pain and disability reported following an episode of acute pain.

The following chapter evaluates the current methods of evaluation of trunk movement characteristics, considered opinion about the underlying mechanism for the onset of LBP and the mechanisms for the effectiveness of core stability exercises as an intervention for the treatment of LBP.

Chapter 2

Literature Review

2.1 Summary

This chapter explores what is known of the effect of Core Stability Exercises (CSE) on acute non-specific low back pain to date. The chapter also explores the depth of existing knowledge of movement characteristics of the trunk in terms of its higher order kinematics. The research questions, as a direct consequence of the chapter conclusion, are then stated.

2.2 Historical factors that influence the management of low back pain

The main cause of LBP has previously been suggested to be vascular deficiency (Jayson, 1996). This is because there is greater relevance of the effects of smoking on vascular integrity rather than height, weight, inherited factors, spinal movements, muscle strength or even radiological signs for the onset of LBP (Jayson, 1996). However, this proposition originates from a heavily medical oriented opinion and an organic orientation upon which an onset can be related. This interpretation also seems to suggest that mechanical non-specific LBP can be experienced in the absence of both functional movement and the central neuromodulation that may influence segmental and global spinal movements.

Anecdotal evidence from the clinical environment suggests that non-specific LBP does respond to intervention if efficient movement is restored to spinal segments. An inability to adequately demonstrate this may be a reason why the prevalence of LBP has not improved over the years despite intensive research. Indeed, even technological advances in diagnostics and intervention have not

reduced the economic burden of LBP (Dagenais et al., 2008). Data from Australia, Belgium, Japan, Korea, Netherlands, Sweden, United Kingdom and United States suggests that LBP is reported to be the 4th most expensive health condition with both direct and indirect economic costs (Dagenais et al., 2008) and physiotherapy as an intervention is one of the largest components of those direct costs (17%) (Dagenais et al., 2008). It is therefore justifiable that physiotherapists continue to seek a method to demonstrate effectiveness of intervention and be able to justify associated costs within healthcare delivery. This may be achievable by demonstrating both efficiency and effectiveness through the quantification of the effects of intervention.

Historical assessment of LBP in a clinical environment consists of both a subjective self reporting system and an objective assessment of function to evaluate functional ability (Petty, 2006). This process precedes the development of hypotheses upon which an explanation for reported symptom behaviour can be developed. Subsequent Intervention involves various management strategies. Each strategy however usually includes muscle strengthening programmes. This is because previous studies have suggested that LBP causes weakness in trunk musculature (Hodges and Richardson, 1996; Hodges and Richardson, 1997; Barr et al., 2005; Barr et al., 2007).

2.3 Acute non-specific low back pain

Acute non-specific low back pain is an episode of LBP that has lasted for up to 6 weeks (BackCare, 2007; Kinkade, 2007). It has also been described as lasting for up to 3 months (Smith et al., 2002; Gullick, 2008) but the authenticity of this description lacks credibility because one point of view is that the length of time of

onset during which other secondary effects of LBP may become apparent may be driven by central neuromodulation (Jayson, 1996). Acute LBP can also influence gait depending upon its severity (Taylor et al., 2004), however kinematic analysis of the influence of LBP on gait has not been adequately demonstrated (Taylor et al., 2004).

2.3.1 Classification of low back pain

The Quebec Task Force Classification (QTFC) (Spitzer, 1987) has been used successfully to classify LBP patients by defining differences in the extent of pain and types of pain. The method has been used to categorise sciatica as a classification in which pain radiates down the leg beyond the knee and thus indicates the severity of symptoms and the likelihood of future surgical intervention (Atlas et al., 1996). Within the sample evaluated by the study, the non-surgical group demonstrated better improvement in outcome compared to the surgical group (Atlas et al., 1996). However, the QTFC cannot differentiate between acute and chronic LBP and thus does not effectively demonstrate discriminant validity (George and Delitto, 2005). It therefore may be considered to be a taxometric assessment which can be used to classify types of low back pain.

The heterogeneous nature of acute LBP suggests that it cannot be treated by a single mode of treatment (Abbott, 2008) there is therefore a need to match intervention to clinical findings for meaningful treatment outcomes (Abbott, 2008). Delitto et al. (1995) proposed a Treatment Based Classification (TBC) system (Table 2.1). This system utilises subjective history and symptoms for LBP as a method to assist in the physiotherapy decision-making process to decide on an appropriate intervention (George and Delitto, 2005).

Table2.1: Treatment Based Classification -adapted from George & Delitto (2005)

Classification	Key History/Clinical findings	Intervention
Specific Exercise Extension syndrome Flexion syndrome Lateral shift syndrome	1. Posture preference is extension 2. Pain with lumbar flexion 3. Pain 'centralises' with lumbar extension but intensity increases with flexion tests 1. Posture preference is flexion 2. Pain with lumbar extension 3. Pain 'centralises' with lumbar flexion but intensity increases with extension tests 1. Frontal plane deformity 2. Unilateral side flexion restriction with lumbar movement testing 3. Improvement with pelvic translocation	Extension exercises and avoidance of activities involving flexion Flexion exercises and avoidance of extension movements Passive or active pelvic translocation exercises
Mobilisation Lumbar mobilisation Sacroiliac (SIJ) mobilisation	1. Local/unilateral LBP 2. "Opening pattern" or "Closing pattern" during trunk movement tests 1. Local pain at PSIS, buttock or lateral thigh pain 2. Three fourths SIJ test cluster are positive	Lumbar mobilisation/manipulation techniques and/or range of movement exercises SIJ manipulation, Muscle energy techniques and lumbar range of movement exercises
Immobilisation Immobilisation syndrome	1. Frequent prior episodes of LBP with minimal perturbation 2. History of trauma 3. Generalised ligament laxity 4. "Instable catch" during lumbar flexion tests	Trunk strengthening exercises
Traction Traction syndrome Lateral shift syndrome	1. Signs and symptoms of nerve compression 2. No improvement with lumbar movement testing 1. Visible frontal plane deformity 2. Unilateral side flexion restriction during lumbar movement testing 3. Symptoms worsen with pelvic translocation	Intermittent mechanical traction or autotraction Autotraction

TBC is therefore capable of using information from a clinical examination to classify acute LBP into effective intervention groups and simultaneously reduce self-reported disability (George and Delitto, 2005). However, there is limited evidence to suggest that TBC can be used to discriminate between subgroups of patients presenting with acute LBP (George and Delitto, 2005). The clinical assessment used to classify this cohort of patients relies on palpation using both static and dynamic landmarks which do present challenges in terms of reliability and validity (George and Delitto, 2005). In the clinical environment the ability to repeatedly locate specific lumbar vertebrae using palpation is essential for effective management

using manual techniques. However it has been demonstrated that agreement in identifying comparable lumbar segments ($\kappa=0.37$) and the identification of spinal levels ($\kappa=0.09$) between practitioners is relatively low (Downey et al., 2003). The kappa (κ) is the chance-corrected statistical determination of agreement of a measure with perfect agreement being 1.00 (Altman, 1991). This does therefore suggest that treatment using these techniques need to be viewed within that context because the kappa scores are relatively low.

2.3.2 Management of acute non-specific low back pain

Guidelines for the treatment of LBP suggest that management should involve physical methods of physiotherapy using a biopsychosocial approach (NHS, 2005). What these physical methods may be is ambiguous, however spinal manipulation has been suggested as being beneficial for the treatment of LBP (Assendelft et al., 2003; Haas et al., 2004; Ernst, 2007). Manipulation, however, has not been demonstrated to be better than other forms of treatment (Assendelft et al., 2003). A probable reason for this conclusion has been described earlier (Downey et al., 2003) and is demonstrated within the clinical environment where less than 5% of patients presenting with LBP in primary care receive manipulation (Jackson, 2001). Skill mix of the practitioners, however, may also influence the choice of treatment because different levels of experience influence the clinical reasoning process (Doody and McAteer, 2002) that underpins the preferred intervention.

Although there is depth in guidelines across Europe for the management of LBP within primary care (Abenhaim et al., 2000; ANAES, 2000; Hagen et al., 2002; Hagen et al., 2005; NHS, 2005; Ostelo et al. 2005) compliance with the recommendations is variable and may be dependent upon the fear-avoidance

beliefs of General Practitioners (GPs) (Coudeyre et al., 2006). Furthermore GPs may lack the specialist knowledge to make an initial diagnosis of LBP especially when assessing chronic low back pain (Cayea et al., 2006). There is no current evidence however to suggest that this is also true for acute LBP but the criteria used to generate referrals have been shown to be vague (Stanley et al., 2000). However, current guidelines provided for healthcare practitioners in the United Kingdom suggests that patients should be encouraged to remain active and engage in exercises (NICE, 2009).

A study in Scotland of patients who either self referred or were referred by their GP for physiotherapy treatment demonstrated that there is a difference in the profiles of both groups (Holdsworth et al., 2006). Self-referrers were more likely to complete their treatment with fewer treatment sessions per episode of care and were absent from work for fewer days than those referred by GPs who were much fewer in number (Holdsworth et al., 2006). This may be a reflection of GP referral behaviour.

Cognitive-Behavioural Therapy (CBT) has been advocated as a useful adjunct to the treatment of acute LBP but screening for the subgroup of LBP patients who will most favourably respond to CBT can be useful in preventing acute LBP from becoming chronic (Frank and DeSouza, 2001; Smith et al., 2002; Fritz and George, 2002; Johnstone et al., 2004). A randomised controlled trial has demonstrated the benefits of combining Cognitive behavioural therapy to physical treatment involving exercise (Linton et al., 2005). The transition of LBP from acute to chronic is influenced by risk factors such as stress, anxiety, mood, emotions, cognitive function and pain behaviour (Johnstone et al., 2004). These risk factors have been

found in 17% of patients reporting with acute LBP (Burton et al., 1995 cited in Johnstone et al., 2004) and because physiotherapists are usually the first point of contact with LBP patients (Johnstone et al., 2004) early recognition of these factors and appropriate intervention will benefit these patients. However, incorporating a cognitive behavioural therapy approach within standard physiotherapy intervention is largely resisted because of time restraints, even though there are cost-benefit advantages (Johnstone et al., 2004).

Proctor et al. (2000) cited in Johnstone et al. (2004) proposed that disability caused by LBP is dependent upon the degree to which a patient suffers from distress, psychopathology, depression and catastrophisation of their condition. These factors along with the risk factors identified by Johnstone et al. (2004) therefore suggest that any outcome reliant upon self reporting measures may be subject to bias and distort quantification of acute LBP. Research involving acute LBP therefore, requires a methodology that considers the possible effect of this bias during the procedures.

A minority of patients with work-related LBP that do not return to work account for an appreciable percentage of the costs of treatment and early intervention to prevent disability can therefore be beneficial (Fritz and George, 2002). Understanding the effects of fear-avoidance beliefs is important to reduce the probability of an acute onset of LBP from becoming chronic, especially if it is caused by work related activities (Fritz and George, 2002). However, how and if fear avoidance beliefs are perpetuated by belief systems during the management of LBP by health practitioners is unclear because the relationship dynamics are ambiguous (Fullen et al., 2008). What has been demonstrated however is that using fear

avoidance techniques to treat LBP can reduce disability in the short term (Fritz and George, 2002). There is however, a caveat in that more research is required to demonstrate fear avoidance techniques have a role as a treatment strategy (Fritz and George, 2002). Previous work by Frank and De Souza has already proposed that that a pre-requisite to successful management of LBP and the prevention of an acute onset from becoming chronic is the need for the clinician to be 'positive' and exercise good person management (Frank and DeSouza, 2001).

Acute LBP alone was reported to generate direct costs of £251 million and the gateway to treatment is increasingly via physiotherapists (Lauchlan, 2005) and it is suggested that there is a need to reduce unnecessary tertiary referrals (Lauchlan, 2005). However, much more research has been done on chronic LBP compared to acute LBP. A reason for this may be because most episodes of acute LBP resolve quickly. Pullaim et al. (2003) reports that 70% of LBP patients no longer experience disability at 4 weeks following an onset of LBP (cited in Lau et al., 2008). Another reason may be because of the relative speed of resolution of symptoms; no treatments (including painkillers) for acute LBP have been able to stand up to the rigours of inquiry that would merit evidence based practice (Smith et al., 2002; Rozenberg et al., 2003).

Effective management of LBP during the acute stage is reported to be bed rest (not exceeding 4 days) complimented by painkillers (Rozenberg et al., 2003). This approach has been suggested to be comparable in effect on LBP as a continuation of normal daily activity alone (Rozenberg et al., 2003). This treatment approach however is not recommended (Smith et al., 2002; Kinkade, 2007) because normal activity results in fewer days of sick leave (Smith et al., 2002; Rozenberg et

al., 2003; Kinkade, 2007) even though patient satisfaction is much less (Atlas and Deyo, 2001). This is because it has been demonstrated that patients who receive early physiotherapy intervention respond much more quickly in the short term demonstrated by improvement in outcome measures of pain and global perception of the effect of intervention (Lau et al., 2008). Furthermore, it has been suggested that an assess/advise/treat model of care can offer better outcomes than an assess/advise/wait model of care because of the better psychosocial features demonstrated by improved scores in outcomes of reported pain (Visual Analogue Scale), functional disability (the Roland and Morris Disability Questionnaire), mood (Modified Zung Self Rated Depression Score, Modified Somatic Perception Questionnaire, State-Trait Anxiety Inventory), general health (Euroqol), and quality of life (Short Form 36) (Wand et al., 2004).

Acute LBP is in the main a result of a mechanical deficiency (Atlas and Deyo, 2001) and is in the main not associated with any serious underlying pathology even if there may be evidence of sciatic pain (Kinkade, 2007). Positive identification of a causal relationship between structure and symptoms is difficult even when using sophisticated diagnostic tools such as X-rays, MRI or CAT scans even though 98% of LBP accompanied by radicular symptoms occur at L4/5 or L5/S1 lumbar segments (Atlas and Deyo 2001). A majority of acute LBP may not respond favourably to specific exercises (Atlas and Deyo, 2001).

Spinal manipulation using either high or low velocity manoeuvres to restore function within the lumbar spine is an acceptable choice of treatment for acute LBP but there is uncertainty of the right timing for this type of intervention (Kinkade, 2007; Sizer, 2008). It had previously been proposed that spinal manipulation is

generally of little benefit to the overall management of acute LBP (Smith et al., 2002) and most recent opinion is that spinal manipulation does not provide long term benefit for this group of patients (Kinkade, 2007).

2.4 Characteristics of acute non-specific low back pain

Candotti et al. (2008) investigated the effect of LBP on fatigue indices in a group of sedentary participants to see if it was possible to replicate the results as seen in a group of athletes. The authors collected bilateral EMG and force data during isometric contractions of the iliocostalis lumborum and the longissimus dorsi muscles during 3 repetitions of maximum voluntary contractions (MVC), each contraction lasting for five seconds duration with a 2 minute rest between repetitions. The fatigue test consisted of maintaining 80%MVC for 35 seconds. The post fatigue test consisted of a contraction which was 80% MVC for 10 seconds duration to assess recovery. The authors suggested that there was a need for objective measures to evaluate evolving LBP characteristics during treatment and proposed that EMG activity can provide such information. They proposed that EMG could do this because it can detect changes in the median frequency which is purported to reduce as a result of LBP. The study does also suggest that physiological changes occurring during an episode of LBP can influence trunk activity. Although the objectives of the study were clear the reliability of repeated measures using EMG is not precise. The reliability of EMG can be compromised by potential sources of error involving electrode placement (Soderberg and Knutson, 2000; Suzuki et al., 2002). The study would therefore be strengthened if there was supporting evidence to demonstrate a measure of reliability for the method used to gather the presented data. The sincerity of effort by study participants may also

have influenced the results. This was acknowledged by the authors who considered the effect of the pain adaptation model (Chapter 1) on the participants. As an inclusion criterion, pain was not scaled. The level of pain experienced by the participants before, during and after the study was ambiguous and it is possible that variations in the level of pain could have an affect on the ability to produce reliable MVCs.

Candotti et al., (2008) also found that significant differences were demonstrated unilaterally and proposed that those significant differences, found mainly of the left side were due to the fact that rotation was not restricted during the testing procedure. This argument may not be entirely valid because it implies that trunk movements are one dimensional, but trunk movements are 3-dimensional (Marras and Wongsam, 1986). A more plausible argument may be that all the participants presented with unilateral problems producing movement towards the side of least resistance (McKenzie, 1981). However, an important observation of this study is that the participant group is in the main very ambiguous. The authors did not indicate if the participants were experiencing either acute or chronic episodes of LBP.

Trunk strength evaluation within a clinical environment has traditionally played a significant role within primary care and anecdotal evidence suggests that LBP patients referred for treatment quite often are referred for 'back strengthening exercises'. However, some studies have suggested that measures of trunk strength should be described more precisely in terms of its motor performance or higher order kinematics (Kroemer et al., 1990; Marras et al., 1990).

Higher order kinematics of the trunk can be described in terms of displacement, velocity and acceleration (Kroemer et al., 1990; Marras et al., 1990). Previous work does exist in abundance exploring the behaviour of trunk velocity but there is a paucity of literature exploring the behaviour of trunk acceleration even though acceleration is defined as the rate of change in velocity when there is a change in direction of movement (Ogrodnik, 1997c). Evaluation of acceleration may therefore provide more detail because anecdotal evidence does suggest that LBP is reported by patients when there is a change in trunk direction during functional activity.

2.5 Physical/general exercise and low back pain

Storheim et al. (2003) recruited 93 participants with sub-acute LBP (8-12 weeks) for a randomised controlled trial lasting 18 weeks. They compared the effect of physical exercise and cognitive behavioural therapy (CBT) on sub-acute LBP. Primary outcome measures included pain, disability, sick listing and care satisfaction as primary outcomes and self-efficacy for pain and function, fear avoidance beliefs, emotional distress, generic health status and life satisfaction as secondary outcomes. The study concluded that CBT improved disability and that physical exercise can reduce patients' symptoms. The results suggested that physical exercise as treatment for low back pain requires high motivation among the participants and attrition is greatest among this group who were more likely to be male than female. It was also observed that none of the interventions had an effect on sick listing. A challenge to the study was the fact that no previous data existed to determine a sample size but the authors calculated a sample size using an assumption based upon a pilot study and recommendations from previous studies. They acknowledged this as a limitation. Because of the attrition (18%) the data

analysis involved an 'intention to treat' analysis. An 'intention to treat' analysis is a method by which a direct comparison of the groups can be made by including all participants within the groups to which they were originally allocated (Peacock and Peacock, 2011). By doing so balance between the groups in respect to the subject characteristics is maintained (Peacock and Peacock, 2011).

The control group were excluded from the standard clinical examination during the recruitment phase. The reasons for this omission were not given and it was not clear but it is possible that the omission could have introduced some form of bias into the sample. The underlying mechanisms for the onset of the episode of back pain could have influenced the response within the control group and therefore distort its comparison with the other groups. It was also not clear as to what this standardised clinical examination consisted of.

The randomisation process for the aforementioned study was ambiguous. It is not clear if the envelopes used for allocation were picked in a sequence or shuffled before being chosen by the participants. Once allocated, the participants in the exercise group did not have a consistent exercise routine. Some attended exercise classes twice weekly and others thrice weekly. The control group were treated by their GP but also had no restrictions as to types of their preferred treatment or referrals.

It can therefore be surmised that although exercise can reduce patient symptoms any study using exercise as an intervention may be limited by attrition of participants.

2.6 Review of the literature

The review within this section of the chapter is narrative because of the paucity of literature. This choice of review allowed consideration of a wide scope of information without the constraints of a criterion based selection criteria (Collins and Fauser, 2005). Furthermore a systematic review with a meta-analysis was not considered useful because of inconsistencies in application of intervention and outcome measures (Collins and Fauser, 2005) making comparison between the results of the studies difficult. A realist review that can be useful in identifying and explaining links and interactions between context, mechanisms and outcome (Wong et al., 2010) was also considered but rejected because a common mechanism by which CSE may work is unknown. Furthermore the method is more suited for policy intervention (Wong et al., 2010).

A search of Amed (1990-2011), Cinahl (1990-2011), Medline (1990-2011), Science Direct (1990-2011), SportsDiscus (1990-2011), Scopus (1990-2011) and the Cochrane library (1990-2011) databases for literature on current understanding of trunk movement characteristics and Core Stability (stabilisation) Exercises was conducted. All the databases were searched using the keywords; acute low back pain, stabilisation, trunk acceleration and velocity, Core Stability Exercises and Lumbar Motion Monitor. Articles listed in a recent systematic review (May and Johnson, 2008) were also considered. The search strategy and the articles reviewed are listed (Table 2.2) and the methodological quality of the studies reviewed was tested using PEDro rating; a score on a scale developed to score trials on the Physiotherapy Evidence Database (Maher et al., 2003) (Table 2.3) and the reviewed articles are summarised (Table 2.4).

Although all the studies included compared baseline data, none of them provided evidence of participant blinding. Four studies did not apply 'intention-to-treat' analysis, three of which could not because they were not randomised controlled studies (Hicks, 2005; Herbert, 2006; MacDonald, 2010) and registered the lowest PEDro scores.

The final papers reviewed were chosen because they all evaluated acute LBP and changes in the multifidus muscle. Although similar outcome measures were used the techniques were not consistent. Direct comparison between the studies was therefore not possible. Of the relevant 12 studies identified, 6 were rejected because they were duplications.

Table2.2: Literature Search Strategy

Database	Acute LBP	Stabilisation	CSE	Trunk performance	Trunk Acceleration	Trunk Velocity	LMM	Combination of search words	Relevant No. of Articles	Selected Articles Reviewed
AMED	2643	6653	5786	7277	5087	5863	1598	4	2	1
CINAHL	76	3	1	1	0	0	6	1	0	0
MEDLINE	295058	290361	298714	294369	291438	302523	297475	4	3	2
ScienceDirect	58893	7112	845	365	133	107	47	5	2	0
Scopus	2365	17	7	1	0	0	0	0	0	0
Cochrane	7	19	11	103	11	57	11	0	0	0
Other	21	0	21	0	0	0	0	0	5	3
Total	359063	304165	305385	302116	296669	308550	299137	24	12	6

Key:

Other: May & Johnson (2008)

CSE: Core stability exercises

LMM: Lumbar motion monitor

Table 2.3: Evaluation of methodological quality of the reviewed studies using PEDro rating

Study	1	2	3	4	5	6	7	8	9	10	11	Score
Rasmussen-Barr et al. (2003)	Y	Y	Y	Y	NS	NS	NS	N	N	Y	Y	5/10
Childs et al. (2004)	Y	Y	Y	Y	NS	Y	Y	N	Y	Y	Y	8/10
Hicks et al. (2005)	Y	N	N	Y	NS	N	NS	Y	N/A	Y	Y	5/10
Brennan et al. (2006)	Y	Y	N	Y	N	N	Y	N	Y	Y	Y	6/10
Hebert et al. (2010)	Y	N	N	Y	N	N	N	Y	N/A	N	Y	3/10
MacDonald et al. (2010)	Y	N	N	Y	N	N	NS	Y	N/A	Y	Y	4/10

PEDro items: 1. Specification of eligibility criteria (Not included in the total score); 2. random allocation; 3. concealed allocation; 4. baseline comparability; 5. patient blinding; 6. therapist blinding; 7. assessor blinding; 8. at least 85% follow-up; 9. intention to treat analysis; 10. between group statistical comparisons; 11. point measures and measures of variability. Yes-Y; No-N; NS-Not stated; N/A-Not applicable

Table2.4: Literature review core stability exercises

Study	Sample size and type	Symptom Duration	Intervention and Outcome Measures	Follow up Period	Conclusions
Rasmussen-Barr et al. (2003)	47 participants	>6 weeks +/- radicular pain	Stabilisation exercises (n=24)	3 and 12 months	Stabilisation exercise produced significantly better improvement in disability at 6/52 (50%), 3/12 (67%) and 12/12 (56%). Pain improved by 39% (6/52), 58% (3/12) and 61% (12/12). Participants in the manual treatment group had more episodes of reoccurrence long term.
RCT	Age range: 18-60		Manual treatment (stretches, traction, mobilisation, manipulation) (n=23)		
6/52 duration	Randomisation by lot		Pain (VAS) Disability (ODI and Disability Rating Index)		
Childs et al. (2004)	131 participants	?<16 days. Only 46 (35%) had symptoms for this length of time.	Manipulation plus ROM exercise	1 and 4 weeks	Manipulation was more effective in reducing disability in patients who were positive on the clinical prediction rule compared to a similar patient receiving exercise
RCT	Age range: 18-60		Low stress aerobic and lumbar spine strengthening Exercise	6/12	
4/52 duration	ODI ≥ 30%	+/- radicular pain	Disability (Modified ODI) Pain (VAS)		
Hicks et al. (2005)	54 participants	Symptom duration -Not stated. Assumed to be acute?	'standardised' stabilisation exercises	Not stated	A clinical prediction rule can be used to identify patients who will more likely respond to stabilisation exercises
Prospective cohort study	Age range : > 18	No radicular pain	Disability (ODI)		
8/52 duration					

Brennan et al. (2006)	123 participants (55% male, 45% female) Age range: 18-65 ODI \geq 2.5%	<90 days +/- radicular pain	Manipulation Stabilisation exercises Specific exercises Disability (ODI)	4/52 1 year	Outcome of treatment of LBP can be improved by sub-grouping patients. ODI improved by 56%
Hebert et al. (2010)	40 participants (30 prospective, 10 participants with ongoing Rx) Age range: 18-60 Positive prone instability test, aberrant movement, SLR >91 deg, lx hypermobility, self reported disability	Current episode of pain between T12 and the buttocks.	Nil Rehabilitative Ultrasound Imaging (RUSI)	Nil	Decreased MF activation is more associated with predictive of factors to determine the success of stabilisation exercises than decreased TrA activation
MacDonald et al. (2010)	13 participants with LBP and 14 healthy participants.	Unilateral LBP for 75% of the time. Can be of varying frequency but without a duration exceeding 3 months	Bilateral EMG recording of deep and superficial multifidus during both predictable and unpredictable trunk loading	Nil	Both deep and superficial multifidus activity was subdued after remission of LBP compared to healthy participants. Superficial multifidus activity during predictable trunk loading was not affected.

Key:

Randomised Controlled Trial (RCT)

Visual Analogue Scale (VAS)

Oswestry Disability Index (ODI)

Range of movement (ROM)

Electromyography (EMG)

Multifidus (MF)

Rasmussen-Barr et al. (2003) compared the effect of stability exercises and manual treatment as interventions for an episode of LBP for 6 weeks with follow up periods of 3 and 12 months. The sample was made up of 47 participants aged between 18 and 60 years who presented with an episode of LBP. Participants were allocated to either a stability exercise or a manual treatment group. Randomisation was achieved by allocating the first male and female participants to one of the groups by lot and the others were then assigned separately but consistently to either group.

The design of the study was very good as the authors used stratified randomisation by sex as a method for group allocation of participants comparing two treatments. Unfortunately this design does not provide unequivocal evidence to be able to attribute with confidence, changes in outcome to the described interventions. The absence of a control group further complicates the conclusion of the study because it is not possible to take into account the natural resolution of symptoms in the absence of intervention when there is no treatment. However, it is possible that because the participants were randomised, natural recovery would be equal between both groups. Furthermore the fact that the participants would have different structural biomechanical responses associated with trunk strength, flexibility and balance because of the different length of time of each episode (Standaert et al., 2008) could have been a problem.

The variation in the number of manual treatments used in the study and the lack of consistency in the choice of and length of manual treatment used may have also diluted the true effect of the intervention. It is not possible, therefore, to identify which of the interventions were of most benefit.

Because of the high rate of attrition, the authors concluded that the study should be re-classified as a pilot study and suggested that the study should be repeated with a bigger sample size. An alternative would have been to use an intention to treat analysis which would have provided credible data analysis (Altman, 1991). This problem was dealt with satisfactorily in another study (Storheim et al., 2003).

Childs et al. (2004) compared specifically targeted lumbar strengthening exercises with manipulation using a clinical prediction rule to identify patients most likely to benefit from manipulation. 131 participants with an age range of 18-60 years and who had an Oswestry Disability Index (ODI) score of a minimum of 30% with LBP symptoms of 16 days or less were randomised into a manipulation group with range of movement exercises and a group who performed targeted strengthening exercises for the lumbar spine. Intervention was for a 4 week period with follow up periods of 4 weeks and 6 months. Primary outcome measures were disability and pain. They concluded that the decision process for the use of manipulation as a form of intervention can be enhanced using the clinical prediction rule.

This study has its merits but only 46 (35%) of the participants had symptoms for less than 16 days. This does suggest that the variation in the length of time participants had been experiencing pain could result in recall bias because a majority of the participants were being asked to reflect on their pain experience and disability when they no longer were experiencing pain and/or disability (Chouinard and Walter, 1995). This could account for the very wide confidence interval used to suggest significance in the odds for successful outcome among patients who were positive for the prediction rule and who were randomised into the manipulation

group [60.8 (95% CI 5.2-704.7)]. The data could have also been biased because some participants who were randomised into the exercise group sought other forms of treatment between the 4 week period (end of active intervention) and the 6 month follow up. This was further compounded by the absence of a method to ensure compliance of the exercise routine even though the authors suggest that the strengthening exercises were isolated and targeted in accordance with previously published literature.

Hicks et al. (2005) investigated the possibility of developing a clinical prediction rule for successful use of stabilisation exercises for patients with LBP. During an 8 week period 54 participants were recruited. The age of each participant was greater than 18 years. They identified 4 main prognostic factors for a prediction rule; a positive prone instability test, age less than 40, aberrant trunk movements and straight leg raise greater than 91 degrees. However, there was the possibility that the results from which the conclusions were derived could have been biased. The absence of a control group does not allow a comparison of prognostic factors and effects of intervention between the participants receiving treatment and participants with no intervention and who's LBP resolved naturally without intervention. This would have provided substantiated proof of improvement due to the intervention and added weight to the validity of the prognostic factors.

The exclusion criteria used during the recruitment process also did not consider the mental state of the participants. Poor mental health and other psychological factors such as depression can affect the outcome of intervention (Standaert et al., 2008) and possibly motivation and compliance of the exercise routine (Linton et al., 1996; Frank and DeSouza, 2001; Fritz and George, 2002;).

Although the authors used a Fear Avoidance Behaviour Questionnaire (FABQ) and a Visual Analogue Scale (VAS) to measure fear of pain and subjective pain respectively, it is not clear if any of the participants did not perform the prescribed stability exercises for any reason because of their mental state and what was done with these participants if they could be identified because this information was not provided.

Hicks et al. (2005) used an inclinometer to quantify the available ROM in participants for this study. Although the inclinometer may be reliable (Hicks et al., 2005) there is no reference to the agreement of measure used to quantify its reliability referred to by the authors. However the short confidence interval (0.86-0.95) for which the reliability is described may negate this argument but the suggestion that the straight leg raise test (SLR) and the sit-up test is reliable (k range 0.48-0.77) is weak. The SLR itself was not clearly defined because the authors did not accurately describe where the pain was elicited for it to be positive. Pain in the back region from a SLR is not considered to be positive because it does not invoke radicular pain but rather possible pain from secondary lumbar spine flexion (Petty, 2006). It is entirely possible that restrictions at the end of the SLR may also be caused by tight hamstring muscles. The relevance of the SLR was not adequately provided within the paper. The ambiguity of the efficacy of the SLR as a prognostic factor was equivocal by its relative poor reported sensitivity (0.28, C.I. .13-.51).

The authors (Hicks et al., 2005) also suggest that only 18 (33.3%) of the 54 participants had success with the stabilisation exercises, by deduction a lot more did not have a success. It is not clear if the number of reported episodes of LBP could have influenced trunk behaviour of the participants through repeated

structural and functional adaptation. The authors did acknowledge this in the paper but more discussion could have provided greater clarity.

Brennan et al. (2006) used a randomised controlled trial to investigate the effect of intervention on sub-groups of non-specific LBP. 123 participants reporting with an onset of non-specific LBP of not more than 90 days whose ages ranged between 18-65 years and had a disability score of a minimum of 2.5% on the Oswestry Disability Index (ODI) were randomised into three intervention groups- manipulation, stabilisation exercises and specific exercises. The primary outcome was changes in the ODI at 4 months and 1 year follow-up periods. The authors concluded that non-specific LBP is in all probability a heterogeneous condition with outcomes that are more successful if sub-grouping is used to guide treatment decision-making. An instability test of central (posterior-anterior) PA translation of vertebral segment was used to verify inter-segmental hypo-mobility as an inclusion criterion for allocation to the manipulation group. This approach is problematic because of poor agreement between assessors for the identification of a comparable spinal level indicative of a problem ($k=0.37$) and the poor agreement for the identification of a spinal level palpated ($k=0.09$) (Downey, Taylor et al. 2003). This does mean that if, as reported outcomes rely on the successful sub-grouping of patients there is a need to match reported symptoms to actual spinal segmental levels of impairment and for this process to be consistent between assessors. Indeed, a previous study has suggested that early baseline profiling for low back pain can be useful in predicting long term pain and information gathered at 6 weeks post onset can be useful in predicting both long term pain and disability (Wand et al., 2009). Another issue is the description of what is 'normal' movement during the

stability test. The authors do not provide clarity. Without prior knowledge of the spinal segment behaviour to AP pressure before the onset of the LBP it is not possible to define 'normal' in context of the participants.

The interventions used by the Brennan et al's. (2006) study also provided a lack of specificity of poor discrimination between interventions. The quadruped position was used as a starting position for all groups. Activity in this position would have activated the transversus abdominis and multifidus within both the stabilisation and specific exercise groups. Without further clarity from the authors it is not possible to identify the difference between the stabilisation and specific exercise groups because a comparison against a benchmark was not possible. The natural recovery of a control group would have provided this benchmark to which a tangible meaning to the improvement reported within the study between the two groups could be made.

Brennan et al. (2006) used the ODI alone as an outcome however, the initial assessment included fear-avoidance beliefs and pain. Further valuable information could have been provided if any relationship between the ODI scores and the fear avoidance and pain scores could have been identified and compared throughout the study. This could be useful because the effect of fear-avoidance on the transition from acute to chronic LBP has been established (Fritz and George, 2002).

Hebert et al. (2010) investigated the relationship between prognostic factors for clinical success of stabilisation exercises for the treatment of LBP and changes in muscle activation in the multifidus and transversus abdominis muscles using rehabilitative ultrasound imaging (RUSI). The prognostic factors have been described earlier as a positive prone instability test, age less than 40, aberrant trunk

movements and straight leg raise greater than 91 degrees (Hicks et al., 2005). 40 participants were recruited from two similar studies, aged between 18 and 60 years and had a current episode of LBP sufficient enough to precipitate a self report of disability. The results demonstrated a relationship between the prognostic factors and multifidus activation suggesting that stabilisation exercises increased muscle activation. It was concluded that the activation of the multifidus muscle was therefore more important than that of transversus abdominis for successful management of LBP.

The results could have significant impact on the management of LBP but the prognostic factors used in the study have not been validated (Hebert et al., 2010) limiting the validity of the results. However, there are questions about the method used to support the presence of each of those factors. Similar to Hicks et al, the prone instability test like that used by Brennan et al may not be entirely reliable unless there is prior agreement for the location of each level to be palpated.

Aberrant movement was described as any of the following; a sudden acceleration/deceleration of movement during active flexion/extension or movement outside the sagittal plane, the Gower movement (creeping up the thigh during extension from a flexed position) or the reversal of the lumbo-pelvic rhythm (bending of the knees on return to extension from the flexed position) and a painful arc of trunk movement. Although reported to have a reasonable inter-rater reliability ($k=0.6$), the tests are rather subjective and to try and demonstrate objective quantifiable measurement could be problematic.

Segmental Posterior-Anterior movement as a mobility test has a poor inter-rater reliability ($k=0.3$) but the authors consider this to be fair. This may be a slight

exaggeration. It is also not clear what the levels of agreement were for the RUSI even though the authors report it to be good. A Bland-Altman plot would be very useful to investigate if the reported correlation corresponds to good agreement (Altman, 1991). The methodology used by Hebert et al. (2010) suggests that this information is important to support the validity of the results.

One common limitation not identified by any other studies reviewed is the effect of the age group on the generalisability of the results. Although all the studies had a minimum age of 18, the upper limit of between 60 and 65 could have been a problem. Although the age group most likely to present with an episode of LBP in primary care is 18-55 years of age (Croft et al., 1998), changes in the structural integrity of the spine will differ with advancing age (Gruber et al., 2007; Standaert, et al., 2008). None of the authors interpreted their results in this context within their work. Although older patients with chronic LBP may be reliably assessed by a physical assessment even with the possible biomechanical and/or soft tissue pathologies they may have (Weiner et al., 2006). It is not thought that younger patients can be reliably assessed in the same way (Weiner et al., 2006).

The review suggests that changes in activity within Multifidus and Transversus Abdominis muscles can be observed in acute non-specific low back pain. Although it is suggested that core stability exercises (CSE) may reduce disability caused by acute non-specific low back pain, the success CSE relies on correctly identifying the patients that will respond to CSE very early on during an onset of acute non-specific low back pain. This study was designed to reduce the ambiguity that exists within the review. To do this the study will not only use strict exclusion criteria but consider additional work to help substantiate any findings.

Little is known of the mechanism by which core stability exercises may work. This study, will investigate the effect of a targeted trunk exercise routine using an objective measure as an outcome. However, firstly the tool to be used (The lumbar motion monitor) will be tested for its reliability by investigating the levels of agreement of its measures. Secondly, basic trunk performance characteristics will also be explored with the intention that the information will be used to interpret the primary outcome data obtained by the study.

2.7 Trunk functional performance

There is a logical clinical reasoning process by which CSE are suggested to work (Willardson et al., 2007) (Fig 2.1). The flow diagram demonstrates the physiological effects of trunk neuromodulation and the role of stability within this process. The mechanism by which CSE may influence the process is not entirely clear but it is thought that CSE can restore a balance in fat infiltration within both the Multifidus and Transversus Abdominis muscles and the balance between type I and type II muscle fibre atrophy (Hebert et al., 2010). The maintenance of this balance may be crucial to the efficiency of the multifidus and transversus abdominis in establishing and maintaining trunk performance.

