School of Physiotherapy

Lumbo-Pelvic Motor Control in Adolescents With and Without Low Back Pain

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STATEMENT OF ORIGINALITY

To the best of knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made. This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Roslyn Astfalck

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ABSTRACT

The prevalence of low back pain (LBP) in the adolescent population is high, with rates approaching adult levels. It has previously been shown that those with LBP during adolescence are at greater risk of experiencing LBP in adult life. Concomitantly, the costs of treating LBP are marked - in Australia direct treatment costs in 2001 were estimated at more than $1 billion/year.

Despite the high prevalence and evidence for the progressive development of this condition during adolescence, relatively little is known about the disorder during this life-stage. Previously the disorder in adolescents had been characterised as being dominated by psychosocial factors, despite limited detailed studies in the physical domain. In comparison to the wealth of research investigating LBP in adults, relatively little has been undertaken in adolescence. This is especially true in relation to studies of trunk motor control and the impacts of LBP. Whether results from adult research are transferrable to the younger age group is not known.

Prior evidence in adults suggests that non-specific chronic LBP (NSCLBP), where there is no known patho-anatomical diagnosis, should be studied from a biopsychosocial perspective. Previous research in adults has identified several distinct sub-groups of NSCLBP based on differing physical and psychosocial variables. Identification of sub-groups of NSCLBP is recognised as important in research and clinical management. The aim of this doctoral study was to investigate adolescent NSCLBP, the significance and multifactorial nature of this disorder and more specifically to investigate differences in trunk motor control in a detailed laboratory based study of adolescents with and without NSCLBP and sub-groups of NSCLBP. Better information will help inform the development of successful interventions in this age-group and may assist to decrease the societal cost of this disorder across the life-span.

This dissertation comprises four studies, comparing adolescents with and without NSCLBP and sub-groups of NSCLBP. First, an investigation of the dimensions of pain, disability and kinesiophobia and associated physical and psychosocial features was undertaken. However the main focus of this doctoral research, the

final three studies, was the detailed examination of trunk motor control during sitting, standing and forward bending, all known aggravating factors for NSCLBP. This is the first investigation in an adolescent population of the presence of sub-groups of NSCLBP and the first to investigate physical features in detailed laboratory studies. Further, this is the first study in either an adolescent or adult population to examine spinal regional differences in a lumbar repositioning task.

The findings across the four studies showed that adolescents with NSCLBP, before sub-grouping was conducted, had similar levels of pain to previous adult studies, but lower levels of kinesiophobia, disability and duration of pain. Adolescents with NSCLBP had increased experience of stressful family life events, decreased trunk extensor and squat endurance, increased trunk extensor muscle activation in standing and decreased spinal repositioning error compared with healthy adolescents. Results from this dissertation support that, as in adults, NSCLBP in adolescence is a significant health concern and multifactorial in nature. In contrast to prior reports, these adolescent results indicate that for this group with NSCLBP the disorder is dominated by physical factors.

The laboratory-based aspects of this research provided evidence that, as in adults, sub-grouping adolescents with NSCLBP based on their pain and motor control patterns demonstrates that they are not a homogenous group. Differences were shown between sub-groups and gender representation, trunk extensor and squat endurance, usual and slump sitting postures, range-of-motion during forward bending, levels of trunk extensor muscle activation in forward bending and spinal repositioning error. In fact, the equal and opposite effect of results between sub-groups for sitting posture and both range-of-motion and trunk extensor activation in forward bending resulted in a *wash-out effect* when results were pooled for those with NSCLBP. That differences were only noted with sub-grouping supports the importance of doing so in future research.

Differences were shown between adolescent and adult data based on regional spinal differences. This was so in sitting posture where NSCLBP in adolescents was shown to be more consistently associated with differences in the upper lumbar spine between sub-groups of NSCLBP and healthy adolescents. Regional

differences were also shown in tests of spinal repositioning accuracy, the first study (adolescent or adult) to do so.

Differences between adolescent and adult studies were observed for posture, kinematics, trunk muscle activation and variability in spinal repositioning acuity; suggesting that there are inherent differences in the disorder between life-stages. The noted differences between this current study of adolescents and previous adult studies may be due to immaturity of the motor control system, differences in spinal morphology and/or in maturation of the NSCLBP disorder.

The dissertation concludes that NSCLBP in adolescence is a significant health disorder and is multifactorial in nature. In this group of adolescents it is dominated by physical factors. Whilst this research was of a small group of adolescents with NSCLBP, results broadly support previous postural and kinematic findings from adult studies. Results for trunk muscle activation and accuracy of spinal repositioning suggest that adolescent NSCLBP is not the same as adult NSCLBP. As in adults the consideration of sub-groups of NSCLBP is central to future research and clinical management of the disorder. This investigation of NSCLBP in adolescence provides a contribution towards understanding the disorder and may help inform the development of targeted interventions. Early intervention in NSCLBP during adolescence may help to decrease the large social cost.

LIST OF PUBLICATIONS AND CONFERENCES

Publications

A detailed characterisation of pain, disability, physical and psychosocial features of a small group of adolescents with non-specific chronic low back pain

Authors: Roslyn G Astfalck, Peter B O'Sullivan, Leon M Straker, Anne J Smith

Published in Manual Therapy 2010 15 p 240-247.

Sitting postures and trunk muscle activity in adolescents with and without non-specific chronic low back pain – an analysis based on sub-classification

Authors: Roslyn G Astfalck, Peter B O'Sullivan, Leon M Straker, Anne J Smith, Angus Burnett, Joao Paulo Caneiro, Wim Dankaerts

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Kinematic and muscle activity analysis of standing and forward bending in adolescents with and without non-specific chronic low back pain

Authors: Roslyn G Astfalck, Peter B O'Sullivan, Leon M Straker, Anne J Smith, Angus Burnett, Joao Paulo Caneiro

To be submitted to Clinical Biomechanics.

Lumbar spine repositioning sense in adolescents with and without non-specific chronic low back pain – an analysis based on sub-classification and spinal regions

Authors: Roslyn G Astfalck, Peter B O'Sullivan, Anne J Smith, Leon M Straker, Angus Burnett

To be submitted to Spine.

Conference presentations

Characteristics of non-specific chronic low back pain in an adolescent population.

Authors: Roslyn G Astfalck, Peter B O'Sullivan, Leon M Straker, Anne J Smith,

Musculoskeletal Physiotherapy Australia 15th Biennial Conference (2007)

A biopsychosocial perspective of teenagers with non-specific chronic low back pain

Authors: Roslyn G Astfalck, Peter B O'Sullivan, Leon M Straker, Anne J Smith,

Australian Pain Society Conference (2008).

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LIST OF ABBREVIATIONS

LBP	low back pain
CLBP	chronic low back pain
NSCLBP	non-specific chronic low back pain
OR	odds ratio
AU$	Australian dollars
HPA	hypothalamic-pituitary-adrenal
VE	variable error
AE	absolute error
CE	constant error
SD	standard deviation
VAS	visual analogue scale
EMG	electromyography
sEMG	surface electromyography
BMI	body mass index
MARCA	multimedia activity recall for children and adolescents
ASIS	anterior superior iliac spine
ANCOVA	Analysis of Covariance
SPSS	Statistical Package for the Social Science
SFAI	spinal flexion angle index
FRR	flexion relaxation ratio
TSK	Tampa Scale of Kinesiophobia
Sub-MVIC	sub-maximal voluntary isometric contraction
FB ROM	forward bending range-of-motion
Thoracic ES	thoracic erector spinae

CHAPTER 1 - INTRODUCTION

Adolescence is a developmental period marked by rapid physiological and psychological growth. Individuals during this period undergo considerable physical and functional change (Viel, Vaugoyeau, & Assaiante, 2009); including changes in spinal morphology (Cil et al., 2005), improvements in motor skill (Largo, Fischer, & Rousson, 2003), postural control, balance (Cumberworth, Patel, Rogers, & Kenyon, 2007) and proprioceptive acuity (Viel et al., 2009). Concurrently, the transition from child to adult is characterized by marked hormonal changes, psychological and emotional growth, significant lifestyle and social change and commensurate increases in social expectation and responsibility (LeResche, Mancl, Drangsholt, Saunders, & Korff, 2005). The large degree of flux created by a mix of biological, psychological and social change makes this life-stage a challenging transition (Waylen & Wolke, 2004).

Epidemiological data indicates that low back pain (LBP) during adolescence is a significant public health concern with substantial portions of adolescents experiencing LBP and incidence approaching adult levels (Jeffries, Milanese, & Grimmer-Somers, 2007). For some adolescents, LBP can be transient and of trivial impact, yet for others it is chronic and disabling. Chronicity of LBP during adolescence has been documented as high as 12% (Sjolie, 2004b). Further, it is known that those who suffer chronic LBP (CLBP) during adolescence have a higher risk of experiencing LBP during adulthood (Harreby, Neergaard, Hesselsoe, & Kjer, 1995).

The societal economic burden of LBP is high, with direct costs (diagnosis, treatment and rehabilitation) in Australia in 2001 estimated at AU$1.02 billion (Walker, Muller, & Grant, 2003). The indirect costs (loss of earnings and productivity) are even more marked, estimated at AU$8.15 billion. These costs, for a medium size nation, are compelling and suggest research should focus on cost-effective management (Walker et al., 2003) including preventative medicine and early intervention. The global burden of LBP in 2004 was estimated to be 2.5 million Disability-Adjusted Life Years (DALYs), representing 0.09% of the overall global

disease burden, with the burden being greatest in adolescence to middle age for both sexes (Hoy et al.). Investigating LBP in adolescents provides an opportunity to understand the disorder during its development from adolescence to adulthood; and may assist in decreasing the economic burden of this disorder.

Only a small number of CLBP disorders have a known patho-anatomical diagnosis, while the majority of people experience non-specific CLBP (NSCLBP) - as a diagnosis, based on current biomedical investigations, can not be reached (Weiner, 2008). NSCLBP in adults is associated with multifactorial risk factors across multiple domains (psychosocial, sociodemographic, lifestyle, physical, neurophysiological and genetic) (Balague, Troussier, & Salminen, 1999; Bejia et al., 2005; Burton, 1997; Gatchel, Polatin, & Mayer, 1995; Leboeuf-Yde, Kyvik, & Bruun, 1999; Linton, 2000; Marras, Davis, Heaney, Maronitis, & Allread, 2000; Moseley, 2003; O'Sullivan, 2005; Stevenson, Weber, Smith, Dumas, & Albert, 2001; Truchon, 2001; Truchon & Fillion, 2000; Waddell, 1987, 2004). It is thus considered to represent a biopsychosocial disorder.

Many associations have been reported between LBP in adolescents and a wide range of factors including: psychological (stress, depression, poor wellbeing, hyperactivity, emotional and conduct problems and education strain); social (types and levels of social support); lifestyle (obesity, smoking, alcohol consumption and sedentary behaviour); and physical (sitting and standing, the posture of these positions, lifting or carrying heavy objects, carrying school bags, trunk and quadriceps endurance and levels of physical activity) factors. (Balague et al., 1999; Bernard et al., 2008; Grimmer & Williams, 2000; Harreby et al., 1999; Haselgrove et al., 2008; Korovessis, Koureas, Zacharatos, & Papazisis, 2005; Sjolie, 2002, 2004a; Skoffer, 2007; Skoffer & Foldspang, 2008; Smith, O'Sullivan, & Straker, 2008; Watson et al., 2002, 2003). Much of this work has investigated these factors in isolation, in small groups or from a single domain rather than from a broad biopsychosocial framework. It is for this purpose that this thesis considers not only the largely uninvestigated field of trunk biomechanics in adolescents with NSCLBP but to concomitantly investigate any relationships with broader biopsychosocial factors. This multidisciplinary approach to studying adolescent NSLBP is supported by eminent researchers in this field (Balague, Dudler, & Nordin, 2003).

It is commonly reported that adult NSCLBP is not a homogenous group. Growing evidence demonstrates that NSCLBP should be viewed as a series of sub-groups with differing physical and psychosocial variables that represent each sub-group (Dankaerts et al., 2009; Dankaerts, O'Sullivan, Burnett, & Straker, 2007; Leboeuf-Yde, Lauritsen, & Lauritzen, 1997; Leboeuf-Yde & Manniche, 2001; Linton, 2000; O'Sullivan, 2005). Different classification systems have been developed based on clinically meaningful criteria; with evidence for sub-groups based on the patho-anatomic source of pain, clinical features (signs and symptoms) and psychosocial factors (Boersma & Linton, 2005, 2006; McCarthy, Arnall, Strimpakos, Freemont, & Oldham, 2004) as well as postures and movement behaviours relating to pain (Dankaerts et al., 2007; Dankaerts, O'Sullivan, Straker, Burnett, & Skouen, 2006c; O'Sullivan, 2005). None of these classification systems have been applied to adolescent populations with LBP; hence, the existence of sub-groups in adolescence is unknown.

In adults, sitting, standing and lifting are often cited as risk factors for developing LBP as well as commonly being reported as aggravating factors for LBP, accounting for significant disability relating to the disorder (Dankaerts, O'Sullivan, Burnett, & Straker, 2006a, 2006b; Lee, Helewa, Goldsmith, Smythe, & Stitt, 2001; Macfarlane et al., 1997; O'Sullivan, 2005). Differences in posture, kinematics and levels of trunk muscle activation and the flexion-relaxation phenomenon have been noted between those with and without LBP during usual and slump sitting, standing and forward bending (Christie, Kumar, & Warren, 1995; Dankaerts et al., 2006a; Jackson & McManus, 1994; Kaigle, Wessberg, & Hansson, 1998; Lariviere, Gagnon, & Loisel, 2000; Smith et al., 2008; van Wingerden, Vleeming, & Ronchetti, 2008). Often differences between pain free controls and subjects with NSCLBP were only noted when subjects were sub-classified (Dankaerts et al., 2009). In some studies, differences were specific to the upper or lower lumbar spine regions (Dankaerts et al., 2009; Dankaerts et al., 2006b; Mitchell, O'Sullivan, Burnett, Straker, & Smith, 2008). No studies were identified that concurrently document posture, kinematics and trunk muscle activity in adolescents with and without NSCLBP (when considered as a whole and when classified into sub-groups) during sitting, standing or forward bending.

Deficits in postural control and proprioception have been identified in adults with LBP including greater error in spinal repositioning tasks (Brumagne, Cordo, Lysens, Verschueren, & Swinnen, 2000; Radebold, Cholewicki, Polzhofer, & Greene, 2001). These results support the hypothesis that these patients have impairments in the control of their lumbar spine that expose them to repeated stress and strain, thereby providing a basis for ongoing pain (O'Sullivan, 2005). No previous studies have investigated relationships between spinal repositioning acuity and sub-groups of NSCLBP or of regional spinal differences. To date, no previous studies have investigated spinal repositioning acuity in adolescent populations.

It is the overall aim of this thesis to investigate NSCLBP during adolescence, a period of rapid growth and change, from within a biopsychosocial framework. The thesis has two primary aims.

First, to examine the significance and multifactorial nature of NSCLBP in adolescence through a detailed characterisation in the selected cohort of:

- clinical descriptors of the NSCLBP experience (pain level, duration, disability, kinesiophobia, aggravating factors);
- regular physical activity levels;
- trunk and lower limb endurance; and
- psychosocial influences (stress, depression, behaviour, family functioning).

Second, the main focus of the research, is to investigate trunk motor control in a detailed laboratory based study of adolescents with and without NSCLBP, specifically:

- differences in posture, kinematics and trunk muscle activation during the commonly aggravating activities of sitting, standing and forward bending;
- difference in spinal repositioning sense in sitting;
- differences between lumbar regions;
- identification of sub-groups of NSCLBP in adolescent subjects; and
- a comparison of results from this adolescent research with previously reported adult research findings.

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CHAPTER 2 - LITERATURE REVIEW

2.1 IDENTIFICATION OF LITERATURE

2.1.1 Search strategies

Scholarly databases were methodically searched for relevant literature using the following strategies.

(1) Databases scrutinized – Medline, Proquest Health and Medical Complete, EMBASE and CINAHL.

(2) Year range – no defined year range was applied to searches, to do so would have missed key articles considered cornerstones in lumbar spine research such as Balague et al (1988), Salimen (1984), Beiring-Sorenson (1984), Fairbank et al (1980) and Floyd and Silver (1951). In the main articles were retrieved predominately from the previous decade, however, this was driven by publication rates not currency. Where content has evolved with more recent research, as appropriate, the current view is expressed in this literature review.

(3) As a means of maintaining currency automatic alerts were set in 2005 through PubMed on the following broad search terms – (paediatr* OR pediatr* OR child* or adoles*) AND (low back pain OR LBP OR lumbar pain OR back pain OR spinal pain OR dorsal pain) as well as AND (chronic OR non-specific) AND (low back pain OR LBP OR lumbar pain OR back pain OR spinal pain OR dorsal pain).

(4) The following key word strategies were used in compiling the literature review and methods for this thesis.

I paediatr* OR pediatr* OR child* OR adoles*

AND

1. low back pain OR lumbar pain OR back pain OR spinal pain OR dorsal pain

AND

a. risk factors OR aetiology OR antecedents

b. epidemiology OR occurrence OR prevalence OR incidence OR odds OR risk OR proportion OR recurrence

c. duration OR frequency OR pain level OR intensity OR distribution OR area

d. kinesiophobia OR fear of movement OR disability OR chronicity

e. posture OR sitting OR standing

f. physic* (physical activity etc.) OR sport OR exercise OR transport* OR sitting OR standing OR lifting OR bending OR flexion OR carrying OR bags OR activity OR school OR class*

g. endurance OR fatigue OR strength OR flexibility OR range-of-motion OR ROM OR range

h. psych* OR stress OR depress* OR anxiety OR behav* OR conduct OR hyperactivity OR emot* OR wellbeing OR family functioning OR social OR education OR school OR eating OR self-harm OR conflict OR self-esteem OR self-expect* OR coping OR distress

i. lifestyle OR smoking OR obesity OR BMI OR body-mass OR alcohol OR drugs OR addict* OR activity OR sedentary OR genetic OR work OR employ* OR job OR manual OR television OR computer

2. motor control OR motor performance OR motor skill OR clumsy kids

3. postural control OR balance OR proprioception OR repositioning OR somatosensory OR orientat* OR kinaesthe* OR vestib*

4. spinal development OR spinal growth OR spinal morphology OR spinal curve OR sagittal spin* OR pelvic morph* OR spinopelvic OR postur* OR lordosis OR kyphosis OR musculoskel* matur*

5. change OR growth OR transition OR stage OR maturity OR develop* OR puberty

AND

emotion* OR lifestyle OR social OR biological OR sex*

II chronic low back pain OR non-specific chronic low back pain OR CLBP OR NSCLBP OR chronic spinal pain

AND

1. motor control OR motor performance

2. biopsychosocial OR social OR socio OR psych* OR lifestyle OR physical OR cultur*

3. motor control OR postural control OR balance

4. posture OR sit* OR stand* OR upright OR slump OR bend OR flex* OR exten* OR twist OR rotat* OR flexib*

5. kinesiophobia OR fear of movement OR fear avoidance OR persistence OR disability

6. sub-class* OR sub-group OR homogen* OR heterogen* OR classif* OR assess* OR system OR approach OR dimension OR Quebec OR INTERMED

7. cost OR economic burden OR financial burden OR global burden

8. psych* OR stress OR depress* OR wellbeing OR emot* OR social OR anxiety OR relationships OR self-esteem OR self-expect* OR coping OR distress OR mental

9. lifestyle OR work OR employ* OR job OR manual OR smoking OR alcohol OR drug OR addict* OR activity OR sedentary OR genetic OR obesity OR BMI OR body-mass

10. physic* (physical activity etc.) OR sitting OR standing OR lifting OR bending OR flexion OR carrying

11. endurance OR fatigue OR strength

III spine OR spinal OR lumbar OR back OR trunk

AND

EMG OR sEMG OR electromyogr* OR muscle activation

AND

1. sit* OR stand* OR flexion OR extension OR forward bend* OR bend* OR FRP OR flexion-relaxation OR relax*OR slump

2. biomech* OR kinematic* OR posture OR angle

   AND

   sit* OR stand* OR flexion OR extension OR forward bend* OR bend* OR slump

3. propriocept* OR reposition* OR error

4. motor control OR postural control OR balance

5. regional differences OR upper lumb* OR lower lumb* OR lumbar segment*

6. neurophys* OR CNS OR central nerv* OR HPA OR hypothal*

   AND

   stress OR cognit* OR nociception OR pain

IV measure* OR scale OR categor* OR question* OR checklist

AND

1. body chart OR pain area OR pain distribution OR frequency

2. pain OR level OR VAS OR visual analogue OR pain intensity OR McGill OR SF-MPQ OR MPQ

3. Oswestry OR disability OR quality of life

4. kinesiophobia OR tampa OR TSK OR fear of movement OR fear of injury OR fear of re-injury

5. depression OR anxiety OR family functioning OR family assessment OR stress OR life events OR CBCL OR Child Behav* OR BDI OR Beck* OR McMaster

   AND

   adoles OR child OR pediatr* or paediatr*

6. endurance OR fatigue OR Beiring

   AND

   extensor OR back OR lumbar OR spine OR thigh OR squat OR quadriceps*

7. tanner OR adolescent develop* OR sexual OR maturity

8. MARCA OR physical activity OR pedom* OR IPAQ

(5) Key authors were identified as those often referred to by other researchers or those with numerous publications in the field of motor control and CLBP or adolescent LBP. When these authors were identified a subsequent search was made by author name. An example of key authors in the field of adolescent LBP are Balague, Beiring-

Sorensen, Burton, Grimmer, Harreby, Jones G., LeBoeuf-Yde, Luoto, Salminen, Sihvonen, Sjolie, Taimela, Watson and Wedderkopp.

(6) An ancestry search was completed of each article's reference list. This manual retrospective interrogation unearthed any suitable references not yet identified by database searches.

2.1.2 Critique of literature

The identified literature relating adolescent LBP was of a wide range of sampling methodologies, population groups and countries of origin. All identified literature was qualitatively critiqued for inclusion. Whilst it would have been ideal to only include those studies of large populations, from western world countries, of adolescents during mid-adolescence (14-17 years) and of similar methodology to this thesis, to do so, excluded some important findings. The philosophy of this literature review was of general inclusion to present a holistic picture of what is currently known concerning adolescent spinal pain.

Where required the type of data collection (cross-sectional vs longitudinal or self-report vs parental report), the age of the sample (where the sample deviated from the core adolescent years or considered a restricted age-range), was of a specific population (e.g. nationality or gender) it is mentioned explicitly in the literature review. Some references were of quite a limited demographic sample, whilst these were generally excluded, in the case of Ebrall (1994) a study of male adolescents from a restricted geographic area, this literature was included as it was one of the few studies documenting incidence in Australian adolescents.

2.2 INTRODUCTION

Adolescence, starting with the onset of puberty, is a period of rapid physiological and psychological development that involves considerable morphological, structural and functional change as a child transitions to adulthood (Viel, Vaugoyeau, & Assaiante, 2009). Psychosocial change in adolescence includes development of the self (Steinberg & Morris, 2001) and mature inter-personal relationships; taking responsibility for educational performance, career choices and moving into adult work roles; and requires significant transformation of adolescent-parent relationships (Waylen & Wolke, 2004). The later occurs as the adolescent struggles to gain increased autonomy and independence, whilst still requiring parental support and guidance (Short & Rosenthal, 2008). Family relationships are transformed from hierarchical and autocratic in early adolescence to more egalitarian relations by late adolescence; with commensurate declines in adolescents' feelings of closeness and warmth to their parents (Smetana, Campione-Barr, & Metzger, 2006). As adolescent-parent relationships change, peers become a more regular source of influence and values (Waylen & Wolke, 2004) with antisocial conformity to peers peaking in mid-adolescence (Smetana et al., 2006). A mix of individual biological predispositions, genetic endowment and various ubiquitous social factors make adolescence an adaptive and challenging transition (Waylen & Wolke, 2004).

Adolescence is also linked to the development of many mental health disorders, particularly in females; and development of anti-social behaviour, particularly in males. Maladaptive development and problematic behaviour usually involve an interaction between biology and environment (Waylen & Wolke, 2004). Precocious puberty in girls is linked to increases in emotional disorders (including depression, anxiety and eating disorders), self-harm, parental conflict, behavioural problems (aggression, conduct disorders, delinquency and anti-social behaviour), greater sexual experimentation and decreases in self-esteem (Short & Rosenthal, 2008). Late physical maturation in boys leads to feelings of inadequacy and decreased self-esteem and low self-expectations and levels of personal achievement (Waylen & Wolke, 2004).

While it is recognised that many of the problems that are experienced by adolescents are for the majority transitory in nature – by example few adolescents who experiment with drugs and alcohol go on to become addicts or alcoholics (Steinberg & Morris, 2001) - there are some conditions that are linked with development or exacerbation in adolescence and increased risk of problems in adulthood. These include depression (Steinberg & Morris, 2001; Steinhausen, Haslimeier, & Winkler Metzke, 2006), anxiety, psychotic and eating disorders; obesity and cardiovascular risk; polycystic ovarian syndrome; and pain and somatic symptoms including musculoskeletal disorders (Patton & Viner, 2007). The later category includes migraine and tension headaches, facial, stomach and back pain (LeResche, Mancl, Drangsholt, Saunders, & Korff, 2005; Rhee, 2005). Further, and specific to this context, those who suffer low back pain (LBP) during adolescence have a higher risk for experiencing LBP during adulthood (Harreby, Neergaard, Hesselsoe, & Kjer, 1995).

In traditional cultures 'coming of age' is ritualised with rites of passage and often an abrupt change in societal expectations. In western societies there is often a long *maturity gap* between physical maturity and taking responsibility for one's own life (Waylen & Wolke, 2004). There are currently 1.5 billion people aged between 12 and 24 years; this represents the largest adolescent group ever known. Concomitantly, this group displays the largest documented discrepancy between sexual and psychosocial maturity (Kleinert, 2007). Whilst adolescence is a time that harbours many risks and dangers, it presents great opportunity for preventative medicine and interventions aimed at health, wellbeing (Kleinert, 2007) and correction of maladaptive behaviours and beliefs. The subject of this thesis, understanding the factors associated with non-specific chronic LBP (NSCLBP) during adolescents, will contribute to developing successful interventions to decrease the large social cost and burden of adult LBP (Walker, Muller, & Grant, 2003).

Other than the psychosocial domain it is important to understand the physical morphological changes and alterations in motor control that may have an influence on functioning of the spine as adolescents mature. This chapter first considers the normal development of sagittal spinal curves, motor skill acquisition and trunk postural control, including proprioception, through adolescence. It then progresses to

a current description of the documented problem of adolescent LBP – epidemiology, a description of the pain experience, associated psychosocial, lifestyle and physical factors – and describes the documented evidence, predominately in adults, for postural, kinematic and trunk muscle differences between those with and without LBP. Finally, it considers that NSCLBP (that with no known injury or pathological diagnosis) may represent a collection of clinically substantiated sub-groups with different, and at times opposing, characteristics.

2.3 DEVELOPMENT OF SAGITTAL SPINAL CURVES

During the adolescent growth spurt the rate of growth of the anterior vertebral body exceeds that of the posterior vertebral body, resulting in a decrease in thoracic kyphosis and an increase in lumbar lordosis (Cil et al., 2005). This results in changes in posture and balance. The relationship with development of lumbar lordosis is not linear; however, adults display increased lumbar lordosis compared to adolescents (Mac-Thiong, Berthonnaud, Dimar, Betz, & Labelle, 2004; Mac-Thiong, Labelle, Berthonnaud, Betz, & Roussouly, 2007).

As upper bodyweight increases significantly during growth, changes in spinopelvic morphology are a likely response to maintaining adequate sagittal balance. Spinal sagittal balance is important as it determines the efficiency of trunk posture in balanced standing in terms of skeletal loading, muscle fatigue and energy expenditure (Mac-Thiong et al., 2004). Significantly influencing sagittal spinal geometry, especially the lumbar lordosis, is the development of pelvic morphology (Mac-Thiong et al., 2007), with previous research identifying differences in spinopelvic morphology parameters between healthy adolescents and young adults (Vedantam et al. 1998; Mac-Thiong et al. 2004; Poussa et al. 2005; Mac-Thiong et al. 2007). Key measures of pelvic morphology are pelvic ‘incidence’ and pelvic tilt. Pelvic incidence describes the positional relationship between the sacrum and the innominate bone (Mac-Thiong et al., 2004), while pelvic tilt describes standing antero-posterior pelvic rotation and is a determinant of hip extension (Vedantam, Lenke, Keeney, & Bridwell, 1998), see Figure 2-1. Pelvic incidence and pelvic tilt increase linearly with age and are significantly higher in adult subjects (Mac-Thiong et al., 2007). Increasing pelvic tilt displaces the sacral plate (superior endplate of the

S1 vertebrae) more posteriorly with respect to the hip axis, posteriorly shifting the centre of gravity (Mac-Thiong et al., 2004; Vedantam et al., 1998) and consequently changing the sagittal balance of the spine.

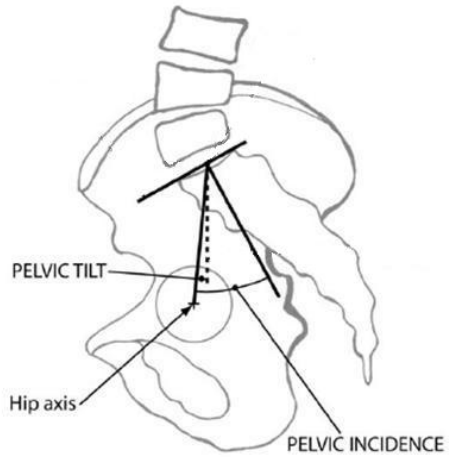

Figure 2-1 – Measures of Pelvic Morphology
Modified from Mac-Thiong et al 2007

Significant differences in spinal morphology have also been shown between males and females during childhood, adolescence and adulthood. It has been shown that:

(1) lumbar lordosis in females adolescents and young adults is greater than males in standing and sitting (Widhe 2001; Dunk & Callaghan 2005; Poussa et al. 2005; Smith et al. 2008; Straker et al. 2008a; Straker et al. 2008b);

(2) thoracic kyphosis is greater in adolescent males (Poussa et al., 2005), being most pronounced at 13-14 years (Mellin & Poussa, 1992);

(3) kyphosis decreases significantly in relation to lordosis with age in females but not in males (sample points were 5-6 years and 15-16 years) (Widhe, 2001); and

(4) thoracic kyphosis increases with age in males aged 8, 11 and 15 years, but there was no comparative age-related change in females (Hellsing, Reigo, McWilliam, & Spangfort, 1987).

One reason gender differences may exist during the adolescent period is that musculoskeletal maturation – including the pubertal growth spurt, completion of musculoskeletal growth and mineralisation of the secondary ossification centre of the vertebra - occurs two years earlier in females (Widhe, 2001). Hence, at least in part, spinal morphological differences seen between genders may be due to differing rates of skeletal maturation. However, as thoracic kyphosis has been shown to be more prominent in males of age 11, 12, 13, 14 and 22 years (Widhe, 2001) and given women display greater lumbopelvic lordosis in sitting than men (O'Sullivan et al. 2006b), explanations for gender based morphological differences during adolescence and adulthood are likely to be more complex.

SUMMARY

- The adolescent growth spurt results in a decrease in thoracic kyphosis and an increase in lumbar lordosis.
- There are several spinopelvic morphology differences between healthy adolescents and young adults.
- Significant differences in spinal morphology have been shown between males and females during childhood and adolescence.
- Gender differences during adolescence may be based in part on differences in rates of musculoskeletal maturation and/or other more complex interactions yet to be identified.

2.4 DEVELOPMENT OF MOTOR SKILL, TRUNK POSTURAL CONTROL, BALANCE AND TRUNK PROPRIOCEPTION

Information on the normal development of motor skill, trunk postural control, balance and trunk during adolescence is not extensive, with many conflicting reports on the age of integration of somatosensory information and maturation of motor skills. Most research in this area focuses on the ontological development of balance, postural strategies for upright bipedal stance and gait and motor skill functioning of the upper limb in early childhood with markedly less research in adolescents. From work in older children and adolescence the following can be understood concerning the development of motor skill, trunk postural control, balance and trunk proprioception.

2.4.1 Motor skill

In general, relationships have been drawn between increased age and improvements in motor function during adolescence (Largo, Fischer, & Rousson, 2003). From previous research it can be concluded that for tasks of greater complexity: the performance plateau is reached later in puberty; increased complexity decreases quality of movement; and increased complexity increases inter-individual variability (Largo, Caflisch, Hug, Muggli, Molnar, & Molinari, 2001; Largo, Caflisch, Hug, Muggli, Molnar, Molinari et al., 2001; Largo et al., 2003). Suggestions that high velocities in physical growth during adolescence are negatively associated with motor competence (Visser & Geuze, 2000) and that puberty is associated with increased awkwardness are not supported by all researchers (Davies & Rose, 2000). This research may be confounded by the presence of gender based differences in adolescent development of motor competence, with males generally performing better than females (Davies & Rose, 2000). Relationships between age, pubertal stage, gender and motor competence are likely to be complex and additionally involve environmental, familial and social influences (Thomas & French, 1985).

2.4.2 Postural control and balance

Dependent on the complexity of the postural or balance task studied and age range of participants, various suggestions have been made as to when postural control reaches adult level. In general, mastery of complex movements, through simultaneous control

of multiple degrees of freedom, gradually improves with age (Assaiante, 1998) with reports of age-related improvements in postural stability (Riach & Hayes 1987; Usui et al. 1995; Nolan et al. 2005; Schmid et al. 2005; Cumberworth et al. 2007). Some of this research reports progressive improvements in balance to late adolescence (Usui et al. 1995; Cumberworth et al. 2007), but as no comparison to adults is made, it is not known when adult levels of postural control are reached. Changes in stature with growth would challenge postural control, hence the noted age-related improvements are likely to be due to the maturation of postural mechanisms including short and long-loop proprioceptive reflexes, visual, vestibular and somatosensory systems and the synergistic organisation of these systems (Riach & Hayes 1987; Nolan et al. 2005).

2.4.3 Development of proprioception

The representation of human body posture is based on a multilink proprioceptive chain running from the eyes to the feet and on multiple sensory inputs which are used to orient the body's posture with respect to the external world (Massion, 1998). It is unclear, however, what role the ontological development of the somatosensory system plays in the maintenance of upright postures during the transition from child to adult (Westcott & Burtner, 2004). The proprioceptive system is of particular importance to somatosensory feedback because it dominates balance control under fixed support surface conditions such as sitting, standing and squatting (Steindl, Kunz, Schrott-Fischer, & Scholtz, 2006).

For proprioceptive repositioning tasks, adults and children make use of three sensory systems - visual, vestibular and somatosensory (Westcott & Burtner 2004; Chow et al. 2007; Viel et al. 2009). Adults have been shown to be selective in the use of these systems, improving spinal repositioning accuracy when visual cues were withdrawn (Preuss, Grenier, & McGill, 2003); however, the immature somatosensory system does not exhibit this degree of plasticity with visual dependence dominating the postural adjustments of young children (Visser & Geuze 2000; Westcott & Burtner 2004; Goble et al. 2005), as well as adolescents with suggested peaks of visual dependence at 15 years in females and 17 years in males (Viel et al., 2009). Further, it has been shown that the vestibular afferent system is not integrated to adult levels until mid-late adolescence (Steindl et al. 2006; Cumberworth et al. 2007; Nandi &

Luxon 2008; Viel et al. 2009). Studies of proprioception during adolescence show age-related improvements in acuity of whole-of-trunk repositioning during standing (Ashton-Miller, McGlashen, & Schultz, 1992) and bilateral upper limb matching (Goble, Lewis, Hurvitz, & Brown, 2005) and decreased postural oscillations in standing (Usui, Maekawa, & Hirasawa, 1995).

Cumulatively, this suggests that the somatosensory system is not fully integrated during adolescence and that this period represents a transition in postural and motor control. Some suggest that puberty and the resulting change in central virtual body image disturbances might lead adolescents to transiently neglect proprioceptive information (Assaiante 1998; Largo et al. 2001; Viel et al. 2009), and supports a period of motor awkwardness during adolescence.

SUMMARY

- Improvements in motor skill have been demonstrated during adolescence.
- Improvements in motor skill are generally linear with age except for indications of quality of movement which has shown to decrease between 12 – 18 years.
- Age-related improvements are noted in postural stability during adolescence.
- Visual dependence peaks during mid-late adolescence; contemporaneous to integration of the vestibular system to adult levels.
- Proprioception improves through adolescence.

2.5 LOW BACK PAIN IN ADOLESCENCE

Most research that has investigated the problem of adolescents with LBP have either documented the pain experience in terms of prevalence and recurrence or investigated associations with a wide variety of psychological, social and physical risks. The documented evidence for LBP in adolescence is as follows.

2.5.1 Epidemiology of child and adolescent low back pain

Many studies investigating LBP in adolescent populations report epidemiology. Amongst this research there are large variations in the groups investigated in terms of average age, gender, socioeconomic, psychosocial and cultural factors. The following trends can be drawn from this large body of evidence.

(1) *Substantial portions of adolescents experience LBP*. During adolescence documented lifetime prevalence rates range from 11.6 – 67% (Burton et al. 1996; Sjolie 2004b); annual prevalence rates range from 11.8 – 60.3% (Burton et al. 1996; Skoffer & Foldspang 2008); monthly prevalence rates range from 10.6 – 30.6% (Harreby et al. 1999; Wedderkopp et al. 2003); and point prevalence rates from 5 – 21% (Leboeuf-Yde & Kyvik, 1998; Masiero, Carraro, Celia, Sarto, & Ermani, 2008). A summary of epidemiological literature reviewed is in Table 2-1.

(2) *Recurrence rates for LBP are high* (ongoing episodic instances of LBP as opposed to a single discrete spell). Documented at 44% of all cases in a 11 year old sample and 59% of all cases in a 15 year old sample, both samples were from the United Kingdom (Burton, Clarke, McClune, & Tillotson, 1996); while rates of 30% in females and 26% in males aged 10-16 years have been reported in a Finnish sample (Taimela, Kujala, Salminen, & Viljanen, 1997).