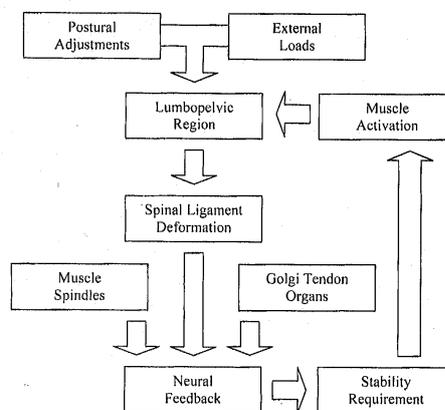


Fig. 2.1 Trunk core stability model (from Willardson 2007b)

Trunk functional performance can be used to quantify incapacity caused by LBP (Marras and Wongsam, 1986; Marras et al., 1993; Marras and Mirka, 1993; Marras et al., 2000) and different outcome measures have been used to describe this trunk performance.

Cox et al. (2000) investigated the correlation between self reporting and functional assessments of the trunk using spinoscopic assessments with the Quebec Back Pain Disability Questionnaire (QBPDQ) and Visual Analogue Scale (VAS). It was shown that trunk velocity and ROM are highly subjective and a better indication of spinal dysfunction and a more robust measure independent of patient influence is required (Cox et al., 2000). The study was a retrospective study over a 3 year period and involved 91 participants. Participants were referred by both physicians and insurance companies for an assessment of work capacity, treatment outcome following injury or surgery in the lumbar spine and residual function for a disability claim. The selection criteria for this study was wide as the participants only had to be able to walk and have an episode of non-specific LBP for a period of 10 weeks to be included. Outcome measures of range of movement (ROM), velocity, range of lordosis (ROL) and estimate of inter-segmental movement (EISM) were observed during flexion-extension and lateral bending movements with the spine either loaded or unloaded. Loading was achieved by applying incremental weights and it was up to participants to determine the level of maximum load. The results suggest that the reliance upon subjective feedback to quantify levels of disability is flawed because there is poor correlation between pain and trunk performance.

Load has an effect on the interaction between simple and complex coordination by encouraging concomitant muscular recruitment to cope with increased levels of mechanical stress applied to the spine (Cox et al., 2000). This process adds a further level of complexity to spinal coordination during functional movements. Although a questionnaire may be more valuable in evaluating the affective state caused by LBP it is not very useful for evaluating biomechanical function. Velocity (rate of change in displacement) is strongly linked to subjective self assessment (Cox et al., 2000) but it is not clear if the rate of change in velocity or in this instance; acceleration during functional movement can be influenced by subjective assessment of capability of performing that functional movement.

Repeated subtle adjustment movements may be required to complete a pre-meditated task in a single plane with tolerated velocity. This may be an underlying mechanism to provide stability. Patients with low back pain perform slower movements than healthy patients (Marras et al., 1999). An inability to perform these subtle adjustments may play a significant role in the predisposition to an onset of acute LBP.

Trunk functional performance is a realistic indicator of recovery from LBP (Marras and Wongsam, 1986; Marras et al., 1993; Marras and Mirka, 1993; Marras et al., 2000; Marras et al., 1999). The natural course of recovery from LBP and the quantification of recovery are dependent upon the outcome measure observed (Ferguson et al., 2000). Kinematic functional performance measures are the most sensitive to improvements during that process particularly during later stages of recovery (Ferguson et al., 2000). The recurrence of LBP can be caused by a time lag between resolution of reported symptoms and the attainment of full functional

performance resulting in errors in motor control (Panjabi, 2003). This mechanism may be of significance as a potential cause of reoccurrence of LBP long after an initial incident and this may underpin the effectiveness of CSE for subsets of individuals with symptoms of LBP.

Ferguson et al. (2000) evaluated the functional performance of the trunk reporting an onset of LBP. They used a sample of 32 participants and allocated them to either an occupational or non-occupational group. The authors did not make it clear as to how the participants were allocated and the occupational group had more men than women (37.5%). This could have affected the functional testing because gender may have influenced the results. The criterion for allocation was solely if their injury was related to occupation or not. The authors justified this method of allocation by suggesting that by controlling the diagnostic category significant differences between the groups were avoided. Although the participants were recruited within the first month of their symptoms being reported it was not made clear how this was verified. The participants may have had symptoms long before reporting to a physician. Anecdotal physiotherapy clinic evidence would indicate this possibility. The effects of a time difference could affect the outcome measures because the condition may have evolved over time and measures observed during the assessment may therefore be different to what could be observed earlier within the natural course of the condition (Panjabi, 2003).

To evaluate functional performance, Ferguson et al. (2000) used the Lumbar Motion Monitor (LMM). Measurements were recorded during trunk flexion-extension movements whilst the trunk was positioned in different degrees of rotation to both the left and right (0, 15, 30 degrees). Varying degrees of rotation

provided graded levels of difficulty requiring different levels of motor coordination (McGill et al., 2003) and changes in muscle recruitment patterns (Cholewicki et al., 1997; Thomas et al., 1998; Granata and Marras, 2000; Granata et al., 2005). The revised protocol for functional assessment using movement in the neutral position within the sagittal plane without rotation only as described in a later study (Ferguson and Marras 2004) is therefore more practical.

Ferguson et al. (2000) used a functional performance probability for the participants in the study by normalising the data for age and gender and using an existing model that distinguishes between asymptomatic and symptomatic patients (Marras et al., 1999) to interpret the results. But the visual and oscillatory feedback system used during the functional performance tests, like the Cox et al. (2000) study may have introduced an element of subjectivity and bias because of the reliance upon complete participant cooperation and willingness to perform the tests to the best of their ability. In the absence of a clearer definition for the cause of onset of the LBP within the participants other than whether it was work related or not, the authors appear to suggest that all categorised injuries are similar in both nature and influence on trunk movement characteristics. This cannot be strictly true because changes in anatomical movement caused by biomechanical changes within the structures may not be identical in either nature or scope. But what may be possible is the ability of participants to influence their trunk movement. It has been suggested that velocity and ROM are subjective (Cox et al., 2000). However the net result of those biomechanical changes influence the severity, irritability and the nature (SIN) of LBP playing a significant role in trunk function (Petty, 2006).

2.8 Trunk velocity

The ability for the trunk to change direction quickly may be important in the prevention of structural trauma. It has been suggested that sudden or unpredictable trunk loading is a common cause of LBP (MacDonald et al., 2010) and following remission Multifidus muscle activity can remain subdued (MacDonald et al., 2010). Activities such as rowing require a rapid change in trunk direction. It has been demonstrated that the lower lumbar segments move into extension as quickly as possible to avoid a position of maximum flexion during peak force production during the stroke phase of rowing (Pollock et al., 2009). This mechanism is initiated and executed by the trunk extensor muscles (Pollock et al., 2009). Velocity as an outcome measure was observed in an investigation into muscle activation and trunk kinematics during rowing by Pollock et al. (2009). Twelve participants performed a standardised 2000m race simulation on an ergometer. Data was collected for 30 seconds during 250m splits. Participants were recruited irrespective of previous injury status (Three had a previous trunk injury involving rib fractures, 3 had a history of LBP). At the time of testing all participants reported to be healthy with no injuries that impacted upon their training. However, the effect of a previous injury may have left residual errors in motor control (Panjabi, 2003; Panjabi, 1994) and possible changes in muscle recruitment patterns (Cholewicki et al., 1997; Granata and Marras, 2000; Granata et al., 2005; Thomas et al., 2008). The use of a mix of different training methods may also have had an influence on muscle coordination (McGill et al., 2003). Different types of rowing requires different muscle recruitment patterns and therefore different levels of muscle activity (Cholewicki et al., 1997; Thomas et al., 1998; Granata and Marras, 2000; Granata et al., 2005). Pollock et al.

observed the angular velocity of the spine using a motion capture system. The measures were calculated by differentiation and the data analysed using a custom written software programme. Although the rowing action is performed in a sitting position, the direction, range and end position of flexion closely mirror the flexed position attained during flexion-extension movements in the sagittal plane when standing.

In Chapter 1 (introduction) it was suggested that relative segmental mobility of the lumbar spine increases sequentially from upper to lower sections of the lumbar spine with the greatest amount of movement occurring at L4/5 (Kulig et al., 2007). Segmental extension movement during the early stages of flexion (Pollock et al., 2009) therefore occurs simultaneously as flexion occurs in the upper segments of the spine. This mechanism influences structural deformation of the lumbar spine and explains why during flexion, deformation of the lower intervertebral discs occurs before that of the upper discs and during extension from the neutral position deformation is mainly at L5/S1 (Kanayama et al., 1995).

Rowing is a sport that renders the trunk to movement similar to day to day functional movement albeit with concentrated repetitions over a short period and exposes the trunk to extreme loading. Understanding the mechanisms by which injury is prevented during this sport can therefore provide an insight into the mechanism by which the trunk copes with extreme loading during this activity. During rowing the lower lumbar segments are moved into extension by extensor muscle activity quickly to avoid a position of maximal flexion during peak force production with most of the extension movement occurring between L3 and S1 (Pollock et al., 2009). However, the relative movement of the pelvis to the trunk is

also important in this process because peak pelvic angular velocity occurs at the onset of co-activation (Pollock et al., 2009). The onset of co-activation is the period between the onset of the first flexor muscle and the end of the last extensor muscle burst (Pollock et al., 2009). This movement characteristic if replicated during trunk flexion-extension movements may suggest a need to establish and maintain an ability to initiate and maintain synergy between lumbar and pelvic structures in response to changes in trunk position. The coordination of the extensors of the spine and pelvis and peak extension angular velocity very early in the cycle before peak loading after the 'catch' phase of the rowing stroke may be an effective strategy to stabilise the spine (Pollock et al., 2009).

The relative position of the innominate bones in the sagittal plane influences not only the size of the lumbar lordosis but also the cause of lumbar dysfunction (Young et al., 2000). The lumbar lordosis will increase as the anterior tilt of the pelvis is increased and vice versa (Young et al., 2000). The rowing position at the beginning of the stroke positions the lumbar spine in minimal lordosis. The lordosis increases as the trunk extends towards the point of peak force and maximum velocity as described earlier. This relationship is observed in various postures of the spine during sitting and standing (Knutson, 2002; Al-Eisa et al., 2006).

Pollock et al. (2009) like the previous studies of Cox et al. (2000) and Ferguson et al. (2000) introduced a degree of subjectivity to the method by using a self directed warm up and thus inconsistency within the method.

Data were collected every 250m of rowing for the duration of the study but only the data from the first 250m was used for analysis. The authors argued that this period represented steady state after the initial "push" and was likely to be before

the onset of significant fatigue. However, no evidence was provided to support this assumption.

Low back pain produces less movement irrespective of the speed at which the test is performed (McGregor and Hughes 2000). This therefore suggests that during a routine objective assessment the actual range of movement measured and the speed at which it is attained may not be indicative of impairment or suggestive of underlying abnormal mechanisms (Cox et al., 2000). The speed of trunk flexion does not influence the range attained in either symptomatic or asymptomatic patients but the speed of extension is greater within asymptomatic participants producing greater ranges of extension (McGregor and Hughes, 2000). The process of trunk kinematic assessment is therefore best performed at the participants' own preferred speed (McGregor and Hughes, 2000).

The difference in ascent and descent velocities between asymptomatic and symptomatic groups observed by McGregor and Hughes (2000) may have been as a result of the different age range of the participants within the respective groups; those with LBP were older. LBP resulted in less movement and speed of execution of trunk flexion-extension and the consistency of measure of velocity favoured measurements conducted at the preferred speed of the participant to perform the task (McGregor and Hughes, 2000). However, there was no difference in this consistency of measurement collected either at participants' preferred or slowest speed (McGregor and Hughes, 2000). The smaller measurements of the difference in range of movement and mean velocity suggest that preferred speed is the most reliable (McGregor, Hughes 2000).

The data sampling rate of 10Hz used by McGregor and Hughes is much smaller than the sampling rate of between 40 and 120Hz used in most current studies investigating trunk kinematics (Marras et al., 2000; Ferguson et al., 2000; Granata and Marras, 2000; Giorcelli et al., 2001; Stodden et al., 2008). McGregor and Hughes (2000) argued that this was adequate to assess simple planar movement but did not provide evidence to support this claim. However, important information could have been missed because the greater the sampling rate the more sensitive the procedure. An ideal conversion of analogue signals to digital form can be achieved if the sampling observes the Nyquist-Shannon theorem in which the sampling rate should be greater than twice the maximum frequency of the signal being sampled (Shannon, 1998). The authors also did not provide information on how randomisation was achieved for the test protocol using variation of test speeds or if there was a rest period between the tests.

An experimental crossover study (Giorcelli et al., 2001) investigated the effects of wearing a belt on trunk kinematics. A comparison was made of lifting two different sized boxes from floor level to a height of 79cms and 60 degrees to the right of a neutral starting position. It was hypothesised that this was similar to stacking shelves. The maximum sagittal flexion and maximum velocity during flexion and extension movements of the trunk were reduced by wearing a belt while lifting both boxes (Giorcelli et al., 2001). Significant reduction in right side flexion and left rotation was only demonstrated when lifting the large box and these parameters only become significant as the trunk begins to function with increasing asymmetry caused by the increasing load (Giorcelli et al., 2001). It is unclear if the same characteristics demonstrated in this study using asymptomatic

participants will be replicated with a symmetrical functional movement such as flexion-extension. It is a possibility that similar responses produced by the belt may be replicated by the Internal Oblique (IO) and external oblique (EO) abdominal muscles of the trunk. In healthy individuals the loss of efficiency through muscle recruitment patterns (McGill et al., 2003) and the affect of an increasing load (either through repetition or actual weight) may cause uncontrolled increases in flexion, rotation, lateral side flexion or various combinations of movement usually associated with problem intervertebral discs (IVD) - with compromise to its anatomical structure (Holm, 1996). The IO and EO by coactivation are actively involved in maintaining trunk stability (Granata and Marras, 1993) but it is suggested that the role of the IO and EO may not be significant in sagittal movements of the spine (Granata and England, 2006) but it remains unclear if this is indeed true given the possible functional similarities with a belt as previously described above. It is unclear if CSE aimed at improving the integrity of the IO and EO could assist in the restoration of the trunk kinematic characteristics to an acceptable level at which they are required to function to ensure trunk stability.

The Transversus Abdominis and Multifidus muscles are often identified by clinicians as the muscles that require improvement in function after an onset of LBP that may cause early functional impairment (Hides et al., 2011). Furthermore it is proposed that both the Transversus Abdominis and Multifidus work together to provide trunk stability through its effects on intra-abdominal pressure and lumbar segmental stiffness respectively (Hides et al., 2011).

2.9 Trunk stability

Granata and England (2006) investigated the influence of pace and direction of movement during trunk flexion and extension on the control of trunk dynamic stability. Their opinion was that kinetic energy and its role in trunk mobility or the onset of LBP have not been fully acknowledged in biomechanical models (Granata and England, 2006). Kinetic energy, described as energy generated by movement is important because it has to be converted/stored (Ogrodnik, 1997b) somewhere within the trunk during activity. This process may involve an effective and efficient strategy which is facilitated by muscle recruitment patterns (Panjabi, 2003) and possible changes in muscle recruitment patterns (Cholewicki et al., 1997; Thomas et al., 1998; Granata and Marras, 2000; Granata et al., 2005) and coordination (McGill et al., 2003). The inability of the trunk to do this and moderate its rate of change may contribute to the predisposition of the lumbar spine to injury and the onset of LBP.

Trunk stability is enhanced by reducing the pace of activity (Granata and England, 2006). Granata and England (2006) describe trunk stability in terms of the Lyapunov exponent (λ_{MAX}) or state of chaos within the system and calculated it using the formula;

$$Y(t) = 1/\Delta t [\ln d_i(t)]$$

The average logarithm of displacement is $[\ln d_i(t)]$, $d_i(t)$ the distance between nearest points and $Y(t)$ the re-constructed state-space. It is best described as the slope of the best fit line created by the equation (Fig. 2.2).

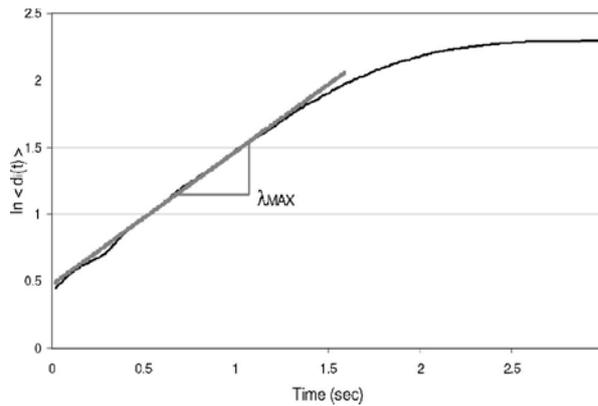


Fig. 2.2: The Lyapunov Exponent (from Granata and England 2006)

Flexion–extension movements of the trunk in both symptomatic and asymptomatic individuals demonstrated that stability is greatest when performing the movement asymmetrically (Fig. 2.3). This is shown by the Lyapunov exponent (λ_{MAX}), the greater the value the more unstable the movement.

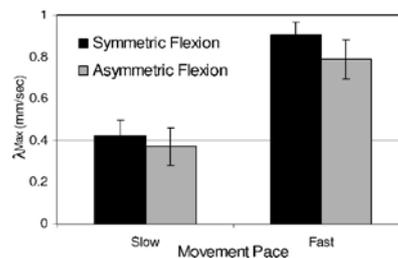


Fig. 2.3: Effect of pace on the stability of the spine (from Granata and England 2006)

Fast asymmetrical flexion creates greater instability than performing a symmetrical flexion slowly (Fig. 2.3). The differences in the stability demonstrated were statistically significant between slow and fast movements ($P < 0.001$) in both symmetric and asymmetric movement. This therefore suggests that neuromuscular control of dynamic stability decreases significantly with increases in pace. The increase in momentum requires an increase in neuromuscular activity to attenuate kinematic instability as the trunk demonstrates changes in velocity and acceleration (Marras and Mirka, 1993; Dolan and Adams, 1993; Granata and England, 2006). Modulation of muscle forces during this process requires the recruitment of large motor units with corresponding limitation in fine motor control during fast paced

movements (Granata and England, 2006). This may explain why seemingly mundane, easy or common asymmetrical movements of the trunk can cause an onset of LBP but the likelihood of onset is dependent upon the speed at which the activity is executed. This may explain anecdotal evidence that suggests LBP is often reported to occur whilst performing tasks that have been previously executed successfully. If the muscle groups associated with 'core stability' are primarily involved in fine motor control it is possible that restoration of this function will enhance stability by altering asymmetrical movement characteristics.

The Lumbar spine accounts for approximately 70% of total trunk movement during flexion-extension movements during lifting tasks in healthy individuals (Granata and Marras, 2000) but the coordination of the important interdependent relationship of the pelvis and lumbar spine (Young et al., 2000) during such tasks is non-linear (Granata and Marras, 2000). The amount of lumbar spine involvement will increase as the magnitude of the load increases (Granata and Marras, 2000). Granata and Marras (2000) found that lumbar spine involvement is increased at slower rates of performing a task such as lifting but is reduced at higher velocity suggesting that there is a greater need for the pelvis to be involved to start the extension component of the lifting task (Granata and Marras, 2000).

The lumbo-pelvic relationship described by Granata and Sandford (2000) correlates with previous observations that lumbar disc distortion starts in the lower lumbar region during extension (Kanayama et al., 1995). The lower segments take more of the strain during the more vigorous part of the process- extension from flexion. How this movement behaviour correlates with the extension observed in the lower lumbar segments during the start of flexion (Pollock et al., 2009) remains

unclear but does explain why lower lumbar segments are more prone to injury than the upper during lifting tasks whilst the upper segments are more involved when the task involves either pushing or pulling (Plouvier et al., 2008) when shear forces generated by the trunk oblique muscles (EO and IO) are primarily responsible (Marras and Granata, 1995; Marras and Granata, 1997b).

2.10 Stability or robustness

Lumbar stability has no specific definition (Standaert et al., 2008) but robustness has been used to describe the adaptability of the trunk to perturbation (Reeves et al., 2007).

Trunk flexion requires summative lumbar segmental flexion (Kulig et al., 2007). The performance of which is highly dependent upon its acceleration that requires magnitude and direction (Ogrodnik, 1997c; Bloomfield, 2006). Because the segment is restrained to a relatively fixed point by soft tissue such as ligaments, it is presumed that movement occurs about a fixed point producing a pivot movement (Fig. 2.4).

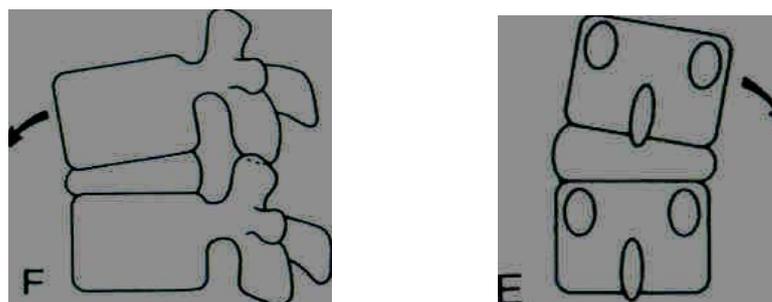


Fig. 2.4: Posterior view of a lateral pivot (F) and lateral view of a flexion pivot (E) of a spinal segment (from MacNab and McCulloch, 1990)

This movement behaviour of the spine is dependent upon perturbations large enough to cause a change in position through a trajectory, which may not be entirely unidirectional through range (Fig 2.5).

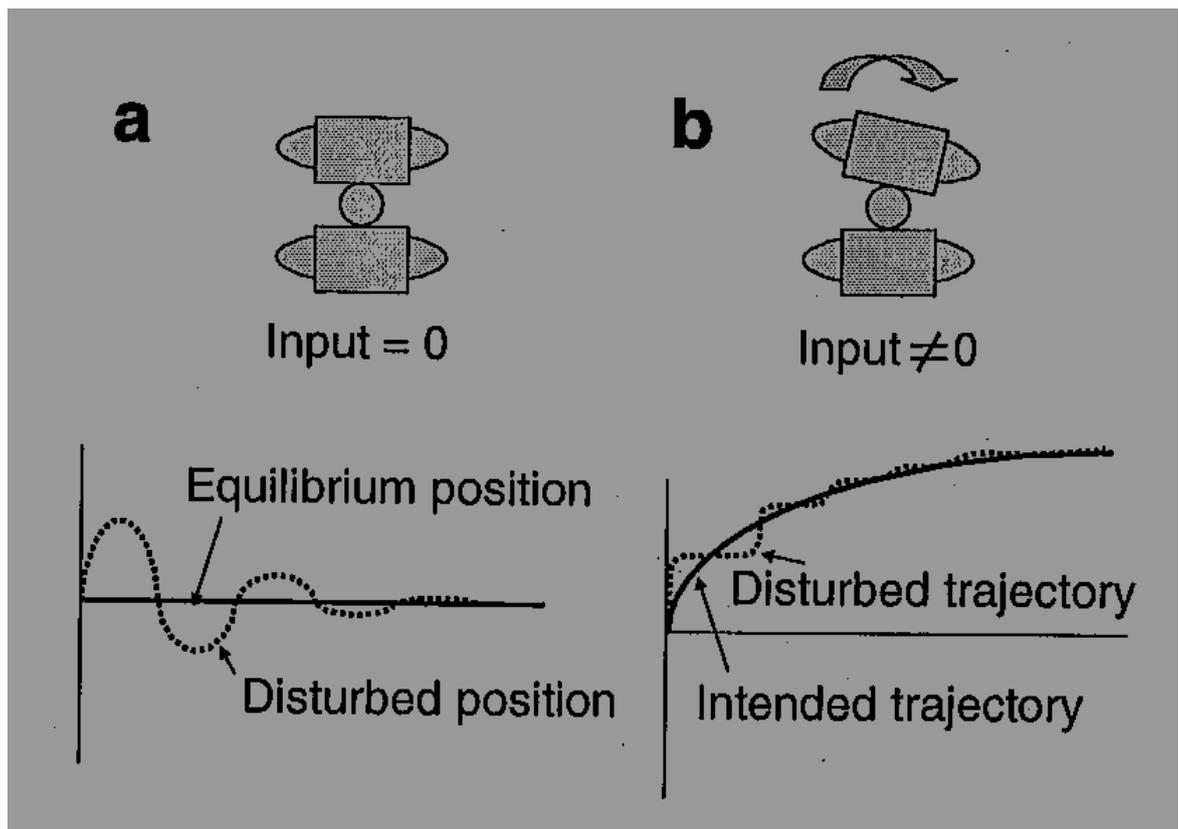


Fig. 2.5: Effect of perturbation on the movement of the spine (from Reeves et al., 2007)

The diagram demonstrates the difference between a state of equilibrium (a) and a change caused by a perturbation (b).

Remodelling occurs within vertebrae through time affecting the ability to adjust to variations in activity (Shao et al., 2002; Sevinc et al., 2008) hence ageing is significant when evaluating the response of the trunk to either intervention or functional activity (Gruber et al., 2007). However, it is suggested that the spine has movement characteristics similar to that of an inverted pendulum with behaviour that will sometimes deviate from the expected norm by demonstrating an inability to maintain robustness (Reeves et al., 2007). A feedback control system (FCS) restores trunk movement back to its intended trajectory if it is altered (Reeves et al., 2007) (Fig 2.5). This therefore suggests that acceleration will play a significant

role in the ability of the spine to readjust itself and restore this intended sagittal trajectory during flexion and extension. Acceleration into both lateral and rotational directions will therefore also be of significance in the execution of the trajectory. The feedback control system (Fig 2.6) suggests that the feedback from intrinsic pathways (short range muscle stiffness and damping) is instantaneous while the feedback from both the reflexive and voluntary pathways has a delay. However, all components of the feedback control system can be used in part or in combination to provide stability through force generation (Reeves et al., 2007).

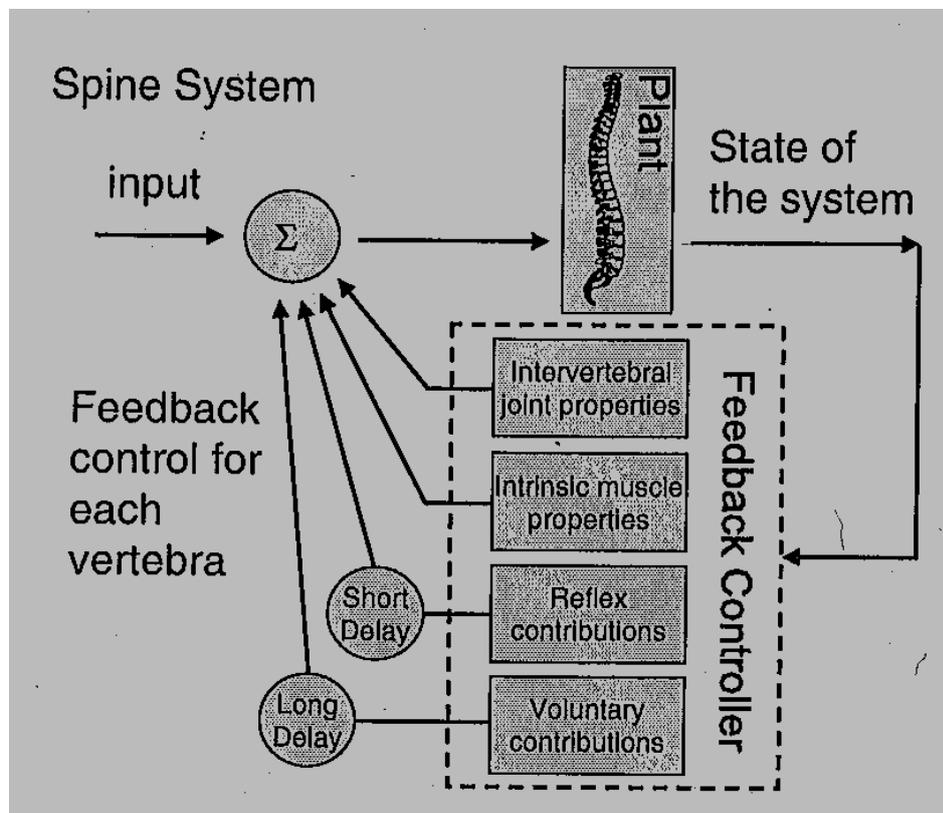


Fig. 2.6: Feedback control system (from Reeves et al., 2007)

The mechanism by which the FCS provides tolerance to perturbation is described as its robustness (Reeves et al., 2007) and it is this principle that this study proposes to critique to offer an explanation for the mechanism by which CSE may influence trunk performance in response to an onset of LBP. The absence/lack of

intervertebral stiffness provided by the passive sub-system (Panjabi, 1994) within any direction of movement caused by perturbation implies that the counteracting force is not proportional to the size of the displacement caused by the perturbation suggesting a possible failure of the FCS (Reeves et al., 2007). The central nervous system (CNS) responds to perturbation by increasing muscle activation (Reeves et al., 2007) irrespective of the fact that it has been shown that LBP patients demonstrate higher trunk muscle co-contraction than the healthy (Marras et al., 2001; Lariviere et al., 2002; van Dieen et al., 2003). The difference between these two groups has been shown to be of clinical significance (Reeves et al., 2007).

In principle, therefore, it has been proposed that there are two main possibilities by which errors in neuromuscular control and loss of robustness can cause LBP (Preus and Fung, 2005 cited in Reeves (1997));

1. Failure of the osteoligamentous structures of the spine creating excessive segmental movement -beyond limits
2. Increased and sustained muscle contraction of muscle after a brief period of instability

The second possibility could account for acute onset of LBP during functional activity such as during trunk movements previously executed with success (Reeves et al., 2007). However, this does not theorise why some episodes of acute LBP occur well within the limits of trunk movement. Anecdotal evidence suggests that these episodes are usually described as sharp twinges whilst performing a movement but not always severe enough to cause an immediate cessation of function. There are suspicions that changes in muscle recruitment in response to a perception of instability may be the answer (Hodges et al., 2003; Moseley et al., 2004). It is

therefore proposed that robustness is directly related to trunk performance requiring input from the FCS responding with a high degree of precision. The resulting trunk movement behaviour in responding to perturbation has been likened to an inverted pendulum (Stepan, 2009).

2.11 Inverted Pendulums

The human body is a multiple inverted pendulum of which the time delay within the neural system required for control can be affected by age, physical and mental state (Stepan, 2009). Three systems are recognised as providing control for this complicated multiple inverted pendulum; the labyrinth (auditory system), eyes (visual system) and mechanoreceptors (touch system) (Stepan, 2009). It is suggested that the time delay affects the recruitment of the superficial component of the multifidus and transversus abdominis (Stepan, 2009). Given the anatomy of these muscles and the assumption that these muscle groups have a role in trunk kinematics (Reeves et al., 2007), this delay could influence the ability of the trunk to accelerate. This mechanism would suggest that the over all response cannot be unduly influenced by subjectivity. In contrast once the trunk has accelerated, its velocity in all probability becomes less independent. Although the deep component of the multifidus creates stability by generating force without torque it is proposed that the net effect of multifidus contraction is to maintain the relative position of vertebrae (Reeves et al., 2007).

Two systems may describe the mechanism by which the trunk moves about the pelvis. One system, a two-degree of freedom system best demonstrated by balancing a stick on the hand, suggests that in order to maintain equilibrium a control force (F) is required at the point of contact through a distance ' χ ' (Fig.2.7).

The angle of displacement of the stick is denoted as ' φ ' with ' m ' the mass of the stick and ' l ' its length (Stepan, 2009).

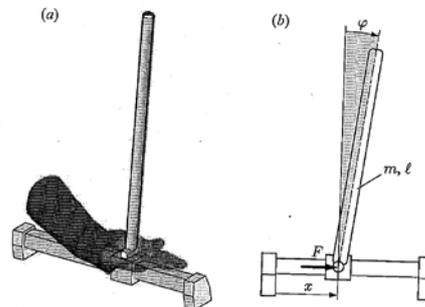


Fig. 2.7: Two-degree of freedom model for balance (from Stepan, 2009)

The second system is described as a one-degree of freedom model. This model can best be demonstrated by trying to maintain balance whilst standing still. Control is achieved through the ankle (Stepan, 2009) (Fig. 2.8). This model may demonstrate a much clearer mechanism than the two-degree system because it considers the influence of a control torque or moment (M) about the ankle ($-M, M$). This system would probably fit more comfortably in describing movement of the trunk about the sacrum in the absence of osteoligamentous connections.

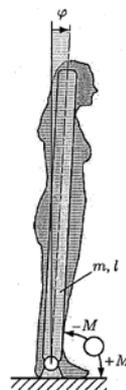


Fig. 2.8: One-degree of freedom model for balance (from Stepan, 2009)

If either of the above systems are assumed to be true and the trunk moves from a relatively fixed point, the sacrum (S), it will in all probability exhibit similar

characteristics of an inverted pendulum albeit with a degree of ‘chaos’ (Granata and England, 2006) as illustrated in Fig. 2.9.

During flexion the trunk is displaced through an angle of θ in relation to its starting point travelling over a displacement ‘A’ to ‘B’ represented by ds . Trunk angular velocity (ω) is expressed as $d\theta/dt$ and its angular acceleration (α) $(d\omega)/dt$.

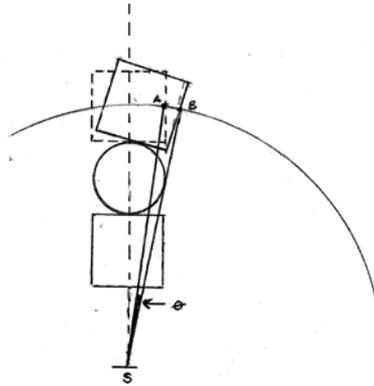


Fig. 2.9: Illustration of inverted pendulum movement of the Trunk

Another important characteristic of pendulum movement is simple harmonic motion (SHM) (Ogrodnik, 1997c). SHM is rhythmic motion about a point, usually the mid-point of the pendulum swing. It is proposed that this is the point during functional movement when the trunk is in a state of ‘balance’ when the force developed by muscle coordination equals the force developed by the perturbation. Further work would be required to support this assumption but it is an interesting possibility. It can be demonstrated in the lumbar spine during repetitive movements whilst performing tasks; the trunk deviates and returns to a starting position (Fig. 2.9). If this holds true it would be possible to propose that from the waveform for the movement;

$$X_t \text{ (angular displacement from midpoint)} = A \sin \omega t \text{ (Fig. 2.10)}$$

(t=time)

The maximum velocity of a pendulum is achieved at the midpoint of the displacement when the amplitude of displacement is zero (Ogrodnik, 1997c).

According to Ogrodnik (1997c), the velocity (**V**) is therefore derived as;

$$V = dx(t)/dt \dots \dots \dots (1)$$

Or

$$V = d(A \sin \omega t)/dt = A\omega \cos \omega t \dots \dots \dots (2)$$

(ω is the frequency and A is the amplitude of the sin wave) (Fig. 2.10)

The acceleration (α) exhibited by such a movement can also be derived as;

$$\alpha = dv_x(t)/dt \dots \dots \dots (3)$$

Or

$$\alpha = d(A\omega \cos \omega t)/dt \dots \dots \dots (4)$$

Or

$$\alpha = -A\omega^2 \sin \omega t \dots \dots \dots (5)$$

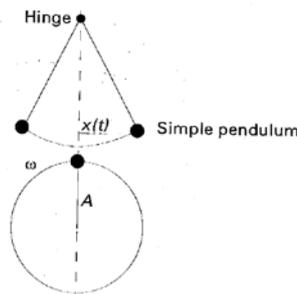


Fig. 2.10: Simple harmonic motion wave (from Ogrodnik, 1997c)

This reinforces the importance of acceleration in initiating the change of direction, a process less likely to be biased by subjectivity unlike velocity.

There is however, a need to translate angular movement into its linear offshoot to appreciate how two fixed points on a vertebra may move in the absence of the osteoligamentous constraint from a point 1 to a point 2 (Fig. 2.11) or from 'A' to 'B' (Fig 2.9).

$$\text{The distance travelled by the point } (ds) = rd\theta \dots \dots \dots (6)$$

The vector velocity $|v| = ds/dt$ (7)

Or

$|v| = R d\theta/dt$ (8)

Or

$|v| = r d\theta/dt$ (9)

Or

$|v| = \omega r$ (10)

Centripetal acceleration (a_c) is required to attain a velocity once there is a change in direction as a vertebra travels in a ‘circular’ path (Fig. 2.11).

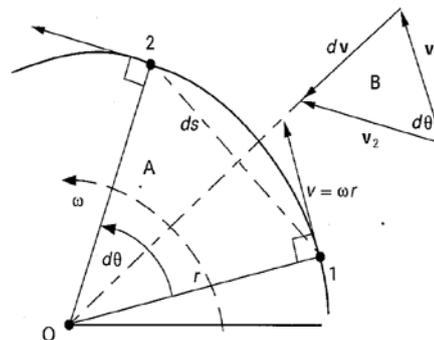


Fig. 2.11: Velocity changes of vertebrae caused by angular movement (from Ogrodnik, 1997c)

If $ds = r d\theta$ (11) (Eq 6.)

$ds/r = dv/|v|$ (12)

Or

$dv = |v| ds/r$ (13)

And

$|a_c| = |dv/dt|$ (14)

$|a_c| = |v|/r ds/dt$ (15)

$|a_c| = |v|^2/r$ (16)

Or

centripetal acceleration (a_c) = $\omega^2 r$ (17)

It is the average cumulative changes in acceleration that this method quantifies and investigates (Fig. 2.11). Therefore force generated by movement is proportional to 'r' and thus the greater the value of 'r' the greater the acceleration and the force developed. This does suggest that the centripetal force is therefore dependent upon the distance of the vertebra from the fixed point (sacrum) suggesting that the closer the vertebra is to the fixed point (sacrum) the greater the effect of cumulative centripetal force produced by trunk movement is experienced. It is therefore proposed that this could be the mechanism by which the L5/S1 segment has become specialised in terms of the relative size of L5 to other vertebrae in the same region. A natural response to a role that is similar to a hinge, upon which the trunk rotates.

2.12 Intra-abdominal pressure

Intra-abdominal pressure (IAP) is thought to play a significant role in the stability of the spine (Cholewicki et al., 1999; Janda and Valenta, 2000). It may not be possible to isolate this role from that of what is commonly termed as 'core stability' muscle activity because of the interdependency of the muscle groups concerned (Chapter One). A mathematical model has been devised to predict levels of IAP and moment occurring at L4/5 movement segment during functional tasks (Janda and Valenta, 2000).

$$\mathbf{IAP=IAP_0 + 0.567735 \cdot M [Pa]}$$

(IAP₀ - initial value of the intra-abdominal pressure during relaxed standing; M- moment produced at the L4/5 motion segment)

The generation of IAP is directly linked to anthropometric values, lumbar lordosis and pelvic tilt during relaxed standing (Youdas et al., 2000) suggesting that the ability to develop and maintain lumbar/pelvic symmetry is an important way by

which excessive loading of the trunk can be dampened. However, IAP responds to changes in posture and for instance it has been demonstrated that IAP is directly related to respiratory activity (Cholewicki et al., 1999; Hodges and Gandevia, 2000).

2.13 Trunk acceleration

Higher order trunk movement characteristics are valid and reliable measures to determine sincerity of effort (Marras et al., 2000). Velocity can be used to classify trunk movement during controlled and uncontrolled sagittal flexion-extension, uncontrolled rotation, uncontrolled side flexion, and repeatability of function (Marras et al., 2000). Although it also influences the central set and acceleration (Marras et al., 2000) it is only possible when there is a change in direction during the task. This may also be true during a unidirectional task if a change in velocity is required to respond to pain or discomfort at different points through the range of activity.

Low Back Pain affects the characteristics of the central set or the recruitment pattern of trunk muscles during movement (Marras et al., 2000). A recruitment pattern of movement is developed and maintained by day to day activity (Hsieh et al., 1992) and is well developed for common tasks such as those involving trunk flexion (Marras et al., 2000). The relationship between acceleration and velocity during a movement can be demonstrated using a phase plane (Fig. 2.12) using a set of Rho numbers to represent the distance in the phase plane space between each point within it and the centroid of the phase plane.

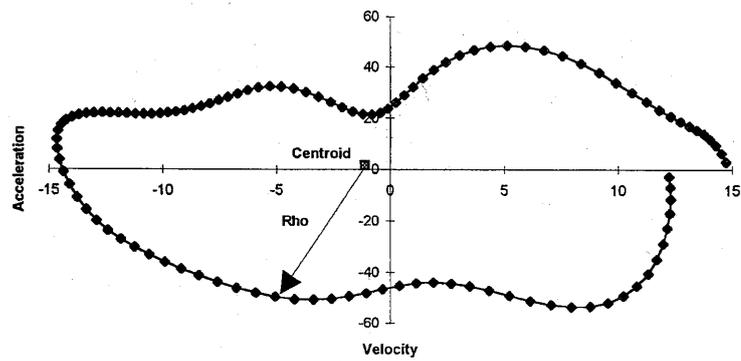


Fig. 2.12: Phase plane of trunk movement (from Marras, 2000)

The consistency of this plot with repeated cycles will therefore demonstrate a sincerity of effort because the closer these phase planes are with repeated measure the more the consistent the effort (Marras et al., 2000).

Physical factors may inhibit or change the characteristics of the central set and produce inconsistent plots demonstrating changes in direction within the tripartite coupling system (sagittal, coronal and axial planes) (Marras et al., 2000). It is proposed that altered acceleration can be observed at those differing points during the completion of a task such as flexion-extension. There is paucity in the literature exploring this hypothesis and it is not clear which of the variables of velocity or acceleration are the most sensitive to changes in direction but given that acceleration is a factor of velocity it would appear that changes in acceleration would be more descriptive of changes in both direction and dysfunction.

It is not clear if acceleration and velocity exhibit a similar behaviour during trunk dynamic functional activity, especially when pain can influence trunk characteristics. Anecdotal evidence does suggest that pain influences trunk mobility and during an episode of LBP is reported to be at the beginning or end of changes in trunk position. It has been reported that LBP reduces trunk acceleration (Marras and Mirka, 1993). However, because of the direct relationship between acceleration and velocity it is assumed that both measures will demonstrate a similar trend. It

may be because of this assumption that there is a paucity of research into the behaviour of trunk acceleration. But it is not clear if the pain reported at the beginning or end of trunk movement is of the same magnitude experienced during the actual movement within which the trunk is expected at some point to reach peak levels of velocity. Hence it is proposed that if this pain is different both in description and magnitude, acceleration or deceleration measures will have more significance for outcome and expectation of intervention.

The subgroup of LBP patients most likely to respond to stabilisation exercises are those with lumbar instability (Hicks et al., 2005) but the diagnosis of instability remains controversial because its measurement and validity rely on static observations (Teyhen et al., 2007). Using the same terminology to define mechanical LBP is therefore a problem unless there is a valid means to observe such instability during trunk movement. The pain experienced during flexion-extension movements of the trunk is thought to be caused by a disruption to the passive osteoligamentous system limiting movement (Teyhen et al., 2007). Loss of neuromuscular control causes instability within the trunk causing the feeling of “slipping” or “catching” during movement (Panjabi, 1994). A flexion-relaxation phenomenon, the period of electromyographic electrical silence of the lumbar paraspinal muscles is evident at the end of range of trunk flexion (Teyhen et al., 2007). This phenomenon is particularly poor in patients with LBP causing segmental hypomobility with reduced linear displacement (Teyhen et al., 2007).

It is a theory that the ability of the trunk to harness efficient neuromuscular control to produce trunk positional changes that will determine if the movement

will produce pain (Panjabi, 2003). Furthermore, it is proposed that this ability is reliant on an ability to accelerate to and maintain an efficient velocity.

2.14 This thesis research questions

The main aim of this thesis was therefore to investigate the effect of core stability exercises (CSEs) on the acceleration of the spine after an acute onset of LBP.

The study was also designed to answer the following research questions;

- Does the kinematics of the spine change with the onset of acute LBP?
- Do CSEs reduce the levels of disability caused by LBP?
- Do CSEs reduce pain caused by LBP?
- Can CSEs be used effectively in primary care to prevent the increasing prevalence of chronic LBP?

2.15 Conclusions

Higher order kinematics is a valid and reliable means of describing trunk movement (Kroemer et al., 1990; Marras et al., 1990) but trunk velocity and range of movement (ROM) can be subjective (Cox et al., 2000). Stability of the trunk during movement is dependent upon the speed of execution and symmetry of the task (McGregor and Hughes, 2000). However, tasks evaluating trunk performance are best done when participants are evaluated performing tasks at their preferred speed (McGregor and Hughes, 2000). Asymmetrical tasks require greater motor control using large trunk muscles; a process that is accompanied by a corresponding loss of fine motor control (Granata and England, 2006). The literature seems to suggest that there is an assumption that both trunk acceleration and velocity will

demonstrate similar characteristics. However it is not clear if the ability to accelerate mirrors the ability to maintain a desired velocity during displacement. This mechanism is worthy of investigation. There is paucity in literature quantifying the effects of core stability exercises using functional objective measures. This study set out to evaluate changes in trunk performance as an effect of a course of core stability exercises. It has been suggested that LBP does reduce trunk acceleration but the behaviour of trunk acceleration in response to core stability exercises as an intervention is not well understood. This is compounded by the fact that previous studies purported to investigate the effects of CSE are not well designed.

Chapter 3

Development of the method

3.1 Summary

This chapter describes the development of the rationale for the method chosen to test the study hypothesis and answer the research questions described in the previous chapter.

3.2 Operational definition of acute non-specific low back pain

Acute LBP is described as an episode of LBP that has lasted for up to 6 weeks becoming chronic if it lasts longer (BackCare, 2007; Kinkade, 2007). It has also been described as lasting for up to 3 months (Smith et al., 2002; Gullick, 2008). The '3 months' definition was used in articles within a systematic review of core stability exercises (May and Johnson, 2008) but the practicality of describing acute non-specific low back pain as lasting for up to 3 months is most probably unacceptable because of the secondary effects of LBP which are largely driven by a process of central neuro-modulation (Jayson, 1996). The latest informed opinion is that an acute episode of low back pain lasts up to 6 weeks (BackCare, 2007).

The National Institute for Health and Clinical Excellence (NICE) suggests that non-specific LBP describes LBP which cannot be attributed to any specific cause and also suggests that exercises and physical activity should be offered to patients with non-specific LBP for a period of 12 weeks in the first instance (NICE, 2009).

3.3 Recruitment of participants

The study was approved by the School of Health Sciences & Social Care Ethics Committee at Brunel University and Oxfordshire NREC ethics committee (Ref. 07/H0606/102) in September 2007.

3.3.1 Inclusion Criteria

Participants of either gender, male or female and aged between 18 and 55 were eligible for inclusion. This age group was chosen because they provide the greatest number of consultations for LBP in primary care (Croft et al., 1998). Each participant's history of onset of non-specific LBP was to be no longer than 6 weeks' duration, a period described as acute (BackCare, 2007).

3.3.2 Exclusion Criteria

Participants were excluded if they did not meet the inclusion criteria as described above and demonstrated evidence through routine physiotherapy assessment of any of the following;

- Degenerative conditions affecting the spine- Loss of bone, joint and intervertebral disc integrity influencing spinal mobility (Gruber et al., 2007).
- Diabetes- Diabetes increases the risk of muscle strength impairment (Bohannon, 2000) and affects the ability to perform the exercises required by the protocol.
- Pregnancy- Underlying mechanism for LBP during pregnancy is ambiguous and may be multi-factorial (Kerr and Grahame, 2003) with approximately 50% of women reporting an incidence of LBP whilst pregnant (Kerr and Grahame, 2003). Hormonal changes affect pelvic ligaments and cause an increase in joint mobility (Kerr and Grahame, 2003).

- Neurological involvement- Peripheral neurological damage will affect muscle response to stimuli and exercise. A study on the ulnar nerve conduction velocity of injured baseball pitchers suggested that although the velocity appeared to be normal they demonstrated suboptimal performance (Wei et al., 2005).
- On-going spinal treatment- Other surgical and non-surgical treatment would contaminate responses to intervention. Contamination of this type can cause a cross-over effect (Altman, 1991).
- On-going legal issues- subjective perception of pain and disability could be affected by expected monetary gain from an injury (Standaert et al., 2008).
- History of depression- Subjective perception of pain could be altered by psychological factors (Standaert et al., 2008).
- Histories of multiple recurrent episodes of low back pain- Biomechanical properties of the structure of the spine are altered during repeat episodes of LBP (Standaert et al., 2008).
- Involvement in other research studies- Participation in multiple studies could compromise safety. Attributable effects of intervention given in this study will be ambiguous (Hicks, 1998).
- English not being their first language- Misinterpretation of study procedure and instruction would jeopardise results and the ability to provide informed consent.

Participants were recruited from 5 locations within Hillingdon Primary Care Trust (PCT). These locations included

1. Church Road Surgery, Cowley

2. The Warren Medical Centre, Uxbridge
3. Uxbridge Health Centre, Uxbridge
4. Eastcote Health Centre, Eastcote; Westmead Clinic, South Ruislip
5. Harefield Health Centre, Harefield

All the Centres operate with a 'hub and spoke system' with Laurel Lodge, the hub, in Hillingdon coordinating physiotherapy provision across those Centres.

Referrals are generated from general practitioner (GP) surgeries within the area but patients referred to a Centre may not necessarily be registered with a GP at the Centre at which they will receive their physiotherapy treatment.

3.3.3 The sample size

The sample size presented within this work needed to be small enough to be managed effectively within the constraints of true micro and macro environmental pressures as described in the following section 3.3.4 but large enough to demonstrate differences between the CSE and control groups (Section 4.3).

3.3.4 Challenges to recruitment

A number of challenges have affected the recruitment process. These include the following;

- ***The waiting list.***

Fluctuations in the length of time patients were on the waiting list could have been significant. This period may also differ according to each location from which participants will be recruited. The waiting list was predicted to range between 6 and 12 weeks depending upon the location. A significant number of patients became ineligible for inclusion because they no longer met the definition of acute non-specific LBP.

- **Local demands.**

The demands of the Commissioners for healthcare delivery within primary care resulted in changes in physiotherapy delivery within the primary care trust. As a result physiotherapy staff were pressurised into implementing queue management strategies to redress disparity in access to services and waiting times. These strategies actively changed during the study to suit prevailing circumstances.

- **Staff turnover.**

There was a continuous change in personnel within and between locations. The structure of physiotherapy career pathways within the NHS precipitated this tendency. This study protocol required physiotherapy staff to be actively involved with the recruitment process. Non-clinical staff was also required to assist in arranging convenient appointment times to ensure that participants' visits for data collection coincided with treatment times.

- **Personal Ethics.**

Some physiotherapy practitioners faced personal dilemmas as they took the view that patients who agreed to take part in the study were in effect 'queue jumping'. Practitioners who relied upon CSE as a primary form of intervention also questioned the ethics and efficacy of withholding such intervention when they were requested not to prescribe CSE because their patient was allocated to a control group. Using alternative treatment methods, albeit for a short period of time (6 weeks) was not an entirely comfortable option for them.

- **Facilities.**

All locations except Eastcote Health Centre operate within either a GP surgery or a room within a Health Centre. These rooms did not offer enough space

within which to accommodate both the normal day to day function and additional space required for data collection. Care was taken to ensure that visits coincided with the least busy time of routine operational procedures.

- **Logistics**

The study did not attract funding from either internal or external sources. All the data for the study, was therefore collected by the researcher alone. This did present difficulties involving travel to and between locations.

3.3.5 The randomisation process

Two hundred opaque envelopes with pieces of paper on which either ‘control’ or ‘experimental’ group were prepared by a colleague who was blinded to the study. The colleague did not have contact with the participants or have any other input to the study. The researcher did not take part in the process and had no knowledge of the allocation of envelopes to groups. Once the envelopes were sealed, they were shuffled and then had a sequence of numbers marked on the exterior of the sealed envelope in a chronological order to denote the order in which participants were recruited. Each sealed envelope was opened in the sequence in which they were numbered by the participant as they are recruited. This was done only after the participant had given their written consent to take part in the study and after the participant was aware that it was not possible to change from the group to which they would be potentially be allocated to. Neither the researcher nor the participant was aware of the contents of the envelope until it was opened by the participant. The participants were therefore not blinded to the allocation.

3.4 Tools and outcome measures

3.4.1 Pain

There are a number of scales that are used to evaluate pain. These include the Brief Pain Inventory (BPI) in either its short or long version (Daut and Cleeland, 1982), Dallas Pain Questionnaire (DPQ) (Lawlis et al., 1989), Numeric Pain Intensity Scale (NPIS) (McCaffery and Beebe 1993), Faces Pain Rating Scale (Bieri et al., 1990), Wong-Baker Faces Pain Rating Scale (Wong and Whaley 1986), Aberdeen Back Pain Scale (ABPS) (Ruta et al., 1994) and the Visual Analogue Scale (VAS) (Huskisson, 1974). The VAS was used for this study because of its ease of use and the ease to which the information was interpreted.

The Visual Analogue Scale (VAS), as a single item measure, is very sensitive to changes in symptoms that can be rated (Paul-Dauphin et al., 1999). The VAS is reliable and valid as an outcome measure (Crossley et al., 2004) and it is a good tool for quantifying both pain and disability in conditions involving chronic musculoskeletal pain but the measures for pain are more reliable than that for disability (Boonstra et al., 2008). Because levels of disability correlate to levels of pain it is realistic however, to assume that the reliability of measures will be similar in the acute phase of a condition by relating consistently with levels of pain (Boonstra et al., 2008). The VAS is also reliable when time variance is a factor (Badia et al., 1999) especially with LBP (Olaogun et al., 2004).

The minimal clinically significant difference in the VAS pain score remains unaffected by levels of pain (Kelly, 2001) which made the VAS a realistic choice for this study to quantify pain during an acute onset of LBP. This is because pain is a single variable/construct and there is the need to consider the complexity of the

recruitment process. 'Pain on the day' of testing was used to evaluate reported pain because it minimised participants' recall bias (Chouinard and Walter, 1995).

The VAS was denoted by a 100 mm line to indicate a range from a state of 'no pain' (0 mm) to that of 'very severe pain' (100 mm). Increased scores indicated more pain.

3.4.2 Disability

There is no preferred functional limitation outcome measure for low back pain (The Chartered Society of Physiotherapy, 2004). However, a number of outcome measures available include the Aberdeen Back Pain Scale (ABPS) (Ruta et al., 1994), Quebec Back Pain Disability Scale (QBPDS) (Kopec et al., 1995), Oswestry Disability Index (ODI) (Fairbank et al., 1980) and the Roland Morris Disability Questionnaire (The Chartered Society of Physiotherapy, 2004). The Oswestry Disability Index (ODI) and the Roland Morris Disability Questionnaire (RMDQ) (Roland and Morris, 1983) are recommended for use by physiotherapists however the setting and location should determine which one is more appropriate for the circumstances (The Chartered Society of Physiotherapy, 2004). The RMDQ was used in this study. The ODI was discounted because of its relative low internal consistency (Cronbach's $\alpha = 0.77$) and because it has a mixture of both capacity and performance based items (The Chartered Society of Physiotherapy, 2004). The ABPS was not used because a relatively long time is required to complete it (The Chartered Society of Physiotherapy, 2004) and the QBPDS was not used because there is not enough evidence to support its use at present (The Chartered Society of Physiotherapy, 2004).

The Roland-Morris Disability Questionnaire (RMDQ) is regarded as the best scale to measure self reported disability (Deyo et al., 1998; Boonstra et al. 2008) and it is both valid and reliable (Roland and Morris, 1983). This scale is recommended for use in primary care studies (Roland and Morris, 1983; Kopec et al., 1995) and has a high intra-class reliability of 0.8 (Kopec et al., 1995, Stratford et al., 1996; Dunn and Croft, 2005). It also has a high degree of sensitivity (Hseih et al., 1992) and been recommended for use without the need for further validation (Grotle et al., 2004; Grotle et al., 2006).

The RMDQ as a tool can easily be used within a clinical environment. The RMDQ consists of a 24-item back pain specific disability scale. The participants were asked to answer 'yes' or 'no' to each question. The sum totals 'yes' score was determined. The change in this score quantified the relative change in pain and disability as a result of intervention.

The RMDQ results of this study will be interpreted with an understanding of the minimal clinically important difference of the RMDQ for LBP. A rule for minimal clinically important difference for RMDQ is shown below (Table 3.1) (Jordan et al., 2006).

Table 3.1: Minimal clinically important difference rule for disability (from Jordan et al., 2006)

- | |
|---|
| <ul style="list-style-type: none">▪ Definitely improved: Patients rating back pain as at least better at 6 months with a reduction > 30% on their RMDQ score.▪ Possibly improved: Patients with an RMDQ score >30% reduced at 6 months but have not rated their back pain as better.▪ Not improved: Patients with less than 30% reduction in RMDQ score at 6 months. |
|---|

3.4.3 Trunk performance

Various methods of obtaining trunk kinematic evaluation have been explored; video analysis (Wickstrom et al., 1996; Neumann et al., 2001; Chang et al.,

2003, Trott and Fisher, 2005; Wong and Lo, 2007), EMG activity (Capodaglio et al., 1995; Oddsson et al., 1997; Chiou et al., 1999; Bonato et al., 2002; Pitcher et al., 2008) and 3-D motion analysis (Nakajima et al., 2007; Pazos et al., 2007). The Lumbar Motion Monitor (LMM) is however, potentially the most practical tool for use in a clinical setting because it is highly portable and the time to set up the equipment is much less labour intensive than the other aforementioned tools. The video analysis and EMG evaluations may have allowed a greater freedom of movement in the trunk than the LMM because of the harnesses required to secure the device to the participant, however, these methods of analysis are labour intensive and require high intra and inter-reliability measures rendering the procedures difficult to transpose into the clinical environment.

The LMM provided objective measures of real time changes in trunk kinematics to quantify LBP by measuring spinal kinematics (Marras and Wongsam 1986; Kroemer et al., 1990; Marras et al., 1990; Marras, 1996). Simultaneous information on displacement, acceleration and velocity of the spine in three dimensions during functional movement was obtained.

The LMM is an electrogoniometer consisting of a number of potentiometers within an exoskeleton capable of detecting and measuring real time movement in 3-dimensions (sagittal, frontal and coronal planes). The LMM was developed at Ohio State University and it has become a useful tool in the quantification of triaxial movement of the spine (Marras and Wongsam 1986).

3.4.3a Calibration of the Lumbar Motion Monitor

The LMM was originally demonstrated to be both valid and reliable with an accuracy of measure of $\pm 0.25\%$ (Marras et al., 1990). The LMM has a sampling rate

of 60Hz and can measure between -35 to +65 degrees in the sagittal plane and between -45 and +45 degrees in both the coronal and frontal planes (Lumbar Motion Monitor, Industrial Analysis Desk Reference Chattanooga Group, Inc.). Further calibration tests in a laboratory environment using a video motion analysis demonstrated its accuracy to be within +/- 0.5 degrees (Parnianpour et al., 2001). This was done by using a reference frame to +/- 30 degrees in the frontal and coronal planes and to +/- 45 degrees in the sagittal plane (Parnianpour et al., 2001).

The manufacturers of the LMM calibrate the LMM before its inaugural use. However, supplementary calibration tests within laboratory conditions for this study demonstrated a 2% discrepancy between actual and recorded data (Appendix 2). This calibration test procedure was carried out by measuring the angle of displacement of the LMM at different angles during both components of forward bend and extension from flexion during a single flexion-extension movement (Appendix 3: a-f). A comparison of the LMM programme output to actual LMM plate angle was made. For this process, the subject was instructed to stand with the feet at shoulder width apart and with the shoulders placed across the chest. A single flexion-extension movement of the trunk was performed and still pictures were taken to measure the angle of the LMM plates. These measurements were taken in neutral and 6 other positions of flexion; 3 during forward bend movement and 3 during backward extension movement of the trunk as it resumed the neutral position.

The 2% difference between the measures suggests that the LMM produces reliable data even when a thin layer of clothing exists between the LMM harnesses and the skin.

3.5 The Lumbar Motion Monitor protocol

The original protocol devised by Marras et al. (1986) consisted of 5 tasks for a single kinematic evaluation of trunk sagittal movement in 0 degrees or neutral, 15 and 30 degrees of rotation to the left and then right (Marras and Wongsam, 1986; Marras, 1996; Gill and Callaghan, 1996). Movements in the sagittal plane with the trunk in these degrees of rotation utilises different muscle recruitment patterns to cope with the increase in the level of difficulty in performing the task (McGill et al., 2003). The study protocol for this research did not consider difficulties performing the task which may be complicated by underlying facet joint pathology (Boyling and Jull 2004) but tested a revised version of the original protocol requiring only one task to provide an evaluation of trunk sagittal movement in neutral (Ferguson and Marras, 2004). This was done using a pilot study. The adjusted protocol resulting from the pilot study was then used for this research project. For testing the adjusted protocol participants stood with their feet shoulder width apart with the arms loosely folded across the chest and performed flexion-extension movements in neutral without rotation to either the right or left.

Although the LMM has been reported as reliable using the Intra-class Correlation Coefficient (ICC) analysis of the data, levels of agreement between measurements were not reported (Ferguson and Marras, 2004). For this study it was therefore imperative that levels of agreement of the reliability for a single task evaluation was demonstrated. This was important because all the data was collected by one researcher who was not be blind to the study aims or objectives.

3.6 Reliability of the LMM using a single task method

3.6.1 Participants for the pilot study to evaluate its reliability

Approval for the pilot study was granted by the School of Health Sciences & Social Care Ethics Committee at Brunel University and Oxfordshire NREC ethics committee (Ref. 07/H0606/102).

Twenty participants were recruited by incidental sampling at Brunel University between February and March 2008 and were classified as belonging to one of two groups (Table 3.1). One group consisted of healthy participants, a mix of both colleagues and students (male =5, female=5). This group had an average age of 38.3 years (SD 8.6) and did not have a recent history of LBP. No recent history was defined as the 6 months prior to testing. This was judged to be sufficient enough to avoid recall bias (Chouinard and Walter, 1995) and limit any possibility of any carry over of previous treatment effects (Altman, 1991) and provide a wash-out period where any effects of any previous intervention is reduced (Chapter 1 Peacock and Peacock, 2011). The other group of participants were potential participants for the main study (male = 4, female =6) and had an average age of 31.7 years (SD 7.5). All participants in this group had been diagnosed with an acute onset of LBP within a 6 week period. A description of both groups of participants is provided below (Table 3.2).

Table 3.2: Pilot study group descriptive

		Minimum	Maximum	Mean	Std. Deviation
<u>Healthy Participants</u> (m=5, f=5)	Weight (Kgs)	54.5	99.0	71.2	14.4
	Age (Yrs)	21	51	38.3	8.6
	Height (cms)	154.0	183.0	171.9	11.2
<u>LBP Participants</u> (m=4, f=6)	Weight (Kgs)	45.0	113.0	74.5	21.3
	Age (Yrs)	20	44	31.7	7.5
	Height (cms)	157.0	191.0	171.3	12.0

3.6.2 Pilot study procedure

The Lumbar Motion Monitor (LMM) was used to collect data to explore the intra-rater reliability of the equipment. The equipment consists of a light weight exoskeleton within which are a set of potentiometers. The exoskeleton was connected, via an umbilical lead to a laptop containing specialised software (Lumbar ProSoft 2.0, NexGen Ergonomics, Canada) for data collection and analysis (Fig. 3.1). The exoskeleton was positioned on the participant with a 2-piece harness, one for the thorax and the other for the pelvis; both harnesses were secured in place with Velcro strapping.

Before collecting data the anthropometric measurements (age, height and weight) for the participants were entered into the computer software. The potentiometers were then calibrated with the exoskeleton firmly in place within its holding case. A zero- calibration check procedure using explicit instructions from the manufacturers using the LMM software was performed before data was collected from each participant and between each set of data.

A harness size (small, medium or large) which allowed for the exoskeleton to be placed on the participant's trunk without demonstrable movement whilst standing erect in the neutral position was selected. The exoskeleton was then attached and tightly secured in place onto the harness and tightly secured with the locking mechanism provided.

For each set of data collected, each participant was asked to stand with their feet shoulder width apart and their arms loosely folded across the chest. The participant was instructed to perform trunk flexion-extension movements in a sagittal plane for 8 seconds. The movement flexion-extension in the sagittal plane

without rotation to either side of midline were performed at the participants' preferred speed (McGregor and Hughes, 2000; Al-Eisa et al., 2006) to ensure natural trunk movement (Al-Eisa et al., 2006). No other instruction was given to the participant. Previous studies that used the LMM (Marras and Wongsam, 1986; Marras et al., 1990; Ferguson and Marras 2004) did not do this. No other encouragement or stimulus was provided. Two sets of data (Test 1 and Test 2) were collected with a 10 minute rest period in-between each measurement. This prevented data contamination by cross over effects (Altman, 1991; Hicks, 1998).



Fig. 3.1: The Lumbar Motion Monitor exoskeleton

3.6.3 Results of the pilot study

The LBP group demonstrated slower acceleration compared to the healthy participants within all kinematic variables during both tests 1 and 2 (Table 3.3) (Fig. 3.2). The LBP group were unable to increase trunk acceleration with repeated measure (Fig. 3.2). There was no correlation between sex, height or weight with any sagittal acceleration values.

Table 3.3: Pilot study group comparison (Acceleration)

		Sagittal Acceleration (Deg/s ²)		Lateral Acceleration (Deg/s ²)		Rotation Acceleration (Deg/s ²)	
		Average (SD)	Peak (SD)	Average (SD)	Peak (SD)	Average (SD)	Peak (SD)
Healthy	T1	215.9 (149.5)	627.1 (363.6)	42.6 (37.6)	175.5 (130.0)	20.8 (16.7)	88.9 (57.5)
	T2	253.9 (160.0)	674.5 (298.9)	33.6 (21.4)	130.4 (90.2)	28.6 (21.0)	106.6 (71.1)
LBP	T1	148.8 (103.1)	426.4 (177.3)	31.7 (17.9)	129.1 (60.6)	15.5 (7.3)	61.9 (24.3)
	T2	151.6 (114.3)	416.9 (208.3)	30.3 (22.3)	131.4 (79.3)	16.2 (11.5)	67.1 (34.9)

The mean differences between measurements (T1 and T2) for all kinematic variables were calculated and a two-way mixed ANOVA analysis (SPSS ver. 15 for windows) was used to determine the intra-class correlation coefficient (ICC).

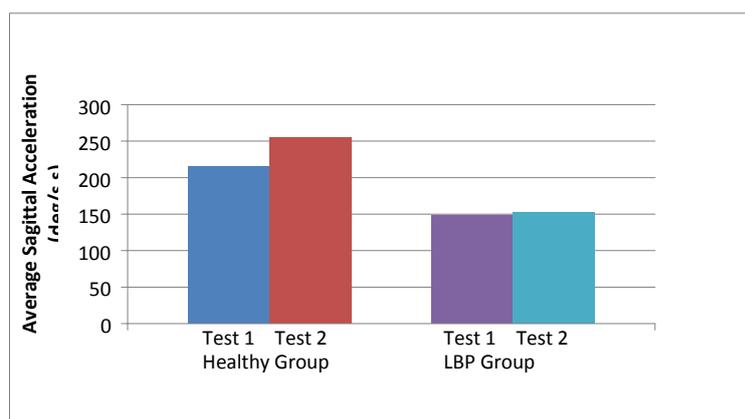


Fig. 3.2: Pilot study comparison of Sagittal Acceleration Test 1 Vs Test 2

Average sagittal acceleration demonstrated the highest ICC at 0.96 (C.I 0.90-0.98) (Table 3.4). This suggests that average sagittal trunk acceleration is the most

reliable of the variables obtained from the LMM for measuring changes in trunk performance produced by an intervention.

Table 3.4: Pilot study Intra-class correlation coefficient (ICC)

Kinematic variable (Deg/s²)	Differences in the mean (SD)	Intra-class Correlation Coefficient	(95% CI)
Average Sagittal Acceleration	20.4 (40.1)	0.96	0.90-0.98
Average Lateral Acceleration	5.2 (19.1)	0.72	0.42-0.88
Average Rotation Acceleration	4.2 (9.1)	0.83	0.62-0.93
Peak Sagittal Acceleration	19.1 (133.6)	0.89	0.75-0.96
Peak Lateral Acceleration	21.9 (62.1)	0.77	0.51-0.90
Peak Rotation Acceleration	11.4 (30.4)	0.83	0.62-0.93

3.6.4 The Bland-Altman plot

The Bland-Altman plot (Bland and Altman, 1986) was constructed using the SPSS programme (Ver. 15 for windows). The raw data was manipulated to determine the difference between the within subject measures of average acceleration (ACCDIF1) in the sagittal plane was first determined. The within subject mean (ACCMean1) was then calculated for the two measures (AAcc.S1 + AAcc.S2/2).

The mean and standard deviation for ACCDIF1 (Table 3.5) were then substituted within two equations (1 and 2) below to determine the boundaries within which approximately 95% of the individual subjects' differences would be expected to be.

Table 3.5: Pilot study acceleration differences

	N	Minimum	Maximum	Mean	Std. Deviation
ACCDIF1	20	-116.14	36.12	-20.4	40.1
Valid N	20				

Mean + 2 X Standard Deviation..... (1)

$$-20.40 + 2 \times 40.12 = 59.84$$

Mean – 2 X Standard Deviation..... (2)

$$-20.40 - 2 \times 40.12 = -100.64$$

Key:
 ACCDIF1 - Difference between the first and second measures of average sagittal acceleration
 ACCMean1 – The mean average sagittal acceleration
 AAcc.S1 + AAcc.S2/2 – The sum of first and second average sagittal acceleration measurements divided by two

A plot of ACCDIF1 (y-axis) against the ACCMean1 (x-axis) was then drawn to produce the Bland-Altman plot (Fig. 3.3)

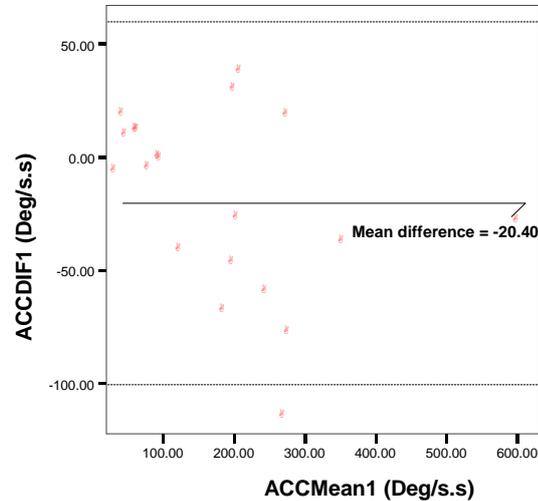


Fig. 3.3: Bland-Altman plot showing limits of agreement of repeated measures for the pilot study

The plot (Fig. 3.3) suggests that the measures were not in very close agreement. However, the high values for the ICC suggests that it remains reasonable to use the LMM as a tool for measuring the primary outcome of trunk acceleration.

3.6.5 Conclusions derived from the pilot study

It was reasonable to use the LMM as a tool for measuring the primary outcome of sagittal trunk acceleration. The disparity in the level of agreement may be because it is not at present possible to attach the LMM harness directly to participants' skin. To do so would be a potential health and safety hazard because of possible cross infection between participants and/or possible skin irritation on each participant. A small amount of unwanted movement may have therefore occurred between the harness and the clothing worn by the participants. Another reason for the disparity could be the fact that trunk performance will change with

repetition i.e a practice effect (Hicks, 1998) irrespective of whether the subjects have LBP or not. Although the harness was applied over loose fitting clothes, this did not directly interfere with lumbar spine movement; the 2% discrepancy demonstrated earlier supports this assumption.

This pilot study has been published in full elsewhere (Aluko et al., 2011) (Appendix 4).

3.7 Evaluation of trunk kinematics

No data is available which evaluates trunk performance within a sample population. This information was useful for analysis of the results of this proposed main study. A further pilot study was therefore required. Approval for this part of the study was also granted by the School of Health Sciences & Social Care Ethics Committee at Brunel University and Oxfordshire NREC ethics committee (Ref. 07/H0606/102) as an amendment.

3.7.1 Recruitment of participants

Participants were recruited from staff and students at Brunel University between September 2009 and March 2010. A request for volunteers to take part in the study was placed on the University intranet. Another verbal request was made to the physiotherapy staff of the Musculoskeletal Physiotherapy Services, Hillingdon Community Health based at Eastcote Health Centre. The combination of these resulted in a total of 50 willing participants agreeing to take part in the study. Each participant gave their written consent to take part.

A short questionnaire (Appendix 5) was used to gather a brief subjective history for each participant to explore the history of their self reported LBP. This questionnaire consisted of simple questions used during a standard subjective

history gathering process for all musculoskeletal conditions in a clinical setting and therefore did not need to be piloted before use. The participants were classified as belonging to either a healthy or LBP group according to that self reported history of LBP. None of the participants reported LBP at the time of testing. A history of LBP was described as an experience of an episode of acute non-specific LBP up to and during the preceding 6 months prior to the date on which the participant was measured as part of the evaluation of trunk kinematics study. 6 months was chosen because it is long enough to prevent recall bias (Chouinard and Walter, 1995) and limit cross over effects (Altman, 1991). On the date on which the participants were tested none of the participants reported any disability in performing day to day activities or underlying pathology that could have interfered with their trunk performance. A description of the groups is shown in table 3.6.

Table 3.6: Database participant descriptive (Healthy participants, n=13; participants with LBP n=37)

Presence of LBP		N	Mean	Std. Deviation
LBP	Age (Years)	37	33.2	12.3
	Height (cms)	37	168.6	8.4
	Weight (Kgs)	37	69.6	15.0
	Last episode of LBP	37	3.1	2.2
	Number of days LBP was present (days)	36	27.0	86.7
No LBP	Age (Years)	13	31.2	13.2
	Height (cms)	13	167.7	10.5
	Weight (Kgs)	13	66.3	16.9

Thirty seven of the 50 participants reported episodes of LBP in the preceding 6 months. These participants had a mean age of 33.2 (S.D 12.3) years, mean height of 168.6 (S.D 8.4) cms and a mean weight of 69.6 (S.D 15.0) kgs. 13 of the fifty participants reported no history of LBP and had a mean age of 31.2 (S.D 13.2) years, mean height of 167.7 (S.D 10.5) cms and a mean weight of 66.3 (S.D 16.9) kgs. The LBP group reported an average of 3.1 (S.D 2.2) weeks proceeding the date on which

they provided data as when they experienced an episode of acute non-specific LBP and reported average duration of an episode to be 27 (S.D 86.7) days.

3.7.2 Procedure to evaluate trunk kinematics using the LMM

The LMM was applied as described in section 3.6.2 above. Data was collected during one cycle of flexion-extension movement during a single 8 second period (Section 3.6.2 above). Each participant was requested to perform the test movement at their preferred speed. No other encouragement or stimulus was provided to ensure as much natural trunk movement as possible (Al-Eisa et al., 2006).

3.7.3 Statistical analysis

A measure of reliability was investigated using the two-way mixed model of intra-class correlation coefficient to evaluate the proportion of the total variance that was due to the variance between subjects alone.

A one way ANOVA analysis was used to investigate difference between and within groups.

Pearson's Correlation Coefficient (r) was used to investigate relationships between factors.

All Analyses were conducted using SPSS (ver. 15 for Windows).

3.7.4 Results

74% of the participants reported a history of LBP. Data were collected during a mean sagittal displacement of 52.7 (S.D 16.8) and 43.3 (S.D 15.0) degrees for the participants with and without a history of LBP respectively. The distribution of data was skewed as demonstrated by the asymmetrical distribution of the

measurements. This therefore required the data to be log-transformed before analysis.

One way ANOVA ($\alpha=0.05$) suggested that average sagittal acceleration was not significantly different either between or within the groups ($p= 0.4$).

Participants who did not report a history of LBP demonstrated slower performance (Table 3.7). This could possibly be because these participants had better control of trunk movement during the measurement process compared to the group who considered they were experiencing an episode of non-specific LBP. Interestingly, none of the participants within this group were actively receiving treatment for their back pain during the period of data collection. However it would be expected that the reverse should hold true given the results demonstrated in section 3.6.3 above.

Table 3.7: Group performance comparison (kinematic evaluation)

Presence of LBP		N	Mean	Std. Deviation
LBP	Sagittal ROM (Max-Min PS) (Degs)	37	52.7	16.8
	Average Sagittal Acceleration (Deg/S.S)	37	359.2	170.1
No LBP	Sagittal ROM (Max-Min PS) (Degs)	13	43.3	15.0
	Average Sagittal Acceleration (Deg/S.S)	13	309.7	150.4

Female participants demonstrated slower mean trunk performance than males whether they reported a history of LBP or not but this was not significant (Table 3.8).