Sample Nationality	Age (years)	Lifetime Prevalence	Annual Prevalence	Monthly Prevalence	Fortnightly Prevalence	Weekly Prevalence	Point Prevalence	Author/s
Australia	14.1 (mean)	47% 51% females 44% males						(Haselgrove et al., 2008)
Australia	13				21.6% females 17% males			(Steele, Grimmer, Williams, & Gill, 2001)
Australia	15				34.1% females 22% males			(Steele et al., 2001)
Australia	17				42.7% females 19% males			(Steele et al., 2001)
Australia	12-19	57% males					16.7% males	(Ebrall, 1994)
United Kingdom	12	11.6%	11.8%					(Burton et al., 1996)
United Kingdom	15	50.4%	21.5					(Burton et al., 1996)
United Kingdom	11-14	28.9% females 25.9% males						(Murphy, Buckle, & Stubbs, 2007)
United Kingdom	11-12.75	22.4%						(Murphy et al., 2007)
United Kingdom	12.75-14	32.4%						(Murphy et al., 2007)
United Kingdom	11-14			24% 29% females 19% males				(Watson et al., 2002)
United Kingdom	13-17						8.5%	(Fairbank, Pynsent, Van Poortvliet, & Phillips, 1984)

Table 2-1 – Epidemiology of adolescent low back pain across various ages, gender and nationalities

Sample Nationality	Age (years)	Lifetime Prevalence	Annual Prevalence	Monthly Prevalence	Fortnightly Prevalence	Weekly Prevalence	Point Prevalence	Author/s
Finland	12.8 (mean)		18.4% females 16.9% males					(Nissinen, Heliovaara, Seitsamo, Alaranta, & Poussa, 1994)
Finland	14		18%					(Taimela et al., 1997)
Finland	16		18.4					(Taimela et al., 1997)
Denmark	15	18% males 32% females	24%				5%	(Leboeuf-Yde & Kyvik, 1998)
Denmark	13-16	58.9% 67.4% females 49.8% males	50.8% 52.1% females 49.3% males	30.6% 36.1% females 24.7% males		13.9% 15.2% females 12.5% males	5.3% 6.1% females 4.3% males	(Harreby et al., 1999)
Denmark	17.1 (mean)	43.1% females 54.1% males		35.6% females 27.1% males				(Andersen, Wedderkopp, & Leboeuf-Yde, 2006)
Denmark	10-16			10.56%				(Wedderkopp, Leboeuf-Yde, Andersen, Froberg, & Hansen, 2003)
Denmark	14-16			21.2% females 18.1% males				(Wedderkopp, Leboeuf-Yde, Andersen, Froberg, & Hansen, 2001)
Denmark	8-10			6.6% females 2.4% males				(Wedderkopp et al., 2001)
Denmark	13			22% 26% females 19% males				(Kjaer, Leboeuf-Yde, Sorensen, & Bendix, 2005)
Denmark	9th grade	64.8%	60.3%					(Skoffer & Foldspang, 2008)
Norway	14-16	66% 74% females 60% in males	58% 71% females 47% males					(Sjolie, 2004c)
Norway	17-19	67% 78% females 57% males	39% 45% females 34% males					(Sjolie, 2004c)

Table 2-1 (con't)– Epidemiology of adolescent low back pain across various ages, gender and nationalities

Sample Nationality	Age (years)	Lifetime Prevalence	Annual Prevalence	Monthly Prevalence	Fortnightly Prevalence	Weekly Prevalence	Point Prevalence	Author/s
Switzerland	10-16	32.5%					9.4%	(Balague, Damidot, Nordin, Parnianpour, & Waldburger, 1993)
Switzerland	12-17	51%						(Balague et al., 1993)
Switzerland	8-16	21%					12%	(Balague et al., 1994)
Switzerland	13	21.3						(Balague et al., 1994)
Switzerland	16	50%						(Balague et al., 1994)
Switzerland	14	27%						(Balague, Dutoit, & Waldburger, 1988)
Switzerland and Spain	15.05 (mean)				39.8%			(Pellise et al., 2009)
Spain	13-15	50.9% males 69.3% females					17.1% males 33% females	(Kovacs et al., 2003)
Italy	13-15		20.5%				21%	(Masiero, Carraro, Celia, Sarto, & Ermani, 2008)
Greece	12-18							(Korovessis, Koureas, Zacharatos, & Papazisis, 2005)
Mozambique	11-16	28%	13.5%	12%				(Prista, Balague, Nordin, & Skovron, 2004)
Japan	9-15	28.8% 51.6% females 48.5% males					10.2% 47.7% females 52.3% males	(Sato et al., 2008)
United States	11-17	30.4%	22%					(Olsen et al., 1992)

Table 2-1 (con't)– Epidemiology of adolescent low back pain across various ages, gender and nationalities

(3) *Significant positive trends are demonstrated between incidence and increased age* (Balague et al., 1994; Burton et al., 1996; Hestbaek et al., 2004; Leboeuf-Yde & Kyvik, 1998; Sato et al., 2008; Steele et al., 2001; Taimela et al., 1997; Troussier, Davoine, de Gaudemaris, Fauconnier, & Phelip, 1994; Watson et al., 2002; Wedderkopp, Andersen, Froberg, & Leboeuf-Yde, 2005). Though the various studies have investigated different age ranges through adolescence they all show the same trends. The study by Leboeuf-Yde and Kyvik (1998) is a very large population based cross-sectional study of individuals from 12-41 years. They showed that:

Lifetime cumulative incidence of LBP ("LBP ever") increased gradually with steep increases in rates in 12-13 year old females and 13-14 year old males. Lifetime incidence rates were greater than 50% in 18 year old women and 20 year old men; beyond these ages estimates were stable.

1-year period prevalence ("LBP in last year") estimates showed similar trends to lifetime incidence. Rates similarly increased most markedly in early adolescence plateauing in the early 20s. More recently this research group identified from this data that there were also significant age-related increases across adolescence in the frequency of long-lasting LBP (LBP episodes greater than 30 days) (Hestbaek et al., 2004).

Cumulatively, these studies demonstrate that LBP begins in early adolescence with incidence increasing rapidly and reaching near adult levels by late adolescence.

(4) *Positive associations are shown between a history of LBP during adolescence and the recurrence of LBP through adult life*. A large cohort study, performed in Denmark, showed that those adolescents who had reported LBP at 14 years had significantly higher *LBP in the last month* (69%, p=0.01), *LBP in the past week* (47%, p=0.04), a higher number of hospital admissions (17%, p=0.02) and reduced work capacity due to LBP (13%, p=0.03) when re-surveyed 25 years later (Harreby et al., 1995). Further, LBP in adolescence was linked with increased risk for LBP in adulthood, odds ratio (OR) 2.23 (Harreby et al., 1995).

(5) *Adolescent females demonstrate significantly higher incidence of LBP than adolescent males* This finding was supported by most studies (Balague et al., 1988; Balague et al., 1995; Balague, Troussier, & Salminen, 1999; Kovacs et al., 2003; Leboeuf-Yde & Kyvik, 1998; Sato et al., 2008; Watson et al., 2002); with only one report of cases being significantly more common in males during an age of peak growth at 15 years (Burton et al., 1996); and one study which showed no gender based differences (Olsen et al. 1992). Odds ratios for the association between female gender and LBP have been documented at 3.1 (95% CI 1.2-8.2) (Sjolie, 2002); 1.6 (95% CI 1.1-2.3) (Balague et al., 1995); and 1.1 (95% CI 1.0-1.2) (Kovacs et al., 2003). Gender differences have previously been explained by (1) earlier spinal maturity (Trevelyan & Legg, 2006), (2) differences in pain threshold and the way in which different genders perceive pain (Masiero et al., 2008), (3) greater spinal flexibility in adolescent females compared to males (Salminen, 1984), (4) in mid-adolescence boys have higher exposure than girls to more strenuous sports activities which may lead to greater exposure to trauma (Burton et al., 1996), or (5) hormone-induced changes at puberty affecting attitudes to or perception of pain (Masiero et al., 2008). That pubertal development in girls is related to increased odds for LBP leads support to this final option (LeResche, Mancl, Drangsholt, Saunders, & Korff, 2005).

(6) *Prevalence rates for chronic LBP (CLBP) in adolescence are high* (CLBP is defined as pain in the low back that has lasted more than three months). The prevalence of CLBP has been documented at 8% (Bejia, Abid et al., 2005; Salminen, Erkintalo, Pentti, Oksanen, & Kormano, 1999) 11.3% (Perry, Straker, O'Sullivan, Smith, & Hands, 2009) and 12% (Sjolie, 2004b). Recurrent and continuous LBP was recorded at 26% in males and 33% in females in a group 10-17 years. With increasing age, a larger proportion of LBP was recurrent or continuous (Taimela et al., 1997). In girls this was documented at 20% at 10 years, 35% at 14 years and 57% at 16 years. In boys this was documented at

10% at 10 years, 30% at 14 years and 42% at 16 years (Taimela et al., 1997).

These trends demonstrate that LBP during adolescence is a significant public health issue with prevalence approaching adult levels (Jeffries, Milanese, & Grimmer-Somers, 2007). This doctoral research of adolescents with NSCLBP provides an opportunity to better understand the disorder at the time of development (Balague et al., 1994; Leboeuf-Yde & Kyvik, 1998; Watson et al., 2002) and provide scientific information that may assist in the development of appropriate clinical interventions.

2.5.2 Duration and levels of pain, disability and kinesiophobia in adolescents with low back pain

While there are many studies providing detailed prevalence data on LBP in adolescence, relatively few studies have quantified the pain intensity, duration or disability of adolescents with LBP (McMeeken et al. 2001; Bejia et al. 2005; Skoffer & Foldspang 2008).

Pain levels in all studies reviewed were documented using a visual analogue scale (VAS) and scored out of 10. In a recent large cohort study Pellise and colleagues found pain levels of 4.2 ± 2.2 in those with isolated LBP and 5.1 ± 2.3 in those with LBP and other pain (Pellise et al., 2009). These levels are similar to another recent study of 173 females (4.7 ± 2.0) (Perich, Burnett, O'Sullivan, & Perkin, 2009). Pellise and colleagues also found that the severity of pain was greater in adolescent females than males and that females were more likely to have LBP in addition to other pain sites or whole body pain (Pellise et al., 2009). In contrast, no gender differences in pain intensity levels were found in another recent study, although reported pain levels were similar (males 4.8 ± 3.2, females 5.0 ± 3.0) (Masiero et al., 2008). These levels can be considered moderately high.

Different definitions are applied in previous research to document the duration of pain, with studies using different categorical measures, these categories and results are documented in Table 2-2. In a small study of adolescent Australian males aged 12-19 years, questions were asked of duration of LBP since original onset (history) and current frequency and duration of episodes of LBP (Ebrall, 1994). Documented

durations were similar to studies of Swiss and Spanish (Pellise et al., 2009), Norwegian (Sjolie, 2004a) and English adolescents (Watson et al., 2002). Previous research identifies that substantive proportions of adolescents are suffering LBP of substantial history, frequency and episodic duration.

Ebrall 1994			Pellise et al 2009		Sjolie 2004a
LBP History	*LBP Frequency*	*Duration of current episodes*	*Duration Isolated LBP*	*Duration LBP & other pain †*	*Duration LBP during preceding year*
46.35% year or longer	14.13% every day	3.27% 'never goes away'	3.7% > week	7.9% > week	12% daily LBP over preceding year
30.29% few months	23.55% 2-3 times/ week	1.09% few months	12.9% 1- 7 days	17.2% 1-7 days	16% > 30 days, but not daily
9.85% few weeks	29.35% 2-3 times/ month	1.82% few weeks	9.5% 12-24 hours	18.7% 12-24 hours	26% 8-30 days
		27.64% few days	73.9% < 12 hours	56.2% < 12 hours	46% 1-7 days
		36.73% few hours			

Table 2-2 – Summary of duration of pain experience in adolescents with low back pain
† Defined as pain in any part of the body during the last month

Disability levels in adolescents with LBP have previously been measured using the Roland-Morris Questionnaire (Roland & Fairbank, 2000), the Hanover Functional Ability Questionnaire (Pellise et al., 2009; Watson et al., 2002) and the Oswestry Scale of Disability (Fairbank, Couper, Davies, & O'Brien, 1980). Pellise and colleagues (2009) reported that in subjects with isolated LBP, 96.8% had negligible disability (scoring 0-6 on the Roland-Morris) with only 3.2% reporting moderate to severe disability (scoring >6), while 5.2% of those with LBP and other pain had moderate to severe disability (scoring >6). Results using the Hanover questionnaire were slightly higher with 10.3% of those with isolated LBP and 11.7% of those with LBP and other pain reporting moderate to severe disability (scores >5) (Pellise et al., 2009). When disability was defined as limitation of normal activities because of LBP it was assessed at 13.5% in a group of similar age (mean age 13.8 ± 0.1 years) (Feldman, Shrier, Rossignol, & Abenhaim, 2001). Using the Oswestry Scale of Disability, disability in a group of (n=173) female adolescent rowers with LBP was documented at 11.1 ± 9.3 %; which is considered mild (Perich et al., 2009).

No study was identified which reported levels of kinesiophobia in an adolescent LBP population, despite kinesiophobia being considered an important predictor for disability related to LBP in adults (Thomas, France, Sha, & Wiele, 2008; Vlaeyen & Linton, 2000).

Collectively, these results suggest that adolescents with LBP have substantive personal history, recurrence rates, significant levels of pain and episodic durations associated with LBP. A small but significant group are affected by CLBP.

SUMMARY

- Substantial portions of young people experience LBP including CLBP.
- Recurrence rates for LBP during adolescence are high.
- Significant positive trends are demonstrated between increased incidence and increased age.
- Positive associations are shown between a history of LBP during adolescence and the recurrence of LBP during adulthood.
- Adolescent females demonstrate higher incidence of LBP than adolescent males.
- Pain intensity of LBP in adolescents can be considered moderately high.
- Only a small group of adolescents with LBP report significant disability.

2.6 ADOLESCENT LOW BACK PAIN VIEWED AS A BIOPSYCHOSOCIAL DISORDER

People with NSCLBP have no known patho-anatomical diagnosis based on current biomedical investigations (Weiner, 2008). Adult NSCLBP is considered to represent a biopsychosocial disorder, with physical (posture and movement patterns, altered trunk muscle activation patterns, trunk muscle strength and endurance, work demands); neurophysiological (pain perception, stress response, central nervous system changes); psychosocial (coping strategies, personality, stress, distress, work satisfaction, personal support); sociodemographic (age, gender, education level,

cultural, financial compensation); lifestyle; and genetic risk factors present (Balague, Troussier, & Salminen, 1999; Bejia et al., 2005b; Burton, 1997; Gatchel, Polatin, & Mayer, 1995; Leboeuf-Yde, Kyvik, & Bruun, 1999; Linton, 2000; Marras, Davis, Heaney, Maronitis, & Allread, 2000; Moseley, 2003; O'Sullivan, 2005; Stevenson, Weber, Smith, Dumas, & Albert, 2001; Truchon, 2001; Truchon & Fillion, 2000; Waddell, 1987, 2004).

While physical, lifestyle and psychosocial risk factors have been associated with adolescent LBP, the majority of the research has investigated these from a single dimension and, as outlined below, often with conflicting results. The text that follows outlines findings regarding adolescent LBP in a biopsychosocial context. This is important because this is the current basis of knowledge concerning adolescent LBP. The vast majority of this research is of 'LBP' and is undifferentiated from 'CLBP' or more specifically 'NSCLBP', the focus of this dissertation. Where research findings are of CLBP or NSCLBP this is clearly indicated by use of the relevant abbreviation.

2.7 PSYCHOLOGICAL, SOCIAL AND LIFESTYLE ASSOCIATED FACTORS

Psychological

Significant positive associations have been demonstrated between adolescent LBP and psychological factors including depressive symptoms; increased perceived stress (Diepenmaat, van der Wal, de Vet, & Hirasing, 2006); poor wellbeing, particularly poor self-perceived fitness (Sjolie, 2002); negative affect (Staes, Stappaerts, Lesaffre, & Vertommen, 2003); hyperactivity (Jones, Watson, Silman, Symmons, & Macfarlane, 2003); emotional (Murphy et al., 2007) and conduct problems (Jones et al. 2003; Watson et al. 2003); and educational strain (Kristjansdottir & Rhee, 2002). Adolescents who are generally more prone to perceive symptoms psychosomatically have reported a higher prevalence of LBP (Vikat et al., 2000). This is reflected in work by Watson, Jones and colleagues who found that LBP was strongly associated with troublesome headaches, abdominal pain, sore throats and daytime tiredness (Jones et al., 2003; Murphy et al., 2007; Watson et al., 2003).

Catastrophising, as a coping technique, has been associated with greater disability in adolescents with CLBP (Lynch, Kashikar-Zuck, Goldschneider, & Jones, 2006). Similar to research findings in adults, adolescents with CLBP have been shown to have higher levels of emotional distress and depression relative to acute LBP subjects (Gatchel, Bernstein, Stowell, & Pransky, 2008).

In a prospective study, high subjective disability due to pain and daytime tiredness were the most significant predictors for the persistence of musculoskeletal pain in pre-adolescents at 1-year follow-up. Further, stressful experiences in childhood have been shown to be associated with an increased risk of CLBP later in life (Kopec & Sayre 2005). Cumulatively these results suggest that psychological distress in young persons may contribute to the persistence of non-specific musculoskeletal pain in pre-adolescents (Mikkelsson, Sourander, Piha, & Salminen, 1997; Vikat et al., 2000) and act as a contributory precursor during adolescence to the development of CLBP in adults.

In *adults* CLBP is associated with, stress; distress; poor cognitive functioning (attitudes, beliefs, perceived health level, somatisation, fear-avoidance and catastrophising); anxiety and depression - including recognised mood and anxiety mental disorders (Demyttenaere et al., 2007; Linton, 2000; Pincus, Burton, Vogel, & Field, 2002; Pincus, Vogel, Burton, Santos, & Field, 2006; Reichborn-Kjennerud et al., 2002). Further, psychosocial factors have been shown to be linked to the transition from acute to chronic LBP and may be used as predictors for developing long-term pain and disability (Linton, 2000). Higher levels of life stress events (number of events and perceived high impact) may have neurophysiological influences, such as tissue on sensitivity thresholds to nociception, as well as influences on motor control patterns. Previously, a pathway has been proposed between psychosocial stress, cognitive appraisal of injury, spine loading, increased risk of LBP and development of disability and chronicity in *adults* (Gatchel, 2004; Gatchel et al., 2008; Marras et al., 2000; Truchon, Cote, Fillion, Arsenault, & Dionne, 2008).

Social

Having several sources of social support, good friends, supportive parents and other adults, is associated with less back pain in adolescents (Kristjansdottir & Rhee, 2002). While a familial chronic pain history has been shown to be associated with both greater disability (Lynch et al., 2006) and greater risk for CLBP in adolescents. This risk is magnified if both carers have LBP (O'Sullivan, Straker, Smith, Perry, & Kendall, 2008). A site-specific association between parental and child pain has been previously shown (Groholt, Stigum, Nordhagen, & Kohler, 2003). Furthermore, adolescent LBP has been shown to be associated with increased stressful events experienced by the family (O'Sullivan et al., 2008). One study showed that those children (7-17 years) from low educated, low income working families had higher odds (OR 1.4) of having either headache, abdominal or back pain and suggests that socio-economic factors may also be important (Groholt et al., 2003) in the occurrence of LBP.

Lifestyle

Other lifestyle factors linked with LBP in adolescents include moderate associations for smoking (Feldman et al., 2001; Harreby et al., 1999; Vikat et al., 2000) and weak associations for drunkenness (Vikat et al., 2000). One study reported that regular smoking in adolescence was associated with persistent LBP in young women, with a linear exposure-response relationship, but not in young men (Mikkonen et al., 2008). As another large study found no association between non-specific LBP in adolescents and both cigarette smoking and alcohol intake (Kovacs et al., 2003), caution should be drawn in interpreting these results as smoking and alcohol consumption could also be secondary consequences of other non-reported psychosocial issues.

While not always linked to lifestyle, obesity has also been associated with LBP in adolescents (Leboeuf-Yde, 2004). Specifically, LBP has been shown to be associated with increased waist girth in boys but not girls (Perry et al., 2009); and increased weight was associated with hyperlordotic standing postures and the presence of LBP (Smith, O'Sullivan, & Straker, 2008).

Evidence exists linking LBP in *adults* to smoking (Bejia, Younes et al., 2005; Leboeuf-Yde, 1999), with odds ratios increasing with the duration and frequency of LBP (Leboeuf-Yde et al., 1999). However, it is suggested that these links are not likely to be causal (Leboeuf-Yde et al., 1999). In one study risk of early retirement due to LBP was moderately associated with being a smoker (OR 1.5) and having a body-mass index in the upper percentile (OR 2.0) (Hagen, Tambs, & Bjerkedal, 2002). In a very large population based study obesity was modestly positively associated with LBP in adults; the authors of this paper suggest that relationships are not likely to be causal but rather may play a role in the development of chronicity (Leboeuf-Yde et al., 1999). Effects for alcohol consumption have shown no relationship (Hagen et al., 2002) or low evidence for increased risk in adults (Demyttenaere et al., 2007).

While some studies suggest that psychosocial rather than physical factors are more important in adolescent LBP (Szpalski et al. 2002; Jones et al. 2003) the multifactorial nature of LBP identified by previous research indicates that NSCLBP in adolescents should be studied from a multi-dimensional perspective (Balague, Dudler, & Nordin, 2003). Previous research identified that some adults with CLBP have dominant psychosocial factors while others do not (Dunn, Jordan, & Croft, 2006), suggesting different sub-groups of NSCLBP exist.

SUMMARY

- Results from previous adolescent and adult studies suggest that the psychosocial dimension is important to the development and persistence of LBP.
- Positive associations are drawn between psychological factors and LBP in adolescence, with highest levels of emotional distress and depression found in those with CLBP.
- Having several sources of social support is associated with less LBP in adolescence.
- Smoking, alcohol and obesity consumption are associated with adolescent LBP.

2.8 PHYSICAL ACTIVITY LEVELS

Evidence also exists linking LBP with both physical activity and physical inactivity.

Sedentary activity

Positive associations between LBP and various measures of physical inactivity have been reported. These include time spent watching television or computer use (Balague et al., 1994; Bejia, Abid et al., 2005; Sjolie, 2004a; Skoffer & Foldspang, 2008) and in one study shown especially in girls but not boys (Sjolie, 2004a), being passively transported to school (Haselgrove et al., 2008; Skoffer & Foldspang, 2008), not being physically active during school breaks (Skoffer & Foldspang, 2008) and sitting at school (Bejia, Abid et al., 2005; Sjolie, 2004c).

Physical activity

In contrast, associations between LBP and physical activity have been variable. Participation in organised sport has shown positive (Grimmer & Williams, 2000; Harreby et al., 1999; Sato et al., 2008; Skoffer, 2007; Skoffer & Foldspang, 2008; Watson et al., 2002), negative (Balague et al., 1993; Burton et al., 1996; Grimmer & Williams, 2000; Sjolie, 2004a) and no associations with LBP (Andersen et al., 2006; Harreby et al., 1999; Wedderkopp et al., 2003; Widhe, 2001).

Positive associations are shown more commonly with increased frequency (Balague et al., 1994; Kovacs et al., 2003), duration (Balague et al., 1993; Masiero et al., 2008) or intensity of sport (Balague et al., 1988; Balague et al., 1994) with one study correlating a high level (time and duration) of sports activity with severe LBP in adolescent males (Harreby et al., 1999). This may link to recent findings that boys with the highest aerobic capacity had a greater risk of back pain during the past month (Perry et al., 2009). In one study of Greek children and adolescents (9-15 years) despite boys participating in more highly strenuous activities, exposure to sport was significantly related to LBP in girls only (Korovessis, Koureas, & Papazisis, 2004).

In contrast, regular sporting involvement has been shown to be protective for LBP (Grimmer & Williams, 2000). Similarly, Wedderkopp and colleagues reported that high physical activity in childhood (9 years) reduced the odds of low back and mid-

back pain in early adolescence (12 years) with linear relationships between activity level and probability of future LBP or mid-back pain (Wedderkopp, Kjaer, Hestbaek, Korsholm, & Leboeuf-Yde, 2009). One study showed that this relationships in adolescent boys, where LBP was associated with physical activity less than 3 times per week, but not so in adolescent girls (Sjolie, 2004a).

Swimming has been associated with a decreased LBP prevalence, while jogging, handball, gymnastics and riding horses were associated with an increased period prevalence risk of LBP (Skoffer & Foldspang, 2008). CLBP has been associated with European football (OR 3.07) in Tunisian adolescents (Bejia et al., 2005a).

Another study determined that the relationship between physical exercise and LBP was U-shaped with LBP associated both with too much and too little physical activity (Vikat et al., 2000). Anderson and colleagues found that those with LBP were less likely to undertake physical activity (Andersen et al., 2006).

In *adults*, moderately increased risk for CLBP is associated with being sedentary[1] (OR 1.31) and engaging in physically strenuous activities (OR 1.22) supporting previous evidence in adolescence that the relationship between physical activity and CLBP is U-shaped (Heneweer, Vanhees, & Picavet, 2009). This study also identified that *adults* participating in sports between 1 and 2.5h/week had a decreased risk of CLBP (OR 0.78) (Heneweer et al., 2009). In contrast to these adult findings and adolescent studies, a recent large systematic review found limited evidence for sedentary behaviour, as measured by exposure to sitting, being a risk factor for developing LBP (Chen, Liu, Cook, Bass, & Lo, 2009).

SUMMARY

- Positive associations are shown between a sedentary lifestyle and LBP in adolescents.
- Curvilinear relationships suggest too much or too little physical activity is associated with LBP in adolescence.

[1] Defined as performing physical activities for less than 30 minutes /day

2.9 PHYSICAL ASSOCIATED FACTORS

Much research has attempted to identify common physical activities associated with LBP, such as prolonged postures (sitting and standing) and work related activities (bending, twisting, carrying and lifting). The aim is often to identify biomechanical risk factors and introduce interventions – in posture or work activities – that may minimise the risk for developing LBP. From previous literature physical associated factors include common provocative postures and activities. In studies of adolescents there has been an interest in trunk endurance, spinal and lower limb flexibility and school bag carriage. The evidence for these physical associated factors is outlined below.

2.9.1 Common provocative postures and activities

Sitting

Sitting has been found to be a common aggravating factor for LBP among children and adolescents (Balague et al., 1988; Balague et al., 1999; Geldhof, De Clercq, De Bourdeaudhuij, & Cardon, 2007; Grimmer & Williams, 2000; Nissinen et al., 1994; Salminen, 1984; Troussier, Davoine, de Gaudemaris, Fauconnier, & Phelip, 1994; Troussier et al., 1999). In some studies LBP has specifically been associated with sitting in the classroom (Bejia, Abid et al., 2005; Troussier et al., 1994; Watson et al., 2002). In an study of Australian adolescents there were consistent indications that those who sat at school for long periods of time had significantly elevated risk of LBP, and that in adolescent girls those with LBP sat for longer than those with no LBP (Grimmer & Williams, 2000). This association between prolonged sitting and reporting LBP in girls but not boys has more recently also been shown in a Finnish sample (Auvinen, Tammelin, Taimela, Zitting, & Karppinen, 2008). A 3-year prospective study of adolescents, between 15 and 18 years, found *LBP provoked by sitting at school* was a strong baseline predictor (OR 5.8) for LBP at follow-up (Sjolie, 2004c). Additionally it has been observed that adolescents at school spend large portions of time in sitting and that those who spend more time flexed, or slumped, report significantly more thoraco-lumbar pain (Geldhof et al., 2007; Murphy et al., 2007; Salminen, 1984). LBP while sitting at school has been associated with twisting the back for more than 10 minutes during class, having a chair that is too low or a backrest that is perceived to be too high (Murphy et al.,

2007). Although associations between various features of school furniture and LBP have not been shown in all studies (Skoffer, 2007), the shortcoming of classroom ergonomics, both in terms of furniture and classroom layout, are documented risk factors (Limon, Valinsky, & Ben-Shalom, 2004; Parcells, Stommel, & Hubbard, 1999; Trevelyan & Legg, 2006).

In *adults* there has been much research interest, over many decades, to determine the optimal sitting posture, in terms of comfort, biomechanics and spinal loading, types of seating and seat design (Harrison, Harrison, Croft, Harrison, & Troyanovich, 1999). Further, interventions aimed at improving the usual sitting posture of patients with LBP is common clinical practice (O'Sullivan, 2004, 2005). Given the extent of information linking sitting to LBP, surprisingly little research has investigated sitting posture and relationships between those with and without LBP (Dankaerts, O'Sullivan, Burnett, & Straker, 2006a, 2006b; Murphy, Buckle, & Stubbs, 2004; Williams, Hawley, McKenzie, & van Wijmen, 1991; Womersley & May, 2006). There is also some detailed information recording the inability of *adult* patients with LBP to accurately reposition the spine in sitting into neutral mid-range positions (Brumagne, Cordo, Lysens, Verschueren, & Swinnen, 2000; Brumagne, Lysens, & Spaepen, 1999; Lam, Jull, & Treleaven, 1999; O'Sullivan et al., 2003).

Recent studies in *adults* have shown that different sitting postures in healthy adults greatly influence trunk muscle activation (Claus, Hides, Moseley, & Hodges, 2009; O'Sullivan et al., 2006b; O'Sullivan et al., 2002). Hyperlordotic or thoracic upright positions are associated with co-activation of the global trunk muscles (thoracic erector spinae and external oblique), while lumbo-pelvic upright sitting has been associated with activation of local spinal muscles (superficial lumbar multifidus and internal oblique) (O'Sullivan et al., 2006b). Slump sitting postures are associated with decreases in activity of superficial lumbar multifidus, thoracic erector spinae and the abdominal internal oblique (O'Sullivan et al., 2002).

In healthy *adults*, relaxation of erector spinae has been shown while moving from upright to slump sitting in superficial lumbar multifidus (O'Sullivan et al., 2006a) and the thoracic erector spinae (at level T9) (Callaghan & Dunk, 2002); with significantly less relaxation in both superficial lumbar multifidus and iliocostalis

lumborum pars thoracis in adults with NSCLBP compared to healthy controls (Dankaerts, O'Sullivan, Burnett, & Straker, 2006a).

Adolescent literature with regard to sitting and LBP is limited to studies recording aggravating factors, gross classroom posture and ergonomics. No detailed laboratory studies of posture or trunk muscle activation in usual or slump sitting were found comparing healthy adolescents to those adolescents with NSCLBP.

Standing

It has been previously reported that non-neutral sagittal standing postures are linked to LBP in adolescent subjects (Smith et al., 2008) and an increase in lumbar lordosis has been noted in young female gymnasts reporting LBP (mean age, 12 years) when compared to those with no history of LBP (Ohlen, Wredmark, & Spangfort, 1989).

Prolonged standing has previously been identified as a risk factor for developing LBP in *adults* (Andersen, Haahr, & Frost, 2007). A study of prolonged standing suggests LBP was linked with how an individual initially stands and not with adopting pain provocative postures over the duration of the task (Gregory & Callaghan, 2008). In *adults,* evidence for linkages between non-neutral standing postures and LBP lack clarity with studies having shown both increased (Christie, Kumar, & Warren, 1995) and decreased (Jackson & McManus, 1994) lumbar lordosis associated with LBP, while other studies have found no relationships (During et al. 1985; Pope et al. 1985; Ahern et al. 1988; Mitchell et al. 2008; Dankaerts et al. 2009). The variation in results between studies may be due to the large variation in lumbar lordosis previously identified in healthy adults (Roussouly, Gollogly, Berthonnaud, & Dimnet, 2005) and the relatively small samples studied.

Conflicting results have also been reported concerning the level of back muscle activation during quiet standing in *adults* with and without LBP, with studies showing either no difference (Ahern, Follick, Council, Laser-Wolston, & Litchman, 1988; Kaigle, Wessberg, & Hansson, 1998) or an increase (Sihvonen, Partanen, Hanninen, & Soimakallio, 1991), although a sizeable meta-analysis found a large effect size for higher muscle activation in trunk muscles in standing for those with LBP (Geisser et al., 2005). As back muscles are known to alter their level of

activation in different standing postures (Lariviere et al. 2000; O'Sullivan et al. 2002a) differences in results maybe due to lack of postural standardization between different studies.

One recent *adult* study identified that those subjects who developed pain during a 2-hour standing task demonstrated trunk flexor-extensor and bilateral gluteus medius muscle co-activation prior to reports of pain. This suggests that muscle co-activation is not an adaptive response to LBP but appears to be a predisposing factor for individuals who experience LBP during standing (Nelson-Wong & Callaghan, 2009).

The only literature found that identified differences between adolescents with or without LBP based on standing posture was that outlined above by Smith and colleagues (2008) and Ohlen and co-workers (1989) linking sub-groups of non-neutral postures to the presence of LBP. No literature was identified that had investigated trunk muscle activation levels in standing in adolescents with or without LBP, CLBP or NSCLBP.

Work activities and forward bending

Other documented activities that provoke LBP in adolescents include lifting or carrying heavy objects and forward bending, especially for females (Harreby et al., 1999). Having a heavy job, defined as periodic or constant heavy load on the lower back for more than 5h per week, increased risk (OR 1.95) of experiencing severe LBP in adolescents (Harreby et al., 1999). In the 3-year prospective study of adolescents one of the strongest predictors for LBP at follow-up was *LBP provoked by manual work* (OR 5.2) (Sjolie, 2004c). No studies were identified that linked work activities to the development of LBP in adolescents.

A large body of research evidence links LBP to work in *adults*, with risk factors including manual materials handling, whole body vibration, physically hard work, lifting and frequent bending or twisting (Bejia et al., 2005b; Lefevre-Colau et al., 2009; Lotters, Burdorf, Kuiper, & Miedema, 2003; O'Sullivan, Cunningham, & Blake, 2009; Xu, Bach, & Orhede, 1997). This has lead to an equally large body of evidence concerning the biomechanics of lifting (Lariviere, Gagnon, & Loisel, 2002) and bending (Esola, McClure, Fitzgerald, & Siegler, 1996; Lariviere, Gagnon, &

Loisel, 2000; Nouwen, Van Akkerveeken, & Versloot, 1987; Paquet, Malouin, & Richards, 1994; van Wingerden, Vleeming, & Ronchetti, 2008) and considerations for guidelines for safe manual handling.

In *adults* the range of spinal flexion during forward bending has been shown to be either limited (Ahern et al. 1988; Kaigle et al. 1998; van Wingerden et al. 2008) or no different (Esola et al. 1996; Lariviere et al. 2000; Mitchell et al. 2008) in LBP patients when compared to healthy subjects. No difference in the extent of maximum flexion has also been reported between LBP and control groups (Paquet, Malouin, & Richards, 1994). On returning to upright from forward bending, adult patients with LBP have been shown to initially demonstrate greater movement through the lumbar spine during the first quarter of movement but not for the remaining intervals when compared to healthy controls (McClure, Esola, Schreier, & Siegler, 1997).

The peak amplitude of back muscle activation during the flexion (forward) phase has been shown to be greater in *adults* with LBP than those without (Lariviere et al., 2000; Nouwen et al., 1987). No adult studies were identified that investigated levels of back muscle activation during the return phase from forward bending between those with and without LBP.

In *adults***,** changes in the back muscle activation whilst moving into full trunk flexion from standing was first described by Fick in 1911 (Floyd & Silver, 1951) and is termed the flexion-relaxation phenomenon.. Flexion-relaxation is a relative decrease (relaxation) near end range flexion (Sihvonen, 1997) of erector spinae muscle activity, particularly lumbar erector spinae, following the normal burst of muscle activation as an individual bends forward (Sihvonen et al. 1991; Kaigle et al. 1998; McGorry et al. 2001). While the amount of relaxation can vary between subjects (Paquet et al., 1994), in healthy adults the presence of flexion-relaxation is consistent during forward bending (Paquet et al. 1994; McGorry et al. 2001). As the erector spinae relax, the gluteal and hamstring muscles then lower the flexed trunk further by allowing the pelvis to rotate around the hips (Neblett et al., 2003). It has been shown that the last part of both lumbar flexion and pelvic rotation happen without back muscle activity or hamstring bracing, respectively (Andersson, Oddsson, Grundstrom, Nilsson, & Thorstensson, 1996; Sihvonen, 1997). Hence, during the

final stages of forward bending the braking mechanism for the lumbar spine is reliant on non-contractile elements such as spinal ligaments and joint capsules (Andersson et al., 1996; Neblett et al., 2003; Paquet et al., 1994).

As early as 1952 it was recognised that the majority of adult patients with LBP did not achieve relaxation of the back muscles during forward bending (Andersson et al., 1996). The absence of flexion-relaxation correlates with the presence of LBP (Sihvonen et al., 1991) and increased disability (Andersson et al., 1996). Further, it has been shown that pain-related fear is significantly associated with reduced lumbar flexion and greater muscle activation at end of range forward bending (Geisser et al. 2004). It is hypothesised that persistent muscle activation (lack of flexion-relaxation) noted in patients with LBP acts as a protective motor pattern in response to sensitised spinal structures (Kaigle et al., 1998; Paquet et al., 1994; Sihvonen et al., 1991).

All of the research reviewed concerning flexion-relaxation during standing has been of adult populations (Floyd & Silver 1951; 1955; Portnoy & Morin 1956; Kippers & Parker 1984; Tanii & Masuda 1985; Nouwen et al. 1987; Sihvonen et al. 1991; Paquet et al. 1994; Andersson et al. 1996; Esola et al. 1996; McClure et al. 1997; Sihvonen 1997; Wolf et al. 1997; Kaigle et al. 1998; Peach et al. 1998; Lariviere et al. 2000; McGorry et al. 2001; Sarti et al. 2001; Dickey et al. 2003; Neblett et al. 2003; Geisser et al. 2004; Olson et al. 2004; Descarreaux et al. 2008; Hashemirad et al. 2008; van Wingerden et al. 2008). No reports of flexion-relaxation in adolescents were found.

It is logical that investigating spinal kinematics and trunk muscle activity during sitting, standing and forward bending may provide valuable insight into the motor control patterns of adolescents with and without NSCLBP. Despite evidence that sitting, standing, lifting, carrying and bending tasks may be risk factors for LBP in adolescents, no studies were found that investigated trunk motor control during these activities in those adolescents with and without LBP or more specifically NSCLBP during these activities.

SUMMARY

Sitting and standing

- Increased reporting of LBP in adolescents is associated with sitting, especially at school.
- Non-neutral spinal postures in sitting and standing are linked with increased adolescent LBP.
- No studies were identified that document differences in levels of trunk muscle activity during sitting and standing and in adolescents with and without NSCLBP.

Forward bending

- Kinematic differences during forward bending have been noted in adults with LBP.
- Range of spinal flexion in forward bending has been shown either to be limited or no different in adults with LBP.
- Adults with LBP demonstrate greater trunk muscle activation during the forward or trunk flexion phase.
- Flexion-relaxation of the back extensors is a consistent and repeatable phenomenon in healthy adults during forward bending and slump sitting but not adults with LBP.
- No studies were identified that investigated kinematics, trunk muscle activation or flexion-relaxation during forward bending in adolescents with or without LBP.

2.9.2 Other physical factors

Muscular endurance

Evidence exists linking adolescent LBP with deficits in trunk extensor endurance (Andersen et al., 2006; Bernard et al., 2008; Biering-Sorensen, 1984; Luoto, Heliovaara, Hurri, & Alaranta, 1995; Salminen, Maki, Oksanen, & Pentti, 1992; Sjolie & Ljunggren, 2001), trunk flexor endurance (Jones, Stratton, Reilly, & Unnithan, 2005) and quadriceps endurance (Bernard et al., 2008). Female adolescent rowers with LBP had poorer trunk and lower limb muscle endurance, as measured by a sustained squat, compared to rowers without LBP (Perich, Burnett, & O'Sullivan, 2006). In addition, the results of a large cohort study show female (but not male) adolescents with diagnosed LBP show both reduced and greater back endurance (Perry et al., 2009) than those with no LBP. These last results suggest a U-shaped relationship between trunk endurance and LBP in adolescence. In one prospective study of adolescent LBP, Sjolie and Ljunggren found low lumbar extension endurance to be predictive of LBP at three year follow-up: the baseline population was 14.7 ± 0.6 years old (Sjolie & Ljunggren, 2001). Further, they noted that girls with long-lasting LBP had far higher values for the ratios of flexion range/trunk extensor endurance and sagittal range/ trunk extensor endurance than boys (Sjolie & Ljunggren, 2001).

School bags

In the main associations are reported between carrying school bags and LBP (Grimmer & Williams, 2000; Haselgrove et al., 2008; Negrini & Carabalona, 2002; Skoffer, 2007; Skoffer & Foldspang, 2008; Watson et al., 2002), with only one study finding no association (Kovacs et al., 2003). Increased risk for LBP has been shown with carrying a school bag greater than 30 mins daily (OR 1.4) (Haselgrove et al., 2008); carrying a backpack asymmetrically (Bejia et al., 2005a; Murphy et al., 2007), or a heavy backpack for body size (Bejia, Abid et al., 2005; Korovessis, Koureas, & Papazisis, 2004). In an Australian study, this association for load carried and low back pain was stronger for boys than girls, further it was shown as the boys aged, elevated risk of LBP was observed related to higher proportions of body weight carried (Grimmer & Williams, 2000). In this research the highest risk was shown for

those aged 12-14 years who carried loads greater than 6% of their body weight (Grimmer & Williams, 2000).

Flexibility

The evidence for spinal flexibility is mixed with some studies finding no correlations with lumbar spine sagittal mobility and LBP (Burton et al., 1996; Feldman et al., 2001; Mierau, Cassidy, & Yong-Hing, 1989; Salminen, Erkintalo, Laine, & Pentti, 1995). An increased likelihood of diagnosed LBP has been associated with both reduced hamstring/lumbar spine flexibility, as measured by a sit-and-reach test, and increased hamstring/lumbar spine flexibility (Perry et al., 2009) which suggests a curvilinear relationship. In a longitudinal study, low maximal lumbar flexion at baseline for boys and low maximal lumbar extension at baseline in girls predicted LBP 3-years later (Kujala, Taimela, Oksanen, & Salminen, 1997). Other risk factors for recurrent LBP include reduced lumbar sagittal and lateral flexion spinal mobility (Jones et al., 2005) and decreased straight leg raise (Mierau, Cassidy, & Yong-Hing, 1989). While high ratios of sagittal spinal mobility/trunk extensor endurance have been found to be predictive of LBP in adolescents three years later (Sjolie & Ljunggren, 2001).

The relationships for both trunk endurance and flexibility suggest that risk of LBP is dependent on the individual's ability to control trunk flexibility, especially during fatiguing tasks.

SUMMARY

- Other activities related with LBP in adolescents include carrying school bags, and trunk and lower limb muscle endurance and flexibility.
- Curvilinear relationships suggest too much or too little trunk endurance and hamstring/lumbar spine flexibility are associated with LBP in adolescence.