Table 3.8: Mean sagittal acceleration (Deg/S²) by level of gender and the presence of low back pain

		Presence of LBP (<i>p</i> =0.84)	
		Yes	No
Gender (<i>p</i> =0.27)	Male	M= 440.4 S.D = 240.9	M= 364.8 S.D = 152.2
	Female	M= 336.8 S.D = 142.3	M = 293.1 S.D = 153.9

More females reported a history of LBP than males (M=8; F=29) and 41% of this group of participants reported an episode within the last month prior to testing.

Neither the length of time of the last reported episode prior to testing (*p*=0.8) nor gender (*p*= 0.27) was significant in the mean sagittal acceleration measures of participants.

Intra-Class Correlation Coefficient (ICC) analysis using a two-way mixed method demonstrated the reliability of the single measure as 0.65 (95%CI 0.40-0.80) and 0.58 (95%CI 0.70-0.85) for participants with and without a history of LBP respectively.

Pearsons' Correlation Analysis (*r*) suggests that there is a stronger correlation between trunk displacement and the mean sagittal acceleration of 0.64 (*p*=0.01) and 0.57 (*p*=0.05) within participants with a history of LBP compared to the healthy participants respectively. The displacement demonstrated by this group was affected by the history of LBP.

A significant correlation between weight and height was demonstrated in both the LBP group (*r*=0.49, *p*=0.01) and the group without LBP (*r*=0.87, *p*=0.01). This suggests that the correlation for the participants who did not report a history of LBP was stronger than in those reporting a history of LBP. A weight/age

correlation only existed in the participants with a history of LBP ($r=0.34$, $p=0.05$) but was not statistically significant at $p=0.05$ in the other group ($r=-0.29$).

3.7.5 Conclusions derived from trunk kinematic evaluation

Within a sample of the population described here, the data suggests that the prevalence of LBP can be demonstrated to be relatively high however a self reported episode of LBP within this sample may not be reliable. From the sample evaluated, more female participants reported an episode of LBP than males. However, whether females reported a history of LBP or not within the sample they consistently demonstrated slower average trunk performance. The reliability of the LMM in both groups of participants without or with a history of LBP was similar but the confidence interval within which the results are reported was smaller in the group who did not report a history of LBP. The results demonstrated by the sample in question may tentatively be applied in general, however, only a much bigger study can provide substantive facts. This information is however used with this in perspective to discuss trunk acceleration in relation to the findings of this research study within chapter 6.

3.8 Development of the intervention

3.8.1 Core stability exercises

The 'core' is described as the lumbopelvic region (Willardson, 2007a; Willardson, 2007b). Muscles that influence trunk performance are two groups 'global' (erector spinae, rectus abdominis) and 'segmental' or those that act across spinal segments (multifidus and transversus abdominis) (Bergmark, 1989). Stabilisation exercises improve the integrity of the segmental muscles (Willardson, 2007a; Willardson, 2007b). Exercise for the treatment and management of LBP is

common but the efficacy of exercise is doubtful (Linton et al., 1996). The comparative effect of therapeutic exercise regimen with active exercises suggests that there is no clinically significant difference (May and Johnson, 2008).

Stabilisation exercises may be useful for the management of chronic LBP but the effects may not be more effective than other methods of management involving activity (May and Johnson, 2008). The effect on acute LBP is not widely reported. This may be because it is assumed that the effects of stabilisation exercises in enhancing neuromuscular control and rectifying dysfunction (Richardson et al., 1999; Norris, 2000; McGill, 2002) may not be required during an acute phase of LBP.

There is no formal definition of core stability exercises or recommendation for any specific grouping of CSE (Standaert et al., 2008). There is also no justification for the choice, combination of, or the number of repetitions and frequency of the chosen exercises (Standaert et al., 2008). However the clinical decision and justification for using stability exercises to improve the integrity of the lumbar multifidus has traditionally been underpinned by a set of belief systems (Table 3.9) (MacDonald et al., 2006). Increases in cross sectional area of the multifidus can be observed within 6 weeks following the introduction of CSE and this increase is directly related to the frequency of the exercise (Sokunbi et al., 2008). Stabilising exercises have been designed to encourage the activation of the deep fibres of the multifidus through low loaded isometric activity with the spine in as much of a natural position as possible (MacDonald et al., 2006; Standaert et al., 2008). The exercise routine that was used in this study and derived from a software package

which accompanied work on core stability exercises (Norris, 2000) is attached within the appendices (Appendices 4 and 5).

Table 3.9: Core stability exercises belief systems (MacDonald et al., 2006)

Belief System	Evidence
Deep multifidus rather than superficial fibres or the erector spinae responsible for spinal stability	Richardson & Jull, 1995; Richardson et al., 1999f
Deep multifidus has the most proportion of type 1 muscle fibres	Porterfield & DeRosa, 1991a,b; Richardson et al., 1999f
Isotonic activity is observed in the deep multifidus during trunk movements and gait	O'Sullivan et al., 1997; Richardson et al., 1999f; Taylor & Sullivan, 2000; Hides, 2004a
Deep multifidus and transversus abdominis co-contract during function	Richardson & Jull, 1995; O'Sullivan et al., 1997; Pool-Goudzwaard et al., 1998; Richardson et al., 1999b; Richardson et al., 2000; Taylor & Sullivan, 2000; Arokoski et al., 2001; Hides et al, 2004
Low back pain induces most changes within the deep multifidus	Norris , 1995a,b; Pool-Goudzwaard et al., 1998; Richardson et al.; 1999d; Arokoski et al., 2001; Hides 2004a,b

3.8.2 Exercise compliance

Compliance in Physiotherapy is important because the effect of intervention is largely reliant upon it (Sluijs et al., 1993). Compliance plays a significant role in the outcome of intervention (Linton et al., 1996). It does not significantly change the perception of pain in LBP; although compliance with exercises can be improved when pain intensity is negligible when compared to a control group (Linton et al., 1996). The fear avoidance model of inactivity is the primary factor in restricting levels of pain and thus by implication compliance (Linton et al., 1996; Frank and DeSouza, 2001; Fritz and George, 2002). Exacerbation of pain may be linked to attempts at becoming active (Linton et al., 1996).

The exercise routine that was used in this study was chosen because they reflected the exercise routines which anecdotal evidence suggest are most commonly used in clinical practice. They were also devised on the assumption that compliance would be enhanced if participants understand the aetiology, onset of

their LBP and the behaviour of their pain. A good relationship with whoever is providing the exercise instruction and the frequency and number of repetitions of the exercise reflecting their lifestyle (allowing for omissions in the routine due to unforeseen circumstances) will also improve exercise compliance (Linton et al., 1996; Frank and DeSouza, 2001; Fritz and George, 2002).

Each participant that was randomised into the experimental group was required to complete an exercise compliance sheet (Appendix 8). The participants were to bring the sheets with them for each treatment session where the sheets will be examined by the treating Physiotherapist. This served two purposes; to suggest to the participant that their progress was being monitored closely and to provide an incentive for compliance. Although each sheet represented the requisite daily exercise compliment, participants were given only enough sheets for 3 weeks at a time. Each participant in the experimental group was inclined to ask for more sheets to complete the remaining 3 week period.

The participants in the experimental group were able to demonstrate the frequency and the number of repetitions that were completed for each of the exercises. The participants were told that if a set of the exercises were inadvertently missed they were not to double up the number of repetitions for the subsequent set of exercises. They were required to leave the corresponding section on the sheet blank. This prevented anomalies in the data caused by the different effects of either high or low repetition of exercises.

Other forms of compliance methods were not be used to avoid adding to the participants' perceived barrier to exercise by impinging on the available time that they have to do the exercise routine (Sluijs et al., 1993).

3.9 The effects of missing data

Because of possible attrition and its possible effects on the results, an ‘intention to treat’ analysis (Altman, 1991) was used. As described in chapter 2, this type of analysis allows direct comparison of the groups in response to the intervention by maintaining the balance in respect to the subject characteristics within each group (Chapter1 Peacock and Peacock, 2011). In order to achieve the ‘intention to treat’ analysis the last measurement obtained from a participant was carried forward to replace any missing data. This is known as the Last Observation Carried Forward (LOCF) (Howell, 1992). This procedure is often preferred (Peacock and Peacock, 2011) however the trend of the data in this instance suggested that this was a reasonable strategy.

3.10 Conclusions

This chapter has set out the method to answer the research questions described in chapter 2. This chapter also defined and justified the use of the RMDQ, VAS and the LMM to describe changes in pain and disability as a direct result of the introduction of core stability exercises.

The following chapter describes the method derived from this chapter that was used to answer the research questions and hypotheses posed in chapter 2.

Chapter 4

Method

4.1 Summary

This chapter describes the method used to collect the data for this study. It provides an insight into the obstacles that the researcher encountered during the study and the decisions made to ensure that the study remained valid. The biggest threat to the success of the study was the frequent local changes to Physiotherapy provision at the behest of the local Primary Care Trust. These changes resulted in a number of amendments (4.6 below).

4.2 Introduction

It remains unclear if CSEs will make a significant difference in the treatment of LBP or indeed if there is a defined subset of patients with non-specific LBP who will respond more favourably than others (Brennan et al., 2006). This study evaluates the effect CSEs have on an onset of acute non-specific LBP.

A significant problem with using CSE is the ambiguity of the underlying mechanism that underpins the clinical decision making process that suggests its use. This process can influence treatment outcome and any cost/benefit analysis within both primary and secondary care. Better clarity can be achieved by providing answers to the following research questions;

- Does an onset of acute LBP change trunk kinematics?
- Can CSEs reduce self reported disability caused by LBP?
- Do CSEs reduce LBP?

The study involved two groups of participants (Control and Experimental) who were experiencing an acute episode of non-specific LBP and comparing the changes in trunk average sagittal acceleration, reported pain and reported disability between participants who had a CSE programme (experimental group) and those who did not (control group).

4.3 The research design

The study was a randomised controlled trial and was approved by the School of Health Sciences & Social Care Ethics Committee at Brunel University and Oxfordshire NREC ethics committee (Ref. 07/H0606/102) in September 2007. The study did not attract any internal or external funding and in view of the time constraints it was decided that the study would proceed within the capabilities of the researcher.

The objectives of this study were;

- To evaluate the effect of Core Stability Exercises (CSE) on trunk performance during flexion-extension movements in the sagittal plane. Performance was to be evaluated during a period of non-specific acute LBP.
- To evaluate changes in disability caused by an acute onset of non-specific LBP during a course of CSE.
- To evaluate the changes in pain during an acute episode of non-specific LBP.

The hypotheses of the study tested were the following;

- CSE will improve average trunk acceleration when performing flexion-extension movements in the sagittal plane.

- CSE will reduce pain during an episode of non-specific LBP.
- CSE will reduce self reported disability caused by an onset of acute non-specific LBP

The study process is shown below (Fig 4.1).

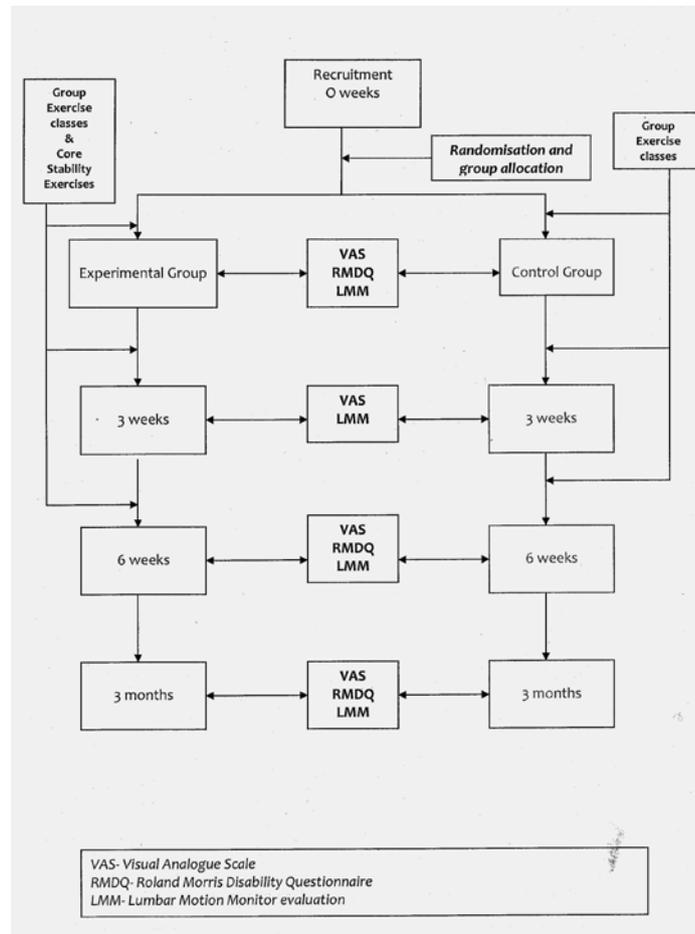


Fig. 4.1: Study flow chart

4.4 The study sample size

A standard formula, $N=2ks^2/d^2$ ($k=10.5$ standard multiplier; s = standard deviation and d = clinically significant difference) would have been the preferred choice for calculating the sample size for this study in the first instance. The sample size calculated would have provided a power of 90% with a significance of 5%. However, the absence of a known clinically significant difference suggested that this approach was not beneficial (Bland, 2009), since no research predating this

study provided a clinically significant difference for the primary outcome measure for changes in mean sagittal acceleration in response to CSE. Although the trunk produces an average sagittal acceleration of 470 deg/s² (Marras et al., 1990) no data existed to suggest a possible differential as a result of an intervention.

Because of the problems with recruitment (chapter 3), the alternative of an estimation of the likely width of the confidence level to a power calculation was used to interpret the findings (Bland, 2009). Clinical implementation of previous research has been impeded by the inability of research to effectively demonstrate its clinical importance; it is often lost in the emphasis of stating the power of the research tests (Domholdt, 2005). This study had to be able to demonstrate its meaningfulness to clinical practice by ensuring that the sample size presented in this work was small enough to be managed effectively within the constraints of true micro and macro environmental pressures and used confidence levels to report the findings. This needed to be done without losing potentially important information or giving misleading interpretation of results (Bland, 2009).

4.5 Study recruitment process

All patients referred between July 2008 and June 2010 for treatment of an acute episode of non-specific LBP within Hillingdon Primary Care Trust in West London were given the opportunity to take part in the study. The recruitment process was continuous with participants randomised to groups as they were recruited. Participants were approached during their first visit for an assessment after being referred for physiotherapy treatment. Physiotherapy staff members in the musculoskeletal outpatients departments of Hillingdon Community Health providers who had agreed to be involved in the recruitment process made the initial

approach to patients who were under their care. The patients who were interested were given the patient information sheet and asked to sign and return the reply slip at their next appointment. Participants who were willing to take part are described below (Table 4.1). The researcher was then notified within a working day of the patient's willingness to participate and informed of the date of the patient's next scheduled treatment session. This next scheduled appointment was the date at which written informed consent was obtained and baseline data collected.

Table 4.1: Participant demographics

<u>Participant</u>	<u>Gender</u>	<u>Age (Years)</u>	<u>Occupation</u>	<u>Onset of symptoms</u>	<u>Period of symptoms (Weeks)</u>	<u>Previous Episode and treatment</u>	<u>Date seen by GP (Days)</u>
1	M	38	Manual	Sudden	5-6	Yes	>7
2	M	45	Driver	Gradual	5-6	No	>7
3	M	31	Office worker	Gradual	6	Yes	2-3
4	F	43	Post woman	Sudden	3-4	Yes	2-3
5	F	28	Office worker	Sudden	6	Yes	2-3
6	M	33	Unemployed	Gradual	5-6	Yes	>7
7	F	21	Student	Gradual	4-5	No	>7
8	F	24	Researcher	Insidious	5-6	Yes	>7
9	F	28	Unemployed	Gradual	6	No	>7
10	F	22	Student	Gradual	5-6	Yes	>7
11	M	40	Airline Officer	Sudden	6	Yes	>7
12	F	55	Teacher	Gradual	6	Yes	>7
13	F	43	Housewife	Insidious	6	No	>7
14	F	32	Office worker	Gradual	6	Yes	>7
15	F	55	Carer	Gradual	5-6	Yes	>7
16	F	55	Housewife	Gradual	6	No	7
17	F	40	Office worker	Gradual	1-2	No	>7
18	F	36	Housewife	Gradual	6	No	>7
19	F	47	Housewife	Sudden	6	No	>7
20	F	27	Housewife	Gradual	5-6	Yes	>7
21	F	28	Housewife	Gradual	4-5	No	4-5
22	F	48	Housewife	Gradual	6	Yes	>7
23	F	32	Housewife	Sudden	6	Yes	2-3
24	F	28	Housewife	Gradual	5-6	No	4-5
25	F	29	Unemployed	Gradual	6	Yes	>7
26	F	39	Office worker	Gradual	6	Yes	>7
27	F	31	Housewife	Gradual	5-6	Yes	2-3
28	F	50	Housewife	Gradual	6	Yes	>7
29	F	50	Unemployed	Gradual	6	Yes	>7
30	F	42	Administrator	Gradual	1-2	No	4-5
31	F	45	Office worker	Gradual	6	Yes	>7
32	F	53	Administrator	Sudden	1-2	Yes	2-3
33	F	45	Housewife	Gradual	6	Yes	>7

Prior to commencement of the study, all general practitioners (GP) who have access to the Musculoskeletal Physiotherapy Services were informed of the study.

This was done with care so as not to change the referral behaviour. This was important for the physiotherapy staff members who had volunteered to be actively involved in the recruitment process because changes in referral patterns would have had consequences on capacity, queue management and general treatment outcomes.

All participants were referred from within primary care but there was a variation between the times they had been experiencing symptoms before they saw their GP. This variation ranged from between 2 and 7 days (Table 4.1). Although this posed a threat to the recruitment process it was not possible to influence this first stage of the care pathway.

An initial informal estimation of the waiting list suggested that referrals for treatment of LBP constituted a significant majority of the referrals on the waiting list for all locations included as a study site (Section 3.3.2). However, the length of the waiting list suggested that a majority of those referrals would not meet the inclusion criteria because they would have been waiting for more than 12 weeks. The local physiotherapy staff members were co-opted into appraising all referrals as they arrived at the locations and recruiting potential participants as quickly as possible. Some physiotherapy staff had reservations about doing so because they considered that those patients could be 'jumping' the queue. The Lead Practitioner/Manager provided valuable support for the study by emphasising the need for local research. This intervention was crucial in changing the view of those staff members. However, a compromise was that a 3 month rather than a 1 year follow up was more realistic. Six participants had been recruited before this decision and had passed the time for the 3 month follow up. The data collected

from these participants at baseline, 3 weeks and 6 weeks were included in the analysis of the results. Although they provided data at the 1 year follow up this data was not included in any analysis within this study and the data that should have been obtained at 3 months was considered to be missing data replaced with the last observations carried forward (LOCF) (See section 3.9).

Changes in access policy and information management by the local Primary Care Trust (PCT) presented a real threat 3 months into the study. A new IT system (RIO) meant the physiotherapy staff no longer maintained control of their diaries and all appointments were made from a central point. In an attempt to improve access and drive down waiting times, the PCT decided that all patients with LBP should have an initial one-to-one assessment and then be referred to 'Core Stability Classes'. The content of the classes included a mixture of exercises aimed at both 'global' muscle and 'intersegmental' muscle activity (Appendix 7 and 8). The protocol for this group of participants is shown in fig 4.1. These classes were provided on a weekly basis and each patient was offered a 5 week course of treatment. Participant grouping for this study was therefore redefined. The control group was redefined from the group that did not perform any exercises to that which consisted of participants who attended the core stability classes only. The experimental group constituted those participants who attended the core stability classes but performed an additional exercise routine (Appendices 6 and 7). The protocol for this group of participants is shown in fig 4.1. Care was taken to avoid duplication of exercises and the use of specific words/phrases such as Transversus Abdominis, Multifidus, core strengthening and stability were avoided during the core stability classes. This was so that the chance of the physiotherapy staff

member introducing bias to the study was minimised and also to avoid potential doubt of the impact of being allocated to a specific group within the minds of the participants.

An advantage of these classes was that data were collected during those class attendances however other contractual obligations of the researcher prevented the researchers' attendance at all the available classes and some potential participants were missed to the recruitment process.

Local turnover of staff did not play a significant role in disrupting the recruitment process. Staff co-opted to assist in the recruitment process was experienced physiotherapists who had permanent non-rotational positions within their respective departments. This meant that there was no need to re-visit the various sites (Section 3.3.2) to maintain levels of interest within the departments to remain actively involved in the recruitment process.

4.6 Randomisation and allocation process

Participants were allocated to groups using the method described in chapter 3. A colleague independent and blind to the study placed notes on which was written either 'experimental' or 'control' group into opaque envelopes. These envelopes were shuffled and then marked in numerical order.

4.7 Study procedure

Every participant received an initial assessment by a suitably qualified member of staff at the nearest physiotherapy outpatient department to which they were referred to by their GP. Once a participant was identified and agreed to take part in the study, the physiotherapist completed a short history sheet (Appendix 11).

These details would have formed part of the standard musculoskeletal subjective history procedure. This sheet provided basic details of the history of onset and nature of the LBP. Each willing participant was then provided with a Participant Information Sheet (Appendix 12). This took place after each participant was offered a place in the core stability classes which was part of the routine care pathway for an acute non-specific LBP patient. Each participant was asked to sign a return slip confirming their willingness to participate in the study and requested to bring this confirmation slip with them to their first core stability class where the researcher met the participants for the first time. Eastcote Health Centre was the location for data collection because it was easier for the participants to attend the same location for measurement at which they were taking part in the CSE programme.

During the initial session, each participant was given the opportunity to ask questions about the study and was given a further opportunity to withdraw. Written informed consent was then obtained (Appendix 13). The participant was then requested to open an envelope marked with the number which represented the order in which they agreed to become a participant in the study. Neither the participant nor the researcher was aware of the contents of the envelope prior to this time. The researcher then re-affirmed the procedure for the study in relation to the group to which the participant had been allocated. The participant was also given a further opportunity to decline taking part in the study.

Baseline measurements of height, weight and age were collected and recorded on the specialist software on a laptop to which the LMM was connected via an umbilical cord through which two-way communication between the LMM exoskeleton and the laptop occurred. Each participant was also required to

complete a RMDQ (Appendix 14) and VAS (Appendix 15). The RMDQ was not required at 3 weeks (Fig 4.1) because it was not considered a long enough period to identify any change in function. It was however, noted that it has been demonstrated that cross sectional area of the multifidus can be increased within 6 weeks of CSE (Sokunbi et al., 2008).

The LMM had already been calibrated by the manufacturers before its initial use (section 3.4.3). However, the 'zero calibration' procedure (section 3.4.3) was performed before each measurement. A harness size (small, medium or large) which allowed for the exoskeleton to be placed on the participant's trunk without demonstrable movement whilst standing erect in the neutral position was selected. The exoskeleton was then attached and tightly secured in place onto the harness and tightly secured with the locking mechanism provided.

The assessment of repeated measures demonstrated during reliability testing of the equipment suggested that some movement can occur between the LMM harness and the skin of the participant. It was, however, not possible to place the LMM directly onto the participants' skin because of health and safety considerations. To reduce unwanted movement to a minimum all participants were evaluated wearing a top made of as thin a material as possible and asked to wear a similar garment for each evaluation.

Each participant was requested to perform as many sagittal trunk flexion-extension movements as possible for 8 seconds. The movement was executed at the participants' preferred speed and within their preferred range of movement. No encouragement verbal, non-verbal or otherwise was offered. No warm up exercise was performed because the interest of the study lay within the natural muscle

recruitment process to effect functional movement without prior warning. All trunk measurements were therefore also taken before each scheduled core stability class. All participants completed the evaluation and none reported an exacerbation of their symptoms.

Following the initial LMM evaluation, the participants allocated to the experimental group were given their CSE instruction (Appendices 4 and 5) by the researcher. The experimental group was required to perform 10 repetitions of 8 CSE three times a day for 6 weeks. This was in anticipation that the participants would be able to complete the routine at least twice a day given their individual personal circumstances involving work commitments and family life. The participants in this group were encouraged to keep an account using a diary (Appendix 8) to demonstrate their compliance with the task. This diary was inspected by the treating physiotherapist at each visit either for treatment or attendance at the core stability classes. The participants in the control group were asked to continue with the classes alone. Participants in the control group received the same face-to-face contact time as those in the experimental group.

Trunk performance of all 33 participants using the LMM procedure was evaluated at 0, 3 and 6 weeks. A further evaluation was made at 3 months for all participants excluding the first 6 participants, three of whom provided an evaluation at 1 year follow up after cessation of the intervention (Fig 4.1). All but the 6 week and 3 month follow-up evaluations coincided with regular attendance at the core stability classes. However, all participants were asked to continue their routine as advised by their treating physiotherapist until their follow up at three months.

4.8 Ethical considerations

The original protocol submitted for ethical approval was changed on three occasions to meet volatile circumstances encountered during the study. These circumstances were out of the control of the researcher. All amendments were substantial and therefore required resubmission to the Oxfordshire NREC ethics committee (Appendix 16)

Procedures were put in place to allow for ethical considerations during the study (Table 4.2).

Table 4.2: Study ethical considerations

<u>Ethical Consideration</u>	<u>Consequences</u>	<u>Procedures</u>
1. Participants changed their mind about taking part in the study	High rates of attrition	Participants were advised at every step that they could withdraw without prejudice at any point in the study.
2. Bias	Participants in the control group could have felt 'disadvantaged' in not having an extra exercise routine	Each participant in the control group was told that at the end of the study they would be offered the same exercise routine.
3. Adverse response to exercises	Increase in subjective pain and discomfort	All participants were instructed to stop any of the exercises at any time they considered their symptoms to have increased.
4. LMM assessments	Increase in pain with measure of outcome	Participants were instructed to perform all test movements at their own preferred speed and range

4.9 Potential sources of error

Potential sources of error during the study and strategies adopted to minimise potential influence on the outcome of the study included the following;

- The success of the study was dependent upon the researcher. To minimise bias the researcher avoided any involvement in the recruitment process, the randomisation of the sample or allocation of participants into groups.
- Although all raw data for each of the outcome measures using the VAS, RMDQ and LMM were collected by the researcher, the VAS score measurement and the evaluation of the RMDQ were carried out by a colleague independent of the study. This was to ensure that any indirect influences that could have been introduced by the researcher were addressed.
- Although the experimental group received exercise instruction from the researcher care was taken to give equal face-to-face time to the control group participants.
- The researcher avoided any cues/prompting during any of the outcome measurement procedures. This was particularly important during the LMM evaluation.
- Similar contact was made with all the participants throughout the study irrespective of the group into which they were allocated.
- Evaluating the intra-rater reliability of the LMM demonstrated a discrepancy between repeated measures (section 3.6.3). Participants were evaluated wearing a similar thin layer of clothing for each evaluation.
- LMM evaluation was not preceded by a 'practice' run to minimise exaggeration of trunk performance resulting from 'practice effect'.

- Participants in the exercise group may not have been entirely accurate with the exercise diary. An assumption was made that the exercise routine would be completed at least twice a day.

4.10 Data preparation

The following procedures were used to prepare the data before analysis;

- The VAS score was measured in centimetres between a minimum of 0 (no pain) to a maximum of 10 (Worst pain). The score was directly proportional to the amount of pain reported. This figure was imported directly and without manipulation for statistical analysis.
- The RMDQ was scored out of a maximum of 24 points. The level of self reported disability due to LBP was directly proportional to the score out of 24. This figure was imported directly and without manipulation for statistical analysis.
- Trunk displacement was defined as the difference between the maximum and minimum trunk position for each evaluation. This figure was imported directly for statistical analysis.
- Average trunk acceleration was provided as an absolute number by the LMM software and did not require manipulation. This figure was imported directly for statistical analysis.
- The CSE routine was recorded by the degree of compliance. The exercise routine was considered to be done if the routine was completed a minimum of twice a day. The total number of days for which the exercise was completed was then directly imported to the

statistical software package without further transformation and used for analysis.

- Where data were log-transformed to give a normal distribution, the results of comparisons between transformed means were back-transformed to give the ratio of geometric means.

4.11 Procedure for testing the hypotheses

All analyses to test the study hypotheses were conducted using SPSS (ver. 15 for windows) (Table 4.3) using an intention to treat analysis.

Table 4.3: Statistical tools to test the study hypotheses

Study Null Hypothesis	Outcome	Measure used	Statistical Analysis
1. Pain experienced during an acute onset of LBP will not be reduced with CSE	Pain	VAS score	Two way mixed ANOVA analysis ($\alpha=0.05$) of differences between and within both the control and experimental groups
2. Self reported disability during an acute episode of LBP will not be reduced by CSE	Disability	RMDQ	
3. Sagittal trunk performance during an acute episode of LBP will not be improved by CSE	Trunk performance	Average sagittal trunk performance	

- A regression analysis was used to investigate the causal relationship between CSE and outcome measures
- Pearson’s correlation co-efficient analysis (r) was used to identify relationships between the 3 outcome variables.
- Intra-Class Correlation Coefficient (ICC) analysis using a two-way mixed method was used to evaluate the reliability of the measure.

4.12 Conclusions

The method described in this chapter was designed to answer the research questions and test the generated hypotheses posed in chapter 2. The outcome measures used provided data to adequately achieve this goal. Reasonable measures were taken to reduce sources of error that could affect the results of the study but total eradication of error could not be entirely guaranteed.

Chapter 5

Results

5.1 Study participants and attrition

Thirty four participants were recruited for this study and more females than males participated (Table 5.1). Variation in compliance with the exercise routine within the experimental group was evident during the 6 weeks active stage of the study (Appendix 17).

Table 5.1: Study group descriptive

	Age (s.d) (Years)	Height (s.d) (cms)	Weight (s.d) (Kgs)
Control (Male= 2, Female=15)	35.8 (9.1)	167.4 (9.0)	73.3 (15.6)
Experimental (Male=3, Female=13)	36.2 (9.8)	166.8 (10.6)	75.9 (18.0)

Although 34 participants were originally recruited, data were collected from only 33 participants. One participant decided not to take part after reflecting on the level of commitment required and withdrew before either randomisation took place or baseline measurements were collected. This participant was excluded from all analyses. However attrition amongst other participants occurred at later stages (Fig 5.1). Measurements not provided by these participants after attrition were dealt with as missing data. No reasons were offered by participants for their decision to withdraw from the study.

Most attrition occurred between the 3rd and 6th week of the study and only 3 of the first 6 participants recruited who were scheduled to provide 1 year follow up data actually did so. These 6 participants did not provide 3 months' follow up data because they had completed the first 6 week phase of the study and had been in

abeyance beyond the 3 months' follow up period before the decision was made to reduce the follow up from 1 year to 3 months. The absent data was therefore treated within the missing data protocol described in Chapter 3. The one year follow up data was not used for any data analysis. Of the remaining 25 participants only 11 completed the whole study; 5 and 6 participants in the experimental and control groups respectively.

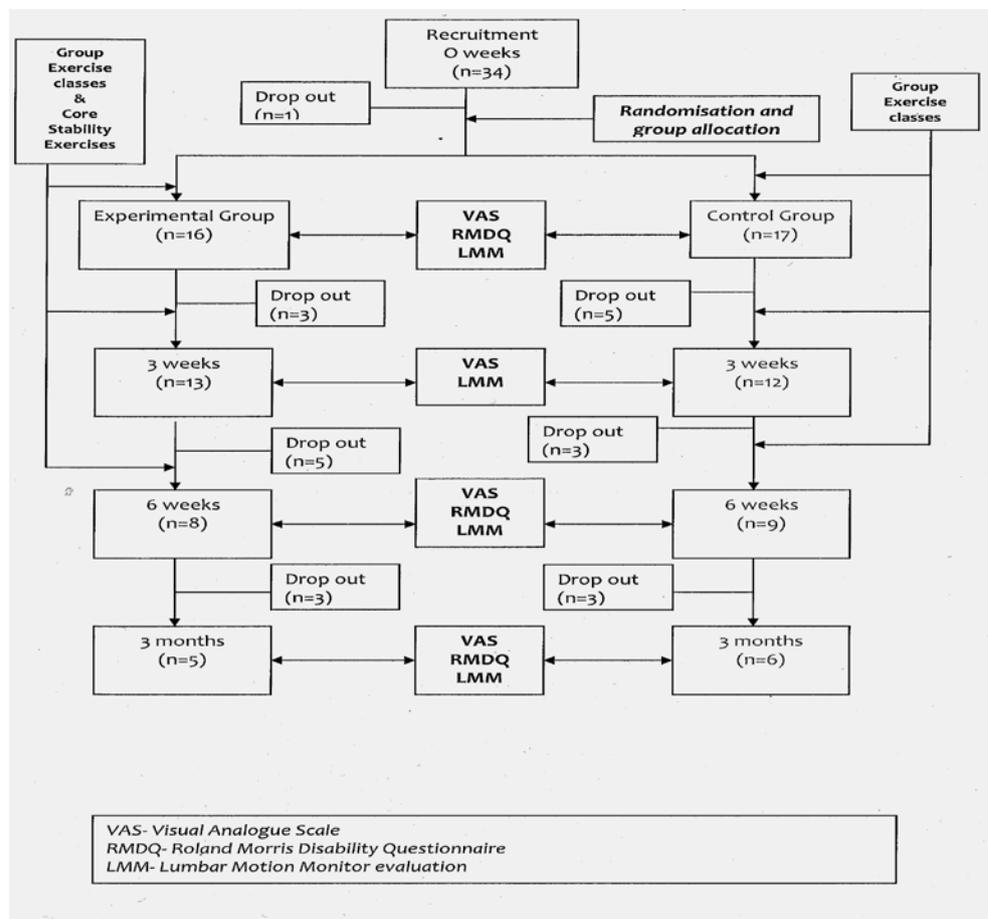


Fig.5.1: Description of sample and attrition

Three participants, following a discussion with their treating physiotherapists decided that they may be disadvantaged by taking part in the study. One participant developed an unrelated orthopaedic problem in the lower limb and decided to end involvement following a tertiary referral to a consultant. The rest of the attrition is unaccounted for because the participants did not provide

a reason and in keeping with the research protocol consent form were not pressed to provide any further information.

5.2 Missing data analysis

The missing data (section 3.9) was replaced with the Last Observation Carried Forward (LOCF) (Howell, 1992). This decision was based upon the fact that it allowed an analysis over the whole time frame of the study and assumed that the data carried forward followed the trend of the data preceding it. The reason for this approach was because the trend of the raw data demonstrated either a sequential improvement or status quo in the outcome measures within both groups of participants. It was therefore assumed that the missing data could be replaced with the data that proceeded without the fear that the results would therefore be over optimistic. It was therefore assumed that bias would be kept to a minimum as the artificial inflation of the effect of intervention was avoided.

5.3 Description of the data

The trend of the data collected is demonstrated in figs 5.2-5.7 below and a comparison of the data between the data including and excluding missing data is also demonstrated in figs 5.9-5.13). The number at the top of each graph denotes the number of each participant during the allocation to group process.