2.9.3 Neurophysiological factors and the development of chronicity

The development of chronicity in LBP can be influenced by changes to the neurophysiology of the central nervous system (CNS) and is in response to interpretation by the CNS that body tissue is in danger. The mechanisms that can contribute to chronicity include nociceptive (any mechanism that stimulates pain sensitive structures) and non-nociceptive mechanisms, including cognitive evaluation (Moseley, 2003). In chronic pain both the nociceptive system and the central virtual body image are altered; changing the sensitivity of nociceptor system to pain input. Additionally, reorganisation of both the primary sensory and motor cortices may occur. Beliefs and attitudes about pain and value of pain threat lead to alterations to cognitive evaluation of the pain condition and can also lead to changes in the central virtual body image, increasing variability and inaccuracy of motor and postural responses (Moseley, 2003).

The presence of stress (either physical or psychosocial) has been shown to have neurophysiological influence. Stressful circumstances are known to activate the endocrine hypothalamic-pituitary-adrenal (HPA) axis and are linked with insufficient inhibition of inflammatory reactions and suppression of the immune system. Prolonged activation of the HPA axis may have direct effects on muscles, bones and nerve tissue (Truchon, 2001) and has been linked to the development of disability in LBP (Truchon, Cote, Fillion, Arsenault, & Dionne, 2008). Pathways have been identified between psychosocial stress, higher levels of muscle tension, spinal loading and increased risk of LBP (Marras et al., 2000).

SUMMARY

- Development of chronicity in LBP is associated with neurophysiological changes including changes to the nociceptive system and central cognitive evaluative mechanisms.
- Pain chronicity is influenced by stress.

2.9.4 Postural control and spinal repositioning sense

The only study of adolescents in this area has shown that reduced kinaesthetic integration in adolescent girls was associated with the presence of CLBP. Kinaesthetic integration was measured with tests of static and dynamic balance (Perry et al., 2009).

Various studies have identified deficits in postural control in *adult* patients with LBP. Proprioception, the awareness of the relative orientations of body parts in space, is fundamental to static and dynamic postural control (Swinkels & Dolan, 1998). In the spine, muscles, ligaments, facet joint capsules, intervertebral discs and the thoracolumbar fascia have been shown to have proprioceptive receptors (Swinkels & Dolan 1998; Lam et al. 1999). In mid-range neutral postures where ligaments and capsules are under minimal tension the proprioceptive receptors in spinal muscles, muscle spindles, are considered to be most important to both controlling trunk movement and being able to accurately determine spine position (Brumagne et al. 1999; Lam et al. 1999; Brumagne et al. 2000). Proprioception is most often measured through tests of repositioning – tasks involve moving from a pre-defined position and returning to that position as accurately as possible.

Various studies have demonstrated proprioceptive deficits in patients with LBP and compared with healthy controls. Studies of *adults* have shown that patients with LBP display: greater variability and error in repositioning tasks (Parkhurst & Burnett 1994; Gill & Callaghan 1998; Brumagne et al. 2000; Newcomer et al. 2000; O'Sullivan et al. 2003); an impaired ability to detect a change in lumbar position (Taimela, Kankaanpaa, & Luoto, 1999); reduced balance, greater body sway and a change in recruitment strategies with balance tasks (Nies & Sinnott 1991; Takala et al. 1997; Luoto et al. 1998a; Mientjes & Frank 1999; Radebold et al. 2001); and deficits in reaction time, possibly as a result of proprioceptive loss (Taimela et al. 1993; Luoto et al. 1998b). A recent study showed a reduction in the use of the hip strategy during standing balance tasks with a commensurate increase in dependence on visual cues in patients with LBP (Mok, Brauer, & Hodges, 2004).

Deficits in proprioception, especially due to dysfunction in muscle spindles, may impair local muscle control during functional tasks leading to abnormal joint and

tissue loading (Parkhurst & Burnett 1994; Brumagne et al. 2000; O'Sullivan et al. 2003). Repetitive abnormal loading of the spine, especially of previously pain-sensitised structures, may contribute to the development and maintenance of CLBP (O'Sullivan et al., 2003) or make the spine more vulnerable to subsequent strain (Brumagne et al., 2000).

Recent evidence for regional differences in lumbar spine posture and movement between the upper and lower lumbar spine supports that the lumbar spine should be considered as two functional regions (Mitchell, O'Sullivan, Burnett, Straker, & Smith, 2008). No previous studies have investigated regional differences in the lumbar spine during repositioning tasks.

Only one study reviewed, that of kinaesthetic integration (Perry et al., 2009), has investigated the role of lumbar proprioception, as measured by static and dynamic balance, finding associations with the presence of CLBP. No study has investigated spinal repositioning task in sitting in an adolescent population either with or without LBP.

SUMMARY

- In adolescent girls reduced ability to maintain static and dynamic balance is associated with the presence of CLBP.
- Deficits in postural control and proprioception have been identified in adults with LBP including greater variability and error in trunk repositioning tasks, reduced balance and deficits in reaction time.
- Proprioceptive deficit may impair trunk motor control, lead to abnormal joint and tissue loading and contribute to the development and maintenance of LBP.
- No previous studies have investigated spinal repositioning acuity in different lumbar spine regions.
- No study has investigated a spinal repositioning task in sitting in an adolescent population.

2.10 CLASSIFICATION SYSTEMS FOR NON-SPECIFIC CHRONIC LOW BACK PAIN

There is growing evidence supporting that adult NSCLBP is not a homogenous group, but rather represents a series of sub-groups based on both physical and psychosocial variables (Dankaerts et al., 2009; Dankaerts, O'Sullivan, Burnett, & Straker, 2007; Linton, 2000; O'Sullivan, 2005). It has been proposed that the heterogeneity of the population makes development of optimal treatments for patients with NSCLBP difficult to identify unless patients are considered a part of one of several distinct sub-groups (Leboeuf-Yde, Lauritsen, & Lauritzen, 1997; McCarthy, Arnall, Strimpakos, Freemont, & Oldham, 2004); and it is the lack of sub-classification of a heterogeneous group that is thought to be why randomized clinical trials (RCTs) for NSCLBP have been largely inconclusive (Leboeuf-Yde & Manniche, 2001; Riddle, 1998).

While the LBP research community appears to be strongly in favour with this view and much research effort has been directed toward developing clinically useful classification systems (Riddle, 1998), there is a more recent dissenting view (Wand & O'Connell, 2008). Wand and O'Connell propose that persistent back pain may be a problem of cortical reorganisation and degeneration, and hence the problem of NSCLBP lies within the brain rather than the back. Hence, they further purport that the results of current RCTs are correct, suggesting that current treatments have limited efficacy due to targeting the wrong pathoanatomical fault. These researchers believe that if treatment modalities were aimed at central cortical structures, irrespective of peripheral signs and symptoms, clinical interventions would be likely to be more effective (Wand & O'Connell, 2008). This supposition is based on the assumption that all NSCLBP patients have a homogenous central cause.

Wand and O'Connell further argue that observable psychological and peripheral biomechanical changes in patients with NSLCBP are epiphenomena incidental to cortical reorganisation and regeneration. While this theory is philosophically plausible, what is lacking are suggested clinical treatment paradigms; and hence the clinician is again left with dealing with a collection of signs and symptoms of multifactorial nature. Hence, there is benefit in identifying smaller groups of patients with homogenous causative mechanisms, which allow for different management

approaches, within the heterogeneous mix of NSCLBP. In light of current knowledge and clinical management paradigms this approach is sound even if at a later date these causative mechanisms are more correctly identified as epiphenomena of a higher order cortical aetiological factor.

Different classification systems have been developed based on clinically meaningful criteria; with evidence for sub-groups based on the patho-anatomic source of pain, clinical features (signs and symptoms) and psychosocial factors (McCarthy, Arnall, Strimpakos, Freemont, & Oldham, 2004). *Patho-anatomic* classification systems follow a traditional medical approach to diagnosing anatomic pathology or identifying the nociceptor source of the pain with diagnostic injections (Bernard et al., 2008; Bogduk, 1995; Dankaerts, O'Sullivan, Straker, Burnett, & Skouen, 2006c; Young, Aprill, & Laslett, 2003). *Clinical feature* classification systems using a cluster of signs and symptoms (Delitto, Erhard, & Bowling, 1995) include those that are prognosis-based (Dionne et al., 1997; Engel, von Korff, & Katon, 1996; Krause, Ragland, Fisher, & Syme, 1998), treatment-based (Delitto et al., 1995) and those that aim to identify the mechanisms underlying the disorder to target clinical management (McKenzie, 1981; O'Sullivan, 2005; Sahrmann, 2001). *Psychosocial* based approaches consider a variety of psychological predispositions and diagnoses (e.g. fear-avoidance beliefs, depression) and social dimensions (e.g. social support, compensation status) (Jones, Edwards, & Gifford, 2002; Main & Watson, 1999). Few systems are validated or reflect a complete biopsychosocial model of NSCLBP.

Multi-dimensional classification systems use a broad range of biomedical, psychological and social inputs to determine sub-groups; examples of these are the Quebec taskforce (Spitzer, 1987) and the INTERMED classification systems (Huyse, de Jonge, Lyons, Stiefel, & Slaets, 1999; Stiefel et al., 1999). However, these systems lack clinical utility as they are too broad.

Following any approach for sub-classification of LBP does not deny that others are valid or have clinical utility. Nor is there any data which directly compares different approaches and hence makes recommendations for use of one over another. Where some approaches have strengths in research or diagnostic settings others have greater clinical utility; and in these regards, the development of classification systems for

NSCLBP is still in its infancy. Buchbinder and colleagues describe a process to critically appraise classification systems consisting of seven criteria: appropriateness of purpose; content validity; face validity; feasibility; construct validity; reliability; and generalisability (Buchbinder, Goel, Bombardier, & Hogg-Johnson, 1996).

Those classification systems that provide a mechanism underlying the disorder provide opportunity for targeted clinical management. The treatment approaches from these systems are designed to reduce the cumulative stress on low back tissues of repetitive pain inducing postures and movements (Maluf, Sahrmann, & Van Dillen, 2000; Van Dillen, Maluf, & Sahrmann, 2009) and are, more often than not, the purview of the physiotherapy profession. While the McKenzie, O'Sullivan and Sahrmann approaches all meet criteria for appropriateness of purpose and feasibility they meet the other criteria in variable ways. The McKenzie system has been shown to have acceptable reliability (kappa coefficients 0.44-1.00) (Petersen et al., 2004) but the categories are more limited in terms of validity and feasibility (Petersen et al., 2004) and it his a strong pathoanatomic basis and lacks clear guidelines for management (Vibe Fersum, O'Sullivan, Kvale, & Skouen, 2009). The Sahrmann approach has good demonstrated reliability and validity for the specific tests used (Van Dillen et al., 1998; Van Dillen et al., 2003) but no work has been conducted to determine how reliably clinicians can classify patients into the five recognised categories (Vibe Fersum et al., 2009). Further, the Sahrmann approach focuses on the movement disorder and does not consider patho-anatomic or psychosocial dimensions (Vibe Fersum et al., 2009).

A classification system has been proposed by O'Sullivan (2000) which is based on the Quebec task force classification system and viewed from a biopsychosocial perspective. This system differentiates between specific LBP versus NSLBP; and those with NSLBP are further categorized based on central or peripheral mediation of pain. This classification system sub-groups patients with localised mechanical provoked LBP (peripheral nociceptive mediation) based on their pain and posture and movement behaviours (O'Sullivan 2005; Dankaerts et al. 2006c). It is hypothesised, that these patients have impairments in the control of their lumbar spine that expose them to repeated stress and strain, thereby providing a basis for ongoing pain. Five distinct clinical patterns are proposed, based on a specific

direction of motor control impairment and the hypothesised mechanism underlying the pain disorder (O'Sullivan, 2004, 2005; Ohlen et al., 1989), these are outlined in Table 2-3.

Flexion Pattern	Definition: Motor control impairment of the lumbar spine with loss of regional lordosis at the symptomatic segment. Flexion pattern disorders are associated with functional loss of motor control into flexion resulting in an excessive abnormal flexion strain Movements and postures involving flexion or the lumbar spine aggravate NSCLBP symptoms Lumbar spine lordosis relieves pain (e.g. standing, sitting with a lumbar roll, walking) Pain provocative postures and functional tasks associated with a flexed lumbar spine (e.g. sitting, lifting and forward bending)
Flexion/Lateral Shifting Pattern	Definition: Motor control impairment of the lumbar spine with a tendency to flex and laterally shift at the symptomatic region Movements and postures involving flexion and rotation in one direction aggravate NSCLBP symptoms Spinal extension and lateral flexion to the opposite side from the shift relieves pain Provocative postures and functional tasks associated with a flexed lumbar spine involve a tendency towards lateral trunk shift during the movement and loading
Active Extension Pattern	Definition: Motor control impairment of the lumbar sine with tendency to hold the lumbar spine actively into hyperlordosis Movements and postures involving extension of the lumbar spine aggravate NSCLBP symptoms Spinal flexion relieves pain (e.g. crook lying or slump sitting) Provocative postures and functional tasks associated with active hyper-extension of lumbar spine (erect sitting, standing, overhead activities, running, swimming)
Passive Extension Pattern	Definition: Motor control impairment of the lumbar spine with a tendency to passively over extend at the symptomatic region of the lumbar spine Movements and postures involving extension of the lumbar spine aggravate NSCLBP symptoms Spinal flexion relieves pain Provocative postures and functional tasks associated with passive hyper-extension of the lumbar spine with segmental hinging at the symptomatic region (e.g. sway standing)
Multidirectional Pattern	Definition: Motor control impairment of the lumbar spine of a multi-directional nature Both flexion and extension provoke NSCLBP symptoms Neutral spinal postures relieve pain Provocative postures and functional tasks associated with either flexed or hyper-extended lumbar spine (e.g. slump sit, squatting and sway stand)

Table 2-3 – Definition and clinical presentation of each clinical pattern of motor control impairment with NSCLBP adapted from Dankaerts et al. 2004.

Evidence for the validity of this classification system includes *adult* studies documenting differences between sub-groups in altered spinal posture (Dankaerts et al., 2009; Dankaerts, O'Sullivan, Burnett, & Straker, 2006b) and motor control deficits (Dankaerts et al., 2006a) in sitting, standing and forward bending. Recent research has demonstrated that clinicians can reliably classify patients using this system (Dankaerts et al., 2006c; Vibe Fersum et al., 2009).

To date there is no strong evidence as to whether these specific sub-groups exist in adolescent NSCLBP populations, although there is a recent finding that adolescent female rowers with pain sensitivity to flexion associated with rowing and whom sat with more flexed spinal postures had poorer back muscle endurance (Perich et al., 2009). Furthermore, sub-groups of adolescents based on differences in standing sagittal spinal posture have been identified. Those with increased (hyperlordotic and sway standing) and decreased lumbar lordosis (flat back) had an increased risk for LBP (Smith et al., 2008). This would infer that, similar to what has been identified in adults, sub-groups of NSCLBP based on provocative postures and motor control impairments may also exist in adolescents. However, to date the findings from adult subjects (Dankaerts et al., 2009; Dankaerts et al., 2006a, 2006b) have not been investigated in adolescents in any detail. No classification system for NSCLBP has been used in other than adult groups; use of the O'Sullivan classification system in an adolescent population will provide some evidence of its generalisability for use in broader clinical settings.

SUMMARY

- In adults, NSCLBP can be considered a collection of sub-groups based on different clinical criteria.
- A classification system based on spinal posture and the movement direction that aggravates LBP has been shown to be valid in sub-grouping adult patients with NSCLBP.
- Deficits in motor control have been identified between adult sub-groups of NSCLBP and healthy adult controls.

SUMMARY (con't)

- There is no strong evidence that specific sub-groups exist in adolescent NSCLBP populations, however some evidence suggests that this might be so.
- No classification systems have been used to investigate adolescent populations with NSCLBP.

Sub-group differences in sitting

Investigating sitting posture in *adults*, Dankaerts and colleagues (Dankaerts et al., 2006a, 2006b) found two distinct sub-groups of NSCLBP, active-extension and flexion, to be different from healthy adults with no LBP. Specifically, compared to adults with no LBP, the active-extension sub-group sat with an increased lordosis and the flexion sub-group sat more kyphotic through the symptomatic lower lumbar spine (Dankaerts et al., 2006b). The two sub-groups can be considered to be sitting at opposite ends of the lumbar posture spectrum with more mid-range neutral postures in the pain free controls. Further, both sub-groups had less available range to actively move from their usual sitting posture to slump sitting (Dankaerts et al., 2006b). In the flexion group this was due to already sitting in flexion and toward end-of-range, while the active-extension group displayed an inability to relax away from extension (Dankaerts et al., 2006b).

Altered levels of trunk muscle activity during sitting have been reported in *adults* with NSCLBP. However, differences between those with and without NSCLBP were only evident when sub-grouped, based on O'Sullivan's classification system (Dankaerts et al., 2006a, 2006b). The active-extension sub-group displayed higher levels of co-contraction of superficial lumbar multifidus, iliocostalis lumborum and internal oblique when compared to the pain-free and flexion sub-group. The flexion sub-group displayed trends for lower levels of trunk muscle activity compared to the pain free group (Dankaerts et al., 2006a).

Sub-group differences in standing

Based on differences in standing spinal posture, postural groups have been identified in *adults* (Norton et al. 2004; Roussouly et al. 2005) and adolescents (Smith et al., 2008). Conflicting results between previous studies for trunk muscle activation during quiet standing may be linked to the presence of different sub-groups of LBP (Danneels et al. 2002; Dankaerts et al. 2009). However, no differences between sub-groups of NSCLBP were shown in a recent study of adults in standing (Dankaerts et al., 2009).

Sub-group differences during forward bending

Using O'Sullivan's classification system a recent study of *adults* identified that lower lumbar angle late in forward bending, sacral angle at mid-range forward bending and activation levels of superficial lumbar multifidus at end-range forward bending were able to discriminate between sub-groups of NSCLBP and healthy controls. These results suggest that there are two different underlying motor control patterns in the active-extension and flexion-pattern sub-groups during forward bending (Dankaerts et al., 2009). Sub-group differences during forward bending have not been examined in adolescents as yet.

Sub-group differences in spinal repositioning

No studies have investigated differences in sub-groups of NSCLBP during spinal repositioning tasks either in adult or adolescent populations.

SUMMARY

- Different postural groups have been identified in adolescents during standing and in adults in sitting, standing and forward bending.
- Differences in sitting posture and levels of trunk muscle activity are only noted when adult patients with NSCLBP are sub-grouped based on O'Sullivan's classification system.
- No studies to date have investigated detailed posture and trunk muscle activation in sub-groups of adolescents with NSCLBP.

2.11 SUMMARY

Despite numerous studies that have investigated the prevalence of LBP in adolescent populations and associated physical and psychological factors, very few studies have examined the problem of NSCLBP in detail in this cohort. Of those that have, even fewer have examined the multiple dimensions of adolescent LBP within a biopsychosocial framework. Unlike previous research in adults, little detailed comparative information is known about posture and trunk muscle activation between adolescents with and without LBP.

Limited information is known concerning CLBP and adolescence despite previously documented high rates. In the psychological domain, CLBP in adolescents has been shown to be associated with emotional distress and depression; while catastrophising as a coping mechanism has been linked with greater disability. Stressful experiences in childhood are associated with increased risk of CLBP later in life. In the social domain, a familial chronic pain history is associated with greater risk for CLBP in adolescents. In the physical domain, CLBP is associated with playing some sports and, specifically in girls, reduced static and dynamic balance. Current evidence on CLBP in adolescents supports that LBP in young populations is most likely dominated by psychosocial factors rather than physical factors (Watson et al., 2003). However, caution should be drawn due to the limited nature of prior investigations in the physical domain.

Adolescent LBP is a prevalent, recurrent condition that increases with age. While significant levels of pain are associated with LBP only a small group are significantly disabled. Adolescent LBP is associated with recurrence in adult life. A wide variety of psychological (stress, depression, poor conduct); social (low support levels); lifestyle (smoking, alcohol, obesity); and physical factors (being sedentary, high activity levels, low and high back endurance; sitting and standing posture) have been associated with LBP during adolescence. The most common aggravating factors include sitting, lifting, forward bending and carrying heavy objects or a school bag. Curvilinear relationships suggest that too much or too little flexibility, trunk endurance or physical activity is associated with LBP in adolescents. The combination of both physical and psychosocial risk factors suggests that this

important health issue should be investigated within a biopsychosocial framework and from a multidisciplinary basis (Balague et al., 2003).

Despite evidence linking LBP in adolescents to certain functional tasks, including sitting and forward bending, there are no detailed reports investigating motor control strategies in either task, including kinematic analyses, trunk muscle activation levels or measures of postural control of the trunk such as proprioception.

Based on findings for differences in adolescent posture profiles in standing associated with LBP, evidence suggests that specific sub-groups of adolescents with NSCLBP may exist. Yet the different clinical sub-groups previously identified in adults with NSCLBP based on directional sensitivity related to altered spinal postures and motor control, have not been investigated in detail in adolescents. It is therefore not known whether the patterns observed in adults with NSCLBP are also displayed by adolescents with the same disorder.

The purpose of the research described in this dissertation is to address current shortcomings in the literature regarding investigations into NSCLBP in adolescents using a multiple domain approach within a controlled laboratory setting. The primary emphasis of this research is to investigate spinal motor control during functional postures and movements. Investigating NSCLBP in adolescence is important as outcomes may inform management of this disorder and assist in identifying strategies to prevent the later progression of NSCLBP to adulthood.

2.12 AIMS

It is the overall aim of this thesis to investigate NSCLBP during adolescence, a period of rapid growth and change, from within a biopsychosocial framework and identify differences between adolescents with and without NSCLBP.

A series of four studies, that investigated different attributes of NSCLBP in adolescence were designed and conducted. The first study investigated this condition from a biopsychosocial perspective, while the remaining studies examined in detail the trunk motor control of common functional postures and movements as well as spinal repositioning sense.

Data for these cross-sectional studies were collected at three different sampling points: during the 14 year Raine Study Assessment; during the screening telephone interview; and, the majority, during one laboratory session. Measures taken at each date point are clearly identified at Table A-4 in Appendix 1. The four studies, outlined below, addressed two main aims. Aims, studies and specific objectives of each study are outlined as follows.

Aim 1 – to investigate a small group of adolescents with NSCLBP from a biopsychosocial perspective.

Study 1 - A detailed characterisation of pain, disability, physical and psychosocial features.

The specific objectives of this study were to:

1.1. Document pain, disability and kinesiophobia in adolescents with NSCLBP (pooled and sub-classified).

1.2. Investigate whether differences exist between the NSCLBP and asymptomatic groups, based on physical and psychosocial factors.

1.3. Investigate whether differences between the NSCLBP and asymptomatic groups in physical and psychosocial factors are clearer when NSCLBP is sub-classified.

Aim 2 – to investigate trunk motor control associated with pain provocative spinal postures and movements in a detailed laboratory based study of adolescents with and without NSCLBP and sub-groups of NSCLBP. This was the main aim of this dissertation.

Study 2 – Spinal and trunk muscle activity in adolescents with and without non-specific chronic low back pain – an analysis based on sub-classification.

The overall aim of this study was to investigate whether spinal kinematic and trunk muscle activity differences exist in both usual and slump sitting between adolescents with NSCLBP (when considered as a whole and when sub-classified) compared to an asymptomatic group.

The specific objectives of this study were to:

2.1. Compare sitting spinal postures between adolescents with NSCLBP (pooled and sub-classified) and asymptomatic groups.

2.2. Compare differences between adolescents with NSCLBP (pooled and sub-classified) and asymptomatic groups in trunk muscle activation patterns in usual sitting and slump sitting.

2.3. Investigate the flexion-relaxation phenomenon in sitting in adolescents with NSCLBP (pooled and sub-classified) and asymptomatic groups.

Study 3 - Kinematic and muscle activity analysis of standing and forward bending in adolescents with and without non-specific chronic low back pain.

The overall aim of this study was to investigate whether spinal kinematic and trunk muscle activity differences exist in standing and forward bending between adolescents with NSCLBP (when considered as a whole and when sub-classified) compared to an asymptomatic group.

The specific objectives of this study were to:

3.1. Compare standing postures and kinematic forward bending profiles between adolescents with NSCLBP (pooled and sub-classified) and asymptomatic groups.

3.2. Compare through-range and end-range forward bending, and lumbar spine range-of-motion when standing and forward bending between adolescents with NSCLBP (pooled and sub-classified) and asymptomatic groups.

3.3. Compare trunk muscle activation during standing between adolescents with NSCLBP (pooled and sub-classified) and asymptomatic groups.

3.4. Compare trunk muscle activation during forward bending between adolescents with NSCLBP (pooled and sub-classified) and asymptomatic groups.

3.5. Investigate the flexion-relaxation phenomenon during forward bending in adolescents with NSCLBP (pooled and sub-classified) and asymptomatic groups.

Study 4 - Lumbar spine repositioning sense in adolescents with and without NSCLBP.

The overall aim of the study was to investigate whether proprioceptive differences, as measured by spinal repositioning sense, exist between adolescents with NSCLBP (when considered as a whole and when sub-classified) compared to an asymptomatic group.

The specific objectives of this study were in an adolescent population to:

4.1. Compare differences in directional bias, accuracy and repeated precision of lumbar spine repositioning between adolescents with NSCLBP (pooled and sub-classified) and asymptomatic groups.

4.2. Investigate differences in spinal repositioning sense in upper and lower lumbar spine regions for adolescents with NSCLBP (pooled and sub-classified) and asymptomatic groups.

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CHAPTER 3 – METHOD DETAILS

As there were some similarities between studies, and due to the brevity required for journal articles, a detailed description of the methods of each of the four studies is provided here.

3.1 SUBJECT RECRUITMENT

3.1.1 Participants

Adolescent participants were drawn from the Western Australian Pregnancy Cohort (Raine) Study, an ongoing longitudinal health research project of 2868 children born at King Edward Memorial Hospital, Perth, Australia which started in 1989. The hospital is the only tertiary maternity hospital in Western Australia, receiving patients from a broad community cross-section including representative socioeconomic and ethnic groups from metropolitan, rural and remote localities. The initial cohort was selected to examine the effects of ultrasound imaging and mothers were initially assessed at 18 weeks of pregnancy. After the children were born, they were assessed at birth and then at one, two, three and five years of age for height, weight, eating habits, motor and speech development, behaviour and information on medical conditions or illnesses. Further follow-ups of the cohort were conducted at eight, ten, fourteen and seventeen years of age. At each follow-up information was collected from both parents or primary caregiver and the child.

The fourteen year survey (2003-2006) was the first to document the prevalence of specific musculoskeletal conditions, including low back pain. Specific measures at this time were levels of physical activity, fitness and motor competence, cardiovascular health, lung function tests, diet, skin prick test for allergies, blood pressure, height, weight and mental health including depression, anxiety, behaviour, family stresses and functioning. The wealth of developmental, environmental and health information collected over the past 20-years provides a extensive database of many factors around the life of children and families; and represents a unique source of information to study health issues with complex causal pathways.

The Raine Study Executive Committee encourages the research community to investigate the cohort through access to the data set. Access to the cohort is tightly controlled to ensure that over burden on participants does not occur and all access is achieved through collaboration with members of an existing project group.

The Raine Study musculoskeletal group is investigating the development of back and neck pain from child to adulthood and evaluating the relative contributions of risk factors from physical (posture, fitness, motor competence, body composition), lifestyle (computer and TV use, physical activity, school bag use, diet, drug and alcohol use) and psychosocial (depression, anxiety, stress, coping, fear of movement, back pain beliefs, carer, family function, socioeconomic status) domains. It is aimed that this research will contribute toward more effective prevention and intervention studies. This doctoral research forms the detailed laboratory study of this large body of work.

In 2006 a list of potential NSCLBP subjects were identified based on data collected from them in the Raine Study 14 year survey (2003-2005). Subjects were approached from across the socioeconomic spectrum, with priority given to those that lived within the metropolitan area of Perth. Given parents of subjects were residents of Australia in 1989, all potential subjects were at least first generation Australians. Potential subjects were ordered based on Raine Study identification number, lowest to highest, and approached consecutively via phone interview to determine whether they met all of the inclusion criteria and none of the exclusion criteria, outlined in Table 3-1.

Inclusion Criteria	Exclusion Criteria
Male or Female Age: 14-16 years BMI: <28 kg/m^2 * Pain Group: • History of NSCLBP ≥ 12 weeks duration • Without peripheral pain referral • Pain in the area from T12 to gluteal folds • Moderate ongoing LBP o Average daily pain level - VAS > 3/10 o Experienced most days of the week • Mechanically induced localised LBP Control Group: • No history of spinal pain (* required for successful superficial EMG recording)	Specific diagnosis associated with LBP such as spondylolisthesis, disc prolapse, inflammatory disorders Presence of other conditions affecting the spine including neurological or metatastic disease Any neurological deficit Any surgery involving the lumbar spine Any diagnosed pelvic or abdominal pain disorder in the last 12 months Pregnancy or less than six months post-partum Any lower limb surgery in the last 2 years Current lower limb injury An inability to understand written or spoken English Inability to assume test postures

Table 3-1 - Inclusion and Exclusion Criteria at time of recruitment

A limitation imposed by the hospital ethics committee to prevent subject overburden was that girls could not be involved both in this study of low back pain and an additional study being conducted concurrently; the additional study was given recruitment priority. Potential subjects who were both suitable and interested were forwarded study information sheets (Appendix 1). At a subsequent telephone call those who were willing to be involved were recruited to the study. Figure 3-1 provides a diagrammatic representation of recruitment flow.

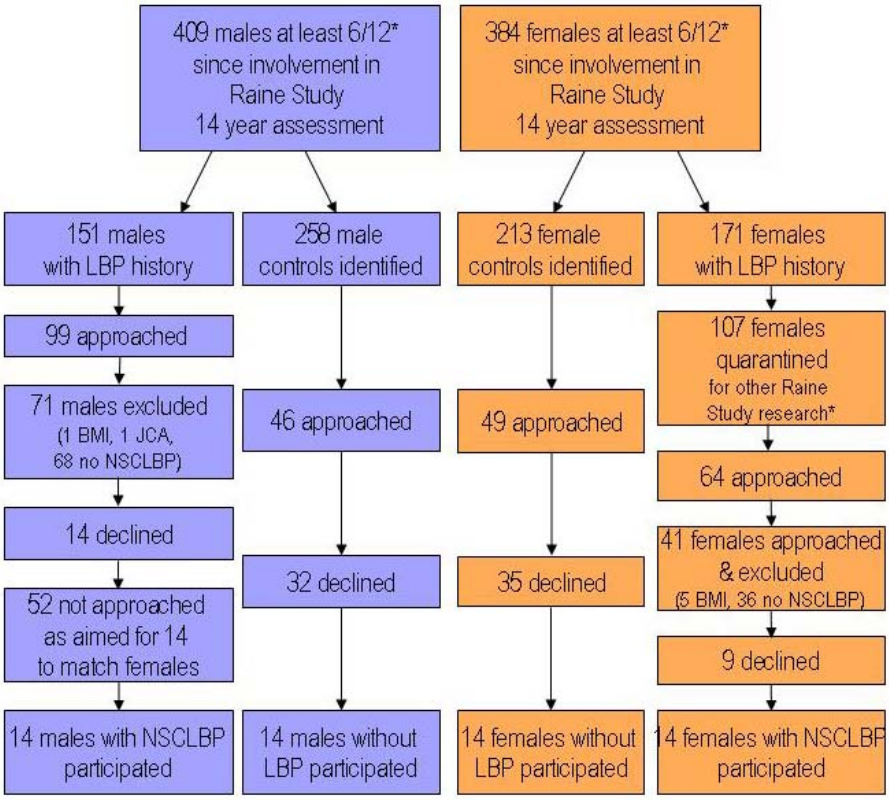

Figure 3-1 – Subject selection flow diagram

*Conditions required by ethics approval

6/12 – 6 months; LBP - Low back pain; BMI – Body mass index; JCA – Juvenile chronic arthritis; NSCLBP – Non-specific chronic low back pain; LBP – Low back pain

Potential subjects were excluded primarily due to insufficient levels of NSCLBP, either it had resolved since reporting it at the 14 year Raine Study assessment or on subjective assessment did not meet the inclusion criteria of current daily average pain at least 3/10 or pain was experienced sporadically. Five females and one male were excluded based on body composition (BMI); this was estimated during telephone interview and subjects were only excluded at this point if BMI was estimated to be greater than 32 kg/m^2. One

male subject was excluded due to suffering juvenile chronic arthritis. Twenty-three potential subjects with NSCLBP (14 males and 9 females) declined to participate in this doctoral study. As maintaining the ongoing relationship between subjects and participation in the Raine Study is of paramount importance, subjects were not cajoled into participation in this additional study into NSCLBP and no reasons for refusal were sought. From telephone interviews only 14 girls with NSCLBP were suitable and willing to be involved in this study. Given the identified differences in the literature between gender and sub-classification of NSCLBP it was decided a priori to keep the group of subjects with NSCLBP gender balanced, hence only 14 boys with NSCLBP were recruited.

A description of the pain group is the subject of Chapter 4, however without attempting to pre-empt the results of this chapter, all subjects with NSCLBP had current pain and had experienced ongoing but not necessarily constant NSCLBP on average for 26.6 ± 12 months. In accordance with the inclusion criteria the primary area of NSCLBP needed to be between T12 and the gluteal folds; experienced most days, 4 or more, of each week; and for a minimum of the previous 12 weeks. Findings from the subjective assessment concerning the pain experience of the subject were confirmed with the parent/caregiver.

A comparable control group of adolescents were identified from the 2003-2005 data on the basis of comparable gender, age (± 6 months), pubertal stage (Tanner & Whitehouse 1976; Tanner 1986) and socio-economic status (Australian Bureau of Statistics Index of Relative Socio-Economic Advantage/Disadvantage index (± 1 quartile) (Trewin, 2001), with 28 recruited to the study. The sample was thus drawn from a broad range of socio-economic groups with no bias evident in the sample. Subjects were selected on willingness and suitability: by chance, and not design, all were white Australians except for one girl with NSCLBP who was of southern Asian heritage.

As the Raine Study cohort was consecutively sampled from the sole tertiary women's hospital in Perth Western Australia they cannot be considered a random sample. Many of characteristics the Raine Study cohort are within a few percentage points of population expectations, however some are not (Kendall, 2003).

Relative to the general Western Australian population differences at birth included larger proportions of low birth weight children and children born before 37 weeks gestation, those who took greater than two minutes to breathe following birth and women who had elective or emergency caesarean section delivery as well as an over representation of twins and triplets. The sample generally started life with a higher level of developmental risk. In terms of family dynamics the cohort displayed a significantly higher proportion of mothers were less than 20 years at time of giving birth and families which were significantly more likely to have an absent father. The occupations of fathers in the cohort differed from the general Western Australian population, with a significantly higher representation of professionals (Kendall, 2003).

After nine years there was a significant decrease in the group that were left to follow up in numbers of participants from multiple births, those whose mother was less than 20 years of age at delivery and whose father was not living with the family (Kendall, 2003).

	NSCLBP (pooled) (n=28)	Control (n=28)	NSCLBP (sub-classified)	
			Extension (n=13)	Flexion (n=15)
Age (years)	15.4 ± 0.5[#]	15.7 ± 0.5[#]	15.4 ± 0.6	15.4 ± 0.5
BMI (kg/m^2)	22.2 ± 3.5	21.2± 2.6	22.8 ± 4.2	21.6 ± 2.8
Index of Relative Socio-Economic Advantage/ Disadvantage	988.9 ± 59.7	979.8 ± 61.9	984.8 ± 51.6	989.1 ± 69.0
Developmental Stage				
Genital	3.5± 0.5	3.4 ± 0.6	3.5 ± 0.5	3.5 ± 0.5
Breast (Girls only)	3.9 ± 0.7	3.8 ± 0.8	3.8 ± 0.6	4.0 ± 0.8
No. female subjects	14	14	10 [$]	4 [$]
No. male subjects	14	14	3[$]	11 [$]
Usual pain (VAS out of 10)	4.4±1.9		5.0±1.3	3.9±2.1
Pain duration (months)	26.6±12		22.8±13.6	29.6±10.0
Kinesiophobia (total score 68)	36.1±10.1		35.9±4.6	36.1±8.7
Disability (%)	17.9±10.1		16.5±7.1	19.0±11.9
Pain area below L3 only			3 [†]	10 [†]
Pain area above and below L3			10 [†]	5 [†]

*All measures were recorded during laboratory testing session in 2006/07.

Values are Mean ± SD

[#] $t_{df} = -2.010_{54}$, p=0.049; [$] $\chi^2 = 7.036_2$, p=0.030; [†] χ^2=5.32, p=0.030

Table 3-2 - Sample Description*

*All measures were recorded during laboratory testing session in 2006/07

Developmental stage was measured with the Tanner Scale of Pubescent Staging. The scale measures genital development on a scale of 1 – 4 and breast development on a scale of 1 – 5 (Tanner & Whitehouse 1976; Tanner 1986) (Appendix 2). Use of the Tanner Scale to measure sexual development was a condition of the Raine Study Executive Committee and was previously included in the 14 year assessment. The Tanner Scale is a self-report scale. Subjects are asked to identify from line diagrams their stage of genital and breast development. The scale was included with consent forms and other questionnaires measuring pain levels, kinesiophobia, disability and pain area; and was completed in a private area of the laboratory. Subjects were given a folder to place all completed questionnaires within; the main investigator discretely checked for satisfactory completion during laboratory testing. No subjects refused to complete the Tanner Scale. The index for socio-economic status is part of the Australian Bureau of Statistics Socio-Economic Indexes for Areas, which is based on postal area (Trewin, 2001).

These factors were selected to limit their potentially confounding effect and thus strengthen the study. Pubertal stage and socio-economic status measures were repeated at time of data collection for this study during one laboratory session at the School of Physiotherapy, Curtin University of Technology through 2006 and early 2007. Controls did not differ from pain subjects on body mass index (BMI), developmental stage and socio-economic status, but were older by 3 months (t_{df}=-2.010$_{54}$, p=0.049), see Table 3-2.

3.1.2 Sample size

Prior adult studies showed two groups of N=28 had sufficient power (>90%) to identify differences in trunk extensor endurance (Latimer, Maher, Refshauge, & Colaco, 1999), spinal angles (Dankaerts, O'Sullivan, Burnett, & Straker, 2006b) and trunk muscle activation (Dankaerts, O'Sullivan, Burnett, & Straker, 2006a) in both usual and slump sitting, forward bending range-of-motion and trunk extensor activation during forward bending (Kaigle, Wessberg, & Hansson, 1998), a flexion-relaxation ratio during forward bending (Paquet, Malouin, & Richards, 1994) and lumbosacral repositioning errors in sitting (Brumagne, Cordo, Lysens, Verschueren, & Swinnen, 2000; O'Sullivan et al., 2003). Group sizes had sufficient power to detect differences of at least a half of one standard deviation in the above measures. There were no previous studies of adolescents that have used these laboratory based measures to quantify aspects of change to the

biomechanical system with LBP. Preliminarily results from concurrent research of adolescents and young adults (Mitchell, O'Sullivan, Burnett, Straker, & Smith, 2008; Perich, Burnett, O'Sullivan, & Perkin, 2009) within the School of Physiotherapy, Curtin University showed that similar measures were useful in discriminating between those with and without pain. As the ethics approval only allowed subjects to attend the university for one 2-hour testing session, rather than limiting the use of scarce subjects to a separate reliability trial it was determined to implement the full laboratory investigation based on power previously determined in adult studies and establish the utility of these methods in adolescents prior to future studies.

3.1.3 Ethics and consent

This research was approved by the Human Research Ethics Committees of Curtin University of Technology and King Edward and Princess Margaret Hospitals, Perth, Western Australia, see Appendix 3. All parents and adolescent subjects provided written informed consent/assent prior to testing. Copies of subject and parental information sheets and consent forms are included at Appendix 1.

3.1.4 Measures

A Pain group only

Pain level

Current and usual pain intensity were measured with a Visual Analogue Scale (VAS). This has high test-retest reliability in adolescents (Stinson et al. 2006) and good validity (von Baeyer, 2009; Williamson & Hoggart, 2005). A copy of the VAS used in this research is at Appendix 4.

Pain area

To determine whether NSCLBP was located primarily in the upper or lower lumbar spine each participant with pain completed a body chart, shading any areas in which they experienced pain. The location of NSCLBP was classified as ‘below L3’ or ‘above and below L3’. Subjects were orientated by identifying various landmarks marked on the chart to the location of these anatomical structures on their body. Commonly identified landmarks were inferior margin of the scapulae and the iliac crests. Body charts have been previously used to indicate area of pain and subsequent classification into pain

regions (Kvale, Skouen, & Ljunggren, 2005). A copy of the body chart used in this research is at Appendix 5.

Disability

Disability was assessed with the Modified Oswestry Disability Questionnaire (Fairbank, Couper, Davies, & O'Brien, 1980). The questionnaire was modified for use in minors by removing the question concerning affect of pain on sex-life (Perich, Burnett, & O'Sullivan, 2006). The design of the questionnaire enables deletion of a question without affecting its validity. The questionnaire was thus measured out of 45 for the remaining 9 questions and converted to a percentage - representing percentage of disability. The Oswestry is reliable and valid for use in adults (Fairbank et al., 1980) and has previously been used in adolescents to determine differences during an intervention study to improve back pain in adolescent female rowers (Perich et al., 2009). A copy of the Modified Oswestry Disability Questionnaire used in this research is at Appendix 6.

Kinesiophobia

Fear avoidance behaviour was quantified by the Tampa Scale of Kinesiophobia (TSK). The TSK measures fear of movement and re-injury. The 17 questions are answered on a 4-point Likert style scale, ranging from 'strongly disagree' to 'strongly agree'. A total score is calculated after inversion of the individual scores of questions 4, 8, 12 and 16. Scores range from 17, indicating no kinesiophobia, to 68 (Lundberg, Styf, & Carlsson, 2004). A score greater or equal to 40 is considered to indicate significant kinesiophobia (Crombez, Vlaeyen, Heuts, & Lysens, 1999). The reliability of the TSK are considered moderate-to-good (Vlaeyen et al. 1995; Swinkels-Meewisse et al. 2003; Goubert et al. 2004), it has good validity (Roelofs et al. 2004) and has previously been used with adolescents (Perich et al., 2006). A copy of the TSK used in this research is at Appendix 7.

Subjective clinical assessment

The history of the disorder and its nature was ascertained during telephone interview which determined subject suitability. Usual pain intensity and duration, aggravating factors (specifically pain provoked with mechanical loading during sustained postures or physical activity) and type and frequency of organised sporting activities participated in were recorded by the interviewer. Additional data concerning LBP associated with sport

and while carrying a school bag were taken from the Raine Study 14 year survey. Standard telephone interview questions are included at Appendix 8.

Functional movement assessment

A video recording from a single camera was taken of each subject with NSCLBP during functional postures and movements (standing, standing to sitting, usual sitting, slump sitting, return to usual sitting, sitting to standing, standing, left leg single-leg-stance, right leg single-leg-stance, standing, forward bending and return to standing, backward bending and return to standing). This sequence was completed twice to record movements from both posterior and postero-lateral views as described by Dankaerts and colleagues (Dankaerts, O'Sullivan, Straker, Burnett, & Skouen, 2006c).

Sub-classification

Pain subjects were classified based on the direction of pain provocation by a specialist musculoskeletal physiotherapist who was independent from data collection. Classification was based on a review of each subject's subjective pain behaviour information and functional movement assessment from video analysis to determine the direction of pain provocation using the O'Sullivan system (O'Sullivan, 2005). The classification system is described in more detail elsewhere (O'Sullivan, 2005) and has been found to be both reliable and valid (Dankaerts et al., 2006c; Vibe Fersum, O'Sullivan, Kvale, & Skouen, 2009). Two separate studies have investigated inter-examiner reliability of classifying subjects into sub-groups: in the first study kappa co-efficient and percentage agreement had a mean between thirteen testers of 0.61 (range 0.47-0.80) and 70% (range 60-84%) respectively (Dankaerts et al., 2006c) while in a more recent study kappa co-efficient and percentage agreement had a mean between four testers of 0.82 (range 0.66-0.90) and 86% (range 73-92%) respectively (Vibe Fersum et al., 2009). A reasonably substantive body of work provides evidence that this system has face validity (Dankaerts et al., 2006a, 2006b; Dankaerts, O'Sullivan, Burnett, & Straker, 2007; O'Sullivan, 2000, 2005) but more recently this system has been able to demonstrate predictive validity with a statistical classification model being able to classify 96.4% of cases and being able to discriminate between sub-groups of NSCLBP, healthy controls and each other based on laboratory analysis of posture and movements commonly reported as aggravating LBP (Dankaerts et al., 2009).

The identified sub-groups used in this research were 'extension pattern', 'flexion pattern' and 'multidirectional'. Table 3-3 outlines a summary of clinical features for the three clinical patterns of NSCLBP utilised in this research. Subjects from 'flexion pattern' and 'multidirectional' groups were combined as the mechanism for pain provocation in sitting and forward bending, the primary physical tasks for this research, is the same (Dankaerts et al., 2006c; O'Sullivan, 2004, 2005).

Flexion Pattern	Movements and postures involving flexion or the lumbar spine aggravate NSCLBP symptoms Spinal extension relieves pain Provocative postures and functional tasks associated with a flexed lumbar spine (e.g. slump sit and squatting)
Active Extension Pattern	Movements and postures involving extension of the lumbar spine aggravate NSCLBP symptoms Spinal flexion relieves pain Provocative postures and functional tasks associated with hyper extension of lumbar spine (hyperlordotic sitting and standing)
Multidirectional Pattern	All movement directions (flexion and extension) provoke NSCLBP symptoms Neutral spinal postures relieve pain Provocative postures and functional tasks associated with either flexed or hyper-extended lumbar spine (e.g. slump sit, squatting and sway stand)

Table 3-3 – Clinical Features of Adolescent NSCLBP Movement Control Disorders

Subjects for this research were classified into these patters based on their direction of pain provocation (Dankaerts et al. 2006c, O'Sullivan 2004, O'Sullivan 2005).

B All subjects

Trunk extensor endurance

Trunk extensor endurance was measured using the Biering-Sorensen test. This test requires subjects to be positioned prone over the edge of a plinth at the transverse level of the anterior superior iliac spines. Physical support was provided to the subject by strapping the subject to the plinth with wide webbing belts across both the superior posterior thigh and leg. While moving into the test position and at the end of the trial subjects were able to support their upper body through their arms on a stool placed at the end of the plinth. When ready to begin the test subjects assumed a horizontal trunk position and crossed their arms across their chest with the palms of their hands placed on

their contra-lateral shoulders. The horizontal position was measured via a pendulum goniometer placed between the subjects' scapulae and was defined as ± 10º. Standardized encouragement was given to participants telling them they were doing well and that they should keep going. Feedback on trunk position was provided by goniometer readings every 5-10 seconds. The duration between assuming the horizontal trunk test position until the subject could no longer maintain a horizontal position was recorded (Biering-Sorensen 1984; Latimer et al. 1999). This method for measuring trunk extensor endurance has high reliability in adolescents (Salminen, Maki, Oksanen, & Pentti, 1992), good validity (Moreau, Green, Johnson, & Moreau, 2001) and can discriminate between those with and without adult NSCLBP (Latimer et al., 1999) .

Thigh muscle endurance

Thigh muscle endurance was measured using a squat test. Subjects were positioned on a stool with hips and knees at 90°, they then raised their buttocks slightly off the stool (approximately 5cm), and were asked to maintain this position for as long as they were able. Fatigue for this test was determined when a subject either sat back on the stool or had moved their buttocks more than 15cm from the stool. Time to fatigue was measured. Standard encouragement to continue and feedback on buttock position relative to the stool was provided to each subject throughout the procedure. This test has been used previously to discriminate between adolescents with and without NSCLBP (Perich et al., 2006).

Physical activity

Measures of physical activity were taken as part of the Raine Study 14 year survey. Raine study participants were free to not consent for any part of any assessment and thus not all consented to participate in the physical activity component. 29 subjects (Pain n=12, Control n=17) completed the Multimedia Activity Recall for Children and Adolescents (MARCA) (Ridley, Olds, & Hill, 2006); 'the number of minutes of moderate to vigorous physical activity/week' was used in this analysis. The MARCA has high reliability (ICC=0.94) and exhibits good content and construct validity (Ridley et al., 2006). 24 subjects (Pain n=11, Control n=13) wore a pedometer (Yamax Digiwalker SW200 (Yamasa Tokei Keiki Co. Ltd., Tokyo, Japan), with established reliability and validity (Hands, Larkin, Parker, Straker, & Perry, 2008), for at least three week days and one weekend day. Data was extrapolated to estimate 'total number of steps/week'.

Comparisons on these data were restricted to NSCLBP and control groups as there were insufficient numbers of participants in NSCLBP sub-groups for statistical analysis.

Psychosocial factors

Levels of subject psychological functioning was measured by the Child-Behaviour Checklist - Youth Self Report Form (CBCL) (Appendix 9) and the Becks Depression Inventory (BDI) (Appendix 10); both are reliable and valid (Achenbach, McConaughy, & Howell, 1987; Beck, Steer, & Garbin, 1988; Harris, Tyre, & Wilkinson, 1993; Ivarsson, Gillberg, Arvidsson, & Broberg, 2002). The Child-behaviour Checklist gives a total behaviour problem score and two broad-band sub-scores, externalizing (E) and internalizing (I). The E-scale includes variables such as aggression, disorderly conduct, delinquent behaviour, hyperactivity and cruelty. The I-scale includes variables such as depression, anxiety, withdrawal and somatising. The CBCL is suitable for children between 4 and 18 years (Achenbach et al., 1987; Harris et al., 1993). The BDI measures 21 symptoms and attitudes, rated 0-3. Symptoms and attitudes include mood, pessimism, sense of failure, lack of satisfaction, guilt feelings, sense of punishment, self-dislike, self-accusation, suicidal wishes, crying, irritability, social withdrawal, indecisiveness, distortion of body image, work inhibition, sleep disturbance, fatigability, loss of appetite, weight loss, and somatic preoccupation (Beck et al., 1988). It is scored by summing the ratings given to each of the 21 items (Beck et al., 1988).

The adolescent's primary carer reported the number of stressful life events within the family unit in the two year period prior to testing, including known difficulties with pregnancy, marriage, children, work, finances, loss of a relative/friend, moving house and other issues (Craufurd, Creed, & Jayson, 1990; Tennant & Andrews, 1976).

The general functioning subscale of the McMaster Family Assessment Device (McMaster) (Appendix 11), a self-report measure of family functioning (Byles, Byrne, Boyle, & Offord, 1988), was used. The McMaster and report of stressful life events have demonstrated reliability and validity (Byles et al., 1988; Craufurd et al., 1990; Tennant & Andrews, 1976).

3.2 MEASUREMENT OF POSTURE AND KINEMATICS (ALL SUBJECTS)

Photographic posture method

Sagittal photographs of usual sitting posture with photo-reflective markers had been taken during the Raine Study 14 year survey. Markers placed on C7, T12, ASIS and greater trochanter were used to measure lumbar angle and trunk angle. Photographs were digitized and analysed using Peak Motus 8 (Peak Performance Technologies, Inc., Centennial, CO, USA). Two-dimensional co-ordinates for each marker were used to determine angle measures, corrected for any image vertical offset using a vertical plumbline present in each photo. From these photographs the lumbar angle was defined as the posterior angle between the line of T12 to ASIS and the line of ASIS to greater trochanter; and the trunk angle was defined as posterior angle between the line of C7 to T12 and the line of T12 to greater trochanter. These measures have demonstrated fair to good inter-rater reliability: ICC's for consistency - lumbar angle, 0.491; trunk, 0.806. SEM's were 15.9 to 4.8 degrees respectively (Perry, Smith, Straker, Coleman, & O'Sullivan, 2008).

Three-dimensional lumbo-pelvic kinematics

Measures of spinal kinematics were collected using Fastrak (3-Space Fastrak, Polhemus Navigation Sciences Division, Vermont, USA). Fastrak has a reported accuracy of 0.2º (Maffey-Ward, Jull, & Wellington, 1996). With the subject in slight spinal flexion, sensors were taped to the skin over the spinous processes of S2, L3 and T12 using double sided tape (3M, Pymble, Australia) and secured with Fixomull sports tape (Beiersdorf AG, Hamburg, Germany) (Burnett et al. 2004; Dankaerts et al. 2006b). Data were collected at 25Hz using a customised program in LabVIEW V8.2 (National Instruments Inc., Texas, USA) The following kinematic variables were measured (see also Figure 3-2).

Sacral Angle – the inclination of the S2 sensor to the vertical; a negative angle indicating anterior sacral tilt.

Lower Lumbar Angle – the angle between two intersecting lines, one indicating the inclination of the sensor at L3 and the other the inclination of the sensor at S2. A negative lower lumbar angle indicating lumbar lordosis.

Upper Lumbar Angle – the angle between two intersecting lines, one indicating the inclination of the sensor at T12 and the other the inclination of the sensor at L3. A negative angle indicating lumbar lordosis.

Lumbar Angle – the angle between two intersecting lines, on indicating the inclination of the sensor at T12 and the other the inclination of the sensor at S2. A negative angle indicating lumbar lordosis.

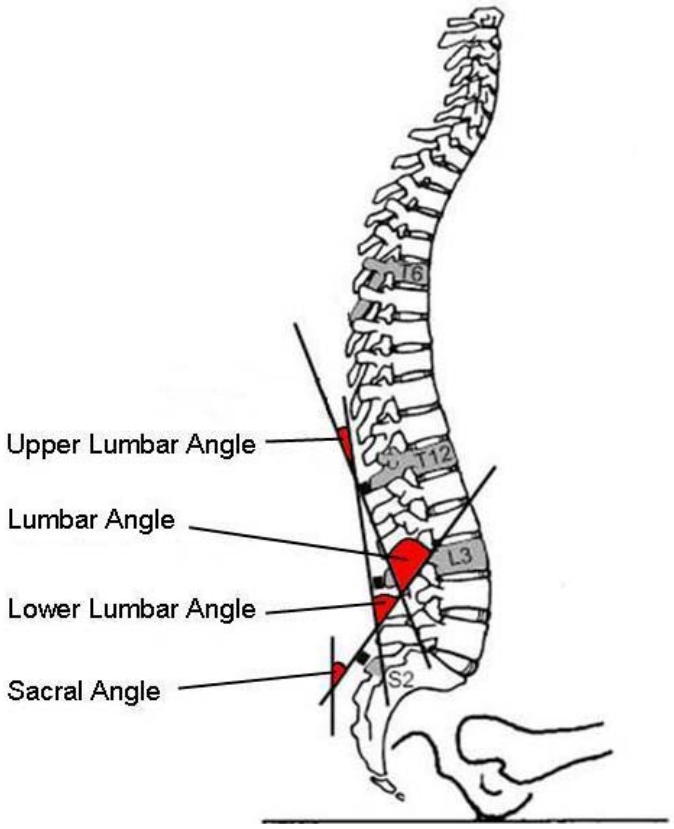

Figure 3-2 – Spinal Kinematic Variables

3.3 MEASUREMENT OF TRUNK MUSCLE ACTIVATION (ALL SUBJECTS)

Surface electromyography (sEMG) was collected bilaterally from three back muscles and two abdominal muscles. Skin preparation included shaving, cleansing with alcohol and lightly abrading with sandpaper to ensure skin impedance was less than 10kΩ (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). Pairs of self-adhesive disposable Ag/AgCl surface electrodes of contact area 1cm^2 (Red Dot, 3M Health Care Products, London,

Canada) were placed parallel to the muscle fibres with a centre-to-centre spacing of 2.5 and positioned as follows:

Superficial lumbar multifidus (multifidus) – parallel to the line between the posterior superior iliac spine and the L1-L2 interspinous space at the level of L5 (De Foa, Forrest, & Biedermann, 1989).

Iliocostalis lumborum pars thoracic (iliocostalis) – midway between the midline and the lateral aspect of the body at the level of the L1 spinous process (Danneels et al., 2002).

Longissimus thoracis pars lumborum (t**horacic erector spinae)** – 5cm lateral to the inferior edge of the T9 spinous process (Dankaerts et al., 2006a).

Transverse fibres of abdominal internal oblique (internal oblique) – 1cm medial to the anterior superior iliac spine (ASIS) and beneath a line joining both ASISs (Ng, Kippers, & Richardson, 1998).

Abdominal external oblique (external oblique) – just below the rib cage and along a line connecting the most inferior point of the costal margin and the contralateral public tubercle (Ng et al., 1998)

Ten channels of sEMG at 1000Hz (bandwidth 10-500HZ, common mode rejection ration >115dB at 60Hz, gain 2000) were sampled with two, eight channel Octopus Cable Telemetric units (Bortec Electronics Inc., Calgary, Canada), one for right sided channels and one for left sided channels. A reference electrode was positioned laterally on the respective right or left iliac crest for each unit. Data was collected using a customised LabVIEW V8.2 program. All channels were visually inspected for heartbeat artefact and where present it was minimised using a fourth-order Butterworth high pass filter with a cut-off frequency of 30Hz (Drake & Callaghan, 2006). Raw EMG data was then demeaned, full wave rectified and band pass filtered (4 - 400 HZ) to generate a linear envelope (Dankaerts et al., 2006a; Dankaerts, O'Sullivan, Burnett, Straker, & Danneels, 2004).

Muscle activation values during each phase were amplitude normalized using the following standardized tasks designed to elicit a stable sub-maximal voluntary isometric contraction (sub-MVIC).

Trunk extensor muscles - subjects lay prone on a plinth, arms by their side and knees bent to 90º, the subject was asked to bilaterally raise their knees from the plinth so that a piece of paper could just pass underneath, they then held this position for 5s.

Trunk flexor muscles - subjects lay in crook lying on a plinth, arms by their side knees at 90º, the subject was asked to bilaterally raise their feet 5cm from the plinth, they then held this position for 5s.

Each task was completed three times. Normalisation values for the three trunk extensors and two trunk flexors studies were calculated as the mean muscle activation level across all three trials. These sub-MVIC normalisation protocols have been shown to be reliable both within-day and between-day (Dankaerts et al., 2004).

3.4 POSTURE AND MOVEMENT TASKS

Three-dimensional lumbo-pelvic kinematic data and trunk muscle activity were recorded during a number of static posture and movement tasks.

Usual and slump sitting

To assess usual and slump sitting, subjects sat on a height adjustable stool (with no back support), hips and knees at 90°, feet positioned shoulder width apart and arms relaxed by their side. To standardize head posture, subjects focussed on a visual target set at eye level 1.5m directly in front. Two sitting positions were investigated: usual sitting - where subjects were asked to 'sit on the stool as you would usually sit'; and slumped sitting – achieved by relaxing the thoraco-lumbar spine and posterior pelvic rotation. Slump sitting was demonstrated by the researcher prior to testing, with no manual feedback provided through the task. Both positions were maintained for five seconds; with three repetitions of the usual/slump/usual sitting task. Sagittal lumbo-pelvic kinematic data and trunk muscle activity were recorded continuously during the task.

Spinal angles were calculated for both usual and slumped sitting postures. The difference between positions, calculated as the slumped sitting spinal angle minus the usual sitting spinal angle, was termed the Spinal Flexion Angle Index (SFAI). Kinematic data was averaged across the three trials for each subject. The intra-class correlation coefficients for kinematic measures ranged from 0.882 to 0.969 with standard error of measures ranging from 1.0 to 1.7º.

The existence of differences in muscle activation levels between left and right sides were examined by use of paired *t*-tests. A significant difference between sides was observed for External Oblique ($p=0.018$) only. For muscles other than External Oblique left and right side data were pooled, whereas, External Oblique was analysed bilaterally. The intra-class correlation coefficients for each EMG-based measure ranged from 0.690 to 0.993 with standard error of measures ranging from 2.6 to 6.0% sub-MVIC.

Flexion-relaxation phenomenon in sitting

Two methods were used to investigate Flexion Relaxation Phenomenon (FRP). A paired *t*-test was used to determine whether a significant difference in muscle activity existed between the usual and slump sitting postures for each muscle within each group. And to allow a direct comparison between groups, a flexion-relaxation ratio (FRR) was calculated by dividing the averaged muscle activation in usual sitting by that in slumped sitting (Burnett et al., 2008; Dankaerts et al., 2006a; Watson, Booker, Main, & Chen, 1997).

Forward bending

Subjects were asked to stand for five seconds in their 'usual' posture, feet shoulder width apart, arms relaxed by their side. Head position in standing was standardised by focusing on a point set at eye level 1.5m directly in front. Subjects were instructed to slowly reach forward toward their toes till they achieved what they perceived was their end of range, they then slowly returned to usual standing. Each phase - standing, forward-bending; end-range forward-bending; return from forward-bending; and standing (phases 1-5 respectively) - lasted five seconds, with the cadence controlled by digital metronome (Figure 3-3). Following familiarization with the timed task, three trials were conducted. This testing procedure has proven to be reliable in adults (Dankaerts et al., 2009). Sagittal

lumbo-pelvic kinematic data and trunk muscle activity were recorded continuously during the task.

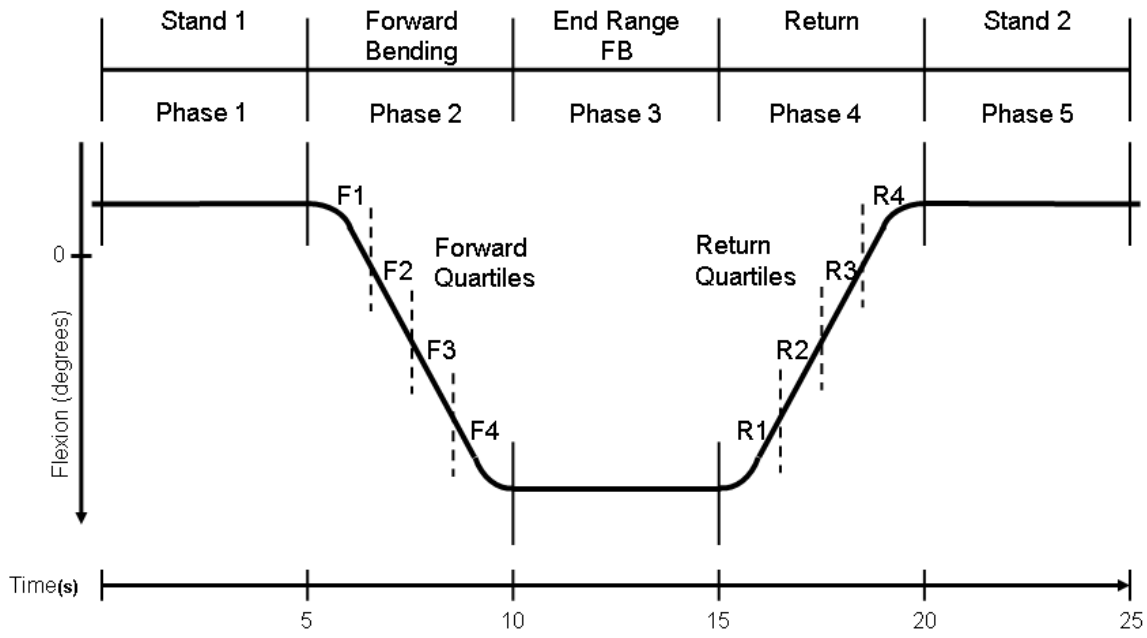

Figure 3-3 – Forward Bending Task - Movement Phases and Quartiles

Static sacral, lower lumbar, upper lumbar and lumbar angles were calculated for usual standing (Phase 1) and end-range forward-bending (Phase 3) as well as the difference between these positions (forward bending range-of-motion). The movement phases 2 and 4 (forward and return) were divided into quartiles based on time, with each quartile measure representing the average position during the respective time epoch (Figure 2). All kinematic measures were averaged across the three trials for each subject. The intra-class correlation coefficients for kinematic measures for phases 1, 3 & 5 ranged from 0.952 to 0.993 with standard error of measures ranging from 1.2º to 18.2º and for forward and return quartiles from 0.733 to 0.972 with standard error of measures ranging from 1.2º to 2.3º.

Normalized muscle activation for each of phases 1, 3 and 5 and for each quartile of the forward and return phases were averaged across the three trials for each subject. Side differences were assessed with paired *t* tests. No differences were found for each pair of muscles hence left and right side results were pooled and the mean value used. The inter-trial reliability for each measure of muscle activation ranged for phases 1, 3 & 5 ranged

from 0.657 to 0.978 with standard error of measures ranging from 2.6 to 8.5 % sub-MVIC and for forward and return quartiles from 0.477 to 0.929 with standard error of measures ranging from 3.4 to 7.2 % sub-MVIC.

Flexion-relaxation phenomenon in forward bending

Due to a lack of consensus in the literature defining the criterion for flexion-relaxation, two flexion-relaxation ratio (FRR) variables were used.

FRR 1. Average muscle activation during Phase 3 divided by that during Phase 2 (Watson et al. 1997; Burnett et al. 2008); for flexion-relaxation to have occurred FRR1 must be less than 1.

FRR 2. Average muscle activation during Phase 3 divided by the peak activation during Phase 4 (Mathieu & Fortin, 2000), (for all muscles the peak occurred during Return Quartile 2 (R2)); for flexion-relaxation to have occurred FRR2 must be ≤0.9 (Mathieu & Fortin, 2000).

3.5 LUMBAR SPINAL REPOSITIONING

Subjects were seated on a soft stool without back support that was height adjusted such that the hip and knee were at 90º flexion, arms were positioned palm-upward on the thighs. They wore shorts and undergarments to reduce sensory input from clothing and a blindfold throughout each trial. Subjects were assisted by the tester to move through their available flexion/extension range of motion three times, they were then positioned by the tester in a neutral upright sitting posture (criterion position) subjects maintained this position for 5 seconds and were asked to remember this position. Subjects were then asked to relax into full lumbar flexion again for 5 seconds before reproducing the criterion position. Prior to testing the task was explained, demonstrated and the subject completed two practice trials. Three measured trials were completed. No feedback on accuracy was provided to subjects between trials. This task has previously been shown to have good reliability in adults both with and without LBP (Lam, Jull, & Treleaven, 1999; Maffey-Ward et al., 1996).

Variables

Three measures were used to estimate repositioning accuracy: constant error (CE), absolute error (AE) and variable error (VE). CE is a measure of bias measured as the signed difference between criterion and finish positions averaged across the three trials. In this study a negative CE indicates overshooting the target. AE is the sign-less difference between positions averaged across three trials. This provides specific information on the accuracy of result but no indication of the direction, i.e. whether the subject under or overshoots (Strimpakos, Sakellari, Gioftsos, Kapreli, & Oldham, 2006). As it has previously been shown that repositioning error in the sagittal plan is equally distributed on either side of the criterion position in neutral (Maffey-Ward et al., 1996), using the absolute value is superior to CE in determining accuracy. VE represents the variability around the average response and represents repeatable precision, it was calculated as the SD of the three trials (Asell, Sjolander, Kerschbaumer, & Djupsjobacka, 2006). If a subject's VE is high they have high variability about their final position, if the VE is low it is not clear without knowledge of the AE how accurate subject's can reposition their spine (Strimpakos et al., 2006).

3.6 DATA COLLECTION

The cross-sectional data for this research was collected at one of three sampling points: during the 14 year Raine Study Assessment; during the screening telephone interview; or at time of laboratory testing. The laboratory testing required each subjects to attend a single two-hour testing session at the School of Physiotherapy, Curtin University of Technology, Perth, Western Australia. Table 3-4 outlines which measures were collected at which sampling point. All information was de-identified before storing.

14 year Raine Study Assessment 2003-2005	Telephone interview 2005/2006	Laboratory testing 2005/2006
Physical Activity: MARCA Pedometer count Sitting posture photos Psychosocial Factors: CBCL BDI McMaster Family Assessment Device Life stress events	Subjective clinical assessment Current socioeconomic data	Height Weight Tanner Scale of Pubertal Staging Descriptive Pain Data: VAS Body chart Short-form McGill Oswestry Disability Questionnaire Tampa Scale of Kinesiophobia Functional movement assessment Trunk extensor endurance Thigh muscle endurance Lumbo-pelvic kinematics and EMG recording during sitting and forward bending tasks Lumbar spine repositioning in sitting

Table 3-4 – Timing of data collection

During the laboratory testing session data was collected in the following order: descriptive pain data, Tanner Scale of Pubertal staging, height, weight, usual sitting posture, slumped sitting posture, lumbar spine repositioning, forward bending, functional movement assessment, trunk extensor endurance and thigh muscle endurance.

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CHAPTER 4 – STUDY 1

A DETAILED CHARACTERISATION OF PAIN, DISABILITY, PHYSICAL AND PSYCHOSOCIAL FEATURES OF A SMALL GROUP OF ADOLESCENTS WITH NON-SPECIFIC CHRONIC LOW BACK PAIN

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This study addresses the first aim to investigate a small group of adolescents with non-specific chronic low back pain from a biopsychosocial perspective.

Study 1 addresses the following thesis objectives to:

1.1. Document pain, disability and kinesiophobia in adolescents with NSCLBP (pooled and sub-classified).

1.2. Investigate whether differences exist between the NSCLBP and asymptomatic groups, based on physical and psychosocial factors; and

1.3. Investigate whether differences between the NSCLBP and asymptomatic groups in physical and psychosocial factors are clearer when NSCLBP is sub-classified.

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4.1 ABSTRACT

Objective: To provide a detailed biopsychosocial evaluation of adolescent NSCLBP compared to those without LBP.

Methods: NSCLBP was described by pain level, duration, levels of disability and kinesiophobia, aggravating factors and functional movements. Each pain subject was sub-classified using the O'Sullivan system. Groups were compared on physical activity levels, sitting posture, trunk extensor and thigh muscle endurance, psychosocial behaviour, depression, family functioning and exposure to stressful life events.

Results: Adolescents with NSCLBP reported moderate levels of pain (4.4/10±1.9), disability (17.9±10.1%) and fear avoidance beliefs (36.1/68±10.1). Differences between control and pain groups were only found for back muscle ($p=0.033$) and squat endurance times ($p=0.032$) and stressful life events ($p=0.030$). Differences in sitting posture between pain and no pain groups were only found when pain subjects were sub-classified (lumbar angle $p=0.001$).

Conclusions: Adolescents with NSCLBP reported moderate pain and disability with deficits in trunk and squat endurance. That they remained physically active is at odds with the activity avoidance and subsequent deconditioning model proposed for adults with NSCLBP. Differences between control and pain groups on history of stressful life events suggest this may contribute to adolescent NSCLBP. Differences with sitting posture are only seen when patients were sub-classified.

4.2 INTRODUCTION

Growing evidence suggests low back pain (LBP) commonly develops in adolescence and increases the risk for LBP in adulthood (Brattberg, 2004). In contrast to adult LBP, the factors associated with chronic LBP (CLBP) during adolescence have not been investigated thoroughly; epidemiological studies report cumulative lifetime prevalence rates for adolescent CLBP of 8% (Bejia et al., 2005; Salminen, Erkintalo, Pentti, Oksanen, & Kormano, 1999).

Subjects with non-specific CLBP (NSCLBP) have no known patho-anatomical diagnosis and it is considered to represent a biopsychosocial disorder in adults (O'Sullivan, 2005; Waddell, 2004). In adolescents the spine undergoes substantial change with periods of rapid growth and development (Grimmer & Williams, 2000). Contemporaneously, the transition from childhood to adulthood is characterised by major lifestyle and psychosocial changes (LeResche, Mancl, Drangsholt, Saunders, & Korff, 2005). Therefore, it may not be appropriate to extrapolate findings from adult LBP research to adolescence. While physical and psychosocial risk factors have been associated with adolescent LBP, the majority of the research has investigated single domains (physical or psychological), often with conflicting results. Few studies have concurrently investigated these factors in an adolescent population with NSCLBP.

Within the physical domain, positive (Grimmer & Williams, 2000; Skoffer, 2007) and negative (Kovacs et al., 2003; Negrini & Carabalona, 2002) correlations have been found between carrying school bags and LBP. Similarly, participation in organised sport has also shown positive (Auvinen, Tammelin, Taimela, Zitting, & Karppinen, 2008; Kovacs et al., 2003) and negative (Balague, Damidot, Nordin, Parnianpour, & Waldburger, 1993; Burton, Clarke, McClune, & Tillotson, 1996) associations with LBP. Prevalence of reported LBP has been moderately associated with increased time spent watching television in adolescents (Balague et al., 1994), while sitting at school was rated highly on scales of disability in adolescents with LBP (Watson et al., 2002). Evidence also exists linking adolescent LBP with deficits in trunk (Luoto, Heliovaara, Hurri, & Alaranta, 1995; Sjolie & Ljunggren, 2001) and lower limb muscle endurance (Perich, Burnett, & O'Sullivan, 2006).

Positive associations have been demonstrated between adolescent LBP and psychosocial factors including depressive symptoms, perceived stress (Diepenmaat, van der Wal, de Vet, & Hirasing, 2006), poor wellbeing (Sjolie, 2002), negative affect (Staes, Stappaerts, Lesaffre, & Vertommen, 2003), hyperactivity (Jones, Watson, Silman, Symmons, & Macfarlane, 2003) and emotional and conduct problems (Jones et al., 2003; Watson et al., 2003). In a prospective study, stressful experiences in childhood were associated with an increased risk of CLBP later in life (Kopec & Sayre, 2005). Catastrophizing and a family history of chronic pain have

both been shown to be associated with greater disability in adolescents suffering CLBP (Lynch, Kashikar-Zuck, Goldschneider, & Jones, 2006).

There is growing supporting evidence that adult NSCLBP is not a homogenous group, but rather represents a series of sub-groups based on both physical and psychosocial variables (O'Sullivan, 2005). A mechanism based classification system has been proposed by O'Sullivan (O'Sullivan, 2000) which groups patients with localised LBP based on spinal posture, the movement direction in which LBP was aggravated during activities (directional sensitivity) and motor control patterns (Dankaerts, O'Sullivan, Straker, Burnett, & Skouen, 2006c). Evidence for the validity of this classification system includes adult studies documenting altered spinal posture (Dankaerts, O'Sullivan, Burnett, & Straker, 2006b) and motor control deficits (Dankaerts, O'Sullivan, Burnett, & Straker, 2006a). To date there is no evidence as to whether these sub-groups exist in adolescent NSCLBP populations.

While some studies suggest that psychosocial rather than physical factors are more important in adolescent LBP (Jones et al., 2003; Szpalski, Gunzburg, Balague, Nordin, & Melot, 2002) the multifactorial nature of LBP identified by previous research indicates that NSCLBP in adolescents should be studied from a multi-dimensional perspective (Balague, Dudler, & Nordin, 2003). To date no study has investigated in detail, both the physical and psychosocial aspects of adolescents with NSCLBP.

The overall aim of this study was to investigate adolescents with NSCLBP from a biopsychosocial perspective and compare them to a pain free control. This study was part of a detailed investigation of motor control characteristics in this population that is the basis for other publications.

The specific objectives were to:

1. describe the level of pain, disability and kinesiophobia in adolescents with NSCLBP;

2. investigate whether differences exist between the NSCLBP and non pain groups, based on physical and psychosocial factors; and

3. investigate whether differences between the NSCLBP and non pain groups in physical and psychosocial factors are clearer when NSCLBP is sub-classified.

4.3 MATERIALS AND METHODS

4.3.1 Participants

Adolescent participants were drawn from the Western Australian Pregnancy Cohort (Raine) Study, an ongoing longitudinal health research project of 2800 children born in a maternity hospital in Perth, Australia. Over the past 18 years children and their families have provided environmental, developmental and health information. Details can be found at www.rainestudy.org.au.

Inclusion Criteria	Exclusion Criteria
Male or Female Age: 14-16 years BMI: <28 kg/m² * Pain Group: • History of NSCLBP ≥ 12 weeks duration • Without peripheral pain referral • Pain in the area from T12 to gluteal folds • Moderate ongoing LBP o Average daily pain level - VAS > 3/10 o Experienced most days of the week • Mechanically induced localised LBP Control Group: • No history of spinal pain (* required for successful superficial EMG recording)	Specific diagnosis associated with LBP such as spondylolisthesis, disc prolapse, inflammatory disorders Presence of other conditions affecting the spine including neurological or metatastic disease Any neurological deficit Any surgery involving the lumbar spine Any diagnosed pelvic or abdominal pain disorder in the last 12 months Pregnancy or less than six months post-partum Any lower limb surgery in the last 2 years Current lower limb injury An inability to understand written or spoken English Inability to assume test postures

Table 4-1 - Inclusion and Exclusion Criteria at time of recruitment

56 subjects were identified based on data collected in the Raine Study 14 year survey (2003-2005) and were recruited ensuring each met all inclusion criteria and none of the exclusion criteria outlined in Table 4-1. A recruitment flow diagram is at Figure 4-1. Controls were selected to ensure comparability to those with NSCLBP on the potentially confounding factors of gender, age (± 6 months), pubertal stage (Tanner, 1986; Tanner & Whitehouse, 1976) and socio-economic status (Australian Bureau of Statistics Index of Relative Socio-Economic Advantage/Disadvantage index (± 1 quartile) (Trewin, 2001). Controls did not differ from pain subjects on BMI, pubertal stage and socio-economic status, but were 3-months older, Table 4-2.

	NSCLBP (pooled) (n=28)	Control (n=28)	NSCLBP (sub-classified)	
			Extension (n=13)	Flexion (n=15)
Age (years)	15.4 ± 0.5[#]	15.7 ± 0.5[#]	15.4 ± 0.6	15.4 ± 0.5
BMI (kg/m^2)	22.2 ± 3.5	21.2± 2.6	22.8 ± 4.2	21.6 ± 2.8
Index of Relative Socio-Economic Advantage/ Disadvantage	988.9 ± 59.7	979.8 ± 61.9	984.8 ± 51.6	989.1 ± 69.0
Developmental Stage				
Genital	3.5± 0.5	3.4 ± 0.6	3.5 ± 0.5	3.5 ± 0.5
Breast (Girls only)	3.9 ± 0.7	3.8 ± 0.8	3.8 ± 0.6	4.0 ± 0.8
No. female subjects	14	14	10 [$]	4 [$]
No. male subjects	14	14	3[$]	11 [$]
Pain area below L3 only			3 [†]	10 [†]
Pain area above and below L3			10 [†]	5 [†]

*All measures were recorded during laboratory testing session in 2006/07.

Values are Mean ± SD

[#] $t_{df} = -2.010_{54}$, p=0.049; [$] $\chi^2 = 7.036_2$, p=0.030; [†] χ^2=5.32, p=0.030

Table 4-2 - Sample Description*

*All measures were recorded during laboratory testing session in 2006/07

Prior adult studies showed two groups of N=28 has sufficient power to identify differences in usual sitting posture (Dankaerts et al., 2006b) and trunk extensor endurance (Latimer, Maher, Refshauge, & Colaco, 1999) of half of one standard deviation in these measures. Ethics approval was obtained and all parents provided written informed consent.

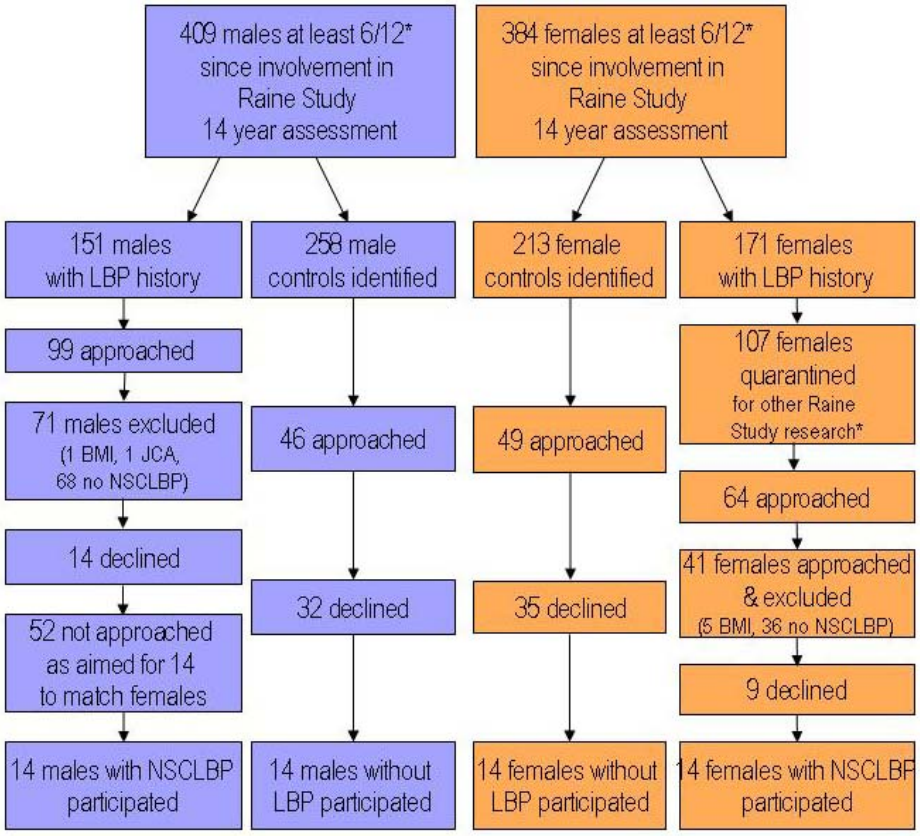

Figure 4-1 - Subject recruitment flow diagram.