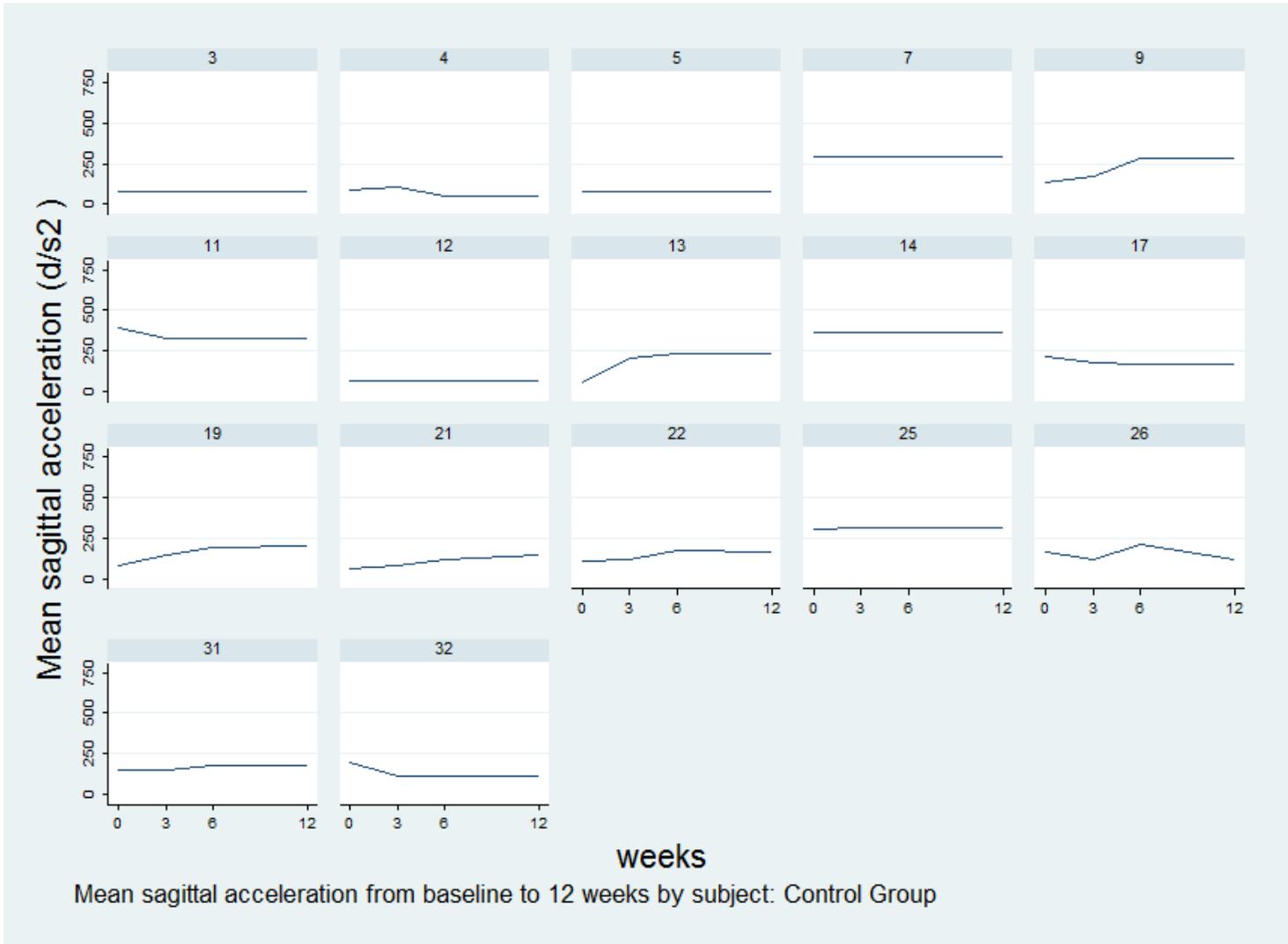


Fig. 5.2: Mean trunk sagittal acceleration (Control group)

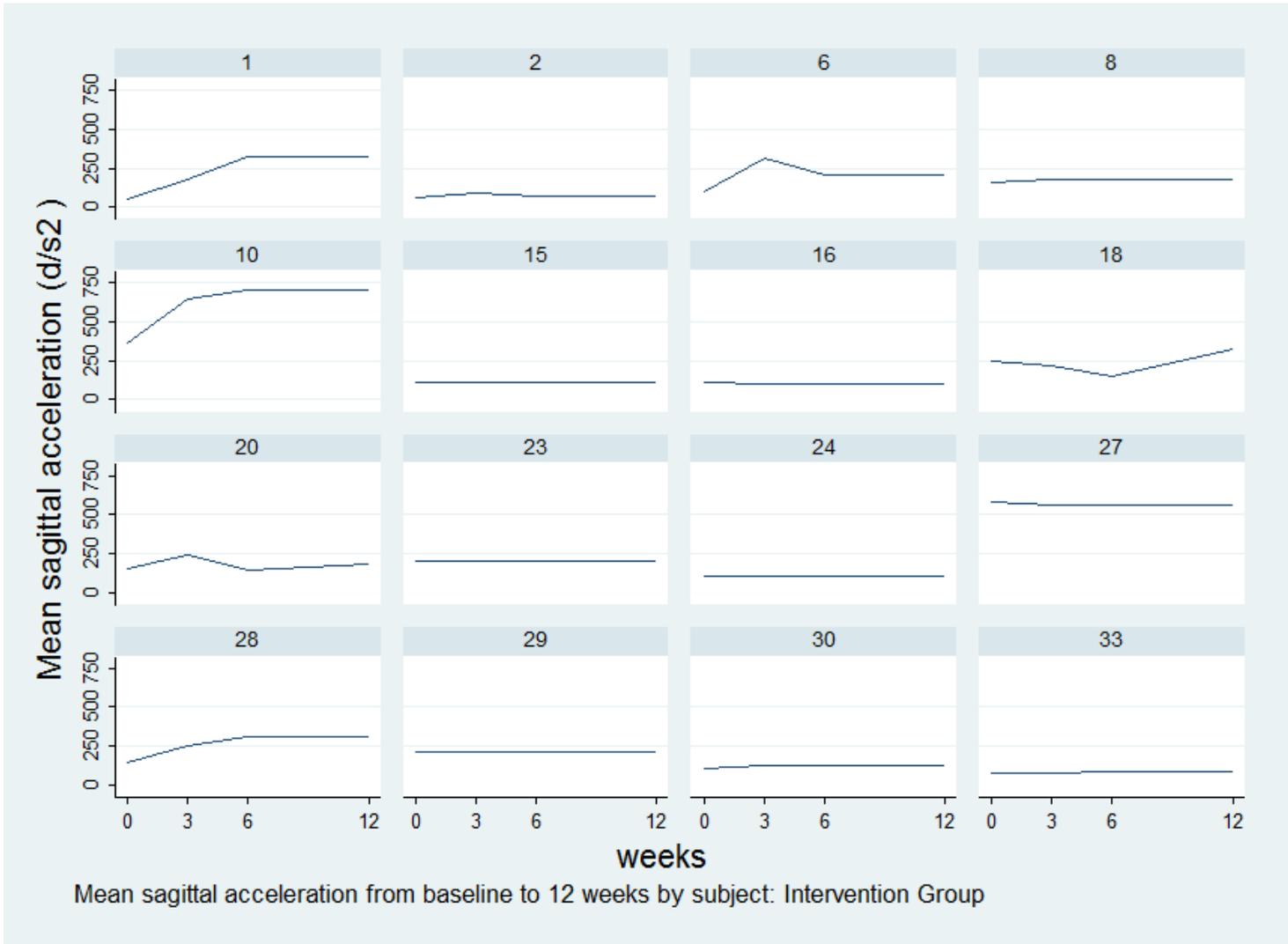


fig. 5.3: Mean trunk sagittal acceleration (experimental group)

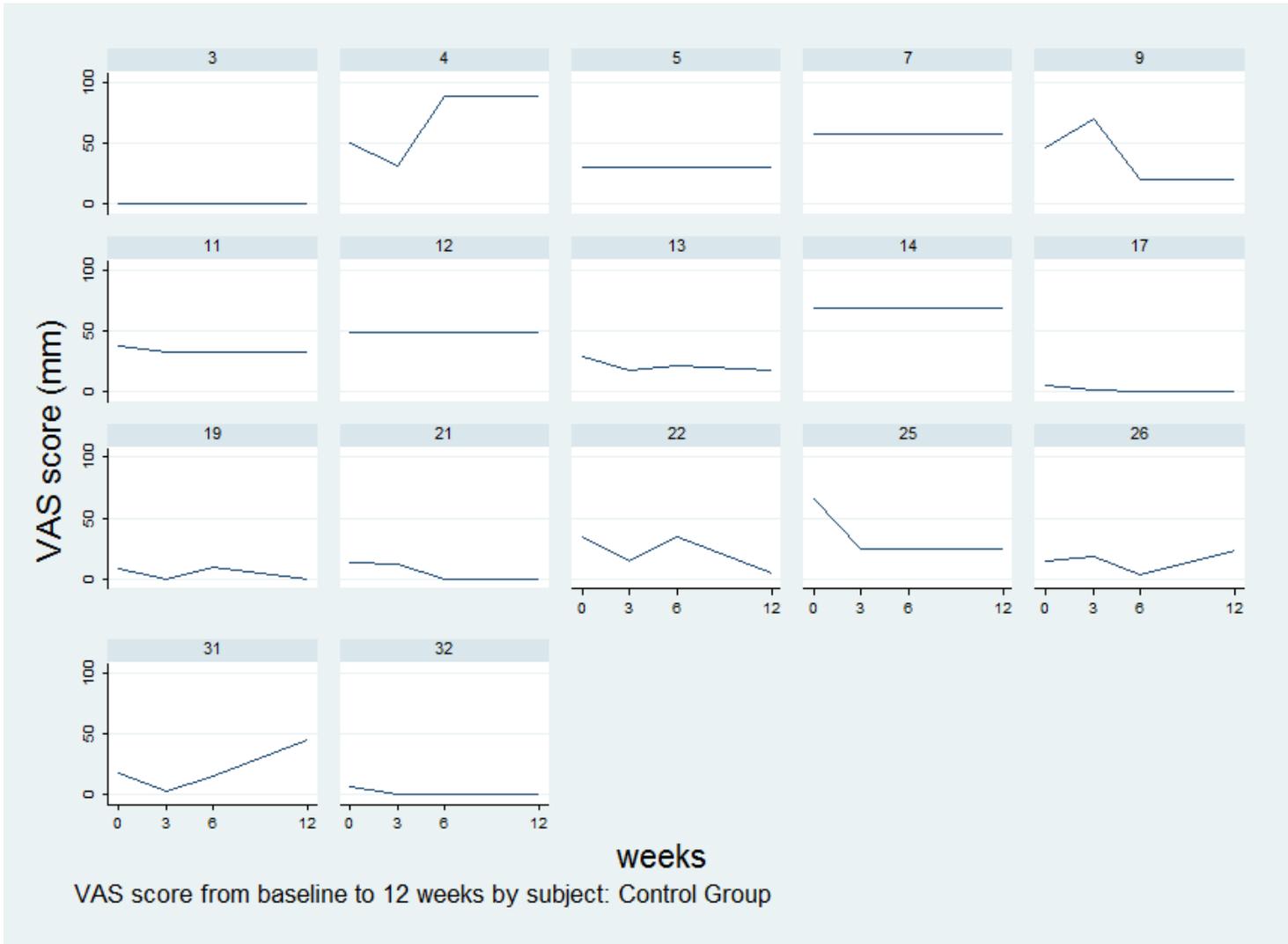


Fig. 5.4: Mean pain scores (control group)

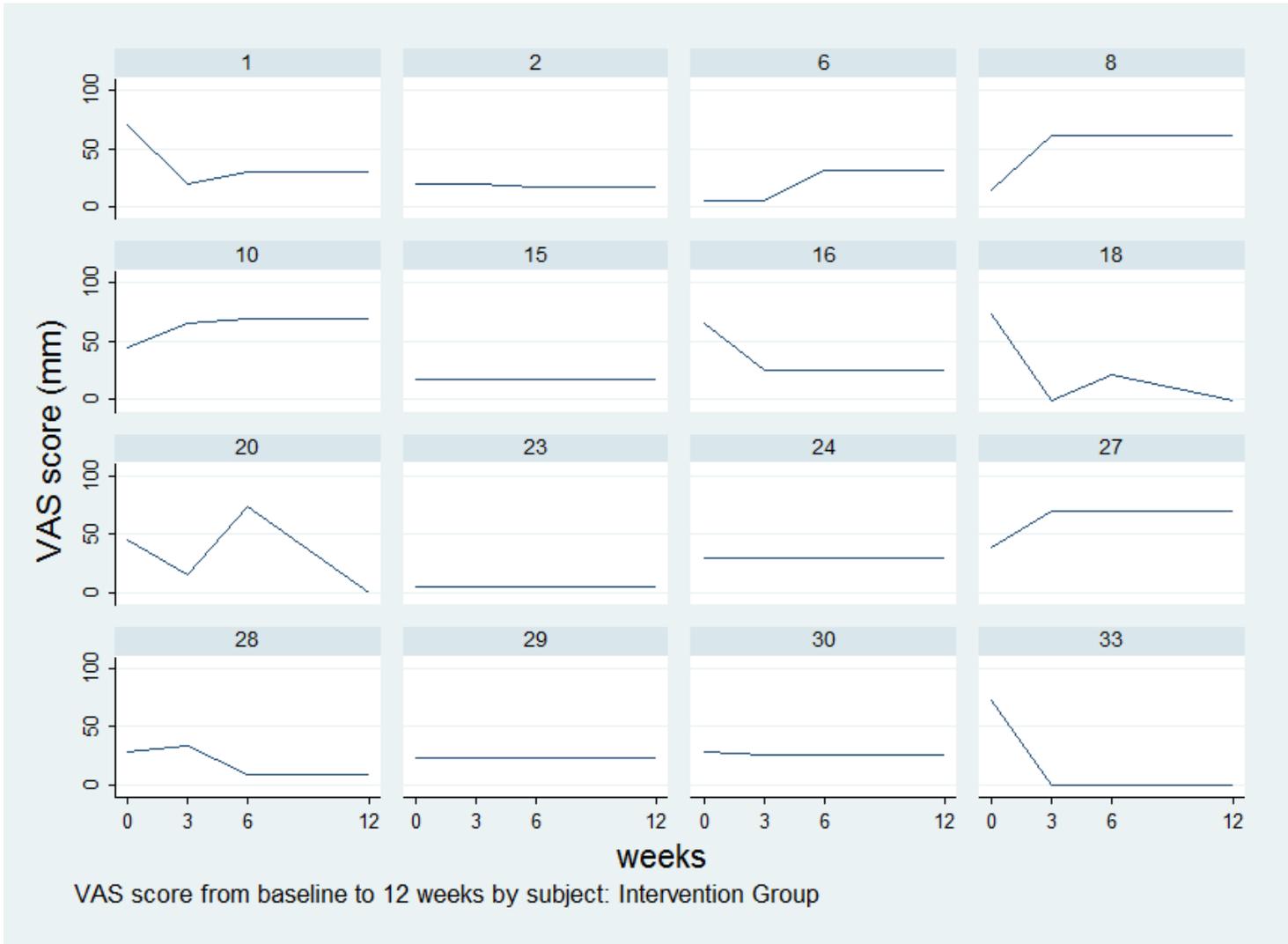


Fig. 5.5: Mean pain score (experimental group)

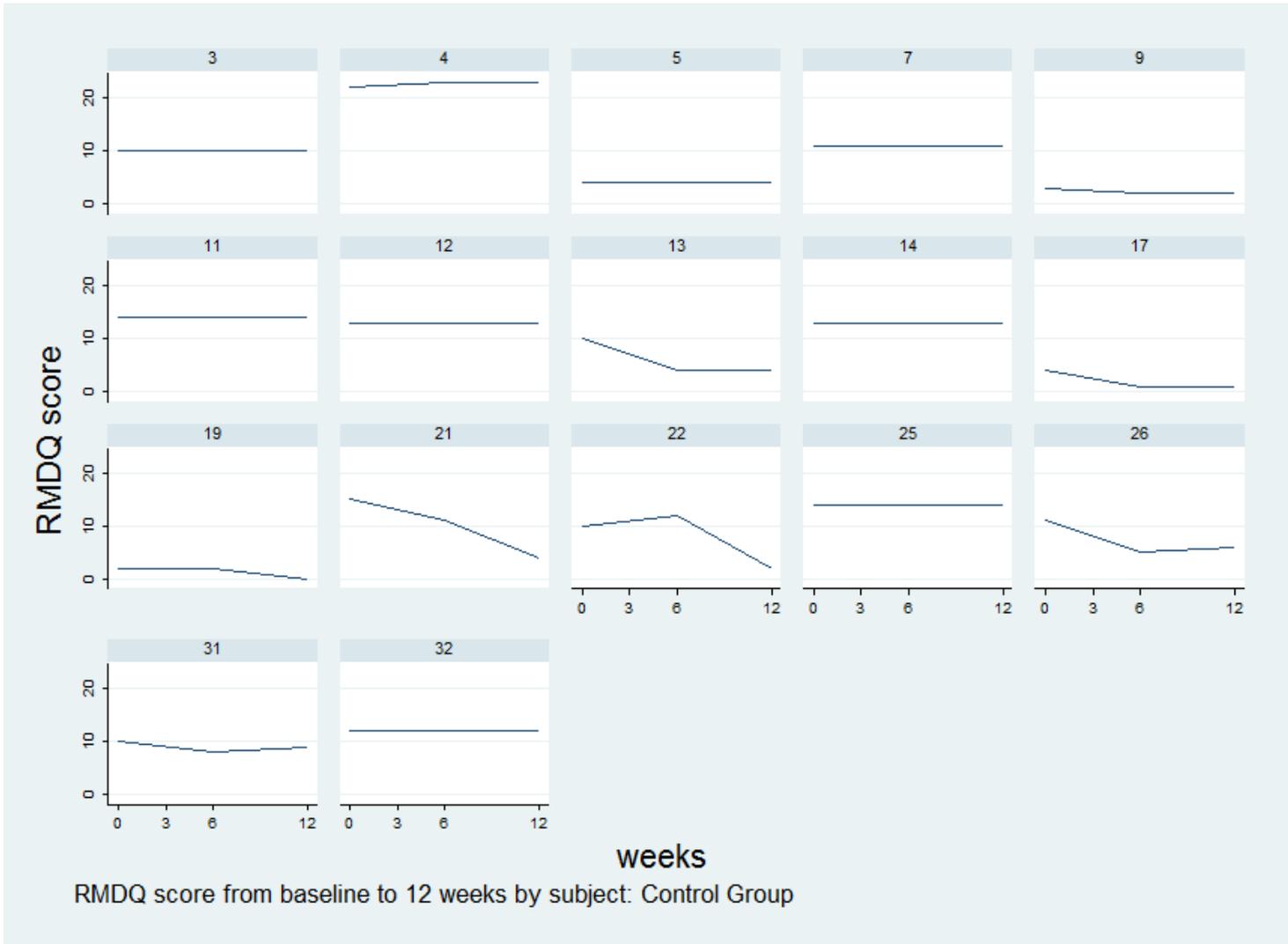


Fig. 5.6: Mean disability scores (control group)

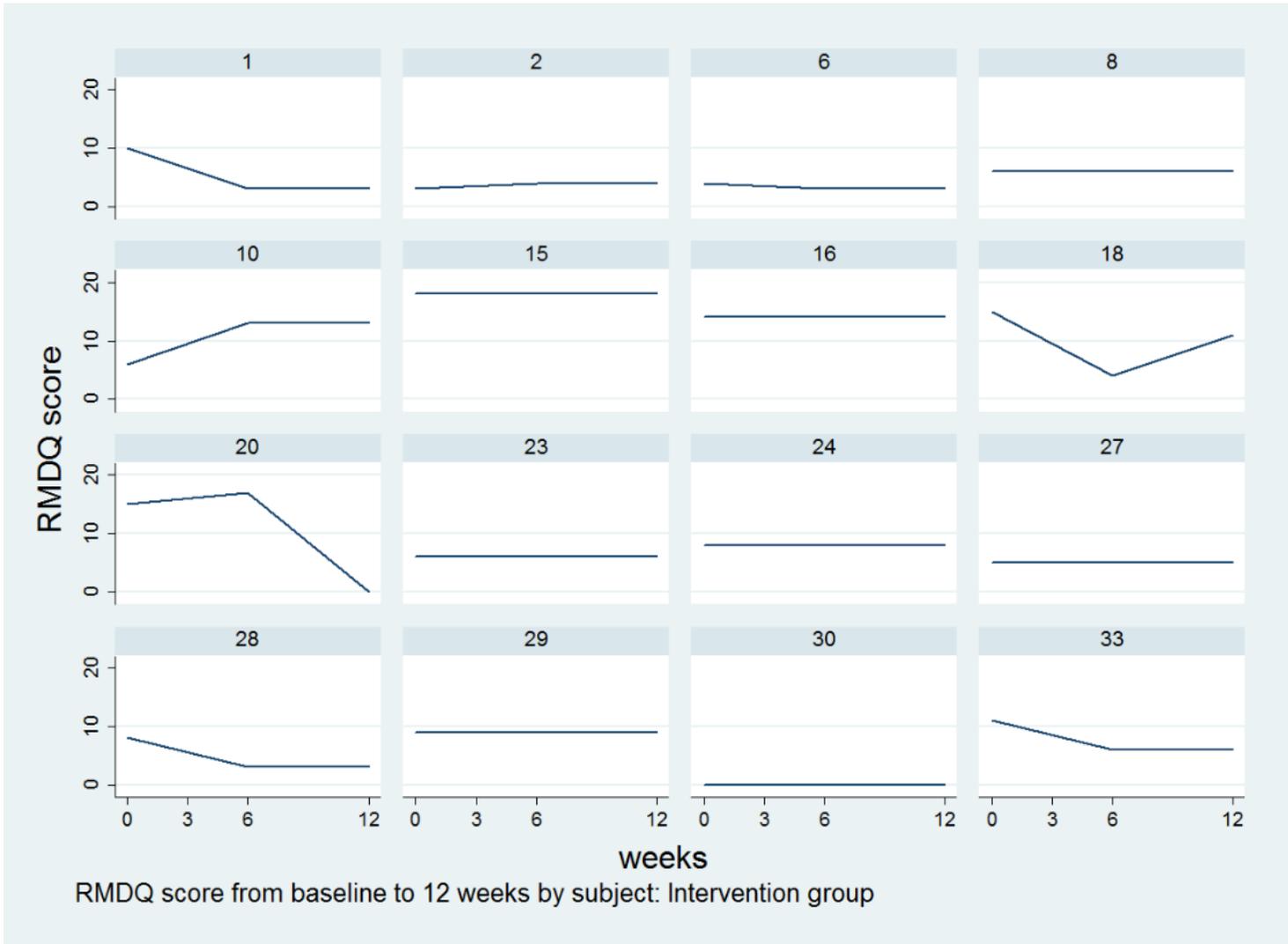


Fig. 5.7: Mean disability scores (experimental group)

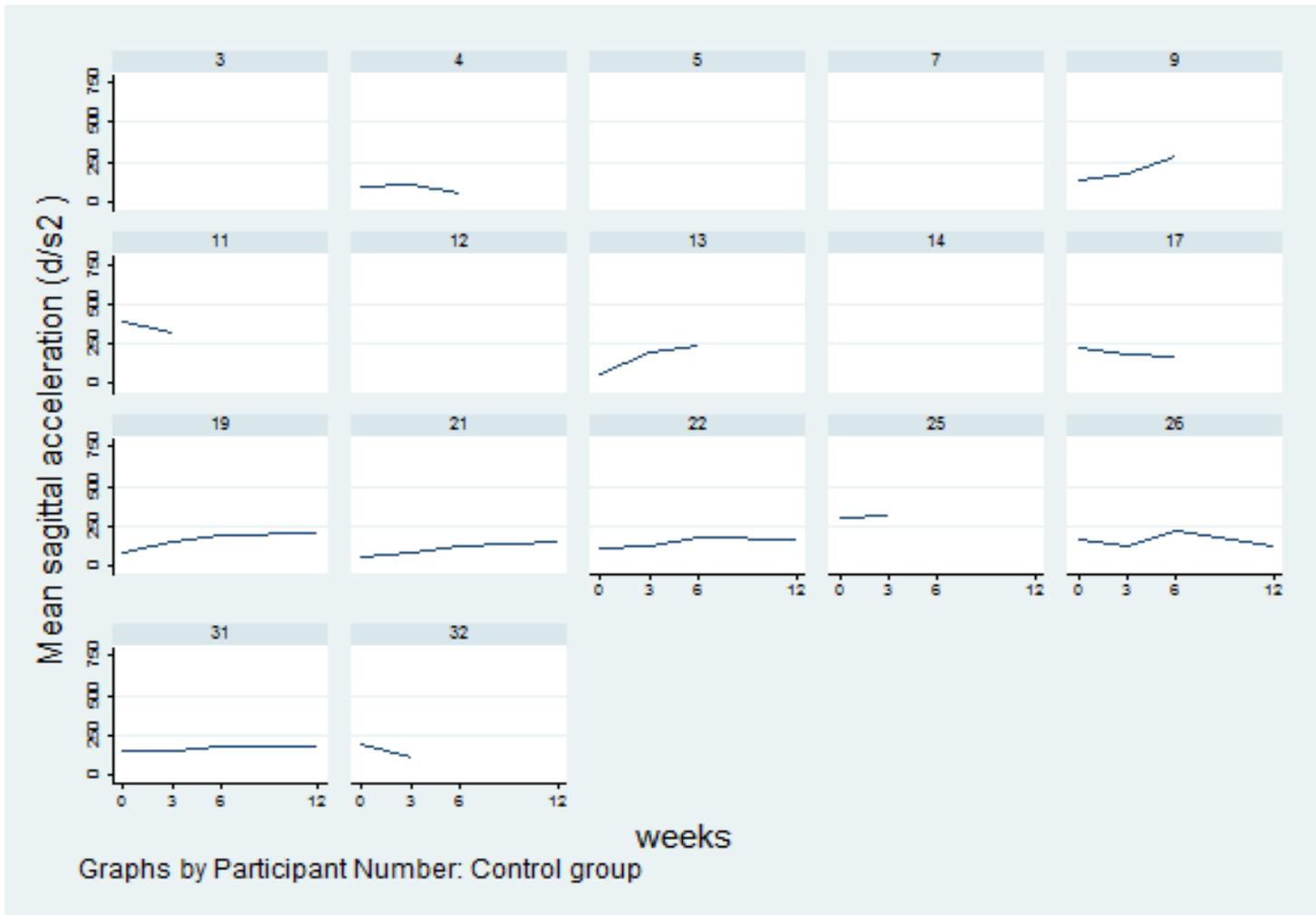


Fig. 5.8: Mean trunk sagittal acceleration (control group) without missing data

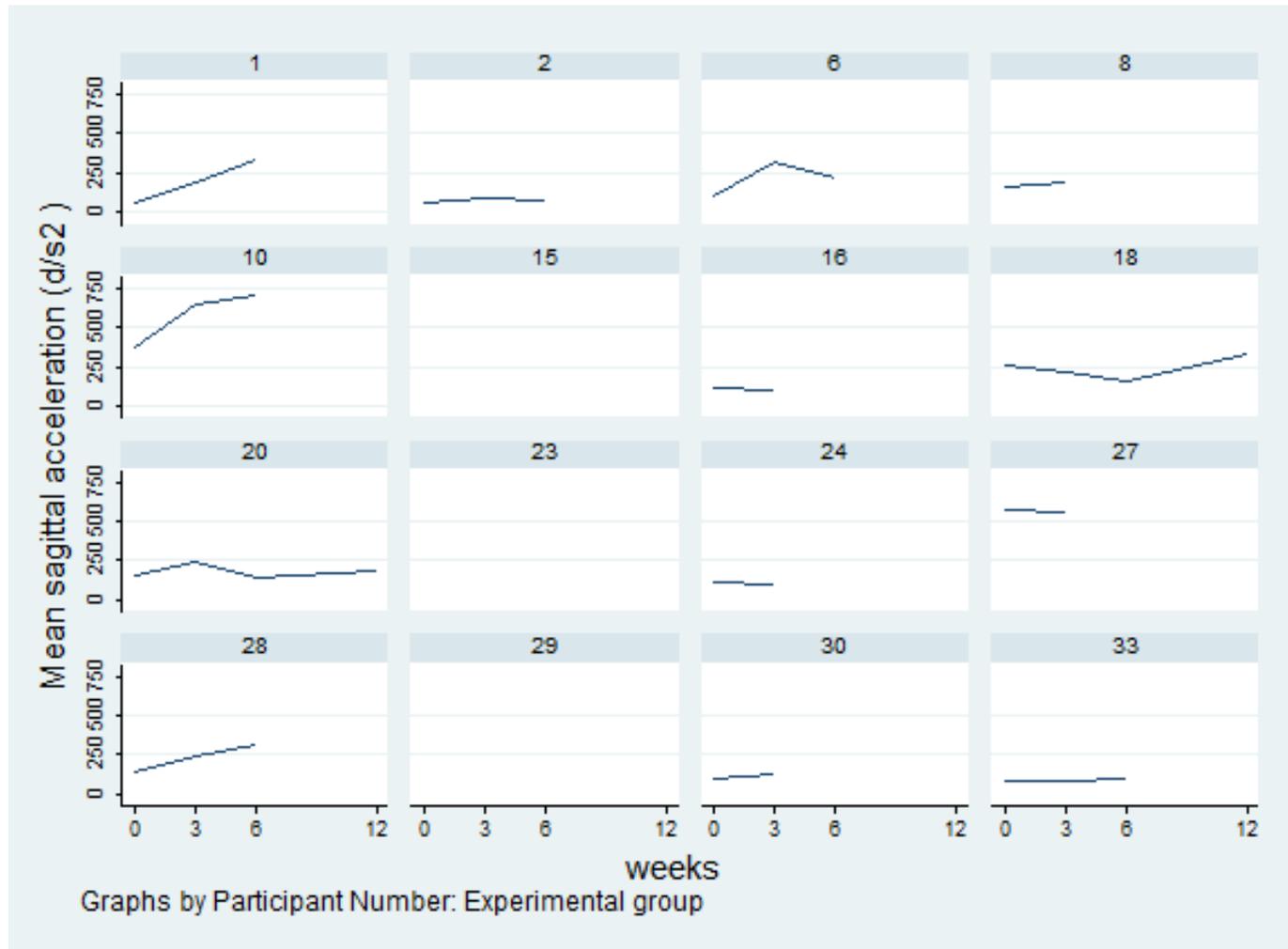


Fig. 5.9: Mean sagittal trunk acceleration (experimental group) without missing data

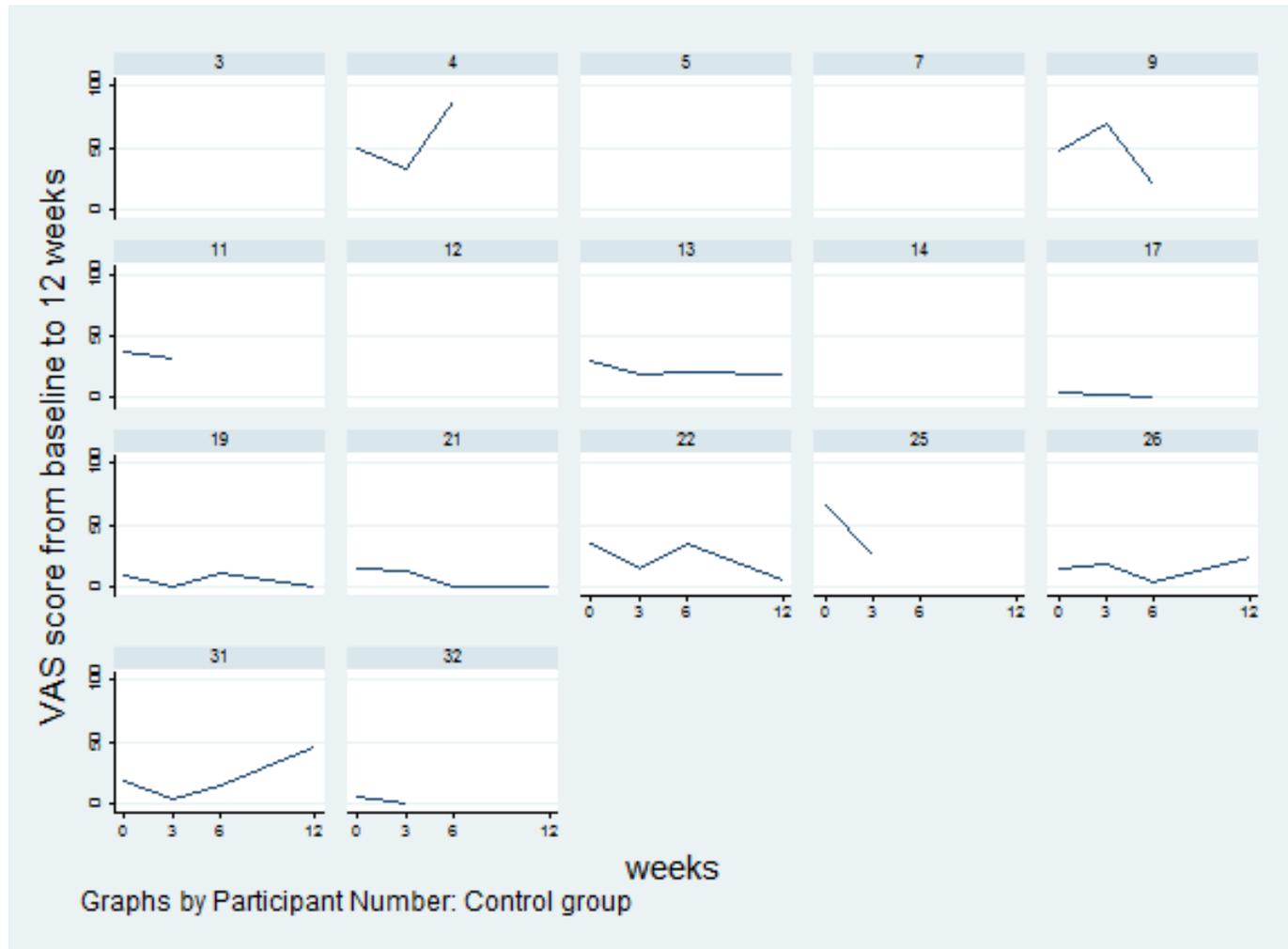


Fig. 5.10: Mean pain scores (control group) without missing data

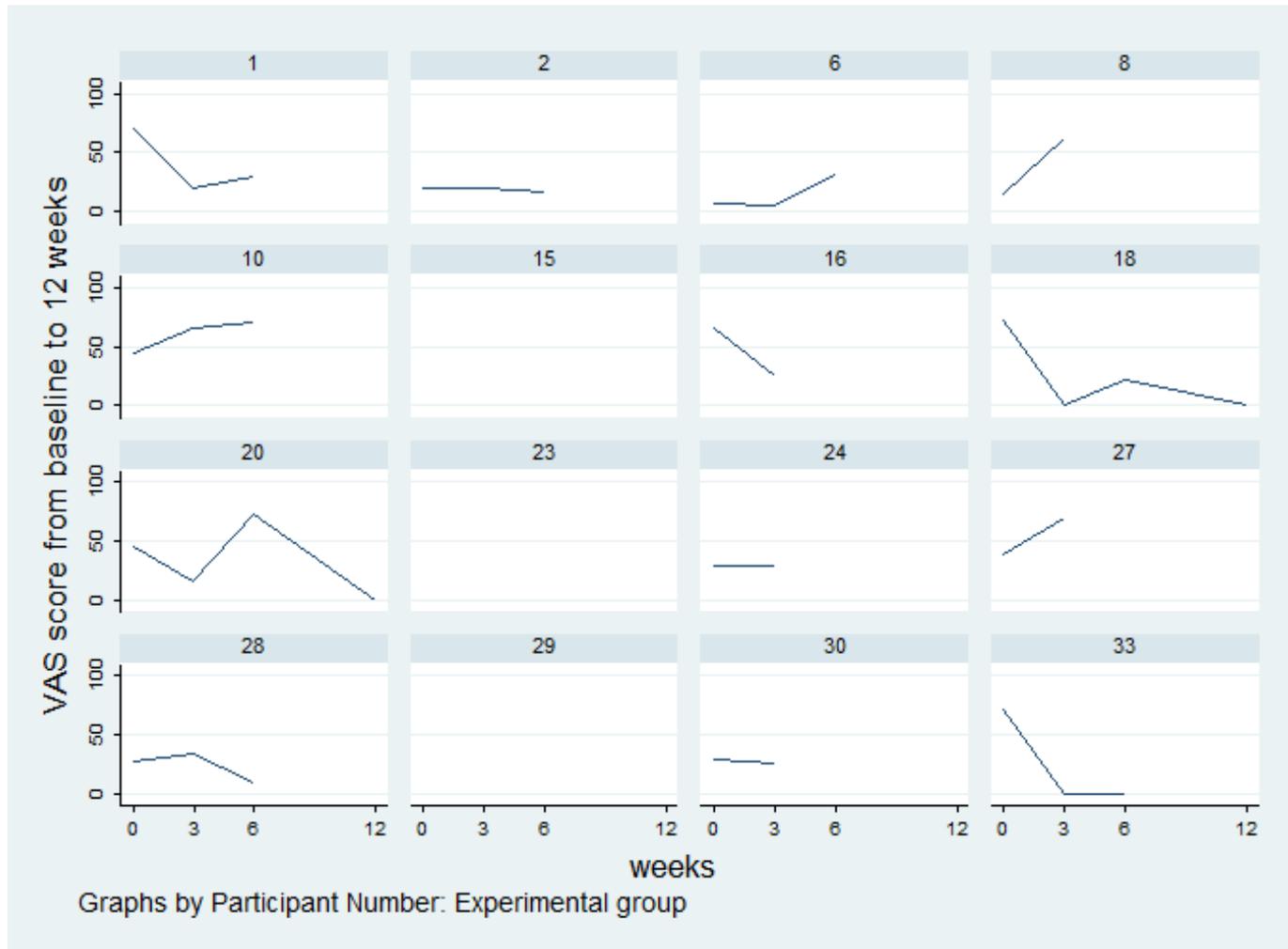


Fig. 5.11: Mean pain scores (experimental group) without missing data



Fig. 5.12: Mean disability scores (control group) without missing data

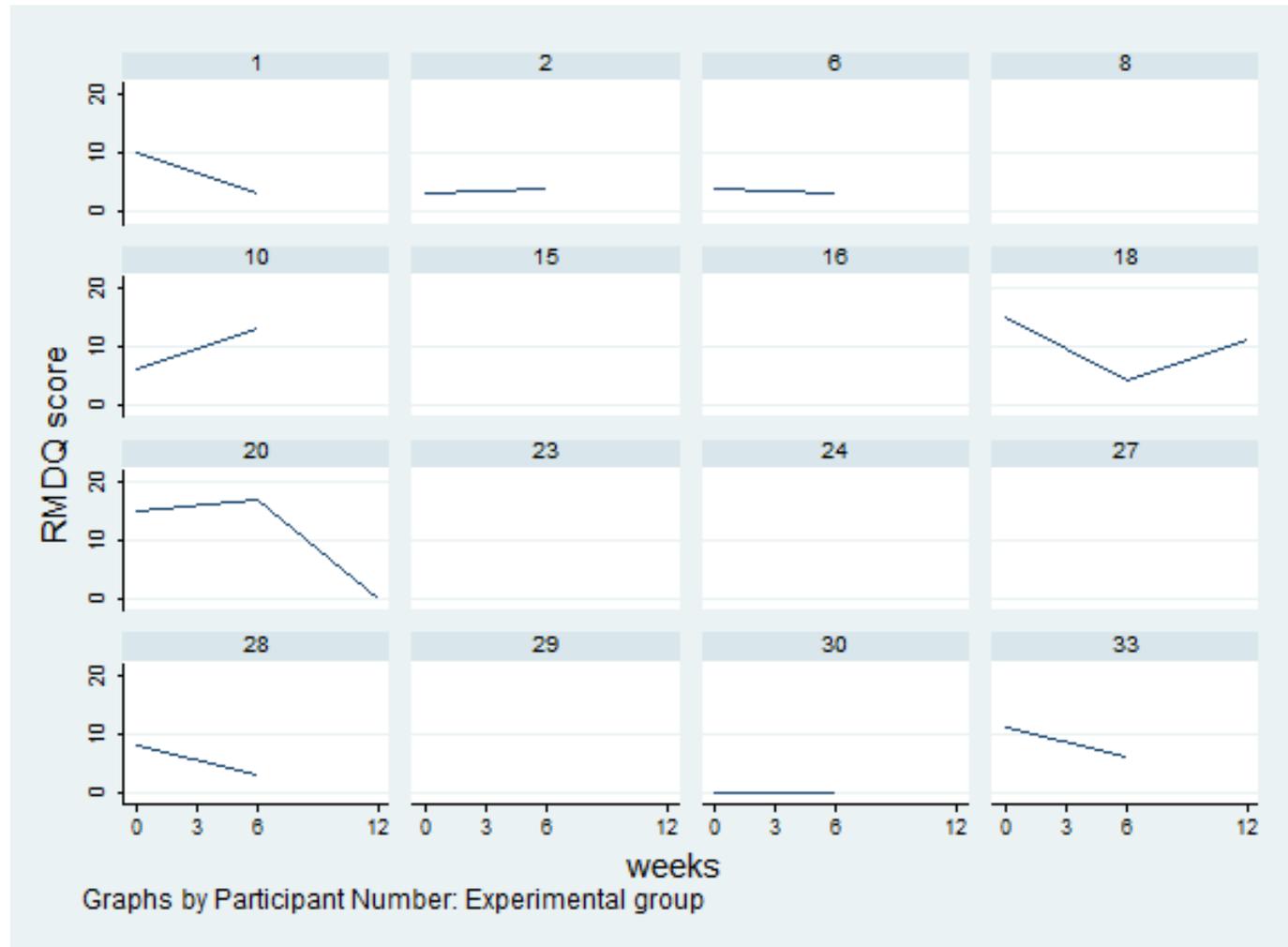


Fig. 5.13: Mean disability scores (experimental group) without missing data

5.4 Data transformation

The data for the outcome measures of mean sagittal acceleration, pain and disability did not demonstrate a normal distribution (Figs 5.2-5.4) and were transformed using the logarithm for analysis. The data were back transformed to provide meaningful results on the original scale. For a comparison of means this gives the ratio of geometric means rather than the difference of arithmetic means.

5.5 Range of movement

The experimental group (m=3, f=13) with a mean age of 36.2 (9.8) years, mean height of 166.8 (10.6) cms and mean weight of 75.9 (18.0) kgs demonstrated greater range of movement during testing at every stage of evaluation including baseline (Table 5.2) when compared to the control group (m=2,f=15) with a mean age of 35.8 (9.1) years, mean height 167.4 (9.0) cms and mean weight of 73.3 (15.6) kgs. The mean difference between the groups was greatest at 3 months even when the difference between the groups narrowed halfway through the study. This was demonstrated even when the mean range remained relatively constant within the experimental group.

Table 5.2: Between group differences in range of movement (ROM)

	Control	Experimental	% Difference between groups
Mean ROM at 0 weeks [(degs (SD))]	37.6 (11.2) [n=17]	41.3 (14.0) [n=16]	9.8
Mean ROM at 3 weeks [(degs (SD))]	34.7 (8.7) [n=12]	42.1 (18.3) [n= 13]	21.3
Mean ROM at 6 weeks [(degs (SD))]	38.3 (13.4) [n=9]	41.1 (16.8) [n=8]	7.3
Mean ROM at 3 months [(degs (SD))]	35.9 (10.2) [n=6]	41.9 (15.7) [n=5]	16.7

5.6 Trunk sagittal acceleration

The experimental group consistently demonstrated greater mean sagittal acceleration than the control group throughout the study (Table 5.3). The

differences, however were not statistically significant at the start of the study (two-sample t-test, $t = -0.2$, 31 d.f., $p = 0.83$) 3 weeks (two-sample t-test-1.1, 31 d.f., $p = 0.28$), 6 weeks (two-sample t-test, $t = -0.5$, 31 d.f., $p = 0.64$) or at 3 months (two-sample t-test, $t = -0.9$, 31d.f., $p = 0.41$).

The control group had better trunk performance at the 3 week stage. At the end of the 6 week active intervention period the control and experimental groups demonstrated overall increases of 15.1 and 29.4% respectively which increased at the 3 month follow up evaluation to 13.0 and 37.0% respectively. A comparison of sagittal acceleration at 3 months to week 6 shows that the control group demonstrated a reduction in performance.

Table5.3: Study outcome measures by group

	Mean sagittal acceleration (s.d) (deg/s ²)			Mean pain score (s.d) (mm) (VAS 1-10)			Mean disability (s.d) (RMDQ 0-24)		
	Control (n=17)	Experimental (n=16)	P value	Control (n=17)	Experimental (n=16)	P value	Control (n=17)	Experimental (n=16)	P value
Baseline	166.0 (110.2)	174.5 (133.7)		31.4 (22.0)	36.4 (23.2)		10.5 (5.0)	8.6 (5.0)	
Analysis									
3 weeks	170.7 (95.5)	225.5 (163.4)		25.3 (23.5)	26.0 (22.0)		-	-	-
Difference between groups adjusted for baseline at 3 weeks.									
Ratio of geometric means (95% C.I)		1.2 (0.9-1.6)	0.2		1.3 (0.8-2.2)	0.3		-	-
6 weeks	191.1 (99.1)	225.8 (178.0)		26.7 (26.0)	31.8 (23.6)		9.4 (5.8)	7.4 (5.4)	
Difference between groups adjusted for baseline at 6 weeks.									
Ratio of geometric means (95% C.I)		1.1 (0.8-1.5)	0.7		1.2 (0.7-2.0)	0.6		1.0 (0.7-1.5)	1.0
3 months	187.5 (99.5)	239.1 (177.5)		27.1 (26.7)	25.9 (23.2)		8.4 (6.2)	6.8 (5.1)	
Difference between groups adjusted for baseline at 3 months.									
Ratio of geometric means (95% C.I)		1.2 (0.8-1.9)	0.9		1.0 (0.5-1.9)	1.0		1.3 (0.8-1.9)	0.3

The ratio of geometric means takes the value 1 when the means are the same in the experimental and control groups. The ratio of 1.2 (0.9-1.6) indicates a 20% improvement in the experimental group with 95% C.I ranging from a 10% worsening to a 60% improvement.

At 3 weeks the improvement in trunk sagittal acceleration in the experimental group was 20% greater than in the control group but this was not statistically significant (95% CI 0.9-1.6, $p=0.2$). Similar improvements of 10% and 20% respectively were observed at 6 weeks (95% CI 0.8-1.5, $P=0.7$) and 3 months (95%CI 0.8-1.9, $P= 0.9$) but again these were not statistically significant (Table 5.3).

5.7 Pain

Mean pain scores were similar in both groups at each stage of the study; the differences in mean pain scores between the groups adjusted for baseline were not statistically significant at 3 weeks (30%) (95%CI 0.8-2.2, $p= 0.3$), 6 weeks (20%) (95%CI 0.7-2.0, $p=0.6$) or 3 months (0%) (95%CI 0.5-1.9, $p=1.0$) (Table 5.3).

Analysis of VAS scores between 3 months and 6 weeks was not possible because of the missing data and the small number of the sample.

5.8 Disability

The data suggests that the differences in disability scores between the groups adjusted for baseline were also statistically insignificant at 6 weeks (0%) (95%CI 0.7-1.5, $p= 1.0$) and 3 months (30%) (95%CI 0.8-1.9, $p= 0.3$) (Table 5.3).

5.9 Between variable relationships

Anecdotal clinical evidence suggests that there would be logical relationships between the variables measured. However, the results do not demonstrate this at any of the time points of the study (Table 5.4).

Table 5.4: Relationship between mean variable scores [Pearson's Correlation Coefficient (2-tailed sig.) $p = .05$]

		Mean pain score (mm)			Mean sagittal acceleration (deg/s.s)			Mean disability score			Range of movement (Deg)		
		3 weeks	6 weeks	3 months	3 weeks	6 weeks	3 months	3 weeks	6 weeks	3 months	3 weeks	6 weeks	3 months
Control group (n=17)	Mean pain score (mm)	1	1	1	.3 (.4)	-.3 (.4)	-.2 (.6)	-	.65 (.0)	.8 (.0)	-.4 (0.1)	-.2 (.5)	-.5 (.1)
	Mean sagittal acceleration (deg/s.s)	.3 (.3)	-.3 (.4)	-.2 (.6)	1	1	1	-	-.2 (.4)	-.2 (.6)	0.2 (.5)	.3 (.2)	.4 (.1)
	Mean disability score	-	0.7 (.0)	.8 (.0)	-	-.2 (.4)	-.2 (.6)	-	1	1	-	-.1 (.7)*	-.4 (.2)
	Range of movement (Deg)	-.4 (.1)	-.2 (.5)	-.5 (.1)	.2 (.5)	.3 (.2)	.4 (.1)	-	-.9 (.7)	-.4 (.2)	1	1	1
Experimental group (n=16)	Mean pain score (mm)	1	1	1	.4 (.2)	.3 (.3)	.4 (.2)	-	.3 (.3)	.2 (.6)	-.0 (.9)*	-.1 (.8)	-.1 (.9)*
	Mean sagittal acceleration (deg/s.s)	.4 (.2)	.3 (.3)	.4 (.2)	1	1	1	-	-.2 (.5)	-.1 (.7)	.6 (.0)	.6 (.0)	.6 (.0)
	Mean disability score	-	.3 (.3)	.2 (.6)	-	-.2 (.5)	-.1 (.7)	-	1	1	-	-.2 (.4)	-.4 (.2)
	Range of movement (Deg)	-.0 (.9)*	-.1 (.8)	-.1 (.9)*	.6 (.0)	.6 (.0)	.6 (.0)	-	-.2 (.4)	-.4 (.2)	1	1	1

Significant correlations are denoted by (*). However, the extent of the correlation and the statistical significance are not informative because of the sample size. In a large sample the small correlations will be significant but the same size of correlation in a small sample will not.

5.10 Conclusions

The results do not decisively demonstrate that CSEs do improve trunk performance, reduce disability and pain.

A comparison of the experimental and control groups showed that the mean sagittal acceleration of the trunk was 20% greater at 3 weeks, 10% greater at 6 weeks and 20% greater at 3 months but none of the differences were statistically significant.

A comparison of the mean pain scores between the groups was demonstrated to be 30% at 3 weeks, 20% at 6 weeks and 0% at 3 months but none of the differences were statistically significant.

A comparison of the mean disability scores between the groups was demonstrated to be 0% at 6 weeks and 30% at 3 months but none of the differences were statistically significant.

Although the results do not provide exhaustive evidence of the effect of CSE there does appear to be improvement which may become more significant with a much larger study because the larger the sample size the greater the power of the study and it will be more probable that significant differences between groups could be demonstrated.

Chapter 6

Discussion

6.1 Introduction

This study set out to test the hypotheses that pain, disability and trunk performance impaired by an onset of non-specific Low Back Pain (LBP) can be improved by Core Stability Exercises (CSE). The hypotheses was tested using a randomised controlled trial conducted on a sample of patients referred for physiotherapy treatment at Musculoskeletal Physiotherapy Services, Hillingdon Community Health following an acute onset of non-specific LBP.

This chapter affirms the originality of this study and contribution to the existing knowledge. It discusses the results generated by the study and examines the meaning of these results in the context of existing knowledge of trunk behaviour as influenced by an onset of acute non-specific LBP. Furthermore, it examines the implication of the results on possible management of acute non-specific LBP in future clinical practice.

There were some important limitations to the design and conduct of the study that meant that the researcher could not be blinded and it was not possible to recruit a very large sample. The chapter will explore the implications of this design in view of these constraints and discuss the consequences of the design on the results.

Finally the chapter will discuss the limitations within the study and highlight the direction in which supplementary work can be done to augment the conclusions of this study.

6.2 Originality of the study

Although the effects (Wong and Deyo, 2001; Pahl et al., 2006) and costs (BackCare, 2007; Dagenais et al., 2008) of LBP are well documented effective control of LBP remains elusive. One of the causes of this is the inability to quantify real time changes in trunk performance and relate those changes to subjective measures of the effects of an onset of LBP.

Physiotherapy practitioners like osteopathy and chiropractic practitioners have relied upon manipulation/mobilisation to rectify aberrant lumbar segment movement patterns suggestive as being the cause of an onset of LBP. The effectiveness of these techniques has been compared to other non-manual interventions and found to be effective only for specific stages of LBP (Assendelft et al., 2003; Haas et al., 2004; Ernst, 2007). The effectiveness of non-specific exercises has also been compared to specific exercises and it is suggested that there is no difference (May and Johnson, 2008). All the studies have relied upon subjective measures as either a primary or significant outcome upon which the results have been interpreted. This study used a Lumbar Motion Monitor (LMM) to demonstrate objective real time measures of trunk performance.

The validity and reliability of the LMM, however, had only been established using a method that was impractical for clinical use and although a revised streamlined method had been shown to be reliable, the agreement for the measurement used to demonstrate its reliability had never been demonstrated. The level of agreement was explored within this study and a subsequent paper was published (Aluko et al., 2011) (Appendix 4). This was important because it provided

evidence of reliability allowing this measure to be used more confidently for this study and by future researchers and clinicians.

No previous evidence was available to interpret trunk behaviour within a sample population. Within this study trunk behaviour of 50 volunteers was quantified and evaluated. A paper demonstrating these findings has also been submitted for publication (Appendix 18). The findings of this study (Appendix 18) suggest that a self reported episode of LBP may not be a reliable indicator of changes in real time measures of trunk performance. Changes in trunk performance due to LBP may also not be cumulative. Furthermore females within the sample demonstrated slower trunk performance. These findings are used to discuss the results of this study.

Although CSEs have become a popular intervention for the treatment of LBP (Willardson, 2007a; Willardson, 2007b) no previous research has explored the mechanism by which they may work. This study was designed with the purpose of doing just that by comparing the changes in subjective measures with an objective measure and investigating if a correlation exists. No existing published research has as yet explored a relationship between self reported measures of either pain or disability with measures of trunk kinematics. This work has attempted to do this by using the Lumbar Motion Monitor.

In order to ensure the effectiveness of the CSE all the participants in the experimental group completed a diary to demonstrate their compliance (Appendix 17). The data suggested that compliance was highest in the early stages of the study. This could account for the observed rapid mean changes within this group. Furthermore it demonstrated that compliance is essential for the true benefits of

CSE to be seen. This observation may be a key element for why previous comparative intervention studies for the management of LBP have not been able to demonstrate significant differences.

6.3 Contribution to existing knowledge

This study demonstrated a 20% difference in mean trunk sagittal acceleration at 3 weeks, 10% at 6 weeks and 20% at 3 months between the experimental and the control groups which was not statistically significant. This study therefore did not conclusively suggest that CSE can improve trunk performance. Similarly the difference in the reduction in pain between the two groups was a statistically insignificant 30% at 3 weeks, 20% at 6 weeks and 0% at 3 months. The difference in the mean disability scores between the 2 groups of 0% at 6 weeks and 30% at 3 months was equally statistically insignificant. The lack of statistical significance may in part be due to the small sample size and is suggestive of the need to conduct this study on a much bigger sample. However, the improvement demonstrated within these outcomes suggests an improved clinical response to an onset of acute non-specific LBP may be achieved if CSE are commenced quickly within an episode and may result in a reduction in the likelihood of an acute onset becoming chronic. It is proposed that a direct impact of such improvement to patients may be increased empowerment, quicker resolution of symptoms and improvement in well being. The advantage to the economy at large may therefore be a reduction in the cost of treatment and therefore a reduction in the burden of LBP on healthcare delivery.

This study provides evidence to suggest a new method to quantify the effects of an acute onset of non-specific LBP using the Lumbar Motion Monitor to evaluate trunk sagittal acceleration. A mechanism by which CSEs work may be by

improving trunk sagittal acceleration. The results of this study therefore suggest that the NICE guideline of encouraging activity and exercise as soon as possible (NICE, 2009) have credence and adds to the evidence-base of practice.

6.4 Results

Trunk displacement demonstrated by participants during data collection improved within both groups of participants. However, the amount of increase was more evident in participants in the experimental group. Although the range of trunk movement during an episode of LBP can be subjective (Cox et al., 2000) the results lend some support to the hypothesis that LBP produces less movement (McGregor and Hughes, 2000). However, the increases were not statistically significant and could be attributed to chance alone. The experimental group may have demonstrated greater increases because of specificity of the intervention compared to the control group.

Although trunk displacement during an episode of LBP can be subjective, the results of this study do suggest that this may only be applicable where a specific range is anticipated for use during trunk kinematic evaluation and therefore becomes an emphasis on the sincerity of effort (Ferguson et al., 2000). This study did not have specific start or end points for trunk movement during the LMM evaluation, participants were therefore not able to regulate movement in anticipation of these points and thus influence their effort to complete the task. Clinical practice involves emphasis upon the range of movement attainable within the patient's tolerance during an assessment. The method used in this study attempted to replicate this. The participants were encouraged to focus on the number of repetitions that could be performed during the data collecting period of

8 seconds without a fixed starting or end point. This approach gave each participant control and ownership of the test, consequently, the range of movement demonstrated was less likely to be manipulated. They were also informed that the study involved an assessment of the quality of movement rather than range. The range was therefore more likely to represent the capability of the participants at the time of testing.

6.4.1 Trunk sagittal acceleration

There is a paucity of literature investigating trunk acceleration. There are however studies that evaluate trunk velocity (Marras et al., 2000; Cox et al., 2000; McGregor and Hughes, 2000) only one study specifically suggests that acceleration may be sensitive to sincere conditions (trunk movement profiles reflecting its musculoskeletal status) at the point where the participant changes direction (Marras et al., 2000). The work of Marras et al has over the years investigated the quantification of 3-dimensional trunk movement. The work (Marras et al., 2000) demonstrated that an acceleration profile may be highly repeatable for sincere conditions. It has also been demonstrated that kinematic functional performance measures are sensitive to improvements during recovery from LBP (Ferguson et al., 2000). The results of this study demonstrate improvement in trunk performance defined as trunk sagittal acceleration, in participants in both the control and experimental groups. Although it is possible that some of this improvement could be due to the natural course of recovery the experimental group did show greater improvement in trunk performance at the end of the active 6 week period of the study. The improvement continued at the 12 week follow up within this group. The improvement at 6 weeks in the control group however was not maintained as this

group demonstrated a reduction at the 12 week follow up. These findings are consistent with the findings of those previous studies (Marras et al., 2000; Ferguson et al., 2000). It may therefore be possible to suggest that CSE can improve and maintain trunk performance more efficiently than the natural course of recovery following an onset of acute LBP. This however, has to be put in context of the statistically insignificant difference between the groups.

The pilot study suggested that acute non-specific LBP may reduce trunk performance; which cannot be improved by repetition (Aluko et al., 2011). This supports a previous finding (Marras et al., 2000) however, this may only be reproduced in a clinical environment if the participant actually has an episode of LBP. A subjective opinion for the presence or absence of LBP may not be strictly reliable (Appendix 18).

The clinical assessment of trunk movement is not functional but rather a global unidirectional anatomical movement (Petty, 2006). Most episodes of LBP occur whilst performing movements involving complex tasks requiring a wide array of muscle recruitment patterns (McGill et al., 2003; McCreary et al., 2003) however, the data for this study was obtained using a global unidirectional anatomical movement which was adapted to increase the level of difficulty by using repetitions to create instability within the movement segments of the lumbar spine (Reeves et al., 2007).

The results of the study do support the suggestion that improved trunk muscle activity and co-contraction increases trunk acceleration (Granata and England, 2006). The mean sagittal acceleration in the experimental group was consistently greater than in the control group. The difference between the groups

at key milestones (3, 6 and 12 weeks) was also not statistically significant. However, the insignificance could be attributed to the sample size. The sample size used in this study was similar to that used in a previous study that used a sample size of 33 to investigate the effect of stabilisation instruction on lumbar acceleration using a uniaxial accelerometer (Webber and Kriellaars, 2004). They were able to demonstrate statistically significant reduction in lumbar acceleration induced by limb movement (Webber and Kriellaars, 2004). It is possible that the difference in results was because the Webber and Kriellaars' study was observing the effect of limb movement rather than adjacent lumbar musculature on trunk acceleration.

The reasons for the insignificant differences in the pain and disability scores demonstrated in this study may also be because an assumption was made that all reported scoring was sincere. All participants, however, had been assessed and considered to have a true episode of LBP prior to agreement to take part in the study. If there were any doubt about the sincerity of the episode, it would be expected that this would be reflected in the rate of attrition. Insincerity of the presence of LBP would be expected to be proportional to the willingness to participate in the study. Attrition, however, was similar within both groups (chapter 5) suggesting that the likelihood of this having affected the results was very low. It is, however possible that the initial referral for treatment by the general practitioner was based more on subjective assessment of the severity of disability and/or pain. This assumption is based upon previous suggestions that disability is reliant upon the level of distress (Proctor et al. (2000) cited in Johnstone et al. (2004)). This may therefore have had an influence on the urgency and timing of their referral from

their GP and ensuing prevalent belief systems (Coudeyre et al., 2006; Cayea et al., 2006; Fullen et al., 2008).

Both groups demonstrated increases in mean acceleration at the end of the study. This is in agreement with previous findings (Marras et al., 2000; Aluko et al., 2011) and agrees with the suggestion that LBP causes segmental hypomobility (Teyhen et al., 2007). However, the increase in acceleration was much greater within the experimental group at 12 weeks. This does suggest that CSE may not only improve trunk acceleration but may also help in maintaining any increase. The reduction in mean acceleration within the control group between 6 and 12 weeks following the end of the active period of the study further strengthens this argument.

Although there is very little evidence to suggest that LBP affects a particular gender more than the other (Walsh et al., 1992; Fritz and George, 2002), this hypothesis could not be tested because of the small number of male participants recruited. However, previous results have already shown that females may consistently demonstrate slower trunk performance (Appendix 18). The reason for the small number of male participants is not clear. Significance in weight and height was not demonstrated in this study. The possibility exists that pelvic pathologies (Frank and DeSouza, 2001) may have a significant affect on general trunk performance within females but it has not yet been demonstrated how these pathologies impact on trunk movement.

An increase in displacement has been reported to be accompanied by an increase in velocity (Cox et al., 2000) and thus by default an increase in acceleration. This trend is not demonstrated by the results of this study. Although both groups

demonstrate an increase in mean acceleration over time, mean displacement does not follow the same trend. There was a negative correlation within the control group between the start of the study and 12 weeks. An exception was between 6 and 12 weeks when the mean acceleration actually decreased within the control group. A possible explanation for this negative correlation could be due to the fact that the previous study (Cox et al., 2000) was retrospective and relied upon patients referred from insurance companies and who may have had other reasons for being motivated to demonstrate good functional movement during the assessment irrespective of the discomfort they were experiencing. Participants in this study were not under the same pressure, fear avoidance (Fritz and George, 2002) however may have inadvertently been reinforced by the encouragement participants were given to concentrate on the number of repetitions rather than the range. This may have given the impression that the range of movement required to perform the test would not aggravate their symptoms. This fact was repeatedly given in the patient information sheet (Appendix 12) and at each point of contact during which data was obtained. The experimental group participants may not have responded this way because they reported a lower mean disability score at the start of the study.

Mean trunk acceleration changed at different stages of the study. The control and experimental groups demonstrated improvements of 2.8% and 29.2% respectively at 3 weeks, 15.1% and 29.4% respectively at 6 weeks and 13% and 37% respectively at 12 weeks. This does suggest that the affects of CSE on sagittal trunk acceleration may be rapid. Previous studies have suggested that specific exercises for the treatment of acute LBP are not significantly better than any other

intervention (May and Johnson, 2008). The results of this study do not change this view.

The results of this study suggest that the significance of the effects of CSE in the early stages following an onset of acute LBP may be underestimated because trunk muscle activity and co-contraction has been shown to increase with trunk velocity and acceleration (Granata and England, 2006). The Multifidus (MF) and Transversus Abdominis (TrA) are accredited with the facilitation of this mechanism (Bergmark, 1989). The rapid response demonstrated within the experimental group suggests that there is a rapid increased ability for the trunk to respond to perturbation by increasing trunk sensitivity to positional change (Reeves et al., 2007). Trunk stiffness reported to be a result of LBP (Owens et al., 2007) is more of a structural response to pain and therefore supports the supposition that LBP produces slower trunk movements (Marras et al., 1999). The ability to accelerate quickly to change in trunk sagittal movement is demonstrated by the results of the pilot study that preceded this study (Aluko et al., 2011). This finding fits well with earlier findings that suggest that the MF and TrA are affected very quickly following an onset of LBP (Hodges and Richardson, 1996; Hodges and Richardson, 1997) and improvement in cross sectional area in the MF can be observed within 6 weeks during of a course of CSE (Sokunbi et al., 2008). The strength of a healthy muscle is directly proportional to its cross sectional area (Jones and Round, 1990) improving the cross sectional area of the MF and TrA through targeted exercise may therefore be beneficial.

Improvement in muscle recruitment and coordination which accompanies increases in trunk acceleration is supported by the findings of Pollock et al. (2009)

that suggest that to avoid excessive loading of the lower lumbar segments, these segments rapidly move into extension during the stroke phase of rowing. The demonstrated improvement in trunk sagittal acceleration suggests that this mechanism is critical for normal trunk function when the lower lumbar segments are incrementally loaded during flexion.

The increase in trunk sagittal acceleration may also increase the range of lordosis (ROL) because the range of lordosis should be directly proportional to the changes in acceleration (Cox et al., 2000). It has been shown that lumbar lordosis alters according to posture (Knutson, 2002; Al-Eisa et al., 2006). This would not be true if there was structural trunk stiffness caused by underlying natural pathology such as natural degenerative change (Gruber et al., 2007; Standaert et al., 2008). An increase in ROL during loading facilitates trunk efficiency during any task involving lifting, carrying or pushing/pulling. This is pertinent because pushing/pulling activities are a main cause of LBP associated with lumbar disc involvement (Plouvier et al., 2008; Marras et al., 2009). Anterior-posterior (AP) shear force across the lumbar spine is increased by an increase in speed of activity and during pushing activities the AP shear force is in the opposite direction to the push and occurs mainly at L5 (Marras et al., 2009).

The inability for the control group to demonstrate a similar trend may be because the muscle recruitment and coordination mechanism were not engaged by core stability exercise training. The net result of this non-engagement may be the reason why any gains achieved within the first 3 weeks of the study is lost at the 6 week stage. The net increase in trunk sagittal acceleration demonstrated at the 3 month stage may be attributable to the participant returning to normal daily

activity. A follow up period of 18-24 months may provide significant evidence of any correlation between any re-occurrence of LBP and the continued absence of this muscle recruitment and coordination mechanism. It has been suggested that reoccurrence is linked to stress, anxiety, mood, cognitive function and pain behaviour (Johnstone et al., 2004) however, it is highly suggestive that a precipitating factor for the onset of these risk factors is the underlying inability for the trunk to adequately compensate for the effects of axial loading on the trunk with consequent frequent and/or periodic episodes of LBP.

The use of a belt has been shown to reduce trunk velocity (Giorcelli et al., 2001) and because acceleration is a factor of velocity it is possible to assume that it will also be reduced. The action of a belt is similar to the action of the global trunk muscles. It is not clear how such a support will influence trunk acceleration in the long term. An increase in the perception of support may increase trunk robustness rather than stiffness in the immediate term but the cumulative effect must become evident when the belt is removed. The use of an artificial support may interfere with the natural muscle coordination required to reduce the natural perception of instability (Hodges et al., 2003; Moseley et al., 2004) or indeed the suggested chaos within the trunk during movement (Granata and England, 2006).

6.4.2 Pain

Although there was no demonstrable statistical difference in pain score between the groups, within the first 3 weeks of the study the experimental group demonstrated a larger mean reduction in reported pain at 3 and 12 weeks. The difference in pain however can be considered to be clinically significant (Kelly, 2001). The experimental group achieved the greatest reduction within the first 3

weeks compared to the control group that demonstrated a slight increase in pain between the end of the study and the follow up at 12 weeks. This result parallels the behaviour of trunk acceleration suggesting that most of the change occurred within the first 3 weeks. However, the study has not demonstrated that there is a causal relationship between the changes in trunk acceleration and pain although a negative correlation between pain and trunk performance has been previously reported (Cox et al., 2000).

It has been suggested that the pain adaptation model reduces trunk velocity (van Tulder et al., 2000). The findings of this study therefore suggest that non-specific LBP may induce the pain-spasm-pain model (van Dieen et al., 2003) rather than the pain adaptation model because the results of this study demonstrate an increase in acceleration accompanied by a reduction in pain (van Dieen et al., 2003).

Clinically this could be very important because treatment/intervention for the pain experienced by an onset of non-specific LBP could be more effective if it is aimed at reducing the excitability of the α -neurons or reducing muscle spindle activity (Johansson and Sojka, 1991). It is possible that CSE act favourably in enhancing both of these activities of α -neurons or reducing muscle spindle activity.

If the TrA and MF are actively involved in stability and respond to trunk perturbation, they will need a high proportion of both fast and slow twitch motor units. They will also require low activation thresholds to facilitate an ease of response to pre-empt trunk perturbation (Barr et al., 2005) and be able to produce prolonged contractions with a relatively low force with low fatigue resistance (Watkins, 1999). The results of this study do suggest that the behaviour of the MF in particular in response to CSE may fit this assumption. The findings of the pilot study

(Chapter 3) demonstrate the possibility that trunk acceleration will increase as recovery develops (Aluko et al., 2011) and these muscles regain normal function. Previous evidence suggests that the deep MF have a high proportion of type 1 fibres compared to the superficial MF (Richardson et al., 1999; MacDonald et al., 2006). It could therefore be speculated that the superficial and deep fibres of the MF have, apart from their similar functions, quite specific functions pertaining to the load placed upon them by trunk displacement. This speculation may be supported by previous work that does suggest that although both the deep MF and the superficial MF produces trunk torque, the deep MF may be primarily involved in generating compressive forces with minimal associated torque (MacDonald et al., 2006). It may be that the CSE routine facilitates this ability to generate the torque efficiently without compromising the structure of the spine.

The results do not demonstrate differences within gender, age, weight or height or correlate any changes with subjective pain. But the difference in structural build between the genders may play a significant role in trunk sagittal acceleration in the fact that females may be more likely to report an episode of acute non-specific LBP (Aluko et al. in preparation) (Appendix 18) than males and because males are more likely to have more muscle bulk because of the higher levels of testosterone (Jones and Round, 1990). The larger muscle size may suggest that males may also have higher thresholds at which the α -neurons are excited or have a greater ability to reduce muscle spindle activity. This assumption does require further enquiry. Exercises designed to increase muscle bulk may not be effective because previous work has suggested that the increase in strength during muscle training is disproportionate to the increase in its cross-sectional area (CSA)

(Jones and Round, 1990; Hansen et al. 2006). Exercises used in physiotherapy are therapeutic and may include an aim of restoring muscle coordination. The TrA and MF, may be affected by an increase in fatty tissue content and/or reduction in trunk intra-abdominal pressure (IAP). The efficiency of the TrA and MF may be reduced in either circumstance; furthermore anecdotal evidence suggests that low back pain is often associated with obesity or Body Mass Index (BMI) and it is often referred to by general practitioners in referrals of patients to physiotherapy reporting with an acute episode of low back pain and obesity is recognised to have a negative effect in reducing LBP induced disability (Yildirim et al., 2007). This may change in the near future because it is now suggested that a better barometer for obesity could be trunk circumference rather than the Body Mass Index (Lean et al., 1995).

The lack of statistical power for the study precipitated the absence of a demonstrable relationship between weight and pain. However, it could be suggested that there ought to be a direct correlation between anthropometric measures and trunk performance because there is an established correlation between poor IAP and moment arm of the trunk during movement (Janda and Valenta, 2000). It is believed that IAP is proportional to anthropometric measures (Youdas et al., 2000). An increase in waist circumference is expected to decrease lumbar lordosis and therefore influence adaptive lengthening of the lumbar MF and its subsequent loss of efficiency. Weak MF may reduce the ability to maintain a natural lumbar lordosis when the spine experiences axial loading (chapter 1). The importance of this mechanism may be linked to the early changes observed within the MF during an onset of LBP (Hodges and Richardson, 1996; Hodges and Richardson, 1997). The TrA by virtue of its anatomical location may remain relatively

unaffected unless there is an increase in waist circumference. This is probably why CSE is thought to be effective because it aims at restoring 'normal' activation of the MF (Hodges and Richardson, 1996; Hodges and Richardson 1997). All the core stability exercises used in this study included activity designed to increase and maintain tension within the MF during the exercise routine by instructing the participant to 'draw the navel towards the spine and hold' during each activity (Appendices 4 and 5).

Bed rest not exceeding 4 days has been a recommendation as a first treatment intervention for an acute onset of non-specific LBP (Rozenberg et al., 2003). The reduction in pain scores demonstrated during the study suggests that CSE may be a more effective alternative. Unlike bed rest, CSE may help maintain a normal level of activity as much as possible and therefore reduce days of sick leave (Smith et al., 2002; Rozenberg et al., 2003; Kinkade, 2007). However, requesting a patient who presents with an acute onset of non-specific LBP to commence a regime of CSE may not be appreciated because even the request to resume normal activity reduces patient satisfaction (Atlas and Deyo, 2001). The use of CSE, however, may be very useful to prevent catastrophisation of the condition and possible associated bouts of depression (Johnstone et al., 2004), facilitate fear avoidance techniques (Fritz and George, 2002) and ferment a positive approach to treatment (Frank and DeSouza, 2001). Unnecessary tertiary referrals could be minimised (Lauchlan, 2005) and it could be speculated that in doing so it is possible to reduce the cost of healthcare delivery.

Within chapter 3, a sample of the participants were asked if they had pain at the time of testing, episodes of LBP and when the last episode was experienced

(Appendix 5). The results suggest that any correlation between self reported pain and the participant responses may not be reliable (Appendix 18). The pain reported by the high proportion of females in that part of this study may be associated with pelvic pathology that is difficult to exclude by history alone (Frank and DeSouza, 2001). It may therefore be difficult for example to differentiate between LBP associated with the female pelvic pathology and pain associated with real time structural/mechanical dysfunction. Recall bias (Chouinard and Walter, 1995) may also be problematic because invariably most sufferers of LBP may have difficulty describing pain that occurred in the past in the context of an active subjective history interview. Asking patients to describe their pain on the day does not adequately describe the fluctuation in intensity that may occur between assessments. These fluctuations may have had an impact on the exercise compliance demonstrated by the reduction during the second half of the study (Appendices 15).

6.4.3 Disability

The results suggest that the trigger for the pain-spasm-pain model to be activated may be a structural change capable of reducing trunk sagittal acceleration with reduced TrA and MF efficiency. However, it is recognised that the sensitivity of the RMDQ in quantifying disability may be not be as high because the participants within this study may not be ‘back pain disabled’ because they did not have the pain long enough to decide that certain movements caused pain unlike individuals with chronic LBP (Beurskens et al., 1996).

The difference in disability between the groups was not only statistically insignificant but also clinically insignificant because the difference was less than 30%

(Jordan et al., 2006). However, the participants within the control group appeared to maintain a higher mean disability scores than the participants in the experimental group throughout the study. This does suggest that CSE may facilitate a reduction in disability however the depth of the facilitation is not effectively demonstrated.

The result in isolation does suggest that CSE may improve disability, however, a possible reason for the insignificant result may be that although all participants were asked to answer the RMDQ on the basis of their pain on the day, participants were keen to express their opinion of the pain for the duration between testing believing that their representation of disability on the day did not reflect what they perceived to be their true experience. Recall bias (Chouinard and Walter, 1995) would therefore become an issue as they may not have been able to accurately quantify their experience. This possibility is enhanced by the fact that all participants enquired at every visit and on more than one occasion during each testing period if they were supposed to report how their pain was in real time or how it had been. They sometimes emphasised the point by trying to suggest that their disability had been much worse than at the time of measurement.

The results do support previous findings that stabilisation exercises can be used effectively to effect changes in disability; the magnitude of which has been used to develop a clinical prediction rule to determine which patients are most likely to respond following an onset of LBP (Hicks et al., 2005).

The trend of the result is not in keeping with two previous studies that demonstrated significant improvement in disability after intervention at 6 weeks (50%) and at 3 (67%) and 12 month (56%) follow up periods (Rasmussen-Barr et al., 2003b). The other study demonstrated a 43.2% improvement after 4 weeks

(Brennan et al., 2006). It may be that this study was more rigorous than the aforementioned studies but this has to be put in context of the smaller sample size. However, both studies (Rasmussen-Barr et al., 2003b; Brennan et al., 2006) used the Oswestry disability Index (ODI), the results of which may have been skewed because of its low internal consistency (The Chartered Society of Physiotherapy, 2004). The significance of the results may therefore be lower than that reported.

The results also differ from the results of Childs et al. (2004) which suggests that like for like on the clinical prediction rule for the treatment of LBP comparing manipulation and lumbar strengthening exercises, manipulation is better than exercise (Childs et al., 2004). Their observation was made using a modified ODI. The discrepancy may be because the exercises used in the study were not specific enough to engage either the TrA or MF either in isolation or together, to effect a change in trunk kinematics. There is, however, a view that suggests that it should not matter because any spinal exercise is a stability exercise (McGill et al., 2003) but the effect of LBP on trunk sagittal acceleration may suggest otherwise (Marras et al., 2000; Aluko et al., 2011).

The missing data had an effect on any within and between group analyses by gender, weight and height. It was therefore not possible to draw any inference from the results. However, it would be expected that there should be a trend given the difference in body shape and muscle size with respect to gender and age (Jones and Round, 1990). It has already been suggested that obesity has a negative effect reducing LBP induced disability (Yildirim et al., 2007).

There were an equal number of dropouts excluding the pre-randomised drop out (control 11, experimental 11) by the end of the study (Fig. 5.1). However, one

participant dropped out because another unrelated problem required orthopaedic intervention and the view was taken that further participation might aggravate the problem requiring surgery. Two other participants could not commit to the time to be continually involved in the study as their personal circumstances changed and the remainder did not offer any explanation other than that a decision had been made to terminate their involvement in the study. Further qualitative analyses may provide more insight into the underlying reasons for the attrition which may be valuable for clinical purposes in understanding compliance with acute LBP home exercise programmes or attendance for treatment. However, a future study may benefit from recognising the complex lifestyles participants may have and the need to factor these complexities into the development of the method stage of the study. Funding may also allow better flexibility for data collection that could suit the participants better.

6.4.4 Variable relationships

6.4.4.1 Start of the study to 3 weeks

The increase in range of movement demonstrated was to be expected however, the sincerity of effort can be in doubt. Albeit, the results do suggest that during the first 3 weeks of the study all activity did produce an increase in discomfort within both groups. This was not unexpected because the participants' behaviour was changed from that of fear-avoidance when patients avoid activity because of the fear of exacerbating pain, to one of activity. However, the study may suggest that the CSE was less aggressive because less pain was provoked. The experimental group were able to demonstrate the most improvement in mean pain scores within this short period of time. It is plausible that the CSE were specific

enough to isolate both movement at lumbar segment level and restrict its affect to the immediate structures i.e the MF, that supports those segments being mobilised. The finding that as movement increased there was a demonstrable increase in trunk sagittal acceleration when the activity reduced spasm within the MF to facilitate trunk flexion may support this view.