Subjects were ordered based on Raine Study identification number, lowest to highest, and approached consecutively via phone interview to determine suitability. Those who were both suitable and interested were forwarded study information sheets. At a subsequent telephone call those who were willing to be involved were recruited to the study. *Criterion required by ethics approval. Abbreviations 6/12 – 6 months; LBP - Low back pain; BMI – Body mass index; JCA – Juvenile chronic arthritis; NSCLBP – Non-specific chronic low back pain; LBP – Low back pain

4.3.2 Measures

A Pain group only

Pain experience

Current pain intensity was measured with a Visual Analogue Scale (VAS), which has high test-retest reliability and good construct validity when used by adolescents (Stinson, Kavanagh, Yamada, Gill, & Stevens, 2006). A body chart was used to indicate area of pain.

Disability was assessed with the Oswestry Disability Questionnaire, modified for use in minors by removing the question concerning the effect of pain on sex-life. The

Oswestry is reliable and valid for use in adults (Fairbank, Couper, Davies, & O'Brien, 1980) and has previously been used in adolescents (Perich et al., 2006).

Fear avoidance behaviour, was quantified by the Tampa Scale of Kinesiophobia, the reliability and validity are considered moderate to good (Goubert et al., 2004; Swinkels-Meewisse, Swinkels, Verbeek, Vlaeyen, & Oostendorp, 2003; Vlaeyen, Kole-Snijders, Boeren, & van Eek, 1995) and it has previously been used with adolescents (Perich et al., 2006).

Subjective clinical assessment

Usual pain intensity and duration, aggravating factors (specifically pain provoked with mechanical loading during sustained postures or physical activity), and type and frequency of organised sporting activities participated in were assessed by interview. Additional data concerning LBP associated with sport and while carrying a school bag were taken from the Raine Study 14 year survey.

Functional movement assessment

A video recording from a single camera was taken by the primary researcher of each subject with NSCLBP during functional postures and movements (usual sitting, slump sitting, sitting to standing, standing, left and right leg single-leg-stance, standing, forward bending and backward bending). This sequence was completed twice to record movements from posterior and postero-lateral views (Dankaerts et al., 2006c).

Sub-classification

Pain subjects were classified based on the direction of pain provocation by a specialist musculoskeletal physiotherapist, independent from data collection, by reviewing each subjects' subjective pain behaviour information and functional movement assessment from video analysis. Details of identified sub-groups are at Table 4-3. The classification system is described elsewhere (O'Sullivan, 2005), and is reliable and valid (Dankaerts et al., 2009; Dankaerts et al., 2006c). As the mechanism in sitting for pain provocation is the same for both 'flexion-pattern' and

'multidirectional', subjects from these groups were combined for this study (O'Sullivan, 2004, 2005).

Flexion Pattern	Movements and postures involving flexion or the lumbar spine aggravate NSCLBP symptoms Spinal extension relieves pain Provocative postures and functional tasks associated with a flexed lumbar spine (eg slump sit and squatting)
Active Extension Pattern	Movements and postures involving extension of the lumbar spine aggravate NSCLBP symptoms Spinal flexion relieves pain Provocative postures and functional tasks associated with hyper extension of lumbar spine (hyperlordotic sitting and standing)
Multidirectional Pattern	All movement directions (flexion and extension) provoke NSCLBP symptoms Neutral spinal postures relieve pain Provocative postures and functional tasks associated with either flexed or hyper-extended lumbar spine (eg slump sit, squatting and sway stand)

Table 4-3 – Clinical Features of Adolescent NSCLBP Movement Control Disorders

Subjects for this research were classified into these patters based on their direction of pain provocation

(Dankaerts et al., 2006c; O'Sullivan, 2004, 2005)

B All subjects

Physical activity

Measures of physical activity were taken as part of the Raine Study 14 year survey. Raine study participants were free to not consent for any part of any assessment and thus not all consented to participate in this component. 29 subjects (Pain n=12, Control n=17) completed the Multimedia Activity Recall for Children and Adolescents (MARCA); 'the number of minutes of moderate to vigorous physical activity/week' was used in this analysis. MARCA is reliable and valid (Ridley, Olds, & Hill, 2006). 24 subjects (Pain n=11, Control n=13) wore a pedometer (Yamax Digiwalker SW200 (Yamasa Tokei Keiki Co. Ltd., Tokyo, Japan), with established reliability and validity (Hands, Larkin, Parker, Straker, & Perry, 2008), for at least three week days and one weekend day. Data was extrapolated to estimate 'total

number of steps/week'. Comparisons on this data were restricted to NSCLBP and control groups due to insufficient participants in NSCLBP sub-groups.

Sitting posture

Sagittal photographs of usual sitting posture with photo reflective markers had been taken during the Raine Study 14 year survey. From photographs the lumbar angle was defined as the posterior angle between line of T12 to ASIS and line of ASIS to greater trochanter; and the trunk angle was defined as posterior intersecting angle between the line of C7 to T12 and line of T12 to greater trochanter. These measures have demonstrated reliability (Perry, Smith, Straker, Coleman, & O'Sullivan, 2008).

Trunk extensor endurance

Trunk extensor endurance is the duration between assuming a horizontal trunk position during the Biering-Sorensen test until the subject could no longer maintain a horizontal position (Biering-Sorensen, 1984), measured via a pendulum goniometer placed between the subjects' scapulae and defined as trunk lowering of 10º. Standardized encouragement and feedback on trunk position was provided throughout the procedure. This method for measuring trunk extensor endurance has high reliability in adolescents (Salminen, Maki, Oksanen, & Pentti, 1992), good validity (Moreau, Green, Johnson, & Moreau, 2001) and can discriminate between those with and without adult NSCLBP (Latimer et al., 1999) .

Thigh muscle endurance

Subjects were positioned on a stool with hips and knees at 90°, they raised their buttocks slightly off the stool (approximately 5cm), and were asked to maintain this position for as long as they were able. Time to fatigue was determined when a subject sat back on the stool or moved their buttocks more than 15cm from the stool. Standard encouragement to continue and feedback on buttock position relative to the stool was provided throughout the procedure. This test has been used previously to discriminate between adolescents with and without NSCLBP (Perich et al., 2006).

Psychosocial factors

Psychological variables were measured by the Child-Behaviour Checklist - Youth Self Report Form and Becks Depression Inventory; both are reliable and valid (Achenbach, McConaughy, & Howell, 1987; Beck, Steer, & Garbin, 1988; Harris, Tyre, & Wilkinson, 1993; Ivarsson, Gillberg, Arvidsson, & Broberg, 2002). The Child-behaviour Checklist gives a total behaviour problem score and two broad-band sub-scores, externalizing (E) and internalizing (I). The adolescent's primary carer reported the number of stressful life events in the two-year period prior to testing, including known difficulties with pregnancy, marriage, children, work, finances, loss of a relative/friend, moving house and other issues (Tennant & Andrews, 1976), as well as the general functioning subscale of the McMaster Family Assessment Device (McMaster) (Byles, Byrne, Boyle, & Offord, 1988) during the Raine Study 14 year survey. The McMaster has demonstrated reliability and validity (Byles et al., 1988; Craufurd, Creed, & Jayson, 1990).

4.3.3 Statistical analysis

Descriptive statistics were used to characterise the pain group. T-tests were used to examine differences between control and NSCLBP (pooled) groups. Mann-Whitney test was used to compare groups for pubescent developmental stage. Pearson Chi-square test was used to test different gender proportions in sub-groups. Differences between NSCLBP sub-groups and controls were analysed using ANCOVA with gender as a covariate, with Least Squares Differences used to analyse differences between sub-groups post-hoc, as well as comparisons of confidence limits for difference and interpretation of effect sizes. In the case of the number of life stress events, non-parametric Kruskal Wallis and Mann-Whitney tests were performed. SPSS V13 for Windows (SPSS Inc. Chicago, IL) was used to perform all statistical tests with α=0.05.

4.4 RESULTS

4.4.1 NSCLBP pain, disability, kinesiophobia and aggravating factors

Adolescents with NSCLBP reported moderate pain intensity (4.4/10±1.9) disability (17.9±10.1%), kinesiophobia (36.1/68±10.1) and an average pain duration of 26.6±12 months (see Table 4-4). Body charts indicated most (64.3%;18/28) also

reported thoracic spinal pain. Statistically significant differences were shown between NSCLBP sub-groups and presence of LBP pain above or below L3 (p=0.030), Table 4-2.

Sitting was the most prevalent (92.9%;26/28) aggravating factor for subjects with NSCLBP. 57.1%(16/28) reported pain only with unsupported sitting and 28.6%(8/28) reported pain with both supported and unsupported sitting. Two subjects could not differentiate what type of sitting aggravated their pain. Oswestry data indicated that pain in sitting contributed most to the overall score of disability. 75.0%(21/28) of subjects with NSCLBP reported sport and carrying a school bag aggravated their LBP.

4.4.2 Controls versus NSCLBP

No statistically significant differences were found between control and NSCLBP (pooled) groups for minutes of moderate/vigorous physical activity/week or weekly pedometer count (p>0.3)(Table 4-4). Most pain subjects (85.7%;24/28) undertook regular organised physical activities, most commonly team sport or dancing, at least three times per week despite this provoking back pain in 75.0%(21/28). No statistically significant differences were noted between control and pain groups for trunk or lumbar angle during usual sitting (Figure 4-2). Adolescents with NSCLBP had lower trunk extensor and squat endurance than controls (p<0.035)(Table 4-4). No statistically significant differences were found for the Child-behaviour Checklist (p>0.5), Becks' Depression Inventory (p>0.6) or the McMaster Family Assessment Device (p>0.7), however adolescents with NSCLBP and their families experienced more stressful events in the previous 2 years than controls (p=0.030)(Table 4-4).

4.4.3 Control versus sub-classified NSCLBP

Thirteen NSCLBP subjects were clinically classified as an active-extension pattern; 12 as multi-directionally sensitised (flexion and extension); and 3 subjects were classified as flexion pattern due to pain provocation relating to flexed postures and activities. As mentioned previously the multidirectional subjects were combined with the flexion-pattern subjects as the directional sensitivity in sitting was the same. Statistically significant gender differences were shown with 10 of 14 (71.4%) girls

classified as active-extension and 11 of 14 (78.6%) boys in the flexion sub-group (p=0.030) (Table 4-2).

Dependent Variable	NSCLBP (pooled) (n=28)	Control (n=28)	NSCLBP (sub-classified)	
			Extension (n=13)	Flexion (n=15)
Usual pain (VAS out of 10)	4.4 ± 1.9		5.1 ± 1.3	3.8 ± 2.1
Pain duration (months)	26.5 ± 11.8		24.8 ± 14.7	28.0 ± 8.7
Kinesiophobia (score out of 68)	36.1 ± 7.1		35.5 ± 4.7	36.7 ± 8.8
Disability (%)	17.9 ± 10.1		17.6 ± 7.9	18.2 ± 11.9
Trunk angle (degrees)	230.9 ± 14.5	230.3 ± 14.2	222.2 ± 13.4	238.5 ± 11.01
Lumbar angle (degrees)	125.3 ±19.8	130.6 ± 15.7#	113.5 ± 16.3#	135.6 ± 16.9#
Trunk endurance (seconds)	88.8 ± 45*	117.7 ± 52.9*	80.6 ± 51.0	96.0 ± 40.3
Squat endurance (seconds)	118.1 ± 69*	172.8 ± 111.6*	106.7 ± 66.4	128.0 ± 71.5
Life Stress (no. events)	2 (2)*	1 (3)*	2 (2)	3 (3)
CBCL Raw Scores:				
Total (out of 162)	42.9 ± 28.6	39.4 ± 18.3	48.5 ± 26.4	38.1 ± 30.1
Internal (out of 60)	11.7 ± 10.7	10.4 ± 7.5	14.3 ± 10.8	9.5 ± 10.3
External (out of 60)	12.8 ± 8.6	11.8 ± 6.3	12.5 ± 7.98	13.1 ± 9.4
BDI Depression (Raw score out of 60)	7.0 ± 7.7	7.0 ± 6.5	6.5 ± 6.5	7.5 ± 8.8
McMaster Family Functioning (score out of 3)	0.8 ± 0.4	0.9 ± 0.6	0.8 ± 0.5	0.9 ± 0.4
	Pain (pooled) (n=12)	Control (n=17)		
Moderate/Vigorous[$] Physical Activity (minutes/week)	1158 ± 618	919 ± 449		
Pedometer[$] (weekly count)	80707 ± 33374	89010 ± 64734		

Table 4-4 – Pain, physical and psychosocial characteristics of adolescents without and with non-specific chronic low back pain (both pooled and sub-classified)

Results are Mean ± SD or Median (IQR)

Note - All results are raw values and have not been adjusted for gender, although gender was used as a covariate for subgroup analyses due to different gender proportions.

*Sig. diff (p<0.05), control vs pain (pooled); #Sig. diff. (p<0.05), control vs extension vs flexion

[$] Small numbers of participants in NSCLBP sub-groups precluded analysis on this basis.

Table 4-4 displays the means and standard deviations for physical and psychosocial factors for controls and NSCLBP sub-groups. No statistically significant differences were shown between control, flexion and active-extension sub-groups for trunk endurance (ANCOVA p=0.105). However, the mean difference and confidence interval estimates after adjustment for gender (Table 4-5) suggest a likely effect of a moderate sized reduction in mean back endurance levels in adolescents with extension-related NSCLBP as compared to controls, but no strong evidence of differences between other groups (Hopkins, 2007; Hopkins, Marshall, Batterham, & Hanin, 2009).

No statistically significant differences were shown between control, flexion and active-extension sub-groups for squat endurance (ANCOVA p=0.085) However, the mean difference and confidence interval estimates after adjustment for gender (Table 4-5) suggest a likely effect of a moderate sized reduction in mean squat endurance levels in adolescents with extension-related NSCLBP as compared to controls, but no strong evidence of differences between other groups.

Dependent Variable	Extension - Control	Flexion - Control	Flexion - Extension
Trunk angle (degrees)	-3.5; ±9.2 p= 0.455	5.6; ±8.5 p= 0.193	9.0; ±10.7 p= 0.095
Lumbar angle (degrees)	-22.6; ±12.0 p<0.001	2.5; ±11.0 p= 0.655	25.0; ±13.9 p= 0.001
Trunk endurance (seconds)	36.5; ±38.5 p= 0.063	-26.8; ±35.3 p= 0.133	9.6; ±44.7 p= 0.668
Squat endurance (seconds)	-72.1; ±38.5 p= 0.040	-43.2; ±62.7 p= 0.174	28.9; ±79.4 p= 0.468

Table 4-5 – Estimated mean differences and 95% CI adjusted for gender

Statistically significant differences were shown for lumbar angle (ANCOVA p=0.001). With the mean difference and confidence interval estimates after adjustment for gender (Table 4-5 and Figure 4-2) suggesting a likely effect of a large sized increase in mean lumbar angle in adolescents with extension-related NSCLBP as compared to both those with flexion-related NSCLBP and healthy controls, but no strong evidence of a difference between controls and those with flexion-related NSCLBP.

No statistically significant differences were shown for trunk angle (ANCOVA p=0.233). However, the mean difference and confidence interval estimates after adjustment for gender (Table 4-5and Figure 4-2) suggest a likely effect of a large sized reduction in mean trunk angle in adolescents with extension-related NSCLBP as compared to those with flexion-related NSCLBP, but no strong evidence of differences between other groups.

In summary, the active-extension sub-group assumed sitting postures with a decreased thoracic kyphosis and increased lumbar lordosis compared to both the flexion and control groups. There was little difference in posture between the flexion and control groups although the graphs would suggest that the spinal posture of the control group was between that of the flexion and active-extension sub-groups (Figures 4-2 & 4-3).

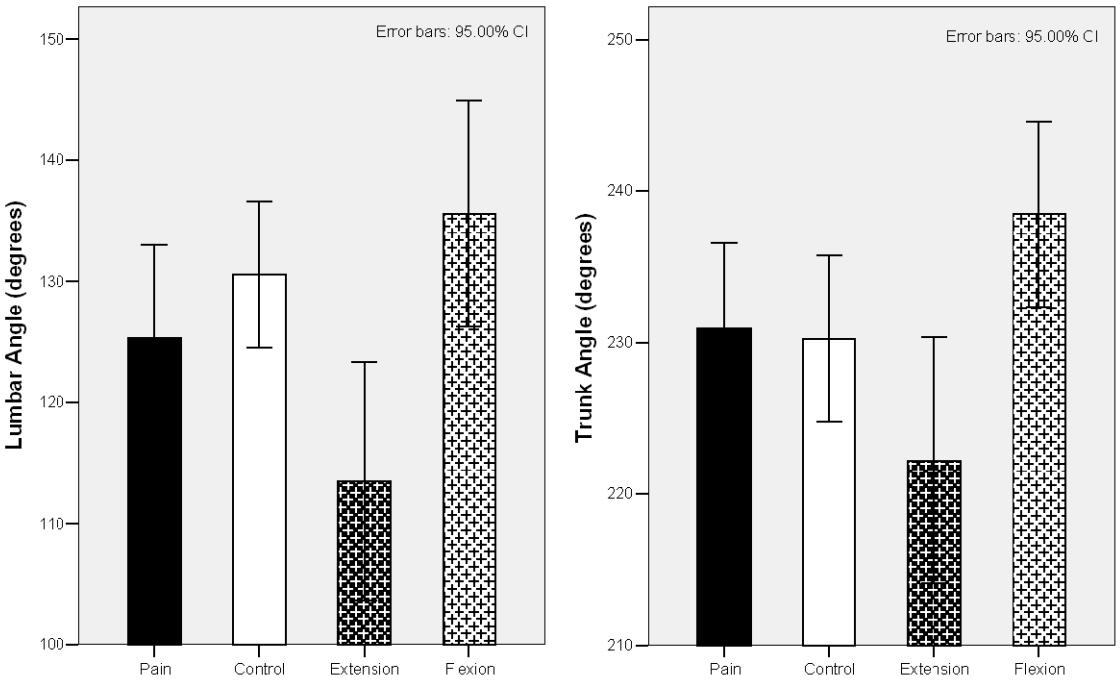

Figure 4-2– Trunk and lumbar angle in usual sitting posture for adolescents without and with non-specific chronic low back pain (both pooled and sub-classified)

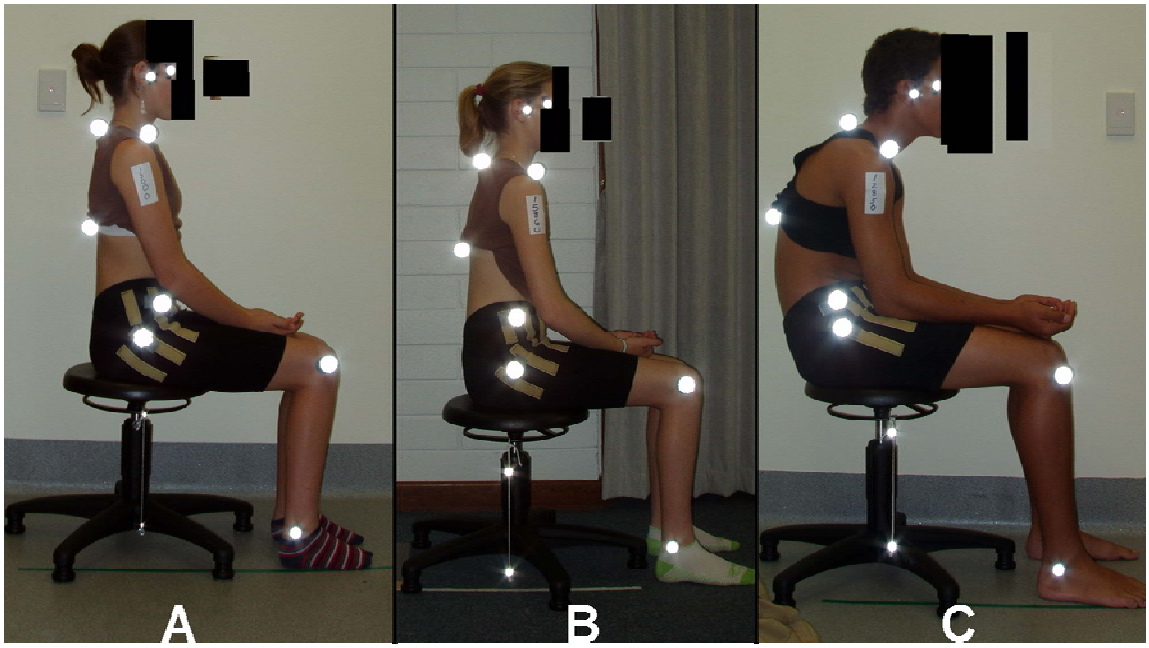

Figure 4-3– Sitting postures: A – Active-Extension; B – Control; C - Flexion

No statistically significant differences were observed between controls and sub-groups on the Child-Behaviour Checklist, Beck's Depression Inventory or McMaster ($p>0.31$). However, comparison of median values shows the flexion sub-group experienced a significantly higher number of stressful events, three times that of the control group ($p=0.018$).

4.5 DISCUSSION

This research demonstrates that NSCLBP in this group of adolescents is not trivial, with teenagers suffering moderate levels of pain and disability over considerable durations. NSCLBP in adolescence is therefore an important health issue. Whilst adolescent NSCLBP shared similar characteristics to previous reports of adult NSCLBP, there were also clear differences.

The adolescents with NSCLBP reported the same level of sporting participation and physical activity levels as controls, despite moderate levels of kinesiophobia and reporting pain provocation from these activities. Adolescents with NSCLBP displayed trunk and squat endurance deficits, consistent with other adolescent (Perich et al., 2006; Salminen et al., 1992) and adult findings (Hamberg-van Reenen et al., 2006; Latimer et al., 1999). These results contrast to adult literature where NSCLBP

is commonly considered to be associated with activity avoidance due to kinesiophobia and subsequent deconditioning leading to poor trunk and lower limb endurance (Verbunt, Seelen, Vlaeyen, van der Heijden, & Knottnerus, 2003; Vlaeyen & Linton, 2000). The results suggest that deficits in trunk extensor and squat endurance are not associated with inactivity but rather suggest that the lower muscle endurance may be related to other processes, which may be genetically or developmentally mediated or related to variables not measured in this study. It is possible poor trunk and lower limb endurance may leave individuals vulnerable to tissue strain during postures, activities of daily living and sporting activities which may in turn lead to the development of LBP.

Observed differences between control and pain groups for 'number of life stress events', suggest difficulties experienced in the psychosocial domain are associated with NSCLBP. Higher levels of life stress events may have neurophysiological influences, such as tissue sensitivity thresholds to nociception, as well as influences on motor control patterns. Previously, a pathway has been proposed between psychosocial stress, spine loading and increased risk of LBP (Gatchel, 2004; Marras, Davis, Heaney, Maronitis, & Allread, 2000).

The lack of statistically significant group differences in this study across a number of psychosocial factors is in contrast to adult studies (Reichborn-Kjennerud et al., 2002) and adolescent research (Sjolie, 2002; Staes et al., 2003; Watson et al., 2003). This may relate to the specific cohort studied, which for example excluded adolescents with a BMI >28 kg/m^2, as it may be that psychosocial factors are more prevalent amongst those excluded. Previous research identified that some adults with CLBP have dominant psychosocial factors and others do not (Dunn, Jordan, & Croft, 2006), suggesting different subgroups exist with NSCLBP. The current cohort may therefore represent a subgroup of the NSCLBP adolescent population with a lower prevalence of psychosocial factors.

This study supports the adult literature that without sub-grouping, differences may not be detected in sitting posture between groups with and without LBP (Dankaerts et al., 2006b; De Looze, Kuijt-Evers, & Van Dieen, 2003). However, when the pain group was classified, statistically significant and clinically meaningful differences

were evident for lumbar angle during usual sitting, concurring with adult findings (Dankaerts et al., 2006b; O'Sullivan, Mitchell, Bulich, Waller, & Holte, 2006), and supporting the importance of sub-classifying patients with NSCLBP (Dankaerts et al., 2006b; O'Sullivan, 2005). The direction of these results (flexion pattern with more flexed postures and active-extension pattern with more extended postures) supports the hypothesis that patients with NSCLBP adopt potentially provocative end range spinal postures in the direction of pain (O'Sullivan, 2000).

While this study was adequately powered to detect moderate effects, as estimated from standard deviations in measures from previous adult studies, it may have been underpowered for the increased variability of these measures in this adolescent population, and thus to detect smaller effect sizes. The trunk extensor endurance, squat endurance and stressful life events results suggest differences may exist between sub-groups which may be important for targeting intervention. Further research with larger populations is needed to investigate this and provide more generalisable results. Irrespective of these limitations, this study provides a detailed insight into NSCLBP in a group of adolescents.

A number of physical factor differences were shown to be dominant in this study of adolescent NSCLBP, however, the study design does not allow the determination of cause and effect. That physical factors dominate the statistically significant differences noted in this study is in contrast to other reports which propose that adolescent LBP is a disorder dominated by psychosocial factors (Jones et al., 2003; Watson et al., 2003). This may relate to the limited nature of the physical factors previously investigated.

This research highlights that there exists a group of adolescents who remain active despite moderate levels of NSCLBP, disability and pain provocation aggravated by physical factors. Deficits were demonstrated in trunk extensor and squat endurance and altered sitting postures which may render an individual vulnerable to spinal strain, increasing the peripheral nociceptive drive. It may be that the increased exposure to life stress events leaves the central nervous system more sensitised to mechanical stress and associated changes in motor control, leaving the spine vulnerable to mechanical strain and pain. The identification of impairments

associated with NSCLBP allows for targeted management. Finally, it is our aim to follow these adolescents longitudinally to determine the long term implications of these disorders during the transition to adulthood.

4.6 CONCLUSION

NSCLBP is a significant condition for adolescents which can be disabling. Adolescent NSCLBP appears similar to adult NSCLBP in terms of the existence of sub-groups and the importance of both physical and psychosocial factors, although the finding that these subjects remained physical active differs from some NSCLBP adult studies. In this study the dominant finding was statistically significant differences in physical factors between adolescents with and without NSCLBP, and between sub-groups of adolescents with NSCLBP.

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CHAPTER 5 – STUDY 2

SITTING POSTURES AND TRUNK MUSCLE ACTIVITY IN ADOLESCENTS WITH AND WITHOUT NON-SPECIFIC CHRONIC LOW BACK PAIN – AN ANALYSIS BASED ON SUB-CLASSIFICATION

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Sitting is a recognised aggravating factor in adolescent low back pain (LBP), especially sitting at school. Spending time flexed or slumped has been linked to the presence of thoracolumbar pain. In adults, altered sitting posture is discriminatory for non-specific chronic LBP (NSCLBP) but only when those with pain are sub-classified. This study, together with studies 3 and 4, addresses the main aim of this dissertation to investigate trunk motor control associated with pain provocative spinal postures and movements in a detailed laboratory based study of adolescents with and without NSCLBP and sub-groups of NSCLBP.

Study 2 addresses the following thesis objectives:

2.1. Compare sitting postures between adolescents with NSCLBP (pooled and sub-classified) and asymptomatic groups.

2.2. Compare differences between adolescents with NSCLBP (pooled and sub-classified) and asymptomatic groups in trunk muscle activation patterns in usual sitting and slump sitting.

2.3. Investigate the flexion-relaxation phenomenon in sitting in adolescents with NSCLBP (pooled and sub-classified) and asymptomatic groups.

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5.1 ABSTRACT

Study design. A preliminary cross-sectional comparative study of adolescents with NSCLBP and healthy controls.

Objective. To investigate whether differences in spinal kinematic and trunk muscle activity exist in both usual and slump sitting in adolescents with NSCLBP.

Summary of Background. Evidence suggests that LBP commonly develops in adolescence and increases the risk for LBP in adulthood. Sitting is an important consideration in adolescents with NSCLBP: currently there are no reports investigating their motor control strategies in sitting.

Methods. 28 adolescents (14 female) with NSCLBP and 28 matched pain-free controls were recruited from a large cohort study. Pain subjects were sub-classified based upon O'Sullivan's classification system. Three dimensional lumbo-pelvic kinematic data and the activation of three back and two abdominal muscles were recorded during usual and slump sitting. The flexion-relaxation phenomenon in sitting was also investigated.

Results. Spinal posture in usual and slump sitting were similar for adolescents with and without NSCLBP. However, differences were identified in both sitting conditions when those with NSCLBP were sub-classified and compared to controls. Muscle activation differences were not consistently identified, with only lower levels of Internal Oblique activation in usual sitting in NSCLBP compared to pain-free controls showing significance. Flexion relaxation was observed in both Iliocostalis and Thoracic Erector Spinae in the NSCLBP group but not controls.

Conclusion. This study provides preliminary results. Differences with sitting posture are only seen when adolescents with NSCLBP are classified. Trunk muscle activation is not a sensitive marker for discriminating sub-groups of NSCLBP during adolescence.

5.2 KEY POINTS

- Spinal kinematics does not discriminate adolescent NSCLBP from pain free controls unless sub-classified.
- Sub-groups of adolescent NSCLBP can be identified on the basis of spinal kinematics.
- Trunk muscle activation is not a sensitive marker for discriminating sub-groups of adolescent NSCLBP.
- Flexion relaxation phenomenon in sitting was evident in Iliocostalis and Thoracic Erector Spinae for adolescents with NSCLBP but not for healthy controls.

5.3 INTRODUCTION

Low-back pain (LBP) in adolescence has high prevalence(Ebrall, 1994) and recurrence' rates (Burton et al. 1996; Taimela et al. 1997) that increase with age (Balague et al., 1994; Leboeuf-Yde & Kyvik, 1998; Taimela, Kujala, Salminen, & Viljanen, 1997; Watson et al., 2002), and is associated with the recurrence of LBP through adult life (Brattberg, 2004; Harreby, Neergaard, Hesselsoe, & Kjer, 1995; Kopec & Sayre, 2005). For some, LBP can be transient and trivial, yet for others it is chronic and disabling. In adolescence, prevalence rates for chronic LBP (CLBP) are documented at 8% (Bejia et al., 2005; Salminen, Erkintalo, Pentti, Oksanen, & Kormano, 1999), with the majority of these disorders classified as non-specific CLBP (NSCLBP) (O'Sullivan, 2004, 2005). Investigating NSCLBP in adolescents may provide insight into a disorder that commonly presents in adulthood.

In adults with LBP, sitting is a common aggravating factor (Balague, Troussier, & Salminen, 1999; Geldhof, De Clercq, De Bourdeaudhuij, & Cardon, 2007) and accounts for significant disability (Dankaerts, O'Sullivan, Burnett, & Straker, 2006a, 2006b; O'Sullivan, 2005). It is reported that adolescents spend large portions of time in sitting, and those who spend more time flexed, or slumped, report more thoraco-lumbar pain (Geldhof et al., 2007; Murphy, Buckle, & Stubbs, 2004; Salminen, 1984; Sjolie, 2004). A recent study of NSCLBP in adolescents found nearly all (92.9%) reported sitting as the most prevalent aggravating factor and contributes most to disability (Astfalck, O'Sullivan, Straker, & Smith, 2007).

There is growing evidence that adult NSCLBP is not a homogenous group, but rather represents a series of sub-groups based on both physical and psychosocial variables. A mechanism based classification system has been proposed by O'Sullivan (2000) which sub-groups patients with localised CLBP based on pain provocative spinal postures and movement patterns (Dankaerts, O'Sullivan, Straker, Burnett, & Skouen, 2006c; O'Sullivan, 2005). Altered spinal postures and trunk muscle activity during sitting have been reported in adults with NSCLBP when sub-classified based on this classification system (Dankaerts et al., 2006b). To date there is no evidence as to whether these sub-groups exist in adolescent NSCLBP populations.

The flexion relaxation phenomenon (FRP) is the presence of myoelectric silence of the back extensors that occurs at end range spinal flexion when moving from standing to forward bending (Kaigle, Wessberg, & Hansson, 1998; McGorry, Hsiang, Fathallah, & Clancy, 2001; Sihvonen, Partanen, Hanninen, & Soimakallio, 1991). This has also been demonstrated in lumbar multifidus in adults when moving from upright to slump sitting (Dankaerts et al., 2006a; O'Sullivan et al., 2006), but is absent in a subgroup with NSCLBP (Dankaerts et al., 2006a). No studies have investigated whether the different subgroups and associated motor control changes identified in adults with NSCLBP are present in adolescents with the disorder.

The overall aim of this paper was to investigate whether spinal kinematic and trunk muscle activity differences exist in both usual and slump sitting in adolescents with NSCLBP (when considered as a whole and when sub-classified) compared to a no-LBP group.

5.4 MATERIALS AND METHODS

5.4.1 Participants

Participants were drawn from the Western Australian Pregnancy Cohort (Raine) Study, a longitudinal cohort of over 2800 children born in a maternity hospital in Perth, Australia (www.rainestudy.org.au). All adolescents with previously documented NSCLBP were identified from data collected on the cohort during 2003-2005 and were screened and recruited by phone interview (in 2006) to ensure each

met participation criteria (Table 5-1). Of those suitable for this study, 28 (14 female) volunteered.

Inclusion Criteria	Exclusion Criteria
Male or Female Age: 14-16 years BMI: <28 kg/m^2 * Pain Group: • History of NSCLBP ≥ 12 weeks duration • Without peripheral pain referral • Pain in the area from T12 to gluteal folds • Moderate ongoing LBP o Average daily pain level - VAS > 3/10 o Experienced most days of the week • Mechanically induced localised LBP Control Group: • No history of spinal pain (* required for successful superficial EMG recording)	Specific diagnosis associated with LBP such as spondylolisthesis, disc prolapse, inflammatory disorders Presence of other conditions affecting the spine including neurological or metatastic disease Any neurological deficit Any surgery involving the lumbar spine Any diagnosed pelvic or abdominal pain disorder in the last 12 months Pregnancy or less than six months post-partum Any lower limb surgery in the last 2 years Current lower limb injury An inability to understand written or spoken English Inability to assume test postures

Table 5-1 - Inclusion and Exclusion Criteria at time of recruitment

A comparable control group were identified from the 2003-2005 data based on gender, age (±6 months), pubertal stage (Tanner, 1986; Tanner & Whitehouse, 1976) and socio-economic status (SES) (Australian Bureau of Statistics Index of Relative Socio-Economic Advantage/Disadvantage index)(±1 quartile) (Trewin, 2001). Measures were repeated during data collection for this study in one laboratory session at the School of Physiotherapy, Curtin University of Technology through 2006-2007. Controls did not differ from pain subjects on BMI, pubertal stage and SES, but were slightly older, mean difference 3 months (p=0.049)(Table 5-2). Prior adult studies showed two groups of N=28 had sufficient power (>90%) to identify differences in spinal angles (Dankaerts et al., 2006b) and trunk muscle activation (Dankaerts et al., 2006a) in both usual and slump sitting of half of one standard deviation in these measures. Ethics approval was obtained and parents provided written informed consent.

	NSCLBP (pooled) (n=28)	Control (n=28)	NSCLBP (sub-classified)	
			Extension (n=13)	Flexion (n=15)
Age (years)	15.4 ± 0.5[#]	15.7 ± 0.5[#]	15.4 ± 0.6	15.4 ± 0.5
BMI (kg/m^2)	22.2 ± 3.5	21.2± 2.6	22.8 ± 4.2	21.6 ± 2.8
Index of Relative Socio-Economic Advantage/ Disadvantage	988.9 ± 59.7	979.8 ± 61.9	984.8 ± 51.6	989.1 ± 69.0
Developmental Stage				
Genital	3.5± 0.5	3.4 ± 0.6	3.5 ± 0.5	3.5 ± 0.5
Breast (Girls only)	3.9 ± 0.7	3.8 ± 0.8	3.8 ± 0.6	4.0 ± 0.8
Usual pain (VAS out of 10)	4.4±1.9		5.1±1.3	3.8±2.1
Pain duration (months)	26.6±12		24.8±14.7	28.0±8.7
Kinesiophobia (total score 68)	36.1±10.1		35.5±4.7	36.7±8.8
Disability (%)	17.9±10.1		17.6±7.9	18.2±11.9
No. female subjects	14	14	10 [$]	4 [$]
No. male subjects	14	14	3[$]	11 [$]

*All measures were recorded during laboratory testing session in 2006/07.

Values are Mean ± SD

[#] $t_{df} = -2.010_{54}$, p=0.049; [$] $\chi^2 = 7.036_2$, p=0.030; [†]

Table 5-2 - Sample Description*

*All measures were recorded during laboratory testing session in 2006/07

5.4.2 Measures

A Pain group only

For the NSCLBP group, pain intensity was measured with a Visual Analogue Scale, which has high test-retest reliability and good construct validity when used by adolescents (Stinson, Kavanagh, Yamada, Gill, & Stevens, 2006). Disability was assessed with the Oswestry Disability Questionnaire (Fairbank, Couper, Davies, & O'Brien, 1980); which was modified for use in minors by removing the question concerning sex-life. The questionnaire was measured out of 45 for the remaining 9 questions and converted to a percentage – representing percentage disability. The Oswestry is reliable and valid for use in adults (Fairbank et al., 1980) and has previously been used in adolescents (Perich, Burnett, & O'Sullivan, 2006). Fear avoidance behaviour was quantified by the Tampa Scale of Kinesiophobia, the reliability and validity are considered moderate-good (Goubert et al., 2004; Swinkels-Meewisse, Swinkels, Verbeek, Vlaeyen, & Oostendorp, 2003; Vlaeyen, Kole-Snijders, Boeren, & van Eek, 1995) and has previously been used with adolescents (Perich et al., 2006).

Subjective clinical assessment

During initial interview each subject with pain was asked a standard series of questions to describe the history and behaviour of their CLBP (aggravating and easing postures and movements and medication usage).

Functional movement assessment

At time of data collection a video recording from a single camera was taken by the primary researcher of each subject with NSCLBP during functional postures and movements (usual sitting, slump sitting, return to usual sitting, sitting to standing, standing, left and right single-leg-stance, forward bending and backward bending). This sequence was completed twice to record movements from both posterior and postero-lateral views as described by Dankaerts and colleagues (Dankaerts et al., 2006c).

Flexion Pattern	Movements and postures involving flexion or the lumbar spine aggravate NSCLBP symptoms Spinal extension relieves pain Provocative postures and functional tasks associated with a flexed lumbar spine (eg slump sit and squatting)
Active Extension Pattern	Movements and postures involving extension of the lumbar spine aggravate NSCLBP symptoms Spinal flexion relieves pain Provocative postures and functional tasks associated with hyper extension of lumbar spine (hyperlordotic sitting and standing)
Multidirectional Pattern	All movement directions (flexion and extension) provoke NSCLBP symptoms Neutral spinal postures relieve pain Provocative postures and functional tasks associated with either flexed or hyper-extended lumbar spine (eg slump sit, squatting and sway stand)

Table 5-3 – Clinical Features of Adolescent NSCLBP Movement Control Disorders
Subjects for this research were classified into these patters based on their direction of pain provocation (Dankaerts et al. 2006c, O'Sullivan 2004, O'Sullivan 2005).

Sub-classification

The pain behaviour and video data was used to sub-classify subjects as described by Dankaerts and colleagues (Dankaerts et al., 2006c), by a specialist musculoskeletal physiotherapist independent of data collection, see Table 5-3.

B All subjects

Three-dimensional lumbo-pelvic kinematic data and trunk muscle activity were recorded during usual and slump sitting. Subjects sat on a height adjustable stool (with no back support), hips and knees at 90°, feet positioned shoulder width apart and arms relaxed by their side. To standardize head posture, subjects focussed on a visual target set at eye level 1.5m directly in front. Two sitting positions were investigated: usual sitting - where subjects were asked to "sit on the stool as you would usually sit"; and slumped sitting – achieved by relaxing the thoraco-lumbar spine and posterior pelvic rotation. Slump sitting was demonstrated by the investigator prior to testing, with no manual feedback provided through the task. Both positions were maintained for five seconds; with three repetitions of usual/slump/usual sitting.

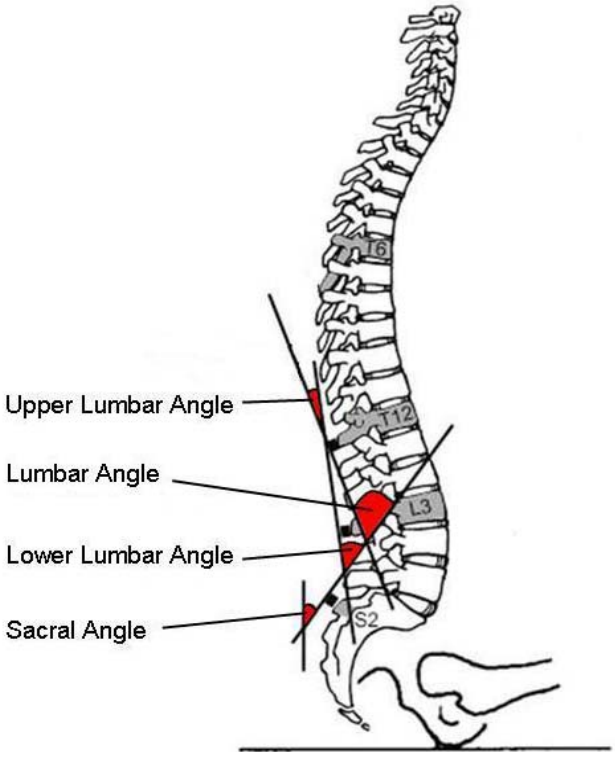

Figure 5-1 – Spinal kinematic variables

Spinal posture

Spinal and pelvic angles were measured using Fastrak (3-Space Fastrak, Polhemus Navigation Sciences Division, Vermont, USA). Sensors were taped to the skin over the S2, L3 and T12 spinous processes. From these sacral, lower lumber, upper

lumbar and lumbar angles were obtained (Figure 5-1). A negative angle indicates anterior sacral tilt for sacral angle measures and lumbar lordosis for all other measures. Procedures for collection and processing of these data and the angle definitions have been outlined elsewhere (Burnett, Cornelius, Dankaerts, & O'Sullivan, 2004; Dankaerts et al., 2006b).