During the first 3 weeks of the study it was not possible from the results to suggest that there was a difference between genders because of the small number of male participants. However, it has already been proposed that women of different age and racial groups demonstrate different amounts of trunk movement (Trudelle-Jackson et al., 2010). The results do not suggest an inference about male participants but there may be a hint of a trend that within both groups male participant trunk range of movement was less influenced by CSE. This was equally true for the older and the heavier male participants within both groups. This would therefore suggest that in the early stages of CSE female patients may experience a far more noticeable improvement in trunk flexibility than a similar male cohort. Conversely, heavier females may have a slower response to CSE than their slimmer counterparts. However, the effect of hormones on range of movement within the female participants is not known (Kerr and Grahame, 2003) and variations in the menstrual cycle within these participants may be expected. An earlier study in the United States of America has found an increase in headaches with the onset of a menstrual cycle in women (Johannes et al., 1995) and a similar study investigating the effects of oestrogen levels on temporomandibular pain also found that this type of pain in women increased when there were low levels of oestrogen (LeResche et al., 2003). This may indicate that the effect of hormonal changes on reported pain

and disability resulting from an acute onset of non-specific LBP remains unclear and is worthy of further investigation. Female participants in this study were not asked about the timing of their menstrual cycle or the stage at which they felt they were at within it.

There was no correlation between changes in trunk sagittal acceleration and any of the other variables at this stage of the study. However, this does suggest that weight loss may not influence the effect of CSE. The implication of which is that asking a patient to lose weight as a pre-requisite for treatment of an onset of LBP using CSE may not be valid or even possible.

6.4.4.2 3 weeks to 6 weeks

During this period, the increase in range of movement demonstrated was associated with an increase in both pain and trunk sagittal acceleration. During this phase of the study improvements in disability are expected (Sokunbi et al., 2008). The reduction in disability demonstrated by the end of the 6 week period (Table 5.10) appears to support this suggestion. It is possible that the reduction in disability may be a direct consequence of an increase in both the range of movement and trunk acceleration.

This mechanism is facilitated by improvement in trunk robustness (Reeves et al., 2007) as the ability of the trunk to change direction in response to perturbation improves. A CSE programme may facilitate this mechanism by improving fine motor control to enhance trunk functional stability by reducing its state of chaos (Marras and Mirka 1993; Dolan and Adams, 1993; Granata and England, 2006) as can be demonstrated by a reduction in the trunk Lyapunov exponent (λ_{MAX}) (Granata and England, 2006). This is all the more important because the study involved a

symmetrical movement of flexion-extension, a direction within which trunk instability is greater than if it was performed with a degree of rotation (Granata and England, 2006). The possible improvement in stability demonstrated by this study is therefore of high clinical importance.

The increase in pain demonstrated during this period may be as a result of an exacerbation of the 'trigger' of the pain-spasm-pain model (van Dieen et al., 2003) induced by the increase in range of movement and the ensuing increased inter-segmental movement. Although movement and sagittal acceleration improved there is no evidence to suggest that structural dysfunction had been reversed at this stage. This finding is in keeping with previous findings to suggest that performance and pain have a negative correlation (Cox et al., 2000). The structural dysfunction may include facet joints, Intervertebral discs (IVD) or ligament damage caused by abnormal force, strain and stress applied to the structures (Atlas and Deyo, 2001). It is not clear what the effect of the timescale for the repair of these structures has on trunk performance and it remains a possible direction for future research.

6.4.4.3 6 weeks to 12 weeks

This period is a relatively inactive period of the study. All intervention had ceased during this phase and it was assumed that all the participants continued with their normal active routine similar to what it was prior to the onset of their episode of pain. All participants had been discharged by their treating physiotherapist. However, the rate of attrition during this period made it impossible to draw inferences from the data. However, it could be that the rate of attrition was directly related to the participants' wellbeing. The premise for this assumption was that

none of the participants (to the researcher's knowledge) reported any reoccurrence or returned to their treating physiotherapist requesting further advice or treatment. However, it could be that the timescale of 3 months was too narrow to assess medium term changes following the cessation of an intervention. Previous studies had a range of follow up periods of 6 months (Childs et al., 2004) to a year (Rasmussen-Barr et al., 2003b; Brennan et al., 2006). The original protocol for this study did have a one year follow up period but enforced changes meant that a 3 month follow up was more realistic given the constraints of the study. Although it has been demonstrated that the majority of the change had occurred within the first 3 weeks of the study and the difference between participant groups maintained at 6 weeks, the long term effects of the intervention may be best judged on trunk performance after a year. However, a control over attrition would need to be improved to ensure that the sample remains truly representative of the participants of the study by maintaining strict inclusion criteria.

6.5 Key findings

From the above discussion the following key findings of this study were deduced;

- Trunk sagittal acceleration may be sensitive to an onset of acute non-specific LBP.
- The effects of CSE on the observed changes within 3 weeks of intervention are not conclusive. However, the possible clinical importance of CSE cannot be ignored and requires further investigation.

- The increase in trunk sagittal acceleration and thus its performance was not demonstrated conclusively shown to be as a result of CSE.
- The reduction in disability caused by acute non-specific LBP observed was not conclusively shown to be as a result of CSE.
- The reduction in pain induced by trunk dysfunction observed was not conclusively shown to be as a result of CSE.
- There may be a positive correlation between increased trunk sagittal acceleration and the range within which the trunk is displaced.
- Within the process of restoration of trunk function following an onset of non-specific LBP, there is a phase within which there may be a negative correlation between the improvement in trunk range of movement and sagittal acceleration and subjective reported pain.

These findings do not in general agree with the suggestion that CSE may not be of benefit to acute LBP patients (Atlas and Deyo, 2001). They do however suggest that they may encourage normal activity as quickly as possible (Smith et al., 2002; Rozenberg et al., 2003; Kinkade, 2007). The study is inconclusive in suggesting that CSE affects trunk performance and thus it remains to be proved if they are effective in preventing acute non-specific LBP from becoming chronic thereby reducing tertiary referrals that may be either unnecessary or expensive (Lauchlan, 2005).

6.6 Mechanism by which CSE may work

Core Stability Exercise may be beneficial for people seeking physiotherapy for an episode of acute non-specific low back pain. The literature review and ensuing discussion of the research results provides an understanding of a possible

mechanism by which acute non-specific LBP is commenced, the effect it has on trunk performance and trunk response to early intervention using CSE.

Before the study commenced there was a difficult debate between the researcher, peers and colleagues independent of the study as to the type of movement that occurs within a lumbar segment. The debate was complicated by the fact that the movement in question involved relatively small displacements based on whether the movement is linear or angular in nature. It was finally concluded that the movement has angular characteristics because the movement was more about deformation of the intervertebral discs, gliding/sliding of the facet joints and the tilting of the vertebral body about an axis (Fig 2.4).

Non-specific acute non-specific low back pain as a symptom is elicited by a structural dysfunction (Atlas and Deyo, 2001). The stress and strain that precipitates dysfunction may or may not be influenced by underlying pathology (Gruber et al., 2007) or hormonal changes (Kerr and Grahame, 2003). However, it is assumed that underlying pathology will reduce structural tolerance to forces applied across the structure and therefore could make it more susceptible to damage.

Newton's Laws of Motion suggest that the force and the acceleration required to produce it are directly proportional (Ogrodnik, 1997c) and it has been shown anecdotally and demonstrated that trunk acceleration is reduced by an onset of acute LBP (Marras et al., 2000; Aluko et al. 2011). But what may be now possible is to suggest that trunk performance is not likely to improve with repeated measure without intervention (Aluko et al., 2011). At the point of onset of an episode of non-specific LBP, local spasm within the MF muscle caused within the

pain-spasm-pain model (van Dieen et al., 2003) may oppose trunk flexion through stiffness and in the process reduce trunk acceleration.

The results of this study suggest that early intervention using CSE may improve trunk performance by increasing its acceleration (at least within the sagittal plane). It is suggested that it may achieve this by facilitating trunk robustness (Reeves et al., 2007) by improving trunk muscle recruitment and coordination of activity (McGill et al., 2003). The significance of the stability exercise programme as an intervention for an episode of acute low back pain is however dependent upon the muscle group the CSE are intended to target. The CSE used in this study isolated both the TrA and MF in accordance to current suggestions that these are the primary muscles activated first to provide trunk stability (Barr et al., 2005) and are most affected by an onset of LBP (Hodges and Richardson, 1996; Hodges and Richardson, 1997). However it has been suggested that the MF muscle is more important than the TrA because greater structural change can be observed within this muscle group within a relatively short time (Sokunbi et al., 2008) following an onset of acute non-specific low back pain.

The anatomy of the MF (Figs. 1.4 and 1.5) suggests that the trunk may be controlled like an inverted pendulum using a mechanism similar to a two-degree of freedom of balance (Fig. 2.7) (Stepan, 2009). The movement of this inverted pendulum requires constant regulation to initiate and maintain movement within a single plane. The evidence may suggest that this mechanism may be provided by the torque produced by the multifidus (MacDonald et al., 2006). Gross pendulum movement is observed in a single plane however, this movement may require constant subtle adjustment in trunk kinematics in 3-dimensions (Marras and

Wongsam 1986) during the whole gross trunk displacement. The importance of a 3-dimensional movement assessment during a functional evaluation of an episode of acute non-specific low back pain therefore becomes apparent. 3-dimensional evaluation of trunk behaviour can therefore be a more useful method of quantifying changes trunk behaviour caused by an episode of acute non-specific low back pain (Marras and Wongsam, 1986; Kroemer et al., 1990; Marras et al., 1990).

Core stability exercises may also facilitate the stability mechanism of the trunk during functional activity by facilitating the restoration of the feedback control system (Reeves et al., 2007) within the two-degree of freedom model for balance. Improvement in the mechanism of this model therefore reduces trunk chaos (Granata and England, 2006).

Good trunk stability may also require good relative movement of the sacrum (and the pelvis) upon which the inverted pendulum system sits and therefore requires good lumbar-pelvic coordination (LPC) during trunk movement (Granata and Marras, 2000). The LPC has been demonstrated to be repeatable and consistent in the absence of LBP (Granata and Marras, 2000). This consistency may enable the multifidus to work at a fairly regular length consistent with Hookean law (Chapter 2) with the elastic limit never exceeded. The core stability exercises may have improved the integrity of the TrA and synonymously restored/maintained the multifidus length.

6.7 Study limitations

The absence of external funding influenced the length of the study and meant that there was a degree of risk of bias within the study. The Researcher not only collected all the data and analysed the data a month after the 3 month follow

up session, but also administered the first CSE instruction for those in the experimental group. A colleague independent to this study however collated the raw VAS and RMDQ scores.

The specialist equipment used to measure the primary outcome would have required both training for participating physiotherapists and additional costs for the acquisition of additional LMM units. However, if there had been multiple data collection points inter-rater reliability could have posed difficulties because individuality amongst the physiotherapists within the process could have threatened consistency.

The study results refer to only one plane of movement however functional movement is three dimensional (Marras and Wongsam, 1986). The test movement used in this study was within the sagittal plane only. Data representing sagittal movement characteristics may therefore be too restrictive to interpret the true natural trunk behaviour during functional movement. It is within this context that the acceleration profile may be highly repeatable for sincere conditions (Ferguson et al., 2000), but only at the point where there is a change in direction (Ogrodnik, 1997c). It is therefore assumed that minor adjustments within the frontal and rotational planes provide the constant change in direction to maintain consistent global movement within a desired direction. This is consistent with the idea that this occurs when a recruitment pattern of muscle fibres (central set) for movement is established (Marras et al., 2000). The relationship between movement characteristics of side flexion and rotation with sagittal movement therefore does need to be better understood.

6.8 Study rigour and suggestions for improvement

The PEDro score (Maher et al., 2003) for the study is shown below (Table 6.1)

Table 6.1: Study PEDro score

1. Specification of eligibility criteria (Not included in the total score)	Y
2. Random allocation	Y
3. Concealed allocation	Y
4. Baseline comparability	Y
5. Patient blinding	Y
6. Therapist blinding	N/A
7. Assessor blinding	N
8. At least 85% follow-up	N
9. Intention to treat analysis	Y
10. Between group statistical comparisons	Y
11. Point measures and measures of variability	Y
Total score	7/10

Yes-Y; No-N; N/A-Not applicable

The score suggests that this study could be improved by seeking funding for research assistants that would allow for the assessor to be blinded and increase the sample size. Improved funding would also help to reduce attrition by significantly retaining the sample size and increasing the manpower required to provide better support for the participants.

Chapter 7

Study conclusions and recommendations for future research

This study set out to investigate the effect of CSEs on trunk sagittal acceleration following an onset of acute non-specific low back pain. The findings suggest that there may be a positive effect of increasing trunk sagittal acceleration however the changes were not statistically significant. Increasing the sample size may improve the level of significance demonstrated in this study.

It is also suggested that it is possible to use the lumbar motion monitor efficiently and effectively to quantify changes in trunk sagittal acceleration during the natural course of recovery following an acute onset of low back pain within a clinical environment.

The reported early changes in trunk sagittal acceleration may suggest that it is possible to detect a true onset of LBP. This may be achieved by quantifying the change in trunk acceleration through repeated functional testing within a short time span. This process will need baseline measurements for direct comparison from an individual. But an accurate demonstration of an onset of non-specific LBP will also require a statistically significant difference in trunk sagittal acceleration below which a change can be considered to be negligible. Further work is required to identify such a threshold and the specificity and sensitivity of such a method will need further investigation. However, the benefits of such advancement in knowledge will be a positive step in reducing the real costs of an onset of non-specific LBP and the detail could be commercially sensitive.

This study has demonstrated the importance of the MF in trunk stability, however, further research is required to unlock the impasse and further explore the difference in function between the deep and superficial fibres. This is because the deductions arrived at from this study do not sit comfortably with the evidence that suggests that the deep MF has a high proportion of type 1 fibres compared to the superficial MF. The only conceivable explanation is that the superficial and deep fibres of the multifidus may have different functions. A recent study does suggest that the deep and superficial fibres of the MF do have different functions and differ between asymptomatic and symptomatic participants.

Further clarification of the role of the TrA within the stability mechanism is also required. Although the TrA may work in synchrony with the MF, the anatomical location and function of the TrA may suggest that it is more directly involved with the regulation of IAP more so than the regulation of either actual involuntary or voluntary inter-segmental movement.

Further research is also required to investigate the effects of pelvic pathology on the onset of non-specific LBP experienced by females. True mechanical LBP can be easily confused with the low back pain associated with pelvic pathology by experienced and less experienced clinicians alike. It is not known if there is a change in trunk kinematics during bouts of LBP that are associated with internal viscera and if those changes are permanent and cumulative. It is suggested that such pain will not respond to CSE.

It is also not clear if the timescale required for the repair of any structural deficit has an effect on trunk kinematics. Non-specific LBP (excluding idiopathic LBP) is usually initiated by structural dysfunction. It is not clear if the improvement

in outcome measured in this study correlates with the repair of the structures involved during previous or repeated episodes of low back pain.

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Appendix 1: Extraction from the Department of Works and Pensions musculoskeletal injury data 2006

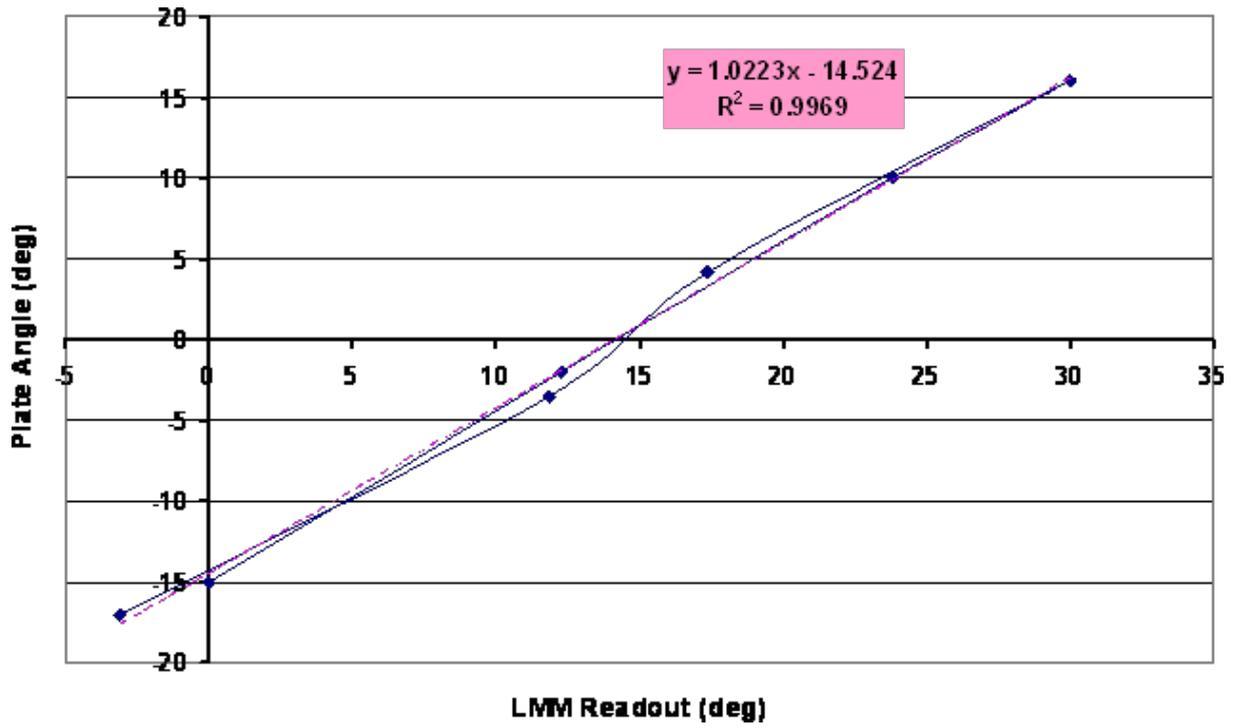
DWP Overall			Region/Nation											
Illness Category	Duration		East Midlands	East Of England	London	North East	North West	Scotland	South East	South West	Wales	West Midlands	Yorks and Hum	Grand Total

Musculoskeletal and Connective Tissue	Long term	WDL	7,313	7,118	19,154	5,446	15,464	19,659	10,323	6,191	7,409	9,442	13,608	121,207
		Occurrences	120	123	226	96	230	304	164	107	126	133	214	1,843
	Short term	WDL	2,936	3,483	5,855	2,777	5,534	7,113	3,702	3,691	2,690	2,844	4,293	44,916
		Occurrences	884	1,043	808	693	1,468	1,843	1,072	1,071	853	887	1,289	12,911
Sub-total WDL			10,249	10,601	25,009	8,223	20,997	26,771	14,024	9,882	10,099	12,286	17,981	166,122
Sub-total Occurrences			1,004	1,166	2,034	789	1,698	2,147	1,236	1,178	979	1,020	1,503	14,754

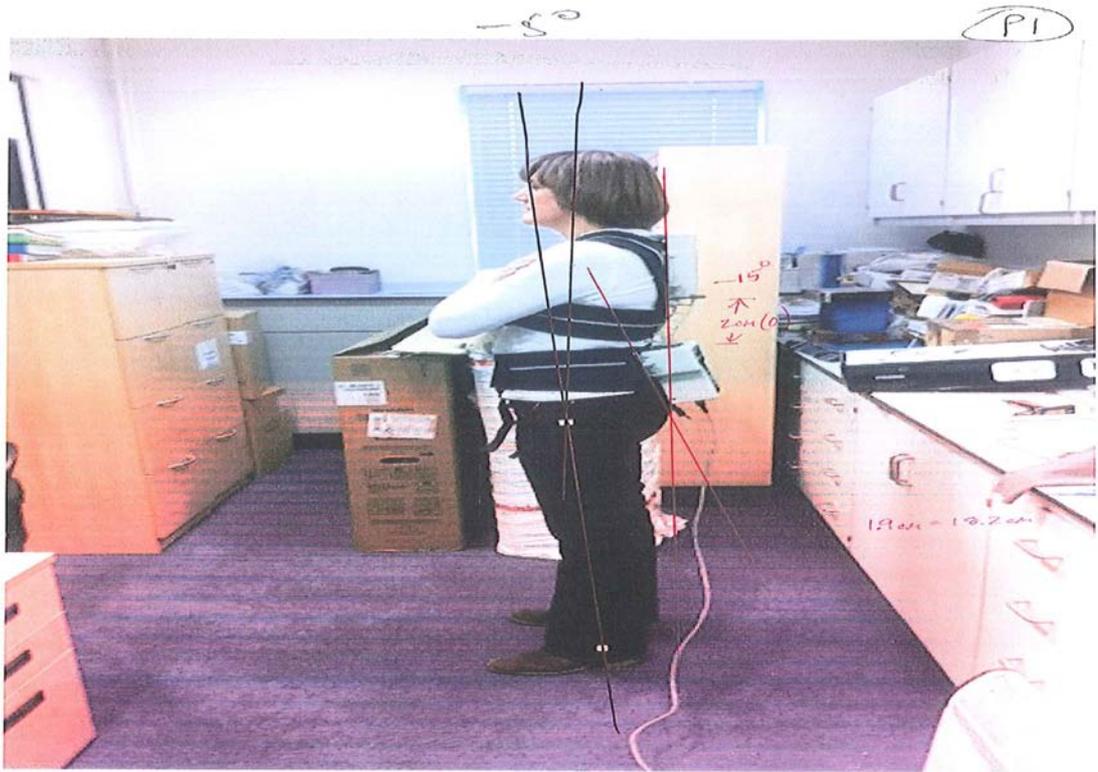
Notes:

1. The “short term” category represents all those spells lasting 28 calendar days or less (full time equivalency), and “long term” all those over 28 days.
2. The period covered by the data is from 1 July 2005 and June 2006.
3. WDL= Working Days Lost

Appendix 2: Laboratory calibration of the LMM



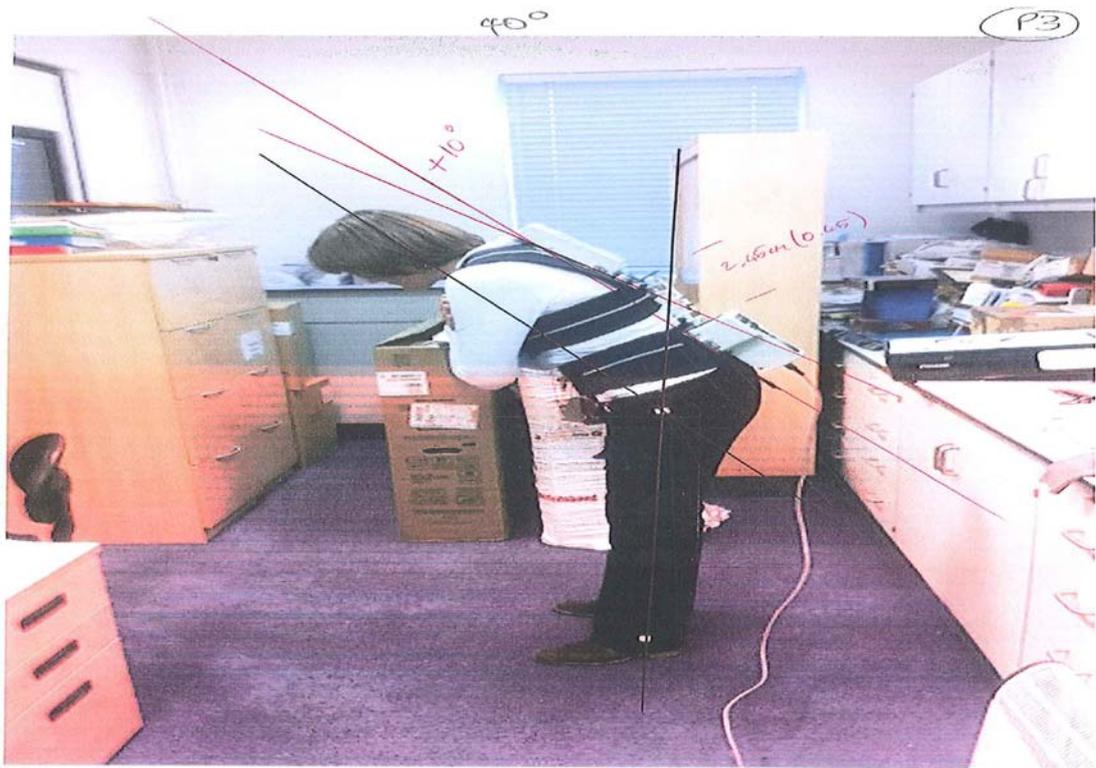
Appendix 3



a



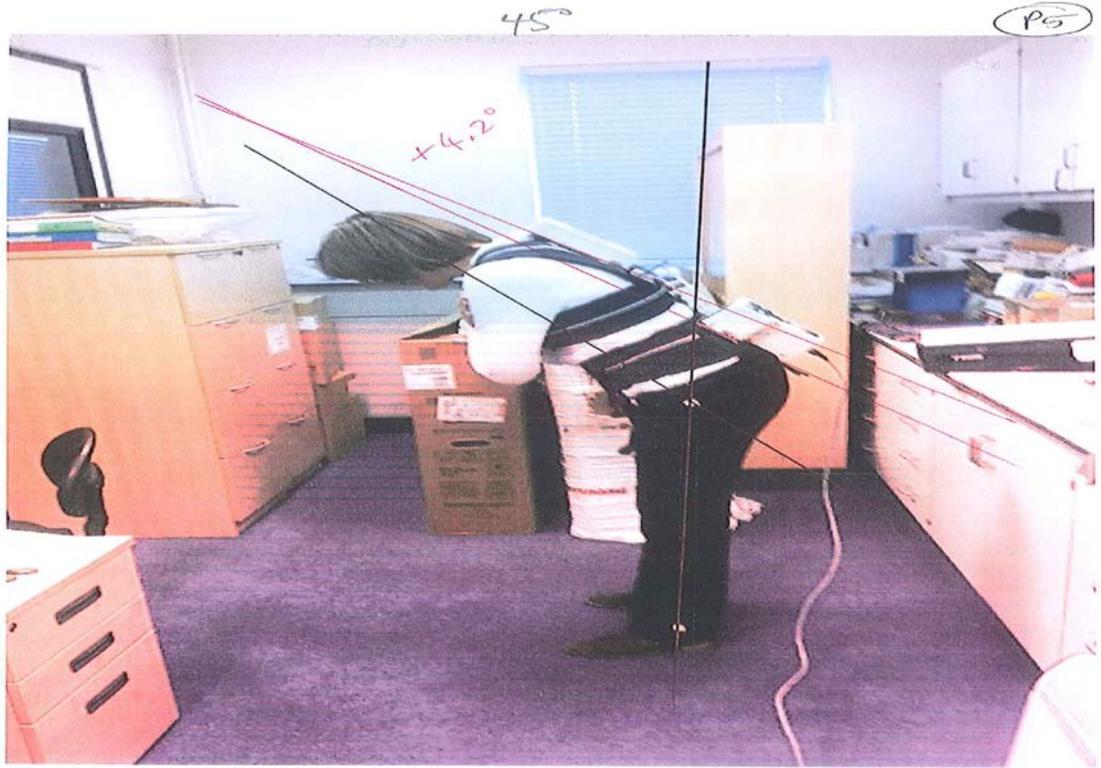
b



c



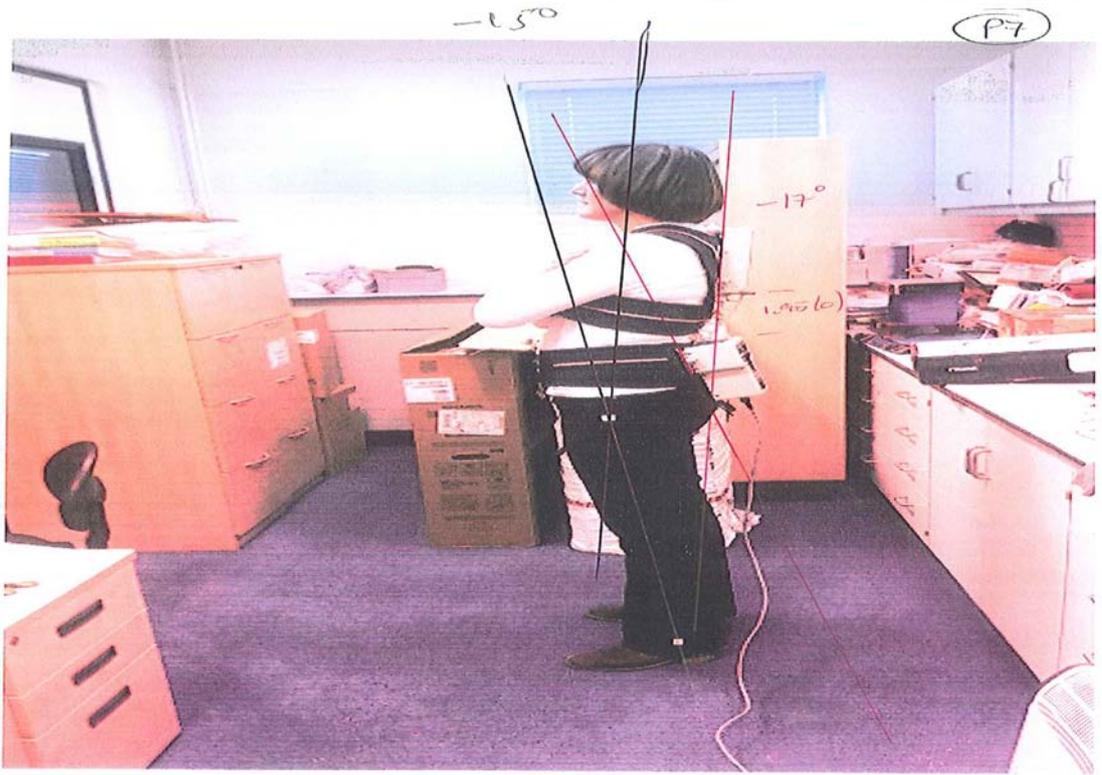
d



e



f



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Appendix 4: Published pilot study: Evaluation of trunk acceleration in healthy Individuals and those with low back pain

Appendix 4 has been removed from this thesis due to the publisher's copyright restrictions. As a result pages 223 – 230 of the thesis are not presented here.

The contents that has been removed is an article with the following citation:

(2011) Aluko, A., DeSouza, L. and Peacock, J., Evaluation of Trunk acceleration in healthy individuals and those with low back pain. International Journal of Therapy and Rehabilitation, 18(1): 18-25.

To obtain a copy of the article please go to http://www.ijtr.co.uk/cgi-bin/go.pl/library/article.cgi?uid=80927;article=IJTR_18_1_18_25 where the article is available for subscribers or available to purchase.

Appendix 5: Short non-standardised questionnaire

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Social Care
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School of Health Sciences and Social Care

Questionnaire
(Version 1, 17th July 2009)

Protocol ref.: 07/03/STF/09 Oxfordshire REC C Ref.: 07/H0606/102

Title: The effect of core stability exercises on the movement of the lower back

This questionnaire is designed to reflect your history of low back pain. Low back pain is defined as a pain between the lowest rib margin and the lower crease of the buttocks. Please answer the following questions as accurately as possible.

Participant No.

1. Have you ever experienced low back pain? YES NO
2. If yes, when was the last episode <1 month 1-3 months 4-6 months 7-9 months 10-12 months >12 months
3. In the last 12 months how many episodes of low back pain have you had?
4. Have you ever had to consult your GP about an episode of low back pain? YES NO

Appendix 6: Study stability exercises 1

The Exercise Routine

Core Stability Exercise Sheet 1

Provided for : A Sample
Provided by : A Aluko

Research
Date : 30/03/2006

Abdominal Hollowing Lying

Lie on your front on a firm surface (not a bed). Focus your attention on your navel and pull your abdomen in to try to create a gap between the surface and your abdomen. Breathe normally-do not hold your breath or take a deep breath. Perform 10 repetitions of each movement. Hold for 3 seconds, breathing normally. Do not hold your breath.



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Straight Leg Raise

Lie on your back with both knees bent. Tighten (hollow) your abdomen and hold it tight throughout the movement. Straighten one leg and lift it to 90° hip flexion without allowing your pelvis to move. Perform 10 repetitions of each movement (10 right limb, 10 left limb). Hold for 1 seconds, breathing normally. Do not hold your breath.



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Abdominal Hollowing Sitting

Sit on a stool or gym bench with your knees apart and below the level of your hips. Lengthen your spine to "sit tall" and place one hand in the small of your back, the other in front of your lower abdomen. Focus your attention on your navel and pull your abdomen "in and up," drawing it away from your front hand. Breathe normally-do not take a deep breath or hold your breath. Perform 10 repetitions of each movement. Hold for 1 seconds, breathing normally. Do not hold your breath.



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Heel Slide

Lie on the floor with your knees bent, one heel on a cloth (if on a wooden floor) or shiny paper (if on carpet). Tighten your abdomen and keep it tight throughout the exercise, breathing normally. Slide your heel away from you, straightening your leg. Maintain your spinal alignment-do not allow your back to arch. Perform 10 repetitions of each movement (10 right limb, 10 left limb). Hold for 1 seconds, breathing normally. Do not hold your breath.



Appendix 7: Study stability exercises 2

Core Stability Exercise Sheet 2

Four-Point Pelvic Shift



Kneel on the ground with your hips directly above your knees and your shoulders directly above your hands. Tighten your abdomen and keep it tight throughout the movement, breathing normally. Sway your pelvis to one side and then to the other side, causing your hips to abduct and adduct. Maintain the neutral position of your spine throughout the action-do not allow your pelvis to tip. Perform 10 repetitions of each movement. Hold for 1 seconds, breathing normally. Do not hold your breath.

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Trunk Curl



Lie on the floor on a mat with your knees bent to 90°, hips flexed to 45°. Tighten (hollow) your abdomen and keep it hollow throughout the movement, breathing normally. Do not allow your abdomen to bulge (bowstring). Curl your trunk, beginning with the head and then the thoracic spine, so that you come up to look between your knees. Keep your lower (lumbar) spine flat on the floor throughout the exercise. Perform 10 repetitions of each movement. Hold for 1 seconds, breathing normally. Do not hold your breath.

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Pelvic Tilt Re-Education, Sitting



Sit on a stool or gym bench with your knees shoulder-width apart. Lengthen your spine (sit tall) and draw your abdomen in. Keeping your shoulders still, tilt your pelvis to increase and then reduce the hollow in the small of your back (lumbar lordosis). The tilting action is helped by trying to sit forward toward your pubic bone (anterior tilt) and then backward onto your sitting bones (posterior tilt). Perform the exercise 10 times in each direction.

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Sitting Knee Raise



Sit on a stool with your feet on the floor. Tighten (hollow) your abdomen and keep it tight throughout the movement, breathing normally. Raise one knee 4-6 inches, maintaining spinal alignment. Do not allow the pelvis to tilt or the back to round. Perform 10 repetitions of each movement (10 right limb, 10 left limb). Hold for 1 seconds, breathing normally. Do not hold your breath.

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Appendix 8: Exercise compliance sheet

Daily exercise diary. Please complete each day.

The effect of core stability exercises (CSE) on the movement of the lower back.

Study No.....

Date :

EXERCISE	REPETITIONS IN THE MORNING	REPETITIONS IN THE AFTERNOON	REPETITIONS IN THE EVENING	TOTAL
1	/10	/10	/10	/30
2	/10	/10	/10	/30
3	/10	/10	/10	/30
4	/10	/10	/10	/30
5	/10	/10	/10	/30
6	/10	/10	/10	/30
7	/10	/10	/10	/30
8	/10	/10	/10	/30

Date :

EXERCISE	REPETITIONS IN THE MORNING	REPETITIONS IN THE AFTERNOON	REPETITIONS IN THE EVENING	TOTAL
1	/10	/10	/10	/30
2	/10	/10	/10	/30
3	/10	/10	/10	/30
4	/10	/10	/10	/30
5	/10	/10	/10	/30
6	/10	/10	/10	/30
7	/10	/10	/10	/30
8	/10	/10	/10	/30

Date :

EXERCISE	REPETITIONS IN THE MORNING	REPETITIONS IN THE AFTERNOON	REPETITIONS IN THE EVENING	TOTAL
1	/10	/10	/10	/30
2	/10	/10	/10	/30
3	/10	/10	/10	/30
4	/10	/10	/10	/30
5	/10	/10	/10	/30
6	/10	/10	/10	/30
7	/10	/10	/10	/30
8	/10	/10	/10	/30

Protocol ref.: 07/03/STF/09 Oxfordshire REC C Ref.: 07/H0606/102

Appendix 9: Core stability exercise class exercise sheets used by Hillingdon Community Health sheet level 1

Built on Physiotools Online LEVEL 1 Page 1 of 4



PhysioTools
Work with the Best

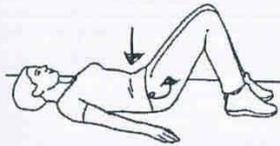
Personal exercise program

Hillingdon PCT
Hillingdon PCT
Kirk House, 97 - 109 High Street, UB7 7HJ, Yiewsley, Middlesex, United Kingdom
Provided by Physiotherapy Department Eastcote Health Centre 20/06/2008
Provided for _____

Lying on your back with knees bent and arms by your side. (neutral spine)

Tighten your stomach muscles and press the small of your back against the floor letting your bottom rise. Hold 5 secs. - relax.

Repeat 10 times.



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Lying on your back with knees bent.

Flatten your spine into the floor and tighten your tummy muscles. Slowly pat your hands on the floor 5 times for your breath in and 5 times for your breath out

Repeat 3 times.

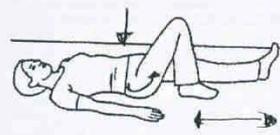


©PhysioTools Ltd

Lying on your back knees bent. Tighten your tummy muscles and flatten the small of your back.

Slowly slide your leg straight and then bend it back to the start

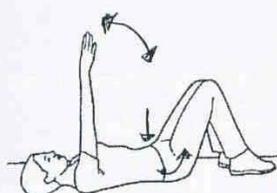
Repeat 10 times each leg.



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<https://pt001a.physiotools.com/>



Lying on your back knees bent and arms by your side, tighten your tummy muscles and flatten the small of your back..

Lift arms up together to point to the ceiling.

Repeat 10 times.

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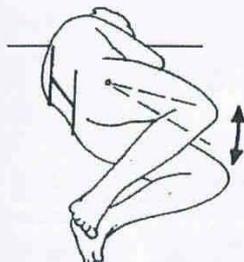
Lying on your back with knees bent. Tighten you tummy muscles

Squeeze your buttocks together and slowly lift your bottom off the floor lifting each vertebrae in your back up one at a time. Return to starting position lowering each vertebrae at a time.