All angles were calculated for both usual and slumped sitting postures. The difference between usual and slumped sitting for each angle was calculated as the slumped sitting spinal angle minus the usual sitting spinal angle and termed the Spinal Flexion Angle Index (SFAI). Kinematic data was averaged across the three trials for each subject. The intra-class correlation coefficients for kinematic measures ranged from 0.882 to 0.969 with standard error of measures ranging from 1.0 to 1.7º.

Spinal muscle activity

Surface EMG was collected from three back [Superficial Lumbar Multifidus (Multifidus); Iliocostalis Lumborum pars Thoracis (Iliocostalis); and Longissimus Thoracis pars Lumborum (Thoracic Erector Spinae)] and two abdominal muscles [Transverse fibres of Abdominal Internal Oblique (Internal Oblique); and Abdominal External Oblique (External Oblique)]. Electrode placements and procedures for skin preparation and data collection are reported elsewhere (Dankaerts et al. 2004; Dankaerts et al. 2006a).

Raw EMG data was visually inspected for heartbeat artefact and where present it was minimised by using a fourth-order Butterworth high pass filter with a cut-off frequency of 30Hz. Raw EMG data was then demeaned, full wave rectified and band pass filtered (4 - 400 HZ) to generate a linear envelope (Dankaerts et al., 2006a; Dankaerts, O'Sullivan, Burnett, Straker, & Danneels, 2004). EMG data was amplitude normalized using standardized tasks designed to elicit a stable sub-maximal voluntary isometric contraction (sub-MVIC). Normalisation protocols have been detailed elsewhere (Dankaerts et al., 2006a), and have been shown to be reliable both within-day and between-days (Dankaerts et al., 2004). Normalized muscle activation for usual and slumped sitting was averaged across the three trials for each subject.

Two methods were used to investigate FRP. A paired *t*-test was used to determine whether a significant difference in muscle activity existed between the two sitting postures for each muscle within each group. And to allow direct comparison between groups, a flexion-relaxation ratio (FRR) was calculated by dividing the averaged muscle activation in usual sitting by that in slumped sitting (Watson et al. 1997; Dankaerts et al. 2006a; Burnett et al. 2008).

The existence of differences in muscle activation levels between left and right sides were examined by use of paired *t*-tests. A significant difference between sides was observed for External Oblique ($p=0.018$) only. For muscles other than External Oblique left and right side data were pooled, whereas, External Oblique was analysed bilaterally. The intra-class correlation coefficients for each EMG-based measure ranged from 0.690 to 0.993 with standard error of measures ranging from 2.6 to 6.0% sub-MVIC.

5.4.3 Statistical analysis

Independent *t*-tests were used to compare the differences in kinematics, SFAI, muscle activation and the FRR between no-LBP and NSCLBP (pooled) groups. ANCOVAs, with gender as a covariate, were used to determine differences between NSCLBP sub-groups and no-LBPs – the omnibus test. Post-hoc pairwise comparisons by Least Squares Differences, with gender as a covariate, were used to analyse differences between sub-groups. Additionally, comparisons of confidence limits for difference and interpretation of effect sizes were used to qualify differences. Paired *t*-tests were used to determine differences in muscle activity between sitting postures. SPSS-V13 for Windows (SPSS Chicago, IL) was used to perform all statistical tests with $\alpha=0.05$.

5.5 RESULTS

5.5.1 Spinal kinematics

No differences in sitting spinal posture were observed between adolescents with and without NSCLBP ($p>0.28$). Differences between groups were only apparent when individuals with NSCLBP were sub-classified. Estimates of differences between those with and without NSCLBP are at Table 5-4A & B.

In usual sitting, statistically significant differences were shown on sub-group analysis for sacral (ANCOVA p=0.001), upper lumbar (ANCOVA p=0.001) and lumbar (ANCOVA p=0.002) angles. Estimated mean difference between sub-groups of NSCLBP and controls after adjustment for gender are at Table 5-4A. The confidence interval estimates suggest a very likely effect of a large sized difference between the extension sub-group and no-LBP for sacral, upper lumbar and lumbar angles (LSD p=0.002,p=0.042,p=0.005 respectively) and between the extension and flexion sub-groups (LSD all comparisons p<0.001) and for the flexion sub-group and no-LBP for upper angle only (LSD p=0.011) see Table 5-4A and Figure 5-2; but no strong evidence of a difference between those with flexion-related NSCLBP and no-LBP for sacral or lumbar angle (Hopkins, 2007; Hopkins, Marshall, Batterham, & Hanin, 2009). No statistically significant differences were shown for lower lumbar angle (ANCOVA p=0.093). However, the estimated differences adjusted for gender, Table 5-4A, suggest differences may exist. The confidence interval estimates suggest a likely effect of a moderate sized difference between the extension sub-group and both the flexion sub-group and the no-LBP group, but no strong evidence of a difference between those with flexion-related NSCLBP and no-LBP (Hopkins, 2007; Hopkins et al., 2009). The direction of these differences demonstrate that adolescents with extension pattern NSCLBP sat with greater anterior pelvic tilt and lumbar lordosis, whereas adolescents with flexion pattern NSCLBP displayed a kyphotic lumbar spine (Figure 5-2).

	Spinal Angle				Trunk Muscle					
	Sacral Angle	Lower Lumbar Angle	Upper Lumbar Angle	Lumbar Angle	Multifidus	Iliocostalis	Thoracic Erector Spinae	Internal Oblique	Left External Oblique	Right External Oblique
	Degrees				% sub-MVIC					
NSCLBP	-0.7±9.7	-4.4±9.0	1.9±7.9	-2.6±13.8	32.9±31.2	36.4±33.0	52.1±29.6	25.6±22.2	31.0±25.7	28.6±27.0
No-LBP	2.0±9.2	-2.2±7.9	0.9±7.5	-1.3±11.7	27.2±23.1	32.2±23.9	59.4±28.8	34.4±28.8	34.7±31.1	22.0±18.7
Extension	-8.2±8.1	-8.7±7.2	-4.0±5.5	-12.8±11.5	35.1±30.4	48.5±29.4	60.6±29.2	24.3±8.9	27.8±13.4	28.3±25.2
Flexion	5.7±5.5	-0.7±9.0	6.9±6.0	6.2±8.7	32.2±31.3	48.1±41.9	50.8±28.9	25.9±20.3	30.2±31.0	19.6±18.0
No-LBP/ NSCLBP	-2.8; ±5.0	-2.3; ±4.68	0.9; ±4.1	-1.4; ±6.9	5.7; ±14.8	4.2; ±15.4	-7.2; ±15.6	-8.8;±13.8 #	-3.7; ±15.3	6.6; ±12.4
No-LBP/ Extension	9.6; ±5.9 #	6.5; ±6	5.4; ±5.3 #	11.8; ±8.1 #	-6.1; ±20.8	-15.5;±23.2	-2.0; ±20.9	12.3 ;±19.0	4.4; ±20.4	-2.8; ±14.7
No-LBP/ Flexion	-3.8; ±6.1	0.4; ±5.3	-6.3; ±4.8 #	-5.9; ±7.5	-8.7; ±19.0	-8.5; ±21.3	7.8; ±19.2	14.1; ±17.4	6.8; ±18.7	-0.9; ±13.5
Extension/ Flexion	-12.8; ±6.9 #	-6.0; ±6.8	-1.7; ±6.0 #	-17.7; ±9.4 #	-2.6; ±24.1	7.0; ±27.0	9.7; ±24.2	1.8; ±22.1	2.4; ±23.7	1.9; ± 17.1

- All group or sub-group values are mean±SD
- All comparisons are mean difference and 95% CI for difference adjusted for gender

# denotes statistically significant comparison at p<0.05

Table 5-4A. Group and Sub-group Means, Standard Deviation and Mean Difference for Spinal Posture and Trunk Muscle Activity in Usual Sitting

	Spinal Angle				Trunk Muscle					
	Sacral Angle	Lower Lumbar Angle	Upper Lumbar Angle	Lumbar Angle	Multifidus	Iliocostalis	Thoracic Erector Spinae	Internal Oblique	Left External Oblique	Right External Oblique
	Degrees				% sub-MVIC					
NSCLBP	10.9±9.6	1.0±9.4	8.1±8.9	9.1±14.0	33.6±30.3	48.3±36.0	55.3±28.9	25.1±15.8	29.1±24.1	23.6±21.7±
No-LBP	14.3±9.5	2.2±9.0	9.1±5.9	11.2±12.0	26.1±23.1	34.7±22.0	60.6±25.3	39.1±30.2	32.8±28.5	21.0±16.8
Extension	4.1±8.7	-4.1±7.9	3.5±5.0	-0.7±11.8	35.2±31.1	41.4±33.7	58.7±32.0	23.8±9.8	31.1±17.2	37.1±33.0
Flexion	16.7±5.9	5.4±8.4	12.1±9.7	17.6±9.7	30.9±32.3	32.0±32.9	46.4±27.1	27.1±29.3	30.9±31.9	21.2±18.6
No-LBP/ NSCLBP	-3.4; ±5.1	-1.2; ±4.9	-0.9; ±4.1	-2.1; ±7.0	7.4; ±14.4	13.6; ±16.0	-5.3; ±25.1	-14.0;±12.9	-3.7; ±14.1	6.5; ±12.3
No-LBP/ Extension	10.1; ±6.1 #	5.6; ±6.0	5.5; ±5.4 #	11.1;±18.3 #	-4.2; ±21.2	-9.5;±22.27	-3.6; ±22	9.0; ±19.8	4.3; ±21.9	-7.7; ±16.7
No-LBP/ Flexion	-0.8; ±7.2	-0.9; ±5.4	-3.4; ±5.0	-4.2; ±7.6	-6.9; ±19.3	-2.6; ±20.3	12.3; ±20.2	1.9; ±18.2	8.1; ±20.1	-3.1; ±15.3
Extension/ Flexion	-10.9; ±7.1 #	-6.5; ±6.9	-8.9; ±6.3 #	-15.3; ±9.6 #	-2.7; ±24.5	7.0; ±25.7	15.9; ±25.5	-7.1; ±23.0	3.8; ±25.4	4.7; ±19.3

- All group or sub-group values are mean±SD
- All comparisons are mean difference and 95% CI for difference adjusted for gender
- # denotes statistically significant comparison at p<0.05

Table 5-4B. Group and Sub-group Means, Standard Deviation and Mean Difference for Spinal Posture and Trunk Muscle Activity in Slump Sitting

	Spinal Angle				Trunk Muscle					
	Sacral Angle	Lower Lumbar Angle	Upper Lumbar Angle	Lumbar Angle	Multifidus	Iliocostalis	Thoracic Erector Spinae	Internal Oblique	Left External Oblique	Right External Oblique
	Degrees				% sub-MVIC					
NSCLBP	11.6±6.1	5.4±5.0	6.3±6.8	11.7±10.0	1.1±0.3	1.1±0.2	1.1±0.3	1.1±1.2	1.0±1.0	0.9±0.2
No-LBP	12.3±8.1	4.4±5.2	8.1±5.3	12.5±9.7	0.9±0.2	1.0±0.2	1.1±0.3	1.2±0.4	0.9±1.0	1.0±0.2
Extension	12.3±6.9	4.6±4.6	7.5±6.4	12.1±10.4	1.0±0.2	1.1±0.2	1.1±0.3	1.1±0.2	1.0±0.2	0.9±0.3
Flexion	11.0±5.4	6.1±5.3	5.2±7.1	11.4±10.1	1.2±0.3	1.1±0.2	1.1±0.3	1.1±0.4	1.0±0.1	1.0±0.2
No-LBP/ NSCLBP	-0.7; ±3.8	1.0; ±2.7	-1.8; ±3.2	-0.8; ±5.2	0.14;±0.12 #	0.11; ±0.12	0.05; ±0.14	-0.13; ±0.20	2E-3; ±0.078	-0.07;±0.12
No-LBP/ Extension	0.5; ±5.6	-0.7; ±4.0	0.1; ±4.6	-0.7; ±7.7	-0.10;±0.16	-0.10;±0.15	0.02; ±0.21	0.13; ±0.27	1E-3; ±0.11	0.09; ±0.15
No-LBP/ Flexion	2.4; ±5.1	-1.3; ±3.6	2.9; ±4.4	1.7; ±7.1	-0.17;±0.15	-0.09;±0.14	-0.06;±0.20	0.18; ±0.25	-3E-3; ±0.11	0.07; ±0.14
Extension/ Flexion	1.9; ±6.5	-0.6; ±4.6	2.8; ±5.5	2.4; ±9.0	-0.07;±0.19	0.02; ±0.18	-0.08;±0.24	0.05; ±0.31	-4E-3; ±0.03	-0.02;±0.18

- All group or sub-group values are mean±SD
- All comparisions are mean difference and 95% CI for difference adjusted for gender
- For kinematics the sitting to slump sitting comparison is the difference Sitting – Slump sitting
- For muscle activity the sitting to slump sitting comparison is the FRP ratio Sitting/Slump sitting
- # denotes statistically significant comparison at p<0.05

Table 5-4C. Group and Sub-group Means, Standard Deviation and Mean Difference for Spinal Posture and Trunk Muscle Activity - Sitting to Slump Sitting

In slump sitting, statistically significant differences were shown on sub-group analysis for sacral (ANCOVA p=0.004), upper lumbar (ANCOVA p=0.023) and lumbar (ANCOVA p=0.007) angles. Estimated mean difference between sub-groups of NSCLBP and controls after adjustment for gender are at Table 5-4B. The confidence interval estimates suggest a very likely effect of a large sized differences between the extension sub-group and no-LBP for sacral, upper lumbar and lumbar angles (LSD p=0.002,p=0.048,p=0.009 respectively) and between the extension and flexion sub-groups (LSD p=0.003,p=0.007,p=0.002 respectively); but no strong evidence of a difference between the flexion sub-group and no-LBP for sacral, upper lumbar or lumbar angle (Hopkins, 2007; Hopkins et al., 2009). No statistically significant differences were shown for lower lumbar angle during slump sitting (ANCOVA p=0.123). However, the estimated differences adjusted for gender, Table 5-4B, suggest differences may exist. The confidence interval estimates suggest a likely effect of a moderate sized difference between the extension sub-group and both the flexion sub-group and the no-LBP group, but no strong evidence of a difference between the flexion sub-group and no-LBP (Hopkins, 2007; Hopkins et al., 2009). The direction of these results indicates that the extension sub-group during slump sitting, sat in more anterior pelvic tilt, lower lumbar lordosis and less lumbar kyphosis when compared to both other groups (Table 5-4B, Figure 5-3). While the flexion group displayed trends towards greater posterior pelvic tilt and lumbar kyphosis than other groups.

There were no differences between no-LBP and sub-groups for SFAI (Table 5-4C, Figure 5-4), indicating each group moved through similar ranges of motion for each measure.

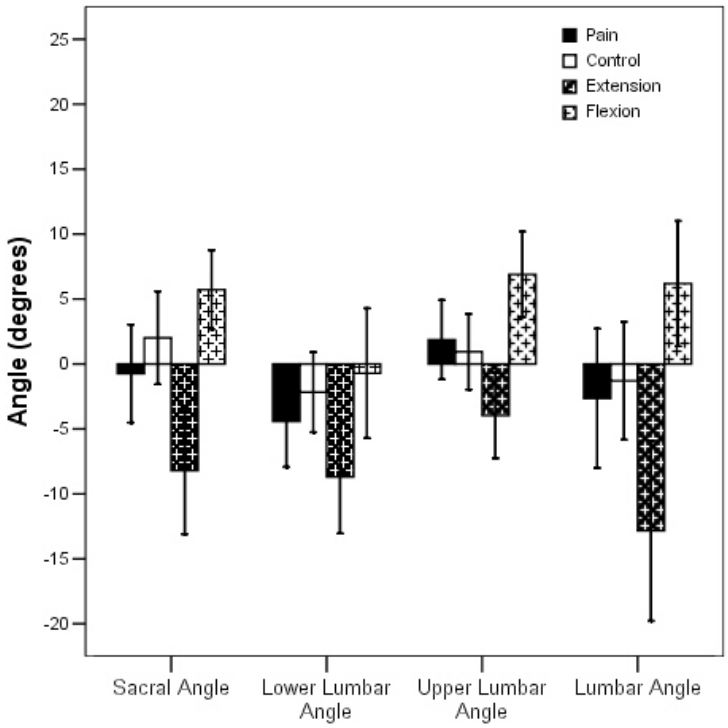

Figure 5-2 – Usual Sitting Posture
Error bars represent 95% CI

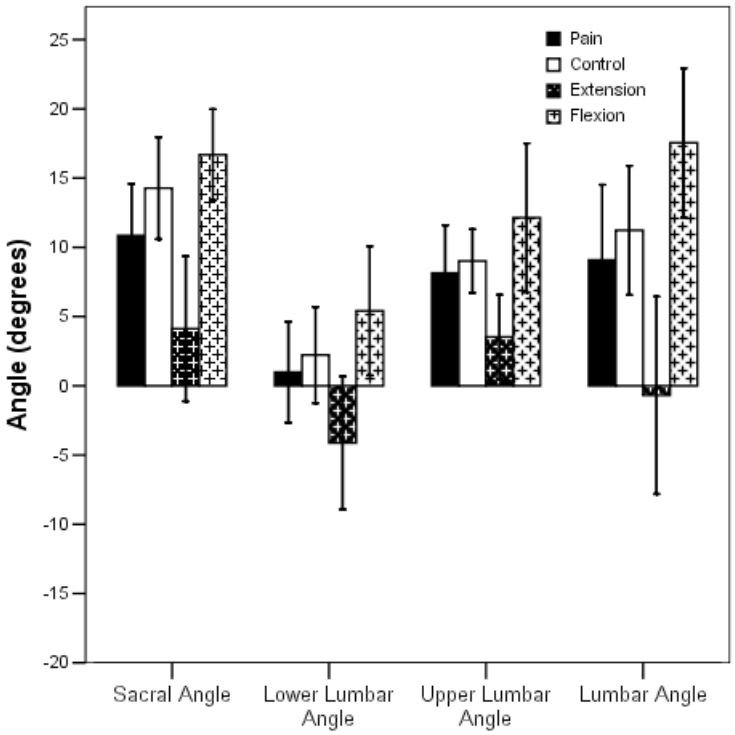

Figure 5-3 – Slump Sitting Posture
Error bars represent 95% CI

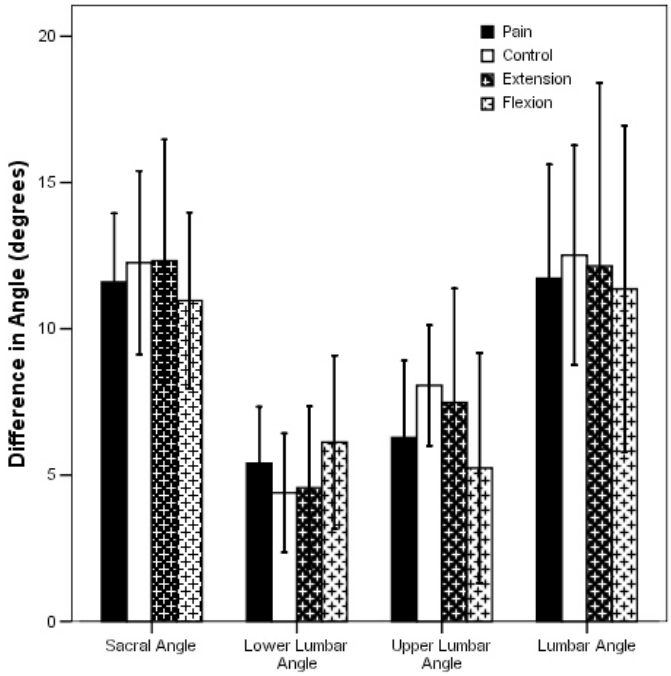

Figure 5-4 – Spinal Flexion Angle Index

Error bars represent 95% CI

5.5.2 Trunk muscle activity

During usual sitting the only difference observed in trunk muscle activity was a significantly greater activation of Internal Oblique in the no-LBP as compared to the NSCLBP (t=-2.170,p=0.034)(Figure 5-5), the confidence interval estimates indicate that the likely effect is for a small size difference. No differences were observed when individuals were sub-grouped. No differences were noted in muscle activation during slumped sitting between no-LBP and NSCLBP groups or sub-groups of NSCLBP (Figure 5-6). Significant reductions in muscle activity between upright and slump sitting were shown for Iliocostalis (t=-2.132,p=0.042) and Thoracic Erector Spinae (t=-2.128,p=0.043) for the pain group and for Iliocostalis (t=-2.333.p=0.038) for the extension sub-group suggesting that flexion relaxation was present in the pain subjects. A significant increase was shown for Multifidus (t=2.760,p=0.010) for controls, Table 5-5. Differences were found between no-LBP and NSCLBP for Multifidus FRR (t=2.397,p=0.020), with the confidence interval estimates indicating that the likely effect is for a moderate size difference between groups. The direction of these results indicates less relaxation of Multifidus in slump sitting for healthy controls than for those with NSCLBP. While not statistically significant (t=-

1.91,p=0.061), the confidence interval estimates for difference suggest a likely effect of a moderate sized increase (less relaxation) between no-LBP and NSCLBP groups for Iliocostalis. No statistically significant differences were shown for the sub-group comparison for Multifidus (ANCOVA p=0.070). However, the estimated differences adjusted for gender suggest differences may exist, Table 5-4B. The confidence interval estimates suggest a likely effect of a moderate sized decrease (more relaxation) between the no-LBP and flexion sub-group (LSD p=0.027), but no strong evidence of a difference between the extension sub-group and either the LBP group or flexion sub-group (Hopkins, 2007; Hopkins et al., 2009). No other muscles displayed differences in flexion-relaxation (Figure 5-7).

		Multifidus	Iliocostalis	Thoracic Erector Spinae	Internal Oblique	Left External Oblique	Right External Oblique
Control	Mean	1.04	-2.52	-1.25	-4.74	1.99	0.99
	SD	2.00	14.44	11.63	13.42	6.82	4.54
	$t_{[27]}$	2.76	-0.92	-0.57	-1.87	1.54	1.16
	p	0.01	0.364	0.574	0.073	0.134	0.258
Pain	Mean	-0.65	-11.89	-3.22	0.44	1.95	4.97
	SD	2.72	29.51	8.00	18.74	7.97	15.64
	$t_{[27]}$	-1.27	-2.13	-2.13	0.13	1.3	1.68
	p	0.214	0.042	0.043	0.902	0.206	0.104
Extension	Mean	0.06	-7.1	-1.86	-0.44	3.35	8.82
	SD	2.76	10.97	7.41	6.14	10.79	21.33
	$t_{[12]}$	0.07	-2.33	-0.9	-0.26	1.12	1.5
	p	0.944	0.038	0.384	0.8	0.285	0.162
Flexion	Mean	-1.27	-16.04	-4.4	1.21	0.74	1.64
	SD	2.76	11	7.41	6.14	10.79	21.33
	$t_{[14]}$	-0.87	-1.59	-2	0.18	0.65	0.85
	p	0.082	0.135	0.066	0.856	0.524	0.411

Means and SD are difference in activity. All values are % subMax.
A negative value indicates presence of FRP.
Bolded values indicate statistically significant differences exist between upright and slump sitting.

Table 5-5. Difference in Muscle activity between Upright and Slump Sitting

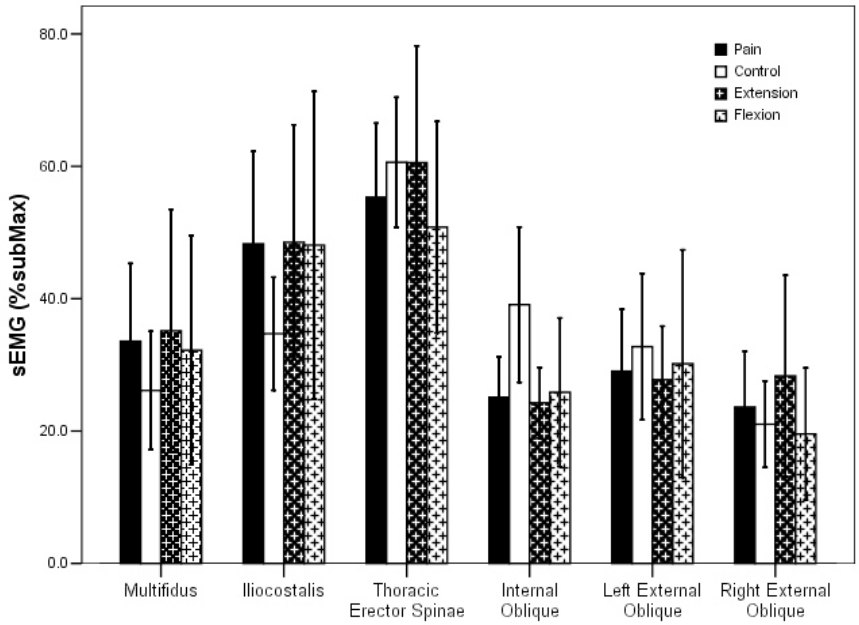

Figure 5-5 – Usual Sitting (Back and Abdominal Muscles)

Error bars represent 95% CI

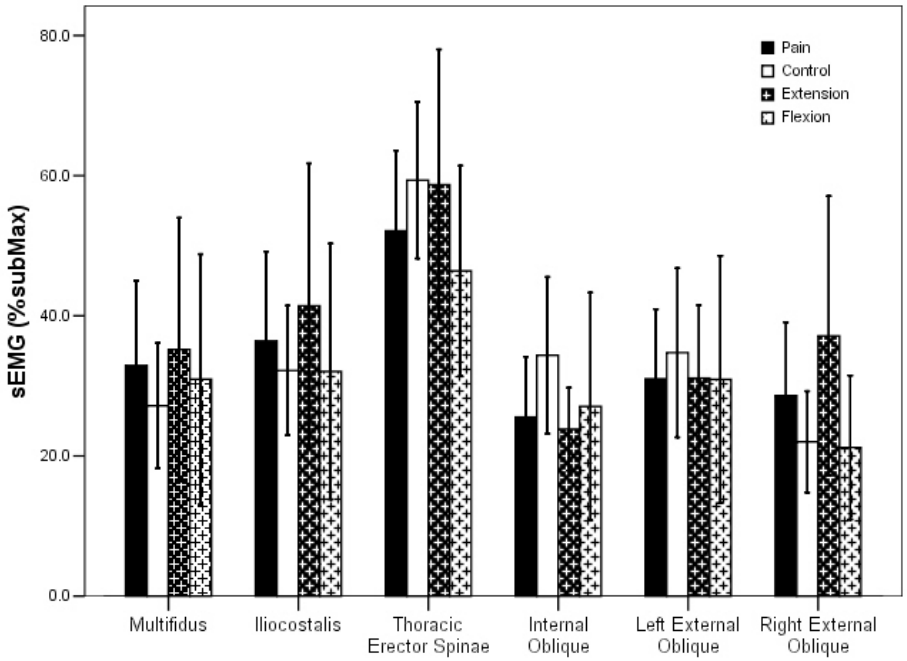

Figure 5-6 - Slump Sitting (back and abdominal muscles)

Error bars represent 95% CI

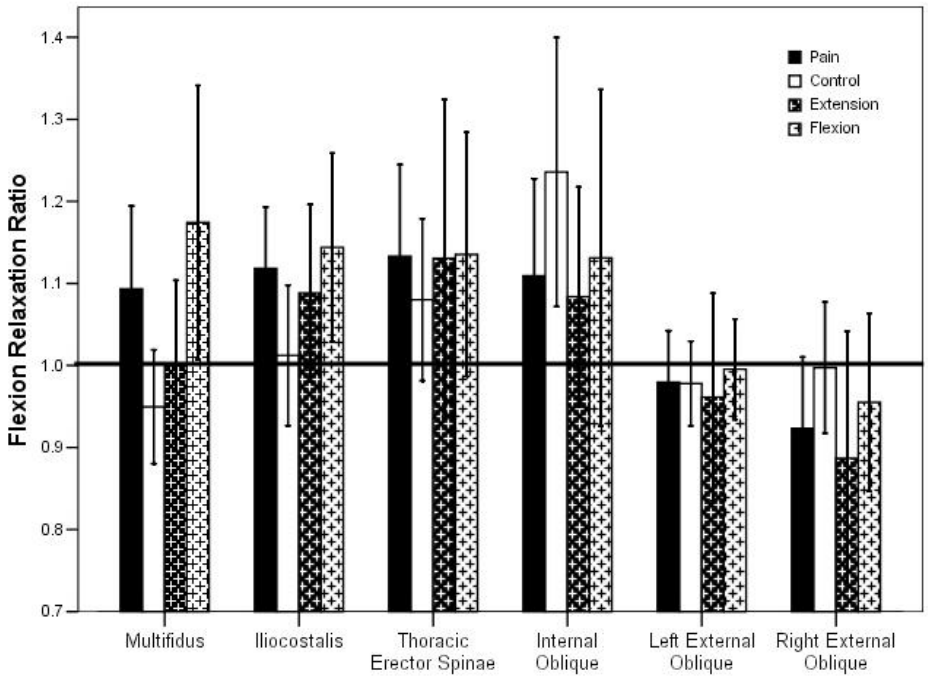

Figure 5-7 –Flexion Relaxation Ratio (back and abdominal muscles)

Error bars represent 95% CI

5.6 DISCUSSION

No differences in spinal posture were observed in either usual or slump sitting between adolescents with and without NSCLBP prior to sub-grouping. These results are similar to adults for usual sitting, but not for slump sitting where differences in adults have been identified between those with and without NSCLBP (Dankaerts et al., 2006b). The levels of trunk muscle activation in adolescents were variable and largely non-discriminatory between groups. In both sitting conditions, only Internal Oblique was different. In our comparable adult study, no EMG differences were shown in usual sitting between no-LBP and NSCLBP groups.

Similar to our adult research (Dankaerts et al., 2006a, 2006b), kinematic differences were only observed once the pain group was sub-classified based on clinical presentation into extension and flexion sub-groups. Postural sub-types have also been documented in adolescents during standing (Smith, O'Sullivan, & Straker, 2008) with non-neutral postures being associated with higher odds for LBP and strong associations between sub-type and gender (Smith et al., 2008). This reinforces the importance of sub-grouping subjects with NSCLBP.

Extension pattern

The sitting posture of the extension sub-group was characterised by anterior pelvic tilt and a lumbar lordosis. All kinematic variables discriminated the extension sub-group from no-LBP and the flexion sub-group, except for the lower lumbar angle, where differences were in a similar direction but not statistically different at α=0.05. These results, although similar to comparable adult research, differ regionally in that the posture of the lower lumbar spine was found most discriminatory between groups in adults (Dankaerts et al., 2006b), whereas in this study of adolescents upper lumbar angle was most discriminatory. These differences may reflect group or maturation differences. Hyperlordotic postures in adults are associated with increased compressive forces on posterior spinal elements, notably the facet joints (Adams & Dolan, 2005; Haberl et al., 2004; Schendel, Wood, Buttermann, Lewis, & Ogilvie, 1993), and hyperlordotic postures are related to LBP in adolescents (Smith et al., 2008), suggesting that these postures may be provocative of LBP.

Muscle activation in the extension sub-group was no different to any other group. This finding is at odds with our adult studies showing greater activation of Multifidus and Iliocostalis in the extension sub-group compared to pain-free subjects (Dankaerts et al., 2006a). These findings may represent the utilisation of spinal postural muscles not measured in this study (such as Iliopsoas or deep back muscles), to maintain hyperlordotic sitting.

Significant gender differences were noted with clinical classification of NSCLBP subjects, similar to our adult study findings (Dankaerts et al., 2006b). These differences may reflect inherent gender responses to pain, or relate to different social, cultural or body image influences in this group.

Flexion pattern

Links between assuming end range flexed postures and increased prevalence of LBP have been reported in both adolescents (Astfalck et al., 2007; Geldhof et al., 2007; Murphy et al., 2004; Perich et al., 2006) and adults (Burnett et al. 2004; O'Sullivan et al. 2006). In usual sitting the flexion group displayed a kyphotic lumbar spine compared to the extension sub-group, with sacral, upper lumbar and lumbar angles

discriminating between sub-groups. Differences were observed between the flexion and control group on the basis of upper lumbar flexion only. This is different to our adult research where the flexion sub-group was able to be differentiated from the extension and no-LBP groups by sacral and lower lumbar angles, which may reflect age based developmental differences. That more males in this study were classified as flexion pattern concords with other sitting and standing postural studies in adolescents that show males present with less lordotic postures and greater thoracic kyphosis than females (Dunk & Callaghan, 2005; Poussa et al., 2005; Smith et al., 2008; Straker, O'Sullivan, Smith, & Perry, 2008; Straker, O'Sullivan, Smith, Perry, & Coleman, 2008; Widhe, 2001). It has been suggested that a flexed thoraco-lumbar posture may increase spinal loading representing a potential mechanism for LBP provocation (Callaghan & McGill, 2001a, 2001b; Granata & Wilson, 2001; Scannell & McGill, 2003).

Levels of muscle activation in the flexion sub-group were not different to any other group. This is at odds with our adult study that demonstrated lower muscle activation in the flexion compared to extension sub-group (Dankaerts et al., 2006a). Slump sitting data suggests that, while kyphotic, adolescents with flexed postures may not be at end of range flexion and therefore retain some degree of active muscle tension during sitting.

Usual to slump sitting

In this research, each group moved through a similar range of motion from usual to slump sitting, although differences between groups were observed in the start and end positions. In our comparable adult study, patients with NSCLBP showed less ability to change lumbo-pelvic posture from usual sitting, particularly through the lower lumbar spine (Dankaerts et al., 2006b). Differences in results may reflect a greater plasticity in the motor system of adolescents with NSCLBP.

Flexion-relaxation was evident in Iliocostalis and Thoracic Erector Spinae for the NSCLBP group, and in Iliocostalis for the extension sub-group but not controls. Antithetically, controls showed a significant increase in the activation levels of Multifidus during slumping. The size of this increase (1.04% sub-MVIC) and is of questionable clinical significance. The FRR discriminated between those with and

without NSCLBP only for Multifidus, with healthy controls exhibiting relaxation of Multifidus in slump sitting less often than those with NSCLBP. Although greater flexion-relaxation in the flexion sub-group was observed, it was not statistically significant at α=0.05. This is at odds with previous adult data showing greater relaxation in Multifidus and Iliocostalis in healthy controls than LBP groups (Dankaerts et al., 2006a). In adults the FRP is also known to be consistent and repeatable; visual analysis of the adolescent data showed a highly variable FRP response across pain and control groups, between subjects and within subject trials. These findings may reflect an immature spinal motor control system, where the loss of flexion-relaxation observed in adult CLBP is not a feature of adolescent CLBP.

Clinical implications

Similar to adults, sub-groups of adolescents with NSCLBP can be identified clinically and confirmed with postural analysis in usual and slump sitting. The direction of postural differences, with extension sub-groups exhibiting hyperlordotic sitting postures and flexion sub-groups kyphotic sitting postures, are similar to those observed in adults (Rose 1989; Dankaerts et al. 2006b; O'Sullivan et al. 2006). The magnitude of the differences in spinal posture are able to be detected clinically as highlighted by the fact that these subgroups were identified visually from video footage. The irony is that, as with previous adult studies, those who reported pain provocation with extension activities and postures sat more extended. Subjects who reported pain provocation with flexion activities and postures sat more flexed than the extension group. This research highlights the potential importance of identifying sub-groups of NSCLBP in the examination, clinical management and scientific investigation of the disorder. This is supported by recent research where a short physiotherapy intervention resulted both in a change in sitting posture and a reduction in LBP in adolescents with NSCLBP (Perich, Burnett, O'Sullivan, & Perkin, 2007).

Unlike adults, muscle activation and FRP were less discriminatory between those with and without pain and sub-groups of NSCLBP. These findings may reflect greater immaturity and plasticity of the spinal motor control system in adolescents. Alternatively, it may reflect increased levels of pain, disability and duration of LBP in the adult group where FRP is absent (Dankaerts et al., 2006a).

Research limitations

It is acknowledged that due to the small sample size the results presented here should be considered as preliminary. Further, the small sample size may have reduced the power of the study to detect differences in muscle activation, although comparable sample sizes in adults have identified differences. While the inclusion and exclusion criteria may also restrict the generalisability of these results, the consistency of postural results with adult data supports the validity and generalisability of these results. Due to the short duration of the sitting tasks, the effects of fatigue on sitting motor control were not considered. Future investigations could include long exposure seated tasks, control for anthropometrical factors such as lumbar spine height and be powered sufficiently to determine interaction of effects of gender and NSCLBP sub-group on sitting posture. The preliminary findings presented here, and a comparison to our previous work in adults raise some interesting observations but require further confirmation by a larger investigation.

5.7 CONCLUSIONS

Whilst the study is preliminary the following conclusions can be made:

1. Sitting spinal posture did not discriminate adolescent NSCLBP from pain free controls unless adolescents with NSCLBP were sub-grouped.
2. Adolescents in flexion and extension pain sub-groups were different from pain free controls on the basis of spinal kinematics, similar to findings in adults.
3. Trunk muscle activation was not a sensitive marker for discriminating sub-groups of NSCLBP in adolescents.
4. Flexion-relaxation in sitting was evident in Iliocostalis and Thoracic Erector Spinae for adolescents with NSCLPB but not for healthy controls.

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CHAPTER 6 – STUDY 3

KINEMATIC AND MUSCLE ACTIVITY ANALYSIS OF STANDING AND FORWARD BENDING IN ADOLESCENTS WITH AND WITHOUT NON-SPECIFIC CHRONIC LOW BACK PAIN

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Lifting and bending are recognised workplace risks for developing LBP. Much previous research has investigated the biomechanics and trunk muscle activation of adults with and without back pain during lifting and bending tasks. Despite evidence for aggravation of LBP in adolescents from lifting and bending there are no current studies that investigate trunk motor control during this activities. This study, together with studies 2 and 4, addresses the main aim of this dissertation to investigate trunk motor control associated with pain provocative spinal postures and movements in a detailed laboratory based study of adolescents with and without NSCLBP and sub-groups of NSCLBP.

Study 3 addresses the following thesis objectives:

3.1 Compare standing postures and kinematic forward bending profiles between adolescents with NSCLBP (pooled and sub-classified) and asymptomatic groups.

3.2 Compare through-range and end-range forward bending, and lumbar spine range-of-motion between standing and end-range forward bending between adolescents with NSCLBP (pooled and sub-classified) and asymptomatic groups.

3.3 Compare trunk muscle activation during standing between adolescents with NSCLBP (pooled and sub-classified) and asymptomatic groups.

3.4 Compare trunk muscle activation at end-range forward bending and during movement phases (forward bending and return) between adolescents with NSCLBP (pooled and sub-classified) and asymptomatic groups.

3.5 Investigate the flexion-relaxation phenomenon during forward bending in adolescents with NSCLBP (pooled and sub-classified) and asymptomatic groups.

To be submitted to Clinical Biomechanics.

6.1 ABSTRACT

Aim. To investigate the spinal kinematics and trunk muscle activation of adolescents with and without NSCLBP during a standing, forward bending and return to upright task.

Scope. 56 adolescent subjects, 28 with NSCLBP, were recruited. Each subject with NSCLBP was sub-grouped based on O'Sullivan's classification system into active-extension or multi-directional pattern disorder. Sagittal lumbo-pelvic kinematic data and muscle activity of three back extensors was recorded during throughout the task. Variables included standing and forward bending spinal posture, spinal range-of-motion through forward bending, muscle activation during task stages and two flexion-relaxation ratios.

Results. No differences were noted based on spinal kinematics during standing, forward bending, forward or return phases or range-of-motion amplitude between those with and without NSCLBP. When sub-classified, the active-extension sub-group displayed restricted range-of-motion in forward-bending compared to both the multi-directional sub-group and controls. Higher muscle activation levels where shown in Iliocostalis during standing in those with NSCLBP compared to controls. Peak muscle activation, during the second quarter of the return phase of forward bending was the most discriminatory time epoch of the task differentiating sub-groups of NSCLBP and healthy controls.

Conclusions. The absence of flexion-relaxation observed in adults with NSCLBP was not a feature of adolescents with NSCLBP.

6.2 INTRODUCTION

Prevalence (Ebrall, 1994) and recurrence (Burton, Clarke, McClune, & Tillotson, 1996; Taimela, Kujala, Salminen, & Viljanen, 1997) rates of low back pain (LBP) in adolescence are high and increase with age (Burton, Clarke, McClune, & Tillotson, 1996; Leboeuf-Yde & Kyvik, 1998; Taimela, Kujala, Salminen, & Viljanen, 1997; Watson et al., 2002). For some 8% of adolescents, LBP can become chronic and disabling (Bejia et al., 2005; Salminen, Erkintalo, Pentti, Oksanen, & Kormano,

1999). The majority of LBP disorders are classified as non-specific chronic LBP (NSCLBP) as no diagnosis can be given (Dankaerts, O'Sullivan, Straker, Burnett, & Skouen, 2006c; O'Sullivan, 2005). As LBP in adolescence is linked with increased risk in adulthood (Balague, Troussier, & Salminen, 1999; Bejia et al., 2005; Salminen et al., 1999), investigating NSCLBP in adolescents may provide insight into the disorder during its development.

It has been previously reported that non-neutral standing postures are linked to LBP in adolescents (Smith, O'Sullivan, & Straker, 2008), and anecdotally in adults (Roussouly, Gollogly, Berthonnaud, & Dimnet, 2005). However, the evidence lacks clarity, perhaps due to the large variation in lumbar lordosis seen in healthy subjects (Roussouly et al., 2005). Studies have shown both increased (Christie, Kumar, & Warren, 1995) and decreased (Jackson & McManus, 1994) lumbar lordosis associated with LBP, while other studies have found no relationship (Ahern, Follick, Council, Laser-Wolston, & Litchman, 1988; Dankaerts et al., 2009; During, Goudfrooij, Keessen, Beeker, & Crowe, 1985; Mitchell, O'Sullivan, Burnett, Straker, & Smith, 2008; Pope, Bevins, Wilder, & Frymoyer, 1985). Based on differences in spinal posture, postural groups have been identified in adults (Norton, Sahrmann, & Van Dillen, 2004; Roussouly et al., 2005) and adolescents (Smith et al., 2008) during standing, with some adolescent postural groups demonstrating higher odds for LBP (Smith et al., 2008).

Conflicting results have also been reported concerning the level of back muscle activation during quiet standing in adults with and without LBP, with studies showing either no difference (Kaigle, Wessberg, & Hansson, 1998) or an increase (Sihvonen, Partanen, Hanninen, & Soimakallio, 1991). This may be linked to the presence of different groups (Dankaerts et al., 2009; Danneels et al., 2002) of LBP or a lack of postural standardization in study designs as the back muscles are known to alter their level of activation in different standing postures (Lariviere, Gagnon, & Loisel, 2000; O'Sullivan et al., 2002).

Similarly, the range of spinal flexion during forward bending has been shown to be either limited (Ahern et al., 1988; Kaigle et al., 1998; van Wingerden, Vleeming, & Ronchetti, 2008) or no different (Esola, McClure, Fitzgerald, & Siegler, 1996;

Lariviere et al., 2000; Mitchell et al., 2008) in adult LBP patients when compared to healthy subjects. No difference in the extent of maximum flexion has also been reported between LBP and control groups (Paquet, Malouin, & Richards, 1994). On returning to upright from forward bending patients with LBP have demonstrated more movement in the lumbar spine in the first quarter of movement but not for the remaining intervals (McClure, Esola, Schreier, & Siegler, 1997).

Changes in the back muscle activation whilst moving into full flexion from standing was first described by Fick in 1911 (Floyd & Silver, 1951). Flexion-relaxation was observed, where a burst of erector spinae (ES) activity occurs as an individual bends forward, particularly lumbar ES, (Kaigle et al., 1998; McGorry, Hsiang, Fathallah, & Clancy, 2001; Sihvonen et al., 1991) followed by a relative decrease (relaxation) near end range flexion (Sihvonen, 1997). While the amount of relaxation can vary between subjects (Paquet et al., 1994), in healthy adults the presence of flexion-relaxation is consistent during forward bending (McGorry et al., 2001; Paquet et al., 1994) and slump sitting tasks (Callaghan & Dunk, 2002; Dankaerts, O'Sullivan, Burnett, & Straker, 2006a; O'Sullivan et al., 2006). As early as 1952 it was recognised that the majority of adult patients with LBP did not achieve relaxation of the back muscles during forward bending (Andersson, Oddsson, Grundstrom, Nilsson, & Thorstensson, 1996). Much of this research has investigated a forward bending task from quiet usual standing and only in adult populations (Descarreaux, Lafond, Jeffrey-Gauthier, Centomo, & Cantin, 2008; Geisser, Haig, Wallbom, & Wiggert, 2004; Hashemirad, Talebian, Hatef, & Kahlaee, 2008; Olson, Li, & Solomonow, 2004; van Wingerden et al., 2008).

Various quantitative criteria have been used to measure flexion-relaxation. Previous methods have included:

(1) Muscle activation in full flexion being less than or equal to 10% of peak muscle activation during the return to standing from forward bending or extension phase (Mathieu & Fortin, 2000).

(2) The ratio of muscle activation in full flexion and that during the flexion (forward) phase being less than one (Paquet et al., 1994; Watson, Booker, Main, & Chen, 1997).

(3) Statistical analysis to determine significantly less muscle activation in full flexion compared to standing or upright sitting (O'Sullivan et al., 2006; O'Sullivan et al., 2002).

(4) The ratio of muscle activation in full flexion and that during upright sitting being less than one (Dankaerts et al., 2006a).

(5) Muscle activation in full flexion being less than or equal to 3% of maximal voluntary isometric contraction (MVIC) (McGill & Kippers, 1994).

(6) Muscle activation in full flexion being greater than or equal to 1% of MVIC less than that in upright sitting (Callaghan & Dunk, 2002).

(7) Visual analysis to determine decreased activation in full flexion compared to standing or upright sitting (Gupta, 2001; Kippers & Parker, 1984; Meyer, Berk, & Anderson, 1993; O'Sullivan et al., 2006).

Despite attempts to compare techniques, there is no current consensus by researchers on what is most clinically or biomechanically meaningful (Burnett et al., 2008).

Recent research has identified different patterns of flexion-relaxation in sub-groups of NSCLBP when adult subjects were classified using O'Sullivan's system based on their pain and movement behaviours (Dankaerts et al., 2006c; O'Sullivan, 2005). O'Sullivan proposed that the 'active-extension' pattern was characterised by pain sensitivity to extension movements and postures with a tendency to maintain the lumbar spine in lordotic postures in sitting, standing and forward bending with associated high levels of back muscle activity. In contrast, the 'flexion' pattern was associated with pain sensitivity to flexion and a tendency to assume flexed sitting and bending postures, while the 'multi-directional' pattern was characterised by pain sensitivity to both flexion and extension, with a tendency to assume flexed spinal postures in sitting, bending and lifting and extended spinal postures in standing

(Dankaerts et al., 2009; Dankaerts et al., 2006a; Dankaerts, O'Sullivan, Burnett, & Straker, 2006b; O'Sullivan, 2005). This research has demonstrated differences are present in the levels of back muscle flexion-relaxation during forward bending tasks between adult sub-groups of NSCLBP and healthy controls. Further, muscle activity and kinematic differences noted during a forward bending task were strong predictors for adult classification into sub-groups of NSCLBP (Dankaerts et al., 2009).

The clinical subgroups observed in adolescents with NSCLBP are similar to that observed in adults (Astfalck, O'Sullivan, Straker, & Smith, 2007). However, to date no study has investigated if the muscle activation and kinematic patterns observed in adults are also present in adolescents with NSCLBP.

This paper aims to investigate the spinal kinematics and trunk muscle activation in adolescents with and without NSCLBP during a standing, forward bending and return to upright task. The hypotheses were that:

1. Kinematic measures of sagittal spinal posture will be different between those with and without NSCLBP and sub-groups of NSCLBP based on standing posture, through-range and end-range forward bending, and lumbar spine range-of-motion between standing and end-range forward bending.
2. Back muscle activation will be different between those with and without NSCLBP and sub-groups of NSCLBP based on electromyographic (EMG) amplitude in standing, at end range forward bending and during movement phases (forward bending and return).
3. Flexion-relaxation will be present in pain free controls and absent in those with NSCLBP, independent of sub-classification.

6.3 MATERIALS AND METHODS

6.3.1 Participants

Participants were drawn from the Western Australian Pregnancy Cohort (Raine) Study, a longitudinal cohort of 2868 children born in a maternity hospital in Perth, Australia (www.rainestudy.org.au). All adolescents with previously documented

LBP were identified from data collected on the cohort during 2003-2005 and were screened and recruited by phone interview (in 2006) to ensure each met participation criteria (Table 6–1). Of those suitable for this study, 28 (14 female) volunteered.

Inclusion Criteria	Exclusion Criteria
Male or Female Age: 14-16 years BMI: <28 kg/m^2 * Pain Group: • History of NSCLBP ≥ 12 weeks duration • Without peripheral pain referral • Pain in the area from T12 to gluteal folds • Moderate ongoing LBP o Average daily pain level - VAS > 3/10 o Experienced most days of the week • Mechanically induced localised LBP Control Group: • No history of spinal pain (* required for successful superficial EMG recording)	Specific diagnosis associated with LBP such as spondylolisthesis, disc prolapse, inflammatory disorders Presence of other conditions affecting the spine including neurological or metatastic disease Any neurological deficit Any surgery involving the lumbar spine Any diagnosed pelvic or abdominal pain disorder in the last 12 months Pregnancy or less than six months post-partum Any lower limb surgery in the last 2 years Current lower limb injury An inability to understand written or spoken English Inability to assume test postures

Table 6-1 - Inclusion and Exclusion Criteria at Recruitment

A comparable control group was identified from the 2003-2005 data based on gender, age (±6 months), pubertal stage (Tanner, 1986; Tanner & Whitehouse, 1976) and socio-economic status (SES) (Australian Bureau of Statistics Index of Relative Socio-Economic Advantage/Disadvantage index)(±1 quartile) (Trewin, 2001). These measures were repeated during kinematic and EMG data collection for this study in one laboratory session at the School of Physiotherapy, Curtin University of Technology through 2006-2007. Controls did not differ from pain subjects on body mass index, pubertal stage and SES, but were slightly older (mean difference 3.2 months t_{df}=-2.010$_{54}$,p=0.049)(Table 6-2). Prior adult studies (Kaigle et al., 1998; Paquet et al., 1994) showed 2 groups of N=28 had sufficient power to identify differences in range-of-motion (Kaigle et al., 1998), trunk extensor activation during forward bending (Kaigle et al., 1998) and a flexion-relaxation ratio (Paquet et al., 1994). Group sizes had sufficient power to detect differences of a standard deviation in these variables. Ethics approval was obtained and parents provided written informed consent.

	NSCLBP (pooled) (n=28)	Control (n=28)	NSCLBP (sub-classified)	
			Extension (n=13)	Flexion (n=15)
Age (years)	15.4 ± 0.5[#]	15.7 ± 0.5[#]	15.4 ± 0.6	15.4 ± 0.5
BMI (kg/m^2)	22.2 ± 3.5	21.2± 2.6	22.8 ± 4.2	21.6 ± 2.8
Index of Relative Socio-Economic Advantage/ Disadvantage	988.9 ± 59.7	979.8 ± 61.9	984.8 ± 51.6	989.1 ± 69.0
Developmental Stage				
Genital	3.5± 0.5	3.4 ± 0.6	3.5 ± 0.5	3.5 ± 0.5
Breast (Girls only)	3.9 ± 0.7	3.8 ± 0.8	3.8 ± 0.6	4.0 ± 0.8
Usual pain (VAS out of 10)	4.4±1.9		5.1±1.3	3.8±2.1
Pain duration (months)	26.6±12		24.8±14.7	28.0±8.7
Kinesiophobia (total score 68)	36.1±10.1		35.5±4.7	36.7±8.8
Disability (%)	17.9±10.1		17.6±7.9	18.2±11.9
No. female subjects	14	14	10 [$]	4 [$]
No. male subjects	14	14	3[$]	11 [$]

*All measures were recorded during laboratory testing session in 2006/07.

Values are Mean ± SD

[#] t_{df} = -2.010$_{54}$, p=0.049; [$] χ^2= 7.036$_2$, p=0.030; [†]

Table 6-2 – Non-specific Chronic Low Back Pain (NSCLBP) and no Low Back Pain Sample Characteristics*

6.3.2 Measures

A Pain group only

For the NSCLBP group pain intensity was measured with a Visual Analogue Scale (VAS), which has high test-retest reliability and good construct validity when used by adolescents (Stinson, Kavanagh, Yamada, Gill, & Stevens, 2006). Disability was assessed with the Oswestry Disability Questionnaire (Fairbank, Couper, Davies, & O'Brien, 1980). The questionnaire was modified for use in minors by removing the question concerning affect of pain on sex-life. The Oswestry is reliable and valid for use in adults (Fairbank et al., 1980) and has previously been used in adolescents (Perich, Burnett, & O'Sullivan, 2006). Fear avoidance behaviour was quantified by the Tampa Scale of Kinesiophobia (TSK), the reliability and validity are considered moderate to good (Goubert et al., 2004; Swinkels-Meewisse, Swinkels, Verbeek, Vlaeyen, & Oostendorp, 2003; Vlaeyen, Kole-Snijders, Boeren, & van Eek, 1995) and has previously been used with adolescents (Perich et al., 2006).

Sub-classification

Sub-classification of pain subjects into sub-groups was conducted independently by a specialist musculoskeletal physiotherapist involved in a previous study demonstrating the reliability of this system (Dankaerts et al., 2006c). Each subject with pain was asked a standard series of questions to describe their NSCLBP. This included the duration, location, frequency and intensity of LBP; pain provoking postures and activities such as sitting, standing, walking, bending, lifting, exercise (type and duration); and type and level of medications used. Video footage was taken of each subject with NSCLBP during functional postures and movements: standing, standing to sitting, usual sitting, slump sitting, return to usual sitting, sitting to standing, standing, left and right leg single-leg-stance, forward bending and return to standing, backward bending and return to standing. Each subject's subjective pain behaviour information and video footage was reviewed to determine the relationship between pain provocative postures and movements. This procedure for clinically classifying NSCLBP subjects has been previously reported, (O'Sullivan, 2005) validated (Dankaerts, 2006; Dankaerts et al., 2009) and found to be reliable (Dankaerts et al., 2006c). There were 13 active-extension pattern (10 female) and 15 multi-directional pattern subjects (4 female), gender distribution being statistically different (p=0.030) (Table 6-2).

B All subjects

Forward bending task

Subjects were asked to stand for five seconds in their 'usual' posture, feet shoulder width apart, arms relaxed by their side. Head position in standing was standardised by focusing on a point set at eye level 1.5m directly in front. Subjects were instructed to slowly reach forward toward their toes till they achieved what they perceived was their end of range, they then slowly returned to usual standing. Each phase - standing, forward-bending; end-range forward-bending; return from forward-bending; and standing (phases 1-5 respectively) - was conducted over five seconds, with the cadence controlled by digital metronome (Figure 6-1). Following familiarization with the timed task to achieve a steady pace, three trials were conducted. Subjects were given a break of two-minutes between trials. This testing procedure has proven to be reliable in adults (Dankaerts et al., 2009). Sagittal lumbo-

pelvic kinematic data and trunk muscle activity were recorded continuously during the task.

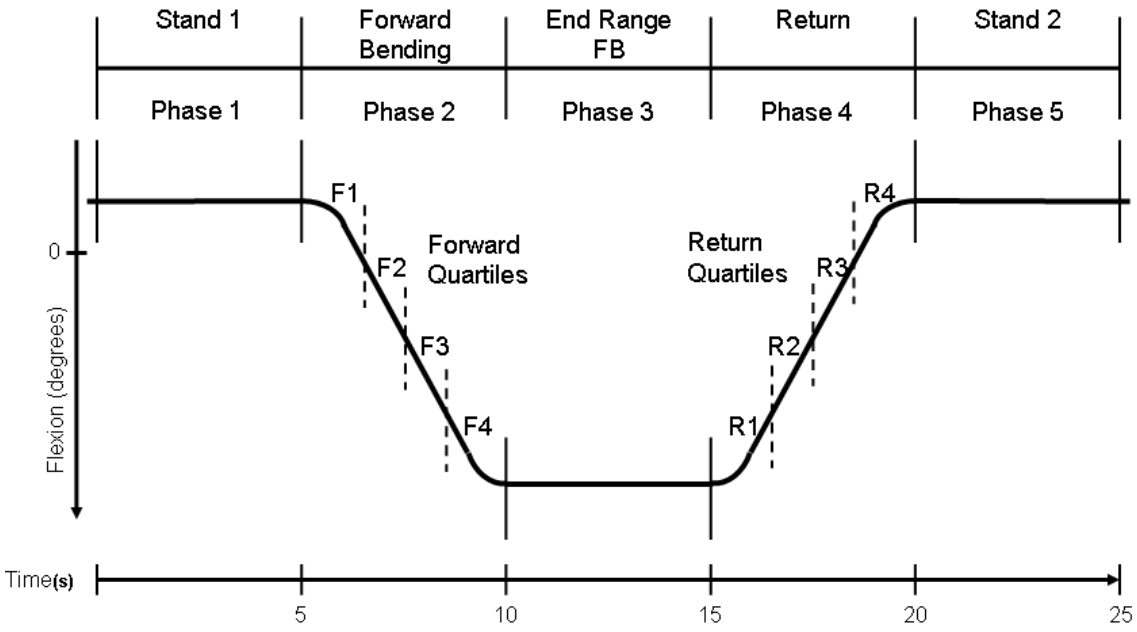

Figure 6-1 – Forward Bending Task - Movement Phases and Quartiles

Spinal kinematics

Measures of spinal kinematics were collected using Fastrak (3-Space Fastrak, Polhemus Navigation Sciences Division, Vermont, USA). Fastrak has a reported accuracy of 0.2º (Maffey-Ward, Jull, & Wellington, 1996). With the subject in slight spinal flexion, sensors were taped to the skin over the spinous processes of S2, L3 and T12 using double sided tape (3M, Pymble, Australia) and secured with Fixomull sports tape (Beiersdorf AG, Hamburg, Germany) (Burnett, Cornelius, Dankaerts, & O'Sullivan, 2004; Dankaerts et al., 2006b). Data were collected at 25Hz using a customised program in LabVIEW V8.2 (National Instruments Inc., Texas, USA) Sacral, lower lumbar, upper lumbar and lumbar angle were measured (see Figure 6-2).

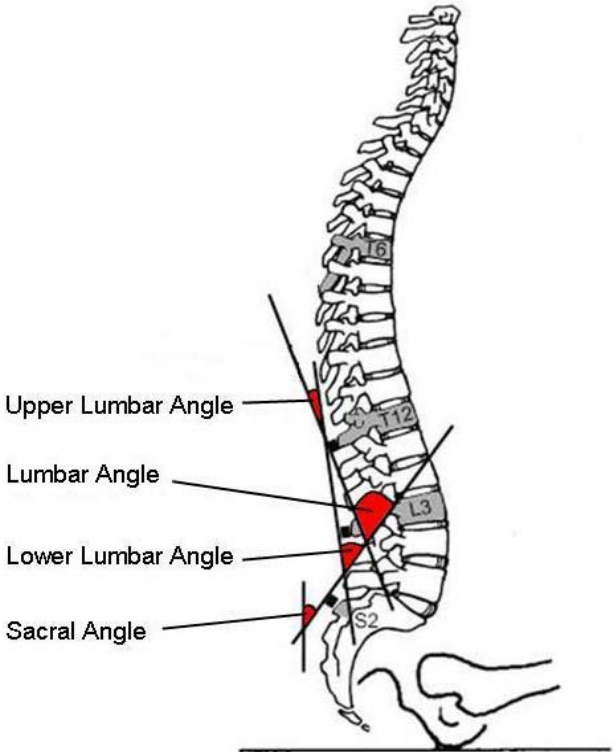

Figure 6-2 – Spinal Kinematic Variables

Sacral Angle – the inclination of the S2 sensor to the vertical; a negative angle indicating anterior sacral tilt. Lower Lumbar Angle – the angle between two intersecting lines, one indicating the inclination of the sensor at L3 and the other the inclination of the sensor at S2. A negative lower lumbar angle indicating lumbar lordosis. Upper Lumbar Angle – the angle between two intersecting lines, one indicating the inclination of the sensor at T12 and the other the inclination of the sensor at L3. A negative angle indicating lumbar lordosis. Lumbar Angle – the angle between two intersecting lines, one indicating the inclination of the sensor at T12 and the other the inclination of the sensor at S2. A negative angle indicating lumbar lordosis.

Static sacral, lower lumbar, upper lumbar and lumbar angles were calculated for usual standing (Phase 1) and end-range forward-bending (Phase 3) as well as the difference between these positions (forward bending range-of-motion). The movement phases 2 and 4 (forward and return) were divided into quartiles based on time, with each quartile measure representing the average position during the respective time epoch (Figure 6-2). All kinematic measures (stand 1, F1-F4, end-range forward bending, R1-R4 and stand 2) were averaged across the three trials for each subject. The intra-class correlation coefficients for kinematic measures for phases 1, 3 & 5 ranged from 0.952 to 0.993 with standard error of measures ranging

from 1.2º to 18.2º and for forward and return quartiles from 0.733 to 0.972 with standard error of measures ranging from 1.2º to 2.3º.

Spinal muscle activity

Surface electromyography (sEMG) was collected bilaterally from three back muscles. Skin preparation included shaving, cleansing with alcohol and lightly abrading with sandpaper to ensure skin impedance was less than 10kΩ (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). Pairs of self-adhesive disposable Ag/AgCl surface electrodes of contact area 1cm^2 (Red Dot, 3M Health Care Products, London, Canada) were placed parallel to the muscle fibres with a centre-to-centre spacing of 2.5 cm and positioned as follows:

> **Superficial lumbar multifidus (Multifidus)** – parallel to the line between the posterior superior iliac spine and the L1-L2 interspinous space at the level of L5 (De Foa, Forrest, & Biedermann, 1989).
>
> **Iliocostalis lumborum pars thoracic (Iliocostalis)** – midway between the midline and the lateral aspect of the body at the level of the L1 spinous process (Danneels et al., 2002).
>
> **Longissimus Thoracis pars Lumborum** (**Thoracic Erector Spinae)** – 5cm lateral to the inferior edge of the T9 spinous process (Dankaerts et al., 2006a).

Six channels of sEMG at 1000Hz (bandwidth 10-500HZ, common mode rejection ration >115dB at 60Hz, gain 2000) were sampled with two, eight channel Octopus Cable Telemetric units (Bortec Electronics Inc., Calgary, Canada), one for right sided channels and one for left sided channels. A reference electrode was positioned laterally on the respective right or left iliac crest for each unit. Data was collected using a customised LabVIEW V8.2 program. All channels were visually inspected for heartbeat artefact and where present it was minimised using a fourth-order Butterworth high pass filter with a cut-off frequency of 30Hz (Drake & Callaghan, 2006). Raw EMG data was then demeaned, full wave rectified and band pass filtered (4 - 400 HZ) to generate a linear envelope (Dankaerts et al., 2006a; Dankaerts, O'Sullivan, Burnett, Straker, & Danneels, 2004). Muscle activation values during each phase were amplitude normalized using a standardized task designed to elicit a

stable sub-maximal voluntary isometric contraction (sub-MVIC) in trunk extensors . The normalisation protocol has been detailed elsewhere (Dankaerts et al., 2006a), and have been shown to be reliable both within-day and between-day (Dankaerts et al., 2004). Normalized muscle activation for each of phases 1, 3 and 5 and for each quartile of the forward and return phases were averaged across the three trials for each subject.

Flexion-relaxation ratio

Due to a lack of consensus in the literature defining the criterion for FR, two flexion-relaxation ratio (FRR) calculations were used.

FRR 1. Average muscle activation during Phase 3 divided by that during Phase 2 (average cross all quartiles) (Burnett et al., 2008; Watson et al., 1997); for flexion-relaxation to have occurred FRR1 must be less than 1.

FRR 2. Average muscle activation during Phase 3 divided by the peak activation during Phase 4 (Mathieu & Fortin, 2000), (for all muscles the peak occurred during Return Quartile 2 (R2)); for flexion-relaxation to have occurred FRR2 must be ≤0.9 (Mathieu & Fortin, 2000).

Side differences were assessed with paired *t* tests. No differences were found for each pair of muscles hence left and right side results were pooled. The inter-trial reliability for each measure of muscle activation ranged for phases 1, 3 & 5 ranged from 0.657 to 0.978 with standard error of measures ranging from 2.6 to 8.5 % sub-MVIC and for forward and return quartiles from 0.477 to 0.929 with standard error of measures ranging from 3.4 to 7.2 % sub-MVIC.

6.3.3 Statistical analysis

Independent *t*-tests were used to determine if differences were present in kinematics, range-of-motion, muscle activation, FRR1 and FRR2 between no-LBP and NSCLBP (pooled) groups. ANCOVAs were used to determine differences between NSCLBP sub-groups and no-LBP with gender as a covariate and Least Squares Differences used to analyse differences between sub-groups post-hoc. Comparisons of confidence limits for difference and interpretation of effect sizes was undertaken

where appropriate. SPSS-V13 for Windows (SPSS Chicago, IL) was used to perform all statistical tests with α=0.05.

6.4 RESULTS

6.4.1 Spinal kinematics

Standing (Phases 1 and 5)

No statistically significant differences in spinal angles in standing were observed for adolescents with and without NSCLBP and between no-LBP and sub-groups of NSCLBP (Figure 6- 3).

End-range forward-bending (Phase 3)

No statistically significant differences between LBP sub-groups and the no-LBP group were noted in spinal angles at end-range forward-bending although trends for differences in lower lumbar flexion at end-range forward-bending were observed (ANCOVA p=0.089). For lower lumbar angle the estimated difference between the active-extension and no-LBP groups was -5.9º (95% CI: -12.1 to 0.3º, p=0.060), between the multi-directional and no-LBP groups was 1.7º (95% CI -4.0 to 7.4º s, p=0.549) and between the multi-directional and active-extension groups was -7.6º (95% CI -14.8 to -0.5º, p=0.037), after adjustment for gender. The confidence interval estimates suggest a likely effect of a large sized reduction in mean lower lumbar angle at end-range forward-bending in adolescents with extension-related NSCLBP compared to those with multi-directional NSCLBP, a moderate sized reduction for those with extension-related NSCLBP compared to those with no-LBP and no strong evidence for a difference between those with multi-directional NSCLBP and no-LBP (Hopkins, 2007; Hopkins, Marshall, Batterham, & Hanin, 2009).

Forward bending and return (Phases 2 and 4)

No statistically significant differences were noted for spinal angles during forward bending (F1-F4) or return (R1-R4) phases for adolescents with and without NSCLBP and between no-LBP and sub-groups of NSCLBP.

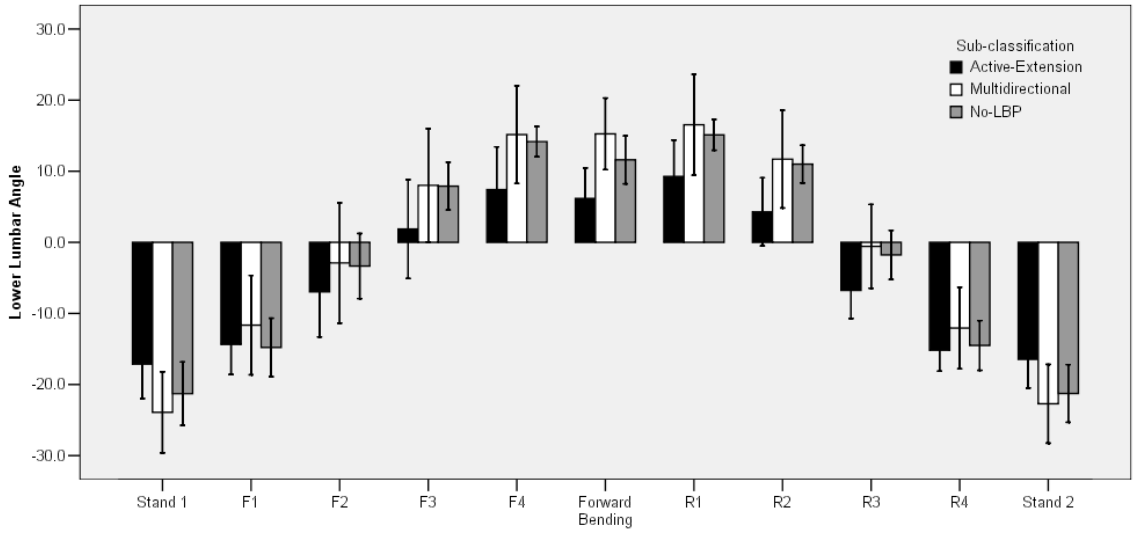

Figure 6-3 – Lower Lumbar Angle through task by sub-group
Error bars = 95% CI

Forward bending Rrnge-of-motion

The range-of-motion from standing to end-range forward-bending was the same for adolescents with and without NSCLBP for each spinal angle, however differences were apparent in lower lumbar angle when those with NSCLBP were sub-classified and compared to controls (ANCOVA p=0.016) (Figure 6-4). The estimated difference between the extension and no-LBP groups was -9.0º (95% CI: -117.5 to -0.6º, p=0.036), between the multi-directional and no-LBP groups was 5.5º (95% CI –2.2 to 13.3º, p=0.156) and between the multi-directional and extension groups was 14.6º (95% CI 4.8 to 24.6º, p=0.004), after adjustment for gender. The confidence interval estimates suggest a likely effect of a large sized reduction in mean lower lumbar forward-bending range-of-motion in adolescents with extension-related NSCLBP compared to those with multi-directional NSCLBP, a moderately large sized reduction for those with extension-related NSCLBP compared to those with no-LBP and no strong evidence for a difference between those with multi-directional NSCLBP and no-LBP.

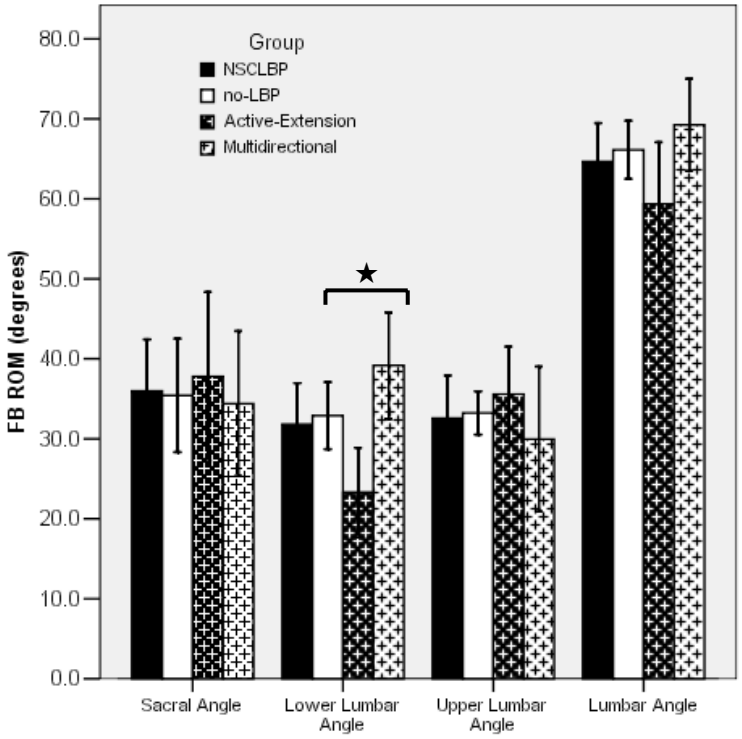

Figure 6-4 – Spinal angle range of motion in forward bending by group and sub-group

Calculated as difference between phases 1 and 3

Error bars = 95% CI,

★Sig difference p <0.05

6.4.2 Trunk muscle activity

Standing (Phases 1 and 5)

In usual standing (Stand 1) muscle activation of Iliocostalis was significantly more (17.6% sub-MVIC, 95% CI 0.2 to 34.9%) for adolescents with NSCLBP compared with those without (p=0.047). No significant difference was shown during Stand 2 (p=0.072), however the estimated difference between NSCLBP and no-LBP groups was of moderate size and in the same direction (16.7% sub-MVIC, 95% CI -1.5 to 35.0%). No differences were observed between sub-groups of NSCLBP and no-LBP or for any other back muscle (Figures 6-5, 6-6, 6-7).

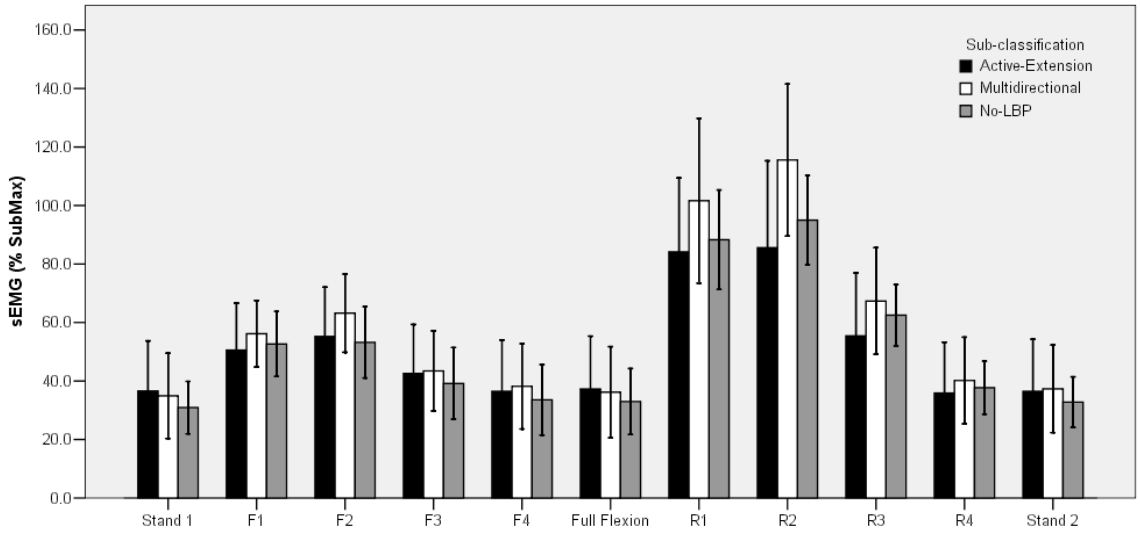

Figure 6-5 – Multifidus activation through forward bending task by sub-group

Error bars represent 95% CI

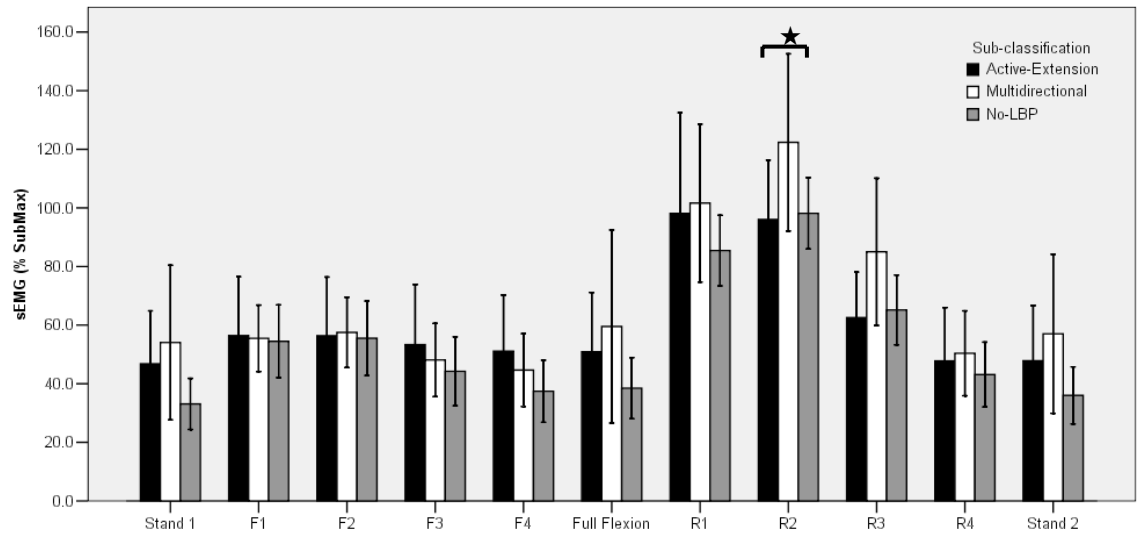

Figure 6-6 – Iliocostalis activation through forward bending task by sub-group

Error bars represent 95% CI

★Sig difference p <0.05 on omnibus test

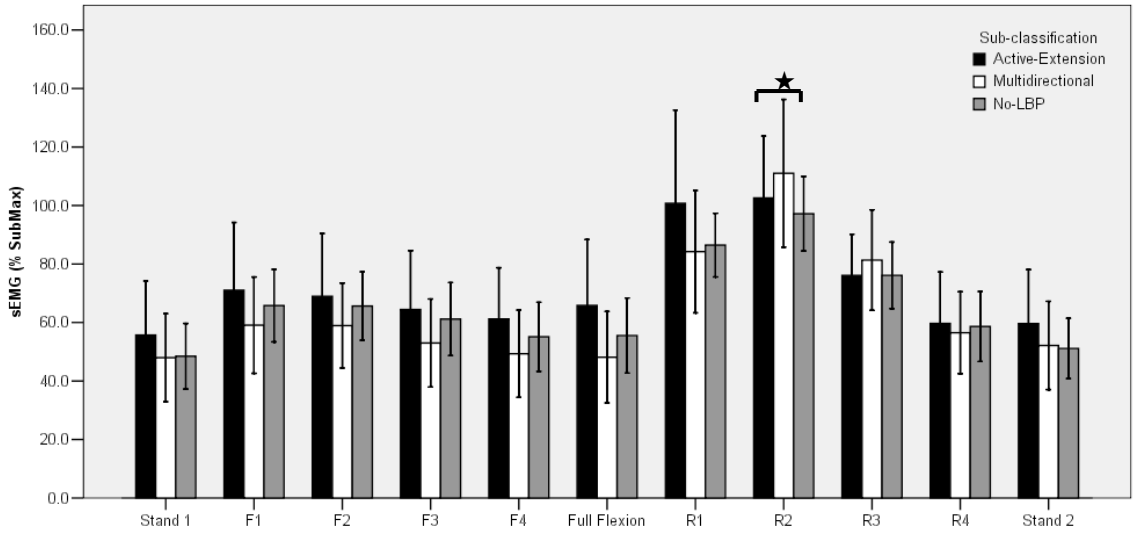

Figure 6-7 – Thoracic Erector Spinae activation through forward bending task by sub-group

Error bars represent 95% CI

★Sig difference p <0.05 on omnibus test

End-range forward-bending (Phase 3)

No differences were noted in back muscle activity at end-range forward-bending between any groups.

Forward bending and return (Phases 2 and 4)

No differences were noted between adolescents with or without NSCLBP during the forward bending (F1-F4) or return quartiles R1, R3 or R4 for any back muscle studied. Back muscle activation during the second quarter of the return phase (R2) demonstrated significant differences for Iliocostalis (ANCOVA p=0.008) and Thoracic ES (ANCOVA p=0.050); with comparable trends for Lumbar Multifidus during R2 (ANCOVA p=0.089), Figures 6-5, 6-6, 6-7.

For Iliocostalis during R2 the estimated difference between active-extension and no-LBP groups was -7.3% sub-MVIC (95%CI: -35.8 to 21.2%, p=0.608), between the multi-directional and no-LBP groups was 38.3% sub-MVIC (95%CI 12.2 to 64.4%, p=0.005) and between the multi-directional and active-extension groups was -45.6% sub-MVIC (95%CI –78.6 to -12.6%, p=0.008) after adjustment for gender. The confidence interval estimates suggest a likely effect of a large sized increase in mean Iliocostalis activation during R2 in adolescents with multi-directional NSCLBP

compared to those with active-extension NSCLBP and no-LBP, and no evidence for a difference between those with active-extension NSCLBP and no-LBP.