Repeat 10 times.

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START POSITION: Lie on the side with the pelvis square and the hips and knees bent. Hollow the stomach to straighten the back to a neutral position

ACTION: Leaving the heels together, slowly lift the top knee by turning the hip out without letting the back or pelvis twist. Keep feet together. ONLY move as far as a stable back and pelvis allow. Slowly return to the start postion maintaining control of the pelvis during the return. Do not strain.

Repeat 10 times. each leg (adpt Sahrman PhD, PT)

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Lying on your side with your knees bent arms out straight in front. Find neutral spine position.

Slowly lift the arm out an up to point towards the ceiling and turn you head to follow the arm movement.

Repeat 10 times each arm.

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20/06/2008

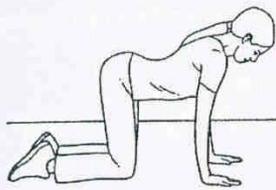
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2/4

Crawling position.

Hollow your back. Keep your neck long and elbows straight.

Repeat 5 times.



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Crawling position.

Let your arms slide along the floor as far as possible. Push your bottom back and down and the chest towards the floor. Breathe out while doing the exercise.

Repeat 5 times.

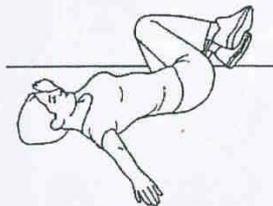


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Lying on your back with your arms in a T-position and knees bent towards the ceiling.

Slowly roll both your legs from side to side without touching the floor.

Repeat 5 times.



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Lying with your knees bent and your feet on the floor.

Lift one knee towards your chest. Place your hands behind the knee and draw it into your chest.

Repeat 5 times.



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Appendix 10: Core stability exercise class exercise sheets used by Hillingdon
Community Health sheet level 2

Built on Physiotools Online Page 1 of 4

LEVEL 2

Personal exercise program

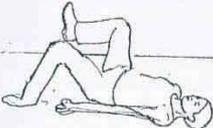
Hillingdon PCT
Hillingdon PCT
Kirk House , 97 - 109 High Street, UB7 7HJ, Yiewsley, Middlesex, United Kingdom

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Provided by Physiotherapy Department Eastcote Health Centre level 2
03/09/2008

Provided for _____

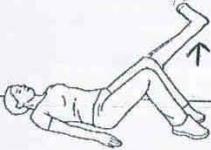
Lying on your back.



Set your abdominal muscles
Take a breath in, as you breathe out raise your right leg to 90 degrees.
Inhale and pulse your arms by your side for 5 and continue pulsing your arm for 5 as you breath out
Repeat on the opposite leg
Repeat 3- 5 times on each side

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Lying on your back with knees bent. Hands resting by your sides.



Inhale and as you breath out bend your hip and knee to 90 degrees
Take another breath as you breath out straighten your knee so that your thighs are level.
Hold this position for 5 secs
Repeat on the other side
Repeat 5-10 times on each side

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START POSITION: Lie on the back with both legs straight and the stomach hollowed. And your arms stretched out overhead at 90 degrees.



Take a breath in. As you breath out slowly slide a leg along the floor whilst taking your shoulders further back behind your head
Hold this position for 5 secs
Make sure that your back doesn't arch away from the floor.
Repeat on opposite side
Repeat 5-10 times on each side

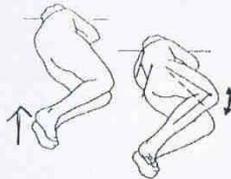
©PhysioTools Ltd

Lying on your back with knees bent.



Lift your hip up and keep it straight while shifting the weight over to one leg. Then straighten the other leg - put it back down and repeat with other leg.
Repeat 5-10 times on each side.

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03/09/2008 PhysioTools Online 1 / 4



START POSITION: Lie on the side with the pelvis square, the hips neutral or flexed to approximately 10 degrees and the knees bent. Hollow the stomach to straighten the back to a neutral position. Lift both feet off the floor, keeping your thighs resting on the floor

ACTION: Leaving the heels together slowly lift the top knee by turning the hip out without letting the back or pelvis twist. ONLY turn out as far as a stable back and pelvis allow. Hold this position with minimal effort.

Hold for 5 secs. Repeat 5-10 times on each side

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Lying on your side with your knees bent and your arms straight out in front of you. Find your neutral position.

Inhale and as you breathe out, circle your uppermost arm overhead until your arm is out to the opposite side. Allow your head to follow the movement. Gently keep circling the uppermost arm, bringing around to the uppermost hip and back to the starting position

Repeat x 5-10 on each side

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Lying on your front with your forehead supported on a towel.



Slowly and gently squeeze your shoulder blades together and gently lift them away from the floor. Lift your hand approx 3cm away from the floor. At the same time, gently lift your breast bone away from the floor.

Hold this position for 5 secs
Repeat 5-10 times

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LEVEL 2

Lying face down with your arms up in line with your body keeping the upper arms as close as possible to your ears and your palms facing the floor



Point your toes and gently lift one hand away from the floor by approx 3 cm and hold this position for 5 secs
Repeat on the opposite side

LEVEL 3

In the same position. Gently lift a hand away from the floor whilst lifting the opposite leg (to the hand) away from the floor and hold this position for 5 secs

Repeat on the opposite side

Repeat 5-10 times on each side

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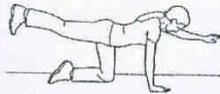
Lying face down with your forehead on the floor, arms outstretched with your elbows at right angles.



Lift your elbows and forearms off the floor squeezing your shoulder blades together.
Hold for 5 secs
Repeat 10 times.

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Crawling position.



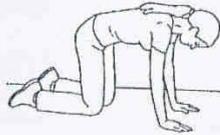
Lift opposite arm and leg to horizontal position. Hold 5 - 10 secs. Try to keep your body still.
repeat on the opposite side
Repeat 3-5 times on each side.

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Crawling position.

Arch your spine whilst letting your head relax between your arms

Repeat 5 times

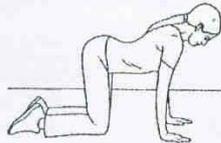


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Crawling position.

Hollow your back. Keep your neck long and elbows straight.

Repeat 5 times.



©PhysioTools Ltd

Crawling position.

Let your arms slide along the floor as far as possible. Push your bottom back and down and the chest towards the floor. Breathe out while doing the exercise.



Repeat 5 times.

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3/4

Lying on your back with knees together and bent.
Slowly roll your knees from side to side keeping your upper trunk still.
Repeat 10 times in each direction



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Lying with your knees bent and your feet on the floor.

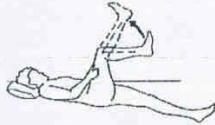
Lift one knee towards your chest. Place your hands behind the knee and draw it into your chest. Hold _____ 5_ secs.



Repeat _____ 3_ times on each side.

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Lying, hold back of knee, and lift your toes towards you. slowly bend and straighten your knee until you feel a tightness.



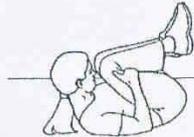
Hold for 10 secs
Repeat on the other side

Repeat x3 on each side

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Lying on your back.

Using your arms pull your knees up towards your chest. Reach with your forehead towards your knees. Hold approx. 5 secs. - relax.



Repeat _2_ times.

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Appendix 11: Short history sheet used by recruiting Physiotherapists

Title: The effect of core stability exercises on the acceleration of the lumbar spine
07/03/STF/09 Oxfordshire REC C Ref.: 07/H0606/102

The following information is important to the research study. For each participant please ensure that each category is completed by placing a circle around the correct response. **Please use ink and write in bold capitals where necessary.**

Study Number: _____ DoB: _____

Gender: Male Female

Location of treatment: Laurel Lodge Church Road Warren Medical Centre Uxbridge Health Centre Eastcote Health Centre
 Physio Direct

Sporting Activity: Yes No

Onset: Gradual Insidious Sudden

Medication: Yes No

Name of Medication:

Period of symptoms: 1-2 weeks 2-3 weeks 3-4 weeks 4-5 weeks 5-6 weeks >6 weeks

Type of Pain: Dull Sharp Don't know

Date seen by GP: same day 2-3days 4-5days 6-7days >7days

Previous treatment: Yes No **If Yes please complete the following items;**

Previous type of treatment: Physiotherapy Chiropractic Osteopathy Massage Acupuncture Medication Other...Please specify.....

Previous Rx outcomes: No change Better Don't know Got worse

Appendix 12: Patient information sheet

Brunel
UNIVERSITY
WEST LONDON

School of Health Sciences and Social Care

School of Health Sciences and
Social Care
Brunel University,
Uxbridge
Middlesex UB8 3PH
Telephone: +44 (0)1895 274000
Web www.brunel.ac.uk

Appendix 3: Patient Information Sheet

(Version 5, 7th May 2008)

Protocol ref.: 07/03/STF/09 Oxfordshire REC C Ref.: 07/H0606/102

Title: The effect of core stability exercises on the movement of the lower back

We would like to invite you to take part in a research study. Before you decide you need to understand why the research is being done and what it would involve for you. Please take time to read the following information carefully. Talk to others about the study if you wish.

Core stability exercises seem to reduce the pain and discomfort experienced during and episode of low back pain, however, we do not understand why and how. This study aims to try and answer these questions by investigating the effect of core stability exercises on the acceleration of the lumbar spine. It is hoped that the results will help devise a proven exercise programme that can help to reduce the effect of the pain on sufferers.

The purpose of this study

We are conducting a research study to investigate if an exercise routine can be used to change the effect of movement on the lower part of the spine. It is thought that movement produces stress and strain and during a sudden onset of low back pain may influence the amount of pain experienced. It is hoped that by establishing whether the exercise routine works we may begin to understand how low back pain starts and develop an efficient and effective method of early treatment and prevention. A previous short study has already been done allowing the procedure and protocol for this study to be adapted appropriately. This research study forms the basis for the award of PhD from Brunel University.

Why you have been chosen.

You have been invited to take part in this study because you have been referred for treatment of low back pain by you GP and your symptoms and initial examination indicates that you are a suitable candidate to be included in the study.

We are hoping to recruit a minimum of 184 participants in total. It is up to you to decide to take part. We will describe the study and go through this information sheet, which we will then give

to you. We will ask you to sign a consent form to show you that you have agreed to take part. You are free to withdraw at any time without giving a reason and this will not affect the standard of care you receive.

What is involved in the study?

The study is in two parts with the first part lasting 6 weeks and the following part involving a 1 year follow up attendance. If you agree to participate, you will be randomly allocated into either of 2 groups. One group will not receive any other additional input from the researcher but will continue to receive treatment from their physiotherapist whilst the other group will, in addition to their treatment from their physiotherapist be asked to do an exercise routine twice a day for 6 weeks. Information about the injury and history of onset as well as weight, height, sex, occupation, hobbies and treatment etc will be recorded during your first visit and participants in both groups will be measured using a Lumbar Motion Monitor at the beginning and at the end of the study as well as at the 1 year follow up. Participants will also be asked to complete a questionnaire which is one page long and should not take more than 10 minutes to complete at the beginning of the study, at the end of the study and at the 1 year follow up. A flow diagram can be found towards the end of this information sheet. We will need to collect data from some of you twice in one day during your first visit. This will enable us to ensure that the measurement collected by the researcher is reliable.

Sometimes we do not know which treatment approach works best for patients. To find out, we need to compare different treatments. We put people into groups and give each group a different treatment. The results are compared to see if one is better. To try and make sure the groups are the same to start with, each participant is put into a group by chance.

Because information and measurements will be collected from you during your routine visit for treatment from your physiotherapist, it is not expected that there will be added costs. No budget has therefore been allowed for reimbursement of any expenses.

What will I need to do in the study?

During each visit you will be asked to complete a questionnaire and then be measured using a Lumbar Motion Monitor. The Lumbar Motion Monitor is an apparatus that measures how the spine moves. You will not be required to undress but it is suggested that you wear loose fitting clothing and comfortable shoes. Females may prefer to wear loose fitting trousers rather than skirts or dresses. The apparatus will be placed on your back with a harness and secured in place with velcro strapping. The procedure is not expected to add to your pain. You will be asked to perform bending and extending movements in neutral within your natural ability as quickly as possible and within pain free range. Each measurement is not expected to last for more than 8 seconds. The exercise routine for those allocated to this group will involve a programme to be done at home twice a day for 6 weeks. Each session will not last longer than 10 minutes at a time and you will be required to keep a diary of when the exercises were done. If you start any medication, change your existing medication or receive any other treatment other than the treatment offered by your local physiotherapist, you will be expected to inform the researcher as soon as possible. You may also receive courtesy phone calls or possible visits if necessary during the 6 week period to offer support and guidance in the event of poor study exercise compliance, an increase in symptoms, problems with the exercises or any other problems associated with the study.

What are the risks?

The first session of the exercise routine is supervised during the initial visit and phone calls/visits will offer support and guidance to ensure that they are done correctly and safely. The Lumbar Motion Monitor assessment is non-invasive and does not involve any procedure that will puncture the skin. From an initial pilot study, it is suggested that there is no indication that your pain will be an increase in your pain. If, however, you do experience any increase in pain or discomfort you must inform the researcher immediately and the measurement will be stopped.

Will I benefit from the study?

We cannot promise the study will help you but the information we get from this study will help improve the treatment of people with low back pain.

It is also important to understand that you will not "own" the results of the study.

Will my details be kept secret?

Yes. We will follow ethical and legal practice and all information about you will be handled in confidence.

Can I chose whether to enter the study or not and can I withdraw from the study if I change my mind?

If you withdraw from the study, we will destroy all your identifiable records, but we will need to use the data collected up to the time of your withdrawal.

Complaints

If you have a concern about any aspect of this study, you should ask to speak to the researcher who will do their best to answer your questions. If you remain unhappy and wish to complain formally, you can do this through the Brunel University Complaints Procedure.

Harm/Compensation

In the event that something goes wrong and you are harmed during the research and this is due to someone's negligence then you may have grounds for legal action for compensation against Brunel University but you may have to pay your legal costs.

In the even that you start any other medication or treatment during the study, you must inform the researcher as soon as possible.

Involvement of the General Practitioner

If you agree to participate in this study your GP will be informed in writing.

The Exercise Routine

Core Stability Exercise Sheet 1

Provided for : A Sample
Provided by : A Aluko

Research
Date : 30/03/2006

Abdominal Hollowing: Lying

Lie on your front on a firm surface (not a bed). Focus your attention on your navel and pull your abdomen in to try to create a gap between the surface and your abdomen. Breathe normally-do not hold your breath or take a deep breath. Perform 10 repetitions of each movement. Hold for 3 seconds, breathing normally. Do not hold your breath.



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Straight Leg Raise

Lie on your back with both knees bent. Tighten (hollow) your abdomen and hold it tight throughout the movement. Straighten one leg and lift it to 90° hip flexion without allowing your pelvis to move. Perform 10 repetitions of each movement (10 right limb; 10 left limb). Hold for 1 seconds, breathing normally. Do not hold your breath.



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Abdominal Hollowing: Sitting

Sit on a stool or gym bench with your knees apart and below the level of your hips. Lengthen your spine to "sit tall" and place one hand in the small of your back, the other in front of your lower abdomen. Focus your attention on your navel and pull your abdomen "in and up," drawing it away from your front hand. Breathe normally-do not take a deep breath or hold your breath. Perform 10 repetitions of each movement. Hold for 1 seconds, breathing normally. Do not hold your breath.



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Heel Slide

Lie on the floor with your knees bent, one heel on a cloth (if on a wooden floor) or shiny paper (if on carpet). Tighten your abdomen and keep it tight throughout the exercise, breathing normally. Slide your heel away from you, straightening your leg. Maintain your spinal alignment-do not allow your back to arch. Perform 10 repetitions of each movement (10 right limb; 10 left limb). Hold for 1 seconds, breathing normally. Do not hold your breath.



Core Stability Exercise Sheet 2

Four-Point Pelvic Shift



Kneel on the ground with your hips directly above your knees and your shoulders directly above your hands. Tighten your abdomen and keep it tight throughout the movement, breathing normally. Sway your pelvis to one side and then to the other side, causing your hips to abduct and adduct. Maintain the neutral position of your spine throughout the action-do not allow your pelvis to tip. Perform 10 repetitions of each movement. Hold for 1 seconds, breathing normally. Do not hold your breath.

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Trunk Curl



Lie on the floor on a mat with your knees bent to 90°, hips flexed to 45°. Tighten (hollow) your abdomen and keep it hollow throughout the movement, breathing normally. Do not allow your abdomen to bulge (bowstring). Curl your trunk, beginning with the head and then the thoracic spine, so that you come up to look between your knees. Keep your lower (lumbar) spine flat on the floor throughout the exercise. Perform 10 repetitions of each movement. Hold for 1 seconds, breathing normally. Do not hold your breath.

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Pelvic Tilt Re-Education, Sitting



Sit on a stool or gym bench with your knees shoulder-width apart. Lengthen your spine (sit tall) and draw your abdomen in. Keeping your shoulders still, tilt your pelvis to increase and then reduce the hollow in the small of your back (lumbar lordosis). The tilting action is helped by trying to sit forward toward your pubic bone (anterior tilt) and then backward onto your sitting bones (posterior tilt). Perform the exercise 10 times in each direction.

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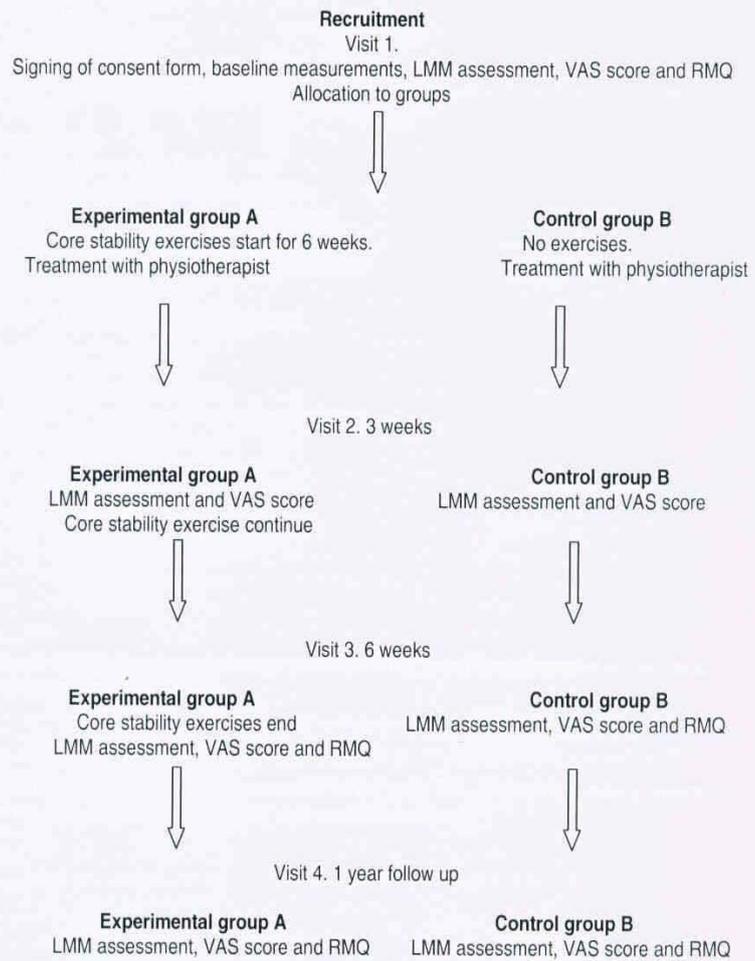
Sitting Knee Raise



Sit on a stool with your feet on the floor. Tighten (hollow) your abdomen and keep it tight throughout the movement, breathing normally. Raise one knee 4-6 inches, maintaining spinal alignment. Do not allow the pelvis to tilt or the back to round. Perform 10 repetitions of each movement (10 right limb, 10 left limb). Hold for 1 seconds, breathing normally. Do not hold your breath.

© Human Kinetics

Flow diagram



Contact Details

Researcher:

Augustine 'Toks' Aluko
Lecturer in Physiotherapy
School of Health Sciences and Social Care
Brunel University
Uxbridge UB8 3PH
Tel: 01895268750
Email: Toks.Aluko@brunel.ac.uk

Supervisors:

Professor Lorraine De Souza
Head of School & Chair of Rehabilitation
School of Health Sciences and Social Care
Brunel University
Uxbridge UB8 3PH
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Email: Lorraine.Desouza@brunel.ac.uk

Professor Janet Peacock
Professor of Medical Statistics
University of Southampton School of Medicine
Southampton General Hospital
Tremona Road
Southampton
Tel: 02380796938
Email: Janet.Peacock@soton.ac.uk

Please tear off the reply slip below and return it to your Physiotherapist at your next treatment session

.....
I have read the information sheet provided for the study 'The effect of core stability exercises on the movement of the lower back' and would like to take part.

.....
Signed

.....
Date

Appendix 13: Consent form



School of Health Sciences and Social Care

School of Health Sciences and
Social Care
Brunel University,
Uxbridge
Middlesex UB8 3PH
Telephone +44 (0)1895 274000
Web www.brunel.ac.uk

Title: The effect of core stability exercises on the movement of the lower back

**Appendix 4: Consent Form:
(Version 4, 1st November 2007)**

Protocol ref.: 07/03/STF/09 Oxfordshire REC C Ref.: 07/H0606/102

Participant Identification Number for this trial:

CONSENT FORM

Title of Project: **The effect of core stability exercises on angular acceleration of the spine**

Name of Researcher: Augustine 'Toks' Aluko

Please initial box

1. I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions.
2. I understand that my participation is voluntary and that I am free to withdraw at anytime without giving any reason, without my usual medical care or legal rights being affected.
3. I understand that IF NECESSARY sections of any of my medical notes may be looked at by responsible individuals from this research group or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to my records.
4. I understand that I must notify the researcher if I commence any form of medication for or any other treatment for low back pain.
5. I agree to take part in the above study.

Name

Date

Signature

Name of Person taking consent
(if different from researcher)

Date

Signature

Researcher

Date

Signature

Appendix 14: Study Roland Morris Disability Questionnaire



School of Health Sciences and Social Care

School of Health Sciences and
Social Care
Brunel University
Uxbridge
Middlesex UB8 3PH
Telephone: +44 (0)1895 274000
Web www.brunel.ac.uk

Protocol ref.: 07/03/STF/09 Oxfordshire REC C Ref.: 07/H0606/102

**Title: The effect of core stability exercises on the movement of the lower back
Roland-Morris Questionnaire**

Participant:.....

Date:.....

When your back hurts, you may find it difficult to do some of the things you normally do. The list below contains some sentences that people have used to describe themselves when they have back pain. When you read them you may find that some of them stand out because they describe you **today**. As you read the list, think of yourself **today**. When you read a statement that describes you **today**, put a tick in the 'Yes' column. If the sentence does not describe you, tick the 'No' column.

ONLY MARK THE BOX IF YOU ARE SURE THAT THE SENTENCE DESCRIBES YOU TODAY

	YES	NO
1. I stay at home most of the time because of my back	----	----
2. I change position frequently to try and get my back comfortable	----	----
3. I walk more slowly than usual because of my back	----	----
4. Because of my back, I am not doing any of the jobs that I usually do around the house	----	----
5. Because of my back, I use a handrail to get upstairs	----	----
6. Because of my back, I lie down to rest more often	----	----

	YES	NO
7. Because of my back, I have to hold on to something to get out of an easy chair	----	----
8. Because of my back, I try to get other people to do things for me	----	----
9. I get dressed more slowly than usual because of my back	----	----
10. I only stand up for short periods of time because of my back	----	----
11. Because of my back, I try not to bend or kneel	----	----
12. I find it difficult to get out of an easy chair because of my back	----	----
13. My back is painful almost all of the time	----	----
14. I find it difficult to turn over in bed because of my back	----	----
15. My appetite is not very good because of my back	----	----
16. I have trouble putting on my socks (or stockings/tights) because of the pain in my back	----	----
17. I only walk short distances because of my back	----	----
18. I sleep less well because of my back	----	----
19. Because of my back pain, I get dressed with help from Someone else	----	----
20. I sit down for most of the day because of my back	----	----
21. I avoid heavy jobs around the house because of my back	----	----
22. Because of my back pain, I am more irritable and bad tempered with people than usual	----	----
23. Because of my back, I go upstairs more slowly than usual	----	----
24. I stay in bed most of the time because of my back	----	----

Score **/24**

Appendix 15: Study Visual Analogue Scale

Protocol ref.: 07/03/STF/09 Oxfordshire REC C Ref.: 07/H0606/102

Title: The effect of core stability exercises on the movement of the lower back

Study No.....

Date.....

Visual Analogue Scale

How bad is your pain **TODAY**? Put an **X** on the line to indicate how bad you feel your pain is **TODAY**.

No Pain _____ Very Severe Pain

Appendix 16: Approved amendments to study



National Patient Safety Agency

National Research Ethics Service

NOTICE OF SUBSTANTIAL AMENDMENT

For use in the case of all research other than clinical trials of investigational medicinal products (CTIMPs). For substantial amendments to CTIMPs, please use the EU-approved notice of amendment form (Annex 2 to ENTR/CT1) at <http://eudract.emea.eu.int/document.html#guidance>.

To be completed in typescript by the Chief Investigator in language comprehensible to a lay person and submitted to the Research Ethics Committee that gave a favourable opinion of the research ("the main REC"). In the case of multi-site studies, there is no need to send copies to other RECs unless specifically required by the main REC.

Further guidance is available at <http://www.nres.npsa.nhs.uk/applicants/review/after/amendments.htm>.

Details of Chief Investigator:	
<i>Name:</i>	Augustine Aluko
<i>Address:</i>	Lecturer in Physiotherapy School of Health & Social Care Brunel University Uxbridge Middlesex UB8 3PH
<i>Telephone:</i>	01895-268750
<i>Email:</i>	Toks.Aluko@Brunel.ac.uk
<i>Fax:</i>	

Full title of study:	The effect of core stability exercises (CSE) on angular acceleration of the lumbar spine
Name of main REC:	Oxfordshire
REC reference number:	07/H0606/102
Date study commenced:	n/a
Protocol reference (if applicable), current version and date:	Version 3, 10 th September 2007

Amendment number and date:	Version 4, 1 st November 2007
-----------------------------------	--

Type of amendment (indicate all that apply in bold)

(a) Amendment to information previously given on the NRES Application Form

Yes No

If yes, please refer to relevant sections of the REC application in the "summary of changes" below.

(b) Amendment to the protocol

Yes No

If yes, please submit either the revised protocol with a new version number and date, highlighting changes in bold, or a document listing the changes and giving both the previous and revised text.

(c) Amendment to the information sheet(s) and consent form(s) for participants, or to any other supporting documentation for the study

Yes No

If yes, please submit all revised documents with new version numbers and dates, highlighting new text in bold.

Is this a modified version of an amendment previously notified to the REC and given an unfavourable opinion?

Yes No

Summary of changes

Briefly summarise the main changes proposed in this amendment using language comprehensible to a lay person. Explain the purpose of the changes and their significance for the study. In the case of a modified amendment, highlight the modifications that have been made.

If the amendment significantly alters the research design or methodology, or could otherwise affect the scientific value of the study, supporting scientific information should be given (or enclosed separately). Indicate whether or not additional scientific critique has been obtained.

Discussions between the researcher, advisors and parties involved in the recruitment process suggested that by increasing the age limit from 44 to 55 there would be an improvement in the recruitment process and in order to avoid confusion, removing the term 'angular' from the title would improve clarity of the findings.

Notice of amendment (non-CTIMP), version 3.1, November 2005

Any other relevant information

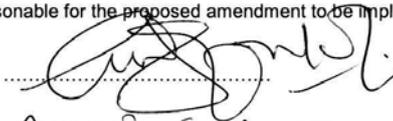
Applicants may indicate any specific ethical issues relating to the amendment, on which the opinion of the REC is sought.

List of enclosed documents		
Document	Version	Date
Research Protocol- The effect of core stability exercises on the acceleration of the lumbar spine Protocol ref.: 07/03/STF/09 Oxfordshire REC C Ref.: 07/H0606/102	Version 4,	1 st November 2007

Declaration

- I confirm that the information in this form is accurate to the best of my knowledge and I take full responsibility for it.
- I consider that it would be reasonable for the proposed amendment to be implemented.

Signature of Chief Investigator:



Print name:

AUGUSTINE AUICO

Date of submission:

1ST NOVEMBER 2007



National Research Ethics Service

Oxfordshire REC C

2nd Floor, Astral House
Chaucer Business Park
Granville Way
Bicester
OX26 4JT

Tel: 01869 604062

Fax: 01869 604055

Email: scsha.OxfordRECC@nhs.net

15 November 2007

Mr A Aluko
Lecturer in Physiotherapy
School of Health and Social Care
Uxbridge
Middlesex
UB8 3PH

Dear Mr Aluko

Study title: The effect of core stability exercises (CSE) on angular acceleration of the lumbar spine
REC reference: 07/H0606/102
Amendment number:
Amendment date: 01 November 2007

The above amendment was reviewed at the meeting of the Sub-Committee of the REC held on 14 November 2007.

Ethical opinion

The members of the Committee present gave a favourable ethical opinion of the amendment on the basis described in the notice of amendment form and supporting documentation.

Approved documents

The documents reviewed and approved at the meeting were:

Document	Version	Date
Protocol	4	01 November 2007
Notice of Substantial Amendment (non-CTIMPs)		01 November 2007

Membership of the Committee

The members of the Committee who were present at the meeting are listed on the attached sheet.

R&D approval

All investigators and research collaborators in the NHS should notify the R&D office for the relevant NHS care organisation of this amendment and check whether it affects R&D approval of the research.

This Research Ethics Committee is an advisory committee to South Central Strategic Health Authority
The National Research Ethics Service (NRES) represents the NRES Directorate within
the National Patient Safety Agency and Research Ethics Committees in England.



Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees (July 2001) and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

07/H0606/102: Please quote this number on all correspondence

Yours sincerely

Miss Kathryn Lucas
Committee Co-ordinator

Enclosures List of names and professions of members who were present at the meeting

Copy to: *Mr Anderson-Ford, School of Health Sciences & Social Care, Brunel University, Kingston Lane, Uxbridge, Middlesex, UB8 3PH*

This Research Ethics Committee is an advisory committee to South Central Strategic Health Authority
The National Research Ethics Service (NRES) represents the NRES Directorate within the National Patient Safety Agency and Research Ethics Committees in England.



National Patient Safety Agency

National Research Ethics Service

NOTICE OF SUBSTANTIAL AMENDMENT

For use in the case of all research other than clinical trials of investigational medicinal products (CTIMPs). For substantial amendments to CTIMPs, please use the EU-approved notice of amendment form (Annex 2 to ENTR/CT1) at <http://eudract.emea.eu.int/document.html#guidance>.

To be completed in typescript by the Chief Investigator in language comprehensible to a lay person and submitted to the Research Ethics Committee that gave a favourable opinion of the research ("the main REC"). In the case of multi-site studies, there is no need to send copies to other RECs unless specifically required by the main REC.

Further guidance is available at <http://www.nres.npsa.nhs.uk/applicants/review/after/amendments.htm>.

Details of Chief Investigator:	
Name:	Augustine Aluko
Address:	Lecturer in Physiotherapy School of Health & Social Care Brunel University Uxbridge Middlesex UB8 3PH
Telephone:	01895-268750
Email:	Toks.Aluko@Brunel.ac.uk
Fax:	

Full title of study:	The effect of Core Stability Exercises on the acceleration of the lumbar spine
Name of main REC:	Oxfordshire
REC reference number:	07/H0606/102
Date study commenced:	TBC
Protocol reference (if applicable), current version and date:	Version 4, 1 st November 2007
Amendment number and date:	Version 5, 7 th May 2008

Any other relevant information

Applicants may indicate any specific ethical issues relating to the amendment, on which the opinion of the REC is sought.

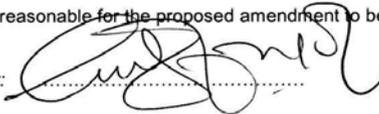
List of enclosed documents

Document	Version	Date
Research protocol	4	1 st November, 2007
Research protocol	5	7 th May 2008
Patient Information sheet	4	1 st November 2007
Patient Information sheet	5	7 th May 2008

Declaration

- I confirm that the information in this form is accurate to the best of my knowledge and I take full responsibility for it.
- I consider that it would be reasonable for the proposed amendment to be implemented.

Signature of Chief Investigator:



Print name:

AUGUSTINE AUKO

Date of submission:

7th May 2008



National Research Ethics Service
Oxfordshire REC C

2nd Floor, Astral House
Chaucer Business Park
Granville Way
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OX26 4JT

Tel: 01869 604 062
Fax: 01869 604 055
Email: scsha.OxfordRECC@nhs.net

04 June 2008

Mr A Aluko
Lecturer in Physiotherapy
School of Health and Social Care
Uxbridge
Middlesex
UB8 3PH

Dear Mr Aluko

Study title: The effect of core stability exercises (CSE) on angular acceleration of the lumbar spine
REC reference: 07/H0606/102
Amendment number: Change of supervisor
Inclusion of visual analogue scale
Amendment date: 07 May 2008

The above amendment was reviewed at the meeting of the Sub-Committee of the REC held on 03 June 2008.

Ethical opinion

The members of the Committee present gave a favourable ethical opinion of the amendment on the basis described in the notice of amendment form and supporting documentation.

Approved documents

The documents reviewed and approved at the meeting were:

Document	Version	Date
Protocol	5	07 May 2008
Participant Information Sheet	5	07 May 2008
Participant Consent Form	5	07 May 2008
Notice of Substantial Amendment (non-CTIMPs)		07 May 2008

Membership of the Committee

The members of the Committee who were present at the meeting are listed on the attached sheet.

This Research Ethics Committee is an advisory committee to South Central Strategic Health Authority
The National Research Ethics Service (NRES) represents the NRES Directorate within
the National Patient Safety Agency and Research Ethics Committees in England.



R&D approval

All investigators and research collaborators in the NHS should notify the R&D office for the relevant NHS care organisation of this amendment and check whether it affects R&D approval of the research.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees (July 2001) and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

07/H0606/102:

Please quote this number on all correspondence

Yours sincerely

Miss Sabrina Harris
Committee Co-ordinator

Enclosures List of names and professions of members who were present at the meeting

Copy to: Brunel University

Appendix 17: Exercise compliance for experimental group (n=16) [x-exercises completed at least twice a day]

Day	Participant study number															
	1	2	6	8	10	15	16	18	20	23	24	27	28	29	30	33
1	X	X	X	X	X	-	-	X	X	-	-	-	X	-	X	-
2	X	X	X	X	X	-	-	X	X	-	-	-	X	-	X	-
3	X	X	X	X	X	-	-	X	X	-	-	-	X	-	X	-
4	X	X	-	X	X	-	-	X	X	-	-	-	X	-	X	-
5	X	X	-	X	X	-	-	X	X	-	-	-	X	-	X	-
6	X	X	X	X	X	-	-	X	X	-	-	-	X	-	X	-
7	X	X	X	X	X	-	-	X	X	-	-	-	X	-	X	-
8	X	X	X	-	X	-	-	X	X	-	-	-	X	-	-	-
9	X	X	X	-	X	-	-	X	X	-	-	-	X	-	-	-
10	X	X	X	-	X	-	-	X	X	-	-	-	X	-	-	-
11	X	X	-	-	X	-	-	X	X	-	-	-	X	-	-	-
12	X	X	X	-	X	-	-	X	X	-	-	-	X	-	-	-
13	X	X	X	-	X	-	-	X	X	-	-	-	X	-	-	-
14	X	X	X	-	-	-	-	X	X	-	-	-	X	-	-	-
15	X	X	X	-	X	-	-	X	X	-	-	-	X	-	-	-
16	X	X	X	-	X	-	-	-	X	-	-	-	X	-	-	-
17	X	X	X	-	X	-	-	-	X	-	-	-	X	-	-	-
18	X	X	X	-	X	-	-	-	X	-	-	-	X	-	-	-
19	X	X	X	-	X	-	-	-	X	-	-	-	X	-	-	-
20	X	X	X	-	X	-	-	-	X	-	-	-	X	-	-	-
21	X	-	X	-	X	-	-	-	-	-	-	-	X	-	-	-
22	X	X	X	-	X	-	-	-	X	-	-	-	X	-	-	-
23	X	X	X	-	X	-	-	-	X	-	-	-	X	-	-	-
24	X	X	X	-	X	-	-	-	X	-	-	-	X	-	-	-
25	X	X	X	-	X	-	-	-	X	-	-	-	-	-	-	-
26	X	X	X	-	X	-	-	-	X	-	-	-	-	-	-	-
27	X	X	X	-	X	-	-	-	X	-	-	-	-	-	-	-
28	X	X	X	-	X	-	-	-	X	-	-	-	-	-	-	-
29	X	X	X	-	X	-	-	-	X	-	-	-	-	-	-	-
30	X	X	X	-	X	-	-	-	X	-	-	-	-	-	-	-
31	X	X	X	-	X	-	-	-	X	-	-	-	-	-	-	-
32	X	X	-	-	-	-	-	-	X	-	-	-	-	-	-	-
33	X	X	X	-	X	-	-	-	X	-	-	-	-	-	-	-
34	X	X	X	-	X	-	-	-	X	-	-	-	-	-	-	-
35	X	X	X	-	X	-	-	-	X	-	-	-	-	-	-	-
36	X	X	X	-	X	-	-	X	X	-	-	-	-	-	-	-
37	X	X	X	-	X	-	-	X	X	-	-	-	-	-	-	-
38	X	X	X	-	X	-	-	X	X	-	-	-	-	-	-	-
39	X	X	X	-	X	-	-	-	X	-	-	-	-	-	-	-
40	X	X	X	-	X	-	-	-	X	-	-	-	-	-	-	-
41	X	X	X	-	X	-	-	-	X	-	-	-	-	-	-	-
42	-	X	X	-	X	-	-	-	-	-	-	-	-	-	-	-

Appendix 18: Submitted paper under review- Quantification of trunk performance in a sample population

Appendix 18 has been removed from this thesis due to the fact that the paper is currently under review and neither the publisher nor the copyright restrictions are known. As a result pages 266 – 278 of the thesis are not presented here.

The contents that has been removed is an article with the following citation:

(n.d.) Aluko, A., DeSouza, L. and Peacock, J., Quantification of trunk performance in a sample population. Submitted.