For Thoracic ES during R2 the estimated difference between the active-extension and no-LBP groups was -1.5% sub-MVIC (95%CI: -27.1 to 24.2%, p=0.909), between the multi-directional and no-LBP groups was 28.0% sub-MVIC (95%CI 4.4 to 51.5%, p=0.021) and between the multi-directional and extension groups was -29.4% sub-MVIC (95%CI -59.0 to -0.2%, p=0.051) after adjustment for gender. The confidence interval estimates suggest a likely effect of a moderate sized increase in mean Thoracic ES activation during R2 in adolescents with multi-directional NSCLBP compared to those with active-extension NSCLBP and no-LBP, and no evidence for a difference between those with active-extension NSCLBP and no-LBP.

For Multifidus during R2 the estimated difference between the extension and no-LBP groups was -21.4% sub-MVIC (95%CI: -55.0 to 12.2% sub-MVIC, p=0.206), between the multi-directional and no-LBP groups was 22.1% sub-MVIC (95%CI -8.7 to 52.8%, p=0.156) and between the multi-directional and extension groups was -43.5% sub-MVIC (95% CI -82.4 to -4.7%, p=0.029) after adjustment for gender. The confidence interval estimates suggest a likely effect of a large sized increase in mean Multifidus activation during R2 in adolescents with multi-directional NSCLBP compared to those with active-extension NSCLBP, a moderate sized increase between those with multi-directional NSCLBP and no-LBP, and no evidence for a difference between those with active-extension NSCLBP and no-LBP.

6.4.3 Flexion-relaxation ratios

For the no-LBP group flexion-relaxation was absent in Thoracic ES using the FRR1 method only but was otherwise present in all other back muscles. For the pooled NSCLBP group and the active-extension sub-group the flexion-relaxation was present in each back muscle irrespective of the measurement criterion. For the multi-directional sub-group the flexion-relaxation was absent in Iliocostalis using the FRR1 method only and present otherwise (Table 6-3). However there were no statistical differences in mean FRR values between adolescents with and without NSCLBP or sub-groups of NSCLBP based on either calculation (Figures 6-8 and 6-9).

	Multifidus				Iliocostalis				Thoracic Erector Spinae			
	NSCLBP	No-LBP	Active-Extension	Multi-directional	NSCLBP	No-LBP	Active-Extension	Multi-directional	NSCLBP	No-LBP	Active-Extension	Multi-directional
FRR1	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓
FRR2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 6-3 – Presence of back muscle flexion relaxation in adolescents with and without non-specific low back pain groups and sub-groups

✓ - indicates presence of flexion-relaxation

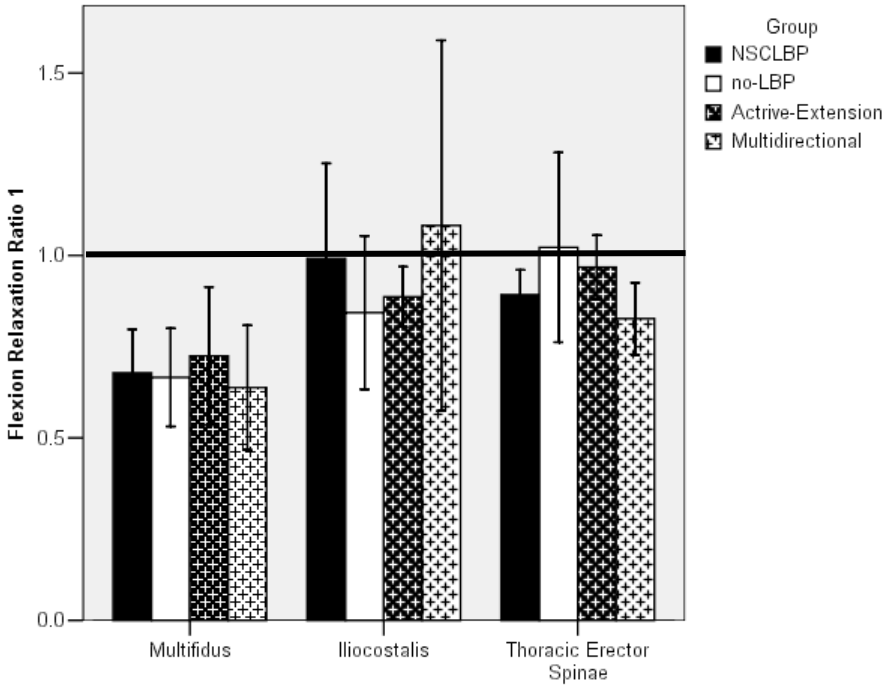

Figure 6-8 –Flexion-Relaxation Ratio 1

Error bars represent 95% CI

For flexion-relaxation to have occurred FRR1 must be <1, indicated by line

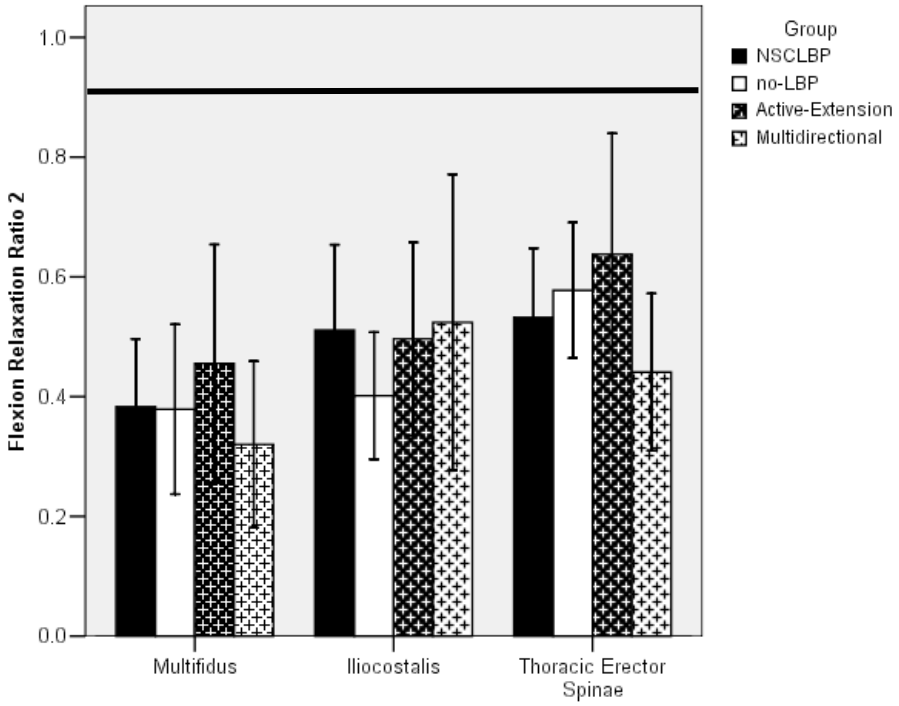

Figure 6-9 –Flexion-Relaxation Ratio 2

Error bars represent 95% CI

For flexion-relaxation to have occurred FRR2 must be <0.9, indicated by line

6.5 DISCUSSION

This study demonstrates that kinematic and trunk muscle activity differences exist between adolescents with and without NSCLBP in standing and forward bending.

Standing

Based on static standing posture, no differences were found between those with and without NSCLBP or sub-groups of NSCLBP. While this finding is similar to previous adult studies (Dankaerts et al., 2009; Mitchell et al., 2008; Pope et al., 1985), although it is different to a recent large adolescent cohort study that was able to differentiate sub-groups of NSCLBP based on standing posture (Smith et al., 2008). Previously noted large variations in sagittal measures of lumbar lordosis found in adults during standing (Roussouly et al., 2005) may help to explain the homogeneity of the current sample and the lack of differences shown between groups.

The greater level of muscle activation of Iliocostalis during quiet standing in the NSCLBP group (50.7% sub-MVIC) compared to no-LBP (33.1% sub-MVIC) is similar to a previous adult study (Sihvonen et al., 1991). However, other adult studies have found muscle activation in standing to be non-discriminatory (Dankaerts et al., 2009; Pope et al., 1985; Watson et al., 1997). It has been recently proposed that increased trunk muscle co-activation during standing may represent a mechanism for LBP by increased spinal loading (Nelson-Wong & Callaghan, 2009).

End-Range Forward-Bending

While end-range forward-bending lower lumbar angles were not statistically different, the active-extension sub-group (6.2±7.1º) had reduced lower lumbar flexion compared with either the multi-directional sub-group (15.3±9.1º) or the no-LBP group (11.6±8.7º). These results show a similar trend to Dankaerts and colleagues, that in adults the active-extension group did not move out of lordosis in forward bending (Dankaerts et al., 2009). These results lend support to O'Sullivan's classification system which proposes different movement and pain sensitisation patterns in sub-groups of NSCLBP (O'Sullivan, 2004, 2005).

Forward Bending and Return

The results from this research in adolescents show no significant kinematic differences between groups or sub-groups during the moving phases of forward bending or return. In previous adult studies, the contribution of the lumbar spine during early forward bending compared to hip flexion has been shown to be both more (Esola et al., 1996; Paquet et al., 1994) and less (van Wingerden, Vleeming, & Ronchetti, 2008) in people with LBP. During the return phase, one study has shown that patients with LBP demonstrate greater lumbar movement in the first quarter of this phase compared to healthy adults (McClure et al., 1997). The noted differences in these results could be due to differences in the cohorts studied (such as age, skeletal or neuromuscular maturity) or the observed effect size in this adolescent population being less than seen in previous adult studies. If real differences are present in the adolescent population, studies with increased group sizes will be required to detect these.

The most substantial trunk muscle activation result in this aspect of the study was the peak activation of Iliocostalis and Thoracic ES activation during the second quarter of the return phase (R2), with a difference shown between sub-groups. Similar non-significant trends were noted for Lumbar Multifidus. The multi-directional sub-group had a peak activity 10-20% sub-MVIC larger than the active-extension or no-LBP groups. The lack of difference between NSCLBP and no-LBP groups is likely due to a *wash-out* of the pooled multi-directional and active-extension sub-group data (Dankaerts et al., 2006b). The increased activation noted in the multi-directional sub-group data maybe related to the greater lumbar flexion angle observed in this group, resulting in a greater extension force needed to return the spine to upright from forward bending. In contrast, it may represent a motor response to flexion loading of pain sensitised spinal structures. These findings are in contrast to a comparable adult study that found increased muscle activation of Superficial Lumbar Multifidus in the last quarter of forward bending discriminated similar sub-groups of NSCLBP but found no difference between sub-groups on returning to upright standing (Dankaerts et al., 2009).

Forward-Bending Range-of-Motion

In the current study of adolescents the kinematic measure showing the greatest difference was lower lumbar forward-bending range-of-motion. While no statistically significant differences were observed when analysed on a group basis (NSCLBP and no-LBP), when those with NSCLBP were sub-classified the active-extension sub-group had reduced forward-bending range-of-motion (23.3±9.2º) compared to the no-LBP (32.9±10.8º) group and the multi-directional sub-group (39.2±12.0º). The reduced range-of-motion of the active-extension and increased range-of-motion of multi-directional sub-groups appeared to have resulted in a ‘wash out’ effect when pooled and compared to the control group (Dankaerts et al., 2006b); and further supports the need to sub-classify patients with NSCLBP. Additionally, it may explain why some previous studies in adults (Esola et al., 1996; Lariviere et al., 2000) and young adolescents (Burton, Tillotson, & Troup, 1989) fail to identify differences between those with and without LBP.

Flexion-Relaxation

The absence of flexion-relaxation in the back muscles during forward bending is commonly reported in adult subjects with LBP (Kaigle et al., 1998; McGorry et al., 2001; Paquet et al., 1994; Sihvonen et al., 1991; Watson et al., 1997). However in contrast, the presence or absence of flexion-relaxation, using two previously reported methods, did not discriminate between those adolescents with and without NSCLBP or sub-groups of NSCLBP. Further, almost all subjects exhibited flexion-relaxation in accordance with the selected quantitative flexion-relaxation ratio criteria. In adults, flexion-relaxation is associated with higher levels of disability (Andersson et al., 1996), the presence of LBP during testing (Sihvonen et al., 1991) and pain-related fear of movement (Geisser et al., 2005). While the group of adolescents with NSCLBP included in this study had clinically significant pain levels, disability and kinesiophobia, yet they remained physically active despite pain provocation (Astfalck et al., 2007). The findings may relate to these factors, or may reflect that the changes in the motor system commonly observed in adult LBP subjects have not yet developed in adolescence. Further research is required to determine this.

Research limitations

This study was powered, based on previous results from adult studies for postural parameters and back muscle activation, to detect a difference of half a standard deviation between those with and without NSCLBP. It is possible that the current sample size was not large enough given the variability in the normal adolescent population and future research should include larger group sizes. The strict inclusion and exclusion criteria for NSCLBP may restrict the generalisability of these results; however, as results are congruent with previous adult findings in adults they have validity.

Clinical implications

The findings of this study lend support to the existence of subgroups within the adolescent LBP population. These subgroups, while showing similarities to adult sub-groups on the basis of some kinematic variables, demonstrate differences in back muscle activation levels. As to whether these differences are a result of pain and/or contribute to pain is the focus of ongoing research. However recent research suggests

that spinal posture in adolescents is amenable to change with specific exercises and results in a reduction of LBP (Perich, Burnett, O'Sullivan, & Perkin, 2007) suggesting these findings may help inform targeted interventions.

6.1 CONCLUSIONS

1. Adolescents with NSCLBP showed some similarities in spinal kinematics to adults with NSCLBP.
2. The active-extension sub-group displayed restricted range-of-motion in forward-bending compared to both the multi-directional sub-group and controls.
3. Higher muscle activation levels where shown in Iliocostalis during standing in those with NSCLBP compared to controls.
4. Peak muscle activation of trunk extensors during the return phase from forward bending was the most discriminatory time epoch differentiating sub-groups of NSCLBP and controls.
5. The absence of flexion-relaxation observed in adults with NSCLBP was not a feature of adolescents with NSCLBP.

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CHAPTER 7 – STUDY 4

LUMBAR SPINE REPOSITIONING SENSE IN ADOLESCENTS WITH AND WITHOUT NON-SPECIFIC CHRONIC LOW BACK PAIN – AN ANALYSIS BASED ON SUB-CLASSIFICATION AND SPINAL REGIONS

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Previous adult research has identified deficits in spinal repositioning sense in adults with LBP. It is considered that deficits may impair the body's ability to maintain neutral postures resulting in abnormal loading of spine structures which may contribute to the development and maintenance of LBP. No previous studies have investigated spinal repositioning sense in NSCLBP in adolescents, across spine regions, or in sub-groups of NSCLBP. This study, together with studies 2 and 3, addresses the main aim of this dissertation to investigate trunk motor control associated with pain provocative spinal postures and movements in a detailed laboratory based study of adolescents with and without NSCLBP and sub-groups of NSCLBP.

Study 4 addresses the following thesis objectives to:

4.1. Compare differences in directional bias, accuracy and repeated precision of lumbar spine repositioning between adolescents with NSCLBP (pooled and sub-classified) and asymptomatic groups.

4.2. Investigate differences in spinal repositioning sense in upper and lower lumbar spine regions for adolescents with NSCLBP (pooled and sub-classified) and asymptomatic groups.

To be submitted to Spine.

7.1 ABSTRACT

Objective: To identify differences in repositioning error in adolescents with and without NSCLBP, sub-groups of NSCLBP and in different spinal regions.

Methods: Spinal repositioning error was measured during a seated task. Variables were constant error (CE), absolute error (AE) and variable error (VE) for lower lumbar, upper lumbar and lumbar angles. Subjects with NSCLBP were sub-classified using O'Sullivan's system.

Results: Significant differences were noted for AE between adolescents with and without NSCLBP, but no differences were found for CE or VE. When sub-grouped there was a pattern for lower AE and higher VE in the flexion sub-group, this group also displayed a tendency to undershoot the criterion position in the lower lumbar spine. Greater VE was noted in the extension sub-group and those with no NSCLBP in the upper lumbar compared to the lower lumbar spine.

Conclusions: Differences in spinal repositioning errors were noted between adolescents with and without NSCLBP and sub-groups of NSCLBP. Those with flexion-pattern NSCLBP had the lowest levels of spinal repositioning ability. Individuals with no-LBP or extension-pattern NSCLBP displayed greater variability in the upper lumbar spine.

7.2 KEY POINTS

- Differences in spinal repositioning directional bias, accuracy and variability were noted between adolescents with and without NSCLBP and sub-groups of NSCLBP.
- Those with flexion-pattern NSCLBP had the lower levels of spinal repositioning ability.
- Greater variability in spinal repositioning was noted in the upper lumbar spine in those with extension-pattern NSCLBP or no-LBP.
- This was the first study to investigate spinal repositioning error during sitting in adolescents, in sub-groups of NSCLBP or in different spinal regions.

7.3 INTRODUCTION

Proprioception is fundamental to static and dynamic postural control (Swinkels & Dolan, 1998). In the spine, spinal muscles, spinal ligaments, facet joint capsules, intervertebral discs and the thoracolumbar fascia all contain proprioceptive receptors (Lam, Jull, & Treleaven, 1999; Swinkels & Dolan, 1998). In mid-range neutral postures, where ligaments and capsules are under minimal tension, proprioceptive receptors in spinal muscles are considered to be most important to both movement and position sense (Brumagne, Cordo, Lysens, Verschueren, & Swinnen, 2000; Brumagne, Lysens, & Spaepen, 1999; Lam et al., 1999).

Previous adult studies have demonstrated proprioceptive deficit in patients with low-back pain (LBP) including: greater variability and error in repositioning tasks (Brumagne et al., 2000; Gill & Callaghan, 1998; Newcomer, Laskowski, Yu, Johnson, & An, 2000; O'Sullivan et al., 2003; Parkhurst & Burnett, 1994); impaired ability to detect a change in lumbar position (Taimela, Kankaanpaa, & Luoto, 1999); reduced balance; greater body sway; change in recruitment strategies during balance tasks (Luoto et al., 1998a; Mientjes & Frank, 1999; Radebold, Cholewicki, Polzhofer, & Greene, 2001; Takala, Korhonen, & Viikari-Juntura, 1997); and deficits in reaction time, possibly as a result of proprioceptive loss (Luoto, Taimela, Alaranta, & Hurri, 1998b; Taimela, Osterman, Alaranta, Soukka, & Kujala, 1993). One study of adolescents showed chronic LBP (CLBP) in females, but not males, is associated with reduced kinaesthetic integration, as measured by gross balance (Perry, Straker, O'Sullivan, Smith, & Hands, 2009).

Proprioceptive deficits, especially due to dysfunction in muscle spindles, may impair local muscle control during functional tasks leading to abnormal joint and tissue loading (Brumagne et al., 2000; O'Sullivan et al., 2003; Parkhurst & Burnett, 1994). Repetitive abnormal loading of the spine, especially of previously pain-sensitized structures, may contribute to the development and maintenance of CLBP (O'Sullivan et al., 2003) or make the spine more vulnerable to subsequent injury (Brumagne et al., 2000).

Humans use three sensory systems - visual, vestibular and somatosensory - for proprioceptive repositioning tasks (Chow, Leung, & Holmes, 2007; Viel,

Vaugoyeau, & Assaiante, 2009; Westcott & Burtner, 2004); with adults able to selectively use these systems, improving spinal repositioning accuracy when visual cues were withdrawn (Preuss, Grenier, & McGill, 2003). The immature somatosensory system does not exhibit this degree of plasticity, with visual dependence dominating postural adjustments in young children (Goble, Lewis, Hurvitz, & Brown, 2005; Visser & Geuze, 2000; Westcott & Burtner, 2004), and during the pubertal growth spurts in adolescence (Viel et al., 2009). Additionally, the vestibular afferent system is not integrated to adult levels till mid-late adolescence (Cumberworth, Patel, Rogers, & Kenyon, 2007; Nandi & Luxon, 2008; Stiefel et al., 1999; Viel et al., 2009). Studies of proprioception throughout adolescence show improved trunk repositioning accuracy (Ashton-Miller, McGlashen, & Schultz, 1992), decreased postural oscillations in standing(Steindl, Kunz, Schrott-Fischer, & Scholtz, 2006; Usui, Maekawa, & Hirasawa, 1995) and improvements in balance (Cumberworth et al., 2007; Nolan, Grigorenko, & Thorstensson, 2005; Riach & Hayes, 1987) with age. Finally, there is growing awareness that motor functions appear and change not only age-specifically but are also highly variable within an age group (Largo et al., 2001a; Largo et al., 2001b; Largo, Fischer, & Rousson, 2003; Riach & Hayes, 1987). These findings suggest that the somatosensory system is not fully integrated during adolescence and that this period represents a transition in postural and motor control. Some suggest that puberty, a period of considerable morphological, structural and functional change which results in significant body-scheme disturbances, might lead adolescents to transiently neglect proprioceptive information (Assaiante, 1998; Largo et al., 2001a; Viel et al., 2009).

To date, no studies have investigated the role of lumbar repositioning sense in adolescents with LBP. This is despite adolescent LBP being a significant problem with high prevalence (Ebrall, 1994) and recurrence (Burton, Clarke, McClune, & Tillotson, 1996; Taimela, Kujala, Salminen, & Viljanen, 1997) rates, which is also associated with the recurrence of LBP through adult life (Harreby, Neergaard, Hesselsoe, & Kjer, 1995). For some LBP can be transient and trivial, yet for others it is chronic and disabling. The majority of CLBP disorders in adults and adolescents are classified as non-specific CLBP (NSCLBP) as no patho-anatomical basis to the disorder can be found (Dankaerts, O'Sullivan, Straker, Burnett, & Skouen, 2006c; O'Sullivan, 2005).

There is also growing evidence that NSCLBP is not a homogenous group, but rather represents a series of sub-groups based on physical and psychological variables (O'Sullivan, 2005). A classification system has been proposed by O'Sullivan (O'Sullivan, 2000) which classifies patients based on their pain and movement behaviours (Dankaerts et al., 2006c; O'Sullivan, 2005). Using this system, sub-groups of NSCLBP have been identified in both adolescent (Astfalck, O'Sullivan, Straker, & Smith, 2007) and adult populations (Dankaerts et al., 2006c; O'Sullivan, 2000, 2004); with altered spinal posture (Astfalck et al., 2007; Dankaerts, O'Sullivan, Burnett, & Straker, 2006b; Dankaerts, O'Sullivan, Burnett, & Straker, 2007) and motor control deficits (Dankaerts, O'Sullivan, Burnett, & Straker, 2006a) identified. Characteristics of the three most common sub-groups are outlined in the methods section (Dankaerts et al., 2006c; O'Sullivan, 2000, 2004). To date no study has investigated whether repositioning error differences exist in these sub-groups. Furthermore, recent research highlights the importance of considering the lumbar spine as two functionally distinct regions, upper and lower lumbar spine (Mitchell, O'Sullivan, Burnett, Straker, & Smith, 2008). To date no study has investigated whether regional differences in repositioning error exist in LBP populations.

The overall aims of this study were to investigate in an adolescent sample:

1. If differences in directional bias, accuracy and variability of lumbar spine repositioning exist between those with NSCLBP (when sub-classified and when pooled) compared to a no-LBP group.
2. If differences in the repositioning ability exist between upper and lower lumbar spine regions and whether these relate to group and sub-group membership.

7.4 MATERIALS AND METHODS

7.4.1 Participants

Participants were drawn from the Western Australian Pregnancy Cohort (Raine) Study, a longitudinal cohort of 2868 children born in a maternity hospital in Perth, Australia (www.rainestudy.org.au). Subject selection processes have been previously outlined (Astfalck et al., Accepted for publication.), participation criteria and sample characteristics are in Tables 7-1 and 7-2. Prior adult studies showed that two groups

of N=28 has sufficient power to identify differences of one standard deviation in lumbosacral repositioning error (Brumagne et al., 2000; O'Sullivan et al., 2003).

Inclusion Criteria	Exclusion Criteria
Male or Female Age: 14-16 years BMI: <28 kg/m^2 * Pain Group: ▪ History of NSCLBP ≥ 12 weeks duration ▪ Pain in the area from T12 to gluteal folds ▪ No peripheral pain referral ▪ Moderate ongoing LBP ▪ Average daily pain level - VAS > 3/10 ▪ Experienced most days of the week ▪ Mechanically induced localised LBP Control Group: ▪ No history of spinal pain (* required for successful superficial EMG recording)	Specific diagnosis associated with LBP such as spondylolisthesis, disc prolapse, inflammatory disorders Presence of other conditions affecting the spine including neurological or metatastic disease Any neurological deficit Any surgery involving the lumbar spine Any diagnosed pelvic or abdominal pain disorder in the last 12 months Pregnancy or less than six months post-partum Any lower limb surgery in the last 2 years Current lower limb injury An inability to understand written or spoken English Inability to assume test postures

Table 7-1 - Inclusion and Exclusion Criteria at Recruitment

	NSCLBP (pooled) (n=28)	Control (n=28)	NSCLBP (sub-classified)	
			Extension (n=13)	Flexion (n=15)
Age (years)	15.4 ± 0.5[#]	15.7 ± 0.5[#]	15.4 ± 0.6	15.4 ± 0.5
BMI (kg/m^2)	22.2 ± 3.5	21.2± 2.6	22.8 ± 4.2	21.6 ± 2.8
Index of Relative Socio-Economic Advantage/ Disadvantage	988.9 ± 59.7	979.8 ± 61.9	984.8 ± 51.6	989.1 ± 69.0
Developmental Stage				
Genital	3.5± 0.5	3.4 ± 0.6	3.5 ± 0.5	3.5 ± 0.5
Breast (Girls only)	3.9 ± 0.7	3.8 ± 0.8	3.8 ± 0.6	4.0 ± 0.8
Usual pain (VAS out of 10)	4.4±1.9		5.1±1.3	3.8±2.1
Pain duration (months)	26.6±12		24.8±14.7	28.0±8.7
Kinesiophobia (total score 68)	36.1±10.1		35.5±4.7	36.7±8.8
Disability (%)	17.9±10.1		17.6±7.9	18.2±11.9
No. female subjects	14	14	10 [$]	4 [$]
No. male subjects	14	14	3[$]	11 [$]

*All measures were recorded during laboratory testing session in 2006/07.

Values are Mean ± SD

[#] $t_{df} = -2.010_{54}$, p=0.049; [$] $\chi^2 = 7.036_2$, p=0.030; [†]

Table 7-2 – Non-specific Chronic Low Back Pain (NSCLBP) and no Low Back Pain (LBP) Sample Characteristics

Values are Mean ± SD, all measures were recorded during one laboratory testing session in 2006/07

7.4.2 Measures

Pain experience

For NSCLBP subjects, pain intensity, extent of disability and level of fear avoidance was measured by Visual Analogue Scale, the Oswestry Disability Questionnaire and the Tampa Scale of Kinesiophobia respectively (Table 7-2). Each scale has sufficient reliability and validity for use in adolescents (Fairbank, Couper, Davies, & O'Brien, 1980; Goubert et al., 2004; O'Sullivan, 2005; Perich, Burnett, & O'Sullivan, 2006; Stinson, Kavanagh, Yamada, Gill, & Stevens, 2006; Swinkels-Meewisse, Swinkels, Verbeek, Vlaeyen, & Oostendorp, 2003; Vlaeyen, Kole-Snijders, Boeren, & van Eek, 1995). To determine distribution of NSCLBP each participant with pain completed a body chart, pain area was classified as 'below L3' or 'above and below L3'.

Subjective clinical assessment

During initial interview each subject with pain was asked a standard series of questions to describe the history and behaviour of their NSCLBP (aggravating and easing postures and movements and medication usage).

Functional movement assessment

During data collection a video recording from a single camera was taken by the primary researcher of each subject with NSCLBP during functional postures and movements (usual sitting, slump sitting, return to usual sitting, sitting to standing, standing, left and right single-leg-stance, forward and backward bending). This sequence was completed twice to record movements from both posterior and postero-lateral views (Dankaerts, O'Sullivan, Burnett, Straker, & Danneels, 2004).

Sub-classification

Pain behaviour reports and video data was used by a specialist musculoskeletal physiotherapist independent of data collection to sub-classify subjects as previously described (Dankaerts et al., 2006c), see Table 7-3. As the mechanism of pain provocation in sitting is the same for both 'flexion-pattern' and 'multidirectional', subjects from these groups (4 for 'flexion-pattern' and 11 for 'multidirectional') were combined for this study and are herewith termed flexion-pattern.

Flexion Pattern	Movements and postures involving flexion or the lumbar spine aggravate NSCLBP symptoms Spinal extension relieves pain Provocative postures and functional tasks associated with a flexed lumbar spine (eg slump sit and squatting)
Active Extension Pattern	Movements and postures involving extension of the lumbar spine aggravate NSCLBP symptoms Spinal flexion relieves pain Provocative postures and functional tasks associated with hyper extension of lumbar spine (hyperlordotic sitting and standing)
Multidirectional Pattern	All movement directions (flexion and extension) provoke NSCLBP symptoms Neutral spinal postures relieve pain Provocative postures and functional tasks associated with either flexed or hyper-extended lumbar spine (eg slump sit, squatting and sway stand)

Table 7-3 – Clinical Features of Adolescent NSCLBP Movement Control Disorders

Subjects for this research were classified into these patterns based on their direction of pain provocation. (Dankaerts et al. 2006c, O'Sullivan 2004, O'Sullivan 2005)

Lumbar spine repositioning task

Subjects were seated on a soft stool without back support that was height adjusted such that the hip and knee were at 90º flexion, and the arms were positioned palm-upward on the thighs. They wore shorts and undergarments to reduce sensory input from clothing and a blindfold throughout each trial. Subjects were assisted by the tester to move through their available flexion/extension range of motion three times, they were then positioned by the tester in a mid-range sitting posture with reference to their available range (criterion position), subjects maintained this position for 5 seconds and were asked to remember this position. Subjects were then asked to relax for 5 seconds into full lumbar flexion before reproducing the criterion position. Prior to testing the task was explained, demonstrated and subjects completed two practice trials. Three measured trials were completed. No feedback on accuracy was provided to subjects between trials. This task has previously been shown to have good reliability in adults both with and without LBP (Lam et al., 1999; Maffey-Ward, Jull, & Wellington, 1996).

7.4.3 Protocol

Collection of spinal kinematics

Measures of spinal kinematics during the repositioning task were obtained using the 3-Space Fastrak (Polhemus Navigation Sciences Division, Vermont, USA), with reported accuracy of 0.2º(Maffey-Ward et al., 1996). With the subject in slight spinal flexion, sensors were taped to the skin over the spinous processes of S2, L3 and T12 using double-sided tape (3M, Pymble, Australia) and secured with Fixomull tape (Beiersdorf AG, Hamburg, Germany) (Dankaerts et al., 2006a). Data was collected at 25Hz using a customised program written using LabVIEW V8.2 (National Instruments Inc., Texas, USA).

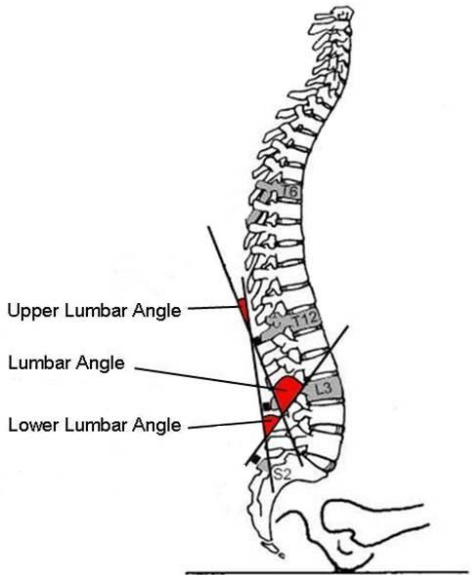

Figure 7-1 – Spinal Kinematics Variables

Lower Lumbar Angle – the angle between two intersecting lines, one indicating the inclination of the sensor at L3 and the other the inclination of the sensor at S2. A negative lower lumbar angle indicating lumbar lordosis. Upper Lumbar Angle – the angle between two intersecting lines, one indicating the inclination of the sensor at T12 and the other the inclination of the sensor at L3. A negative angle indicating lumbar lordosis. Lumbar Angle – the angle between two intersecting lines, one indicating the inclination of the sensor at T12 and the other the inclination of the sensor at S2. A negative angle indicating lumbar lordosis.

Variables. Lower lumbar, upper lumbar and lumbar angles were measured (Figure 7-1). From these data three measures were used to estimate repositioning ability; constant error (CE), absolute error (AE) and variable error (VE). CE is a measure of bias considered as the signed difference between criterion and finish positions - averaged across the three trials. A positive CE indicates overshooting of the criterion position. AE reflects accuracy (Strimpakos, Sakellari, Gioftsos, Kapreli, & Oldham, 2006) as is the unsigned difference between the criterion and finish positions - averaged across three trials. It has previously been shown that repositioning error in the sagittal plane is equally distributed about the criterion position in neutral spine postures (Maffey-Ward et al., 1996), therefore average AE is likely to be superior to average CE in determining accuracy as unsigned values will not cancel each other out when averaged. VE represents the variability of an individual's CE measure. In this study VE was calculated as the SD of the three trials of CE of each individual (Asell, Sjolander, Kerschbaumer, & Djupsjobacka, 2006). Unlike previous research errors were not detrended prior to VE calculation (Asell et al., 2006), as analysis of trial data showed the average of trial effect to be zero. High VE reflects high variability of repositioning, whilst low VE reflects low variability of repositioning, but does not reflect accuracy (Strimpakos et al., 2006).

7.4.4 Statistical analysis

Differences in AE, CE and VE (as calculated above) between the two NSCLBP sub-groups and the no-LBP group were evaluated under general linear models. Generalised estimating equations to account for non-independence of the repeated upper and lower lumbar measures were used to evaluate regional differences in proprioception measures, with region/sub-group interactions modelled to estimate any sub-group effects on regional differences in these measures. Statistical analysis was performed using Stata/IC 10.1 for Windows (Statacorp LP, College Station TX). Statistical significance was set at $\alpha = 0.05$ for all statistical tests.

7.5 RESULTS

7.5.1 Repositioning error

Graphs for individual CE trial results for lower and upper lumbar angle for no-LBP group and extension and flexion sub-groups are shown in Figures 7-2A-C and 7-3A-C. All Repositioning measure means and standard deviations are reported in Table 7-4.

	Lumbar Angle (degrees)			Lower Lumbar Angle (degrees)			Upper Lumbar Angle (degrees)		
	CE	AE	VE	CE	AE	VE	CE	AE	VE
NSCLBP	-0.1±4.2	4.1±2.3	3.1±2.1	-0.6±2.4	2.3±1.5	1.6±1.2	0.5±2.7	2.6±1.6	2.2±1.4
No-LBP	-0.8±2.6	3.1±1.3	2.8±1.6	-1.1±1.8	1.8±1.3	1.2±0.8	0.3±2.6	2.6±1.2	2.2±1.2
Extension	-0.6±3.9	3.4±2.0	2.2±1.0	-0.3±2.1	1.8±1.0	1.0±0.7	-0.3±2.4	2.2±1.5	1.8±1.0
Flexion	0.3±4.5	4.6±2.4	3.8±2.4	-0.9±2.7	2.7±1.7	2.0±1.4	1.3±2.9	3.0±1.7	2.5±1.6

Table 7-4 – Repositioning Errors (CE, AE, VE) for each Trunk Angle and each Group and Sub-group

Values are Mean ± SD, CE – Constant Error, AE – Absolute Error, VE – Variable Error;

A NSCLBP compared to no-LBP

Constant error

No significant differences were shown for CE between adolescents with and without NSCLBP for lower lumbar, upper lumbar and lumbar angle (p=0.387, p=0.523, p=0.179 respectively, Table 7-5).

Absolute error

A statistically significant difference was shown for AE between adolescents with and without NSCLBP for lower lumbar and lumbar angle (p=0.018, p=0.001 respectively) but not upper lumbar angle (p=0.993). Estimated differences were small (≤ 1.0º, Table 7-5).

Variable error

No significant differences were shown for VE between adolescents with and without NSCLBP for lower lumbar, upper lumbar and lumbar angle (p=0.173, p=0.846, p=0.579 respectively, Table 7-5). The magnitude of results, ranging from 1.2±0.8º to 3.1±2.1º, suggests moderate VE existed in each group.

	Lumbar Angle (degrees)			Lower Lumbar Angle (degrees)			Upper Lumbar Angle (degrees)		
	CE	AE	VE	CE	AE	VE	CE	AE	VE
NSCLBP/ No-LBP	-0.7 -1.8 to 0.3 p=0.179	-1.0 -1.6to -0.4 **p=0.001**	-0.3 -1.3±0.7 p=0.579	-0.5 -1.6 to 0.6 p=0.387	-0.5 -0. 9to-0.1 **p=0.018**	-0.4 -1.0 to 0.2 p=0.173	-0.3 -1.1 to 0.5 p=0.523	0.002 -0.4 to 0.4 p=0.993	0.07 -0.6 to 0.7 p=0.846
Flexion/ Extension	0.9 -0.6 to 2.4 p=0.250	1.2 0.4 to 2.0 **p=0.003**	1.6 0.2 to 3.0 **p=0.023**	-0.6 -2.2 to 1.0 p=0.464	0.9 -0.1 to 1.8 p=0.085	1.0 0.2 to 1.8 **p=0.010**	1.5 0.4 to 2.6 **p=0.008**	0.8 0.2 to 1.4 **p=0.010**	0.7 -0.3 to 1.6 p=0.166
No-LBP/ Extension	-0.3 -1.6 to 1.1 p=0.706	-0.4 -1.1 to 0.3 p=0.299	0.6 -0.6 to 1.8 p=0.346	-0.8 -2.2 to 0.6 p=0.261	-0.02 -0.9 to 0.9 p=0.965	0.2 -0.5 to 0.8 p=0.653	0.6 -0.4 to 1.5 p=0.268	0.4 -0.1 to 0.9 p=0.116	0.4 -0.4 to 1.3 p=0.319
Flexion/ No-LBP	1.1 -0.1 to 2.4 p=0.080	1.6 0.9 to 2.2 **p<0.001**	1.0 -0.1 to 2.2 p=0.083	0.2 -1.1 to 1.6 p=0.751	0.9 0.1 to 1.8 **p=0.038**	0.9 0.2 to 1.5 **p=0.010**	1.0 0.0 to 1.9 **p=0.044**	0.4 -0.1 to 0.9 p=0.157	0.2 -0.5 to 1.1 p=0.546

Table 7-5 – Estimated mean difference (CE, AE, VE) for each Trunk Angle and each Group and Sub-group Comparison

Values are Estimated Mean Difference; ±95% CI for Difference CE – Constant Error, AE – Absolute Error, VE – Variable Error

B No-LBP compared to sub-groups of NSCLBP

Constant error

Significant differences were shown for CE between the flexion sub-group and both the extension and no-LBP group for upper lumbar angle (p=0.008, p=0.044 respectively). Estimated difference between groups were 1.5º and 1.0º respectively. No other comparisons were significant. The direction of these results suggests that both the flexion sub-group and control group undershoot the target position in the lower lumbar spine and overshoot the target position in the upper lumbar spine. Although the magnitude (<1.1º) suggests directional bias is small.

Absolute error

Significant differences were shown for AE between the flexion sub-group and no-LBP group for lower lumbar (p=0.038) and lumbar angles (p=<0.00) and between the flexion and extension sub-groups for upper lumbar (p=0.010) and lumbar angles

(p=0.003) but not for other comparisons. Estimated differences between groups range from 0.8º to 1.6º, Table 7-5.

Variable error

Significant differences were shown for VE between the flexion sub-group and both the extension sub-group (p=0.010) and no-LBP group (p=0.010) for lower lumbar angle and between flexion and extension sub-groups for lumbar angle (p=0.023) but for no other comparisons. Estimated differences range between groups from 0.9º to 1.6º, Table 7-5.

7.5.2 Regional differences

Constant error

Significant differences were noted for CE between upper and lower lumbar angles for the flexion sub-group (p<0.001) and the no-LBP group (p=0.001), but no difference between spine regions for the extension sub-group. Estimated differences between regions are in Table 7-6.

There were significant differences for the extension sub-group compared to the flexion sub-group (p=0.008) for the magnitude of CE difference between the upper and lower lumbar angle, but not the no-LBP group (p=0.053), nor the extension/no-LBP comparison. The direction of differences indicates repositioning error in upper lumbar spine is greater than the lower lumbar spine.

	CE	AE	VE
No-LBP	1.4 0.6 to 2.1 p=0.001	0.7 -0.1 to 1.5 p=0.101	1.0 0.6 to 1.5 p<0.001
Extension	0.001 -1.1 to 1.1 p=0.999	0.3 -0.3 to 1.0 p=0.311	0.8 -0.1 to 1.4 p=0.024
Flexion	2.1 1.1 to 3.2 p<0.001	0.7 -0.2 to 1.6 p=0.142	0.4 -0.3 to 1.2 p=0.232

Table 7-6 – Estimated mean difference for repositioning errors (CE, AE, VE) between regions (upper and lower lumbar) for no-LBP group and NSCLBP sub-groups.

The co-efficient represents how much upper lumbar error is greater (positive) or less (negative) than lower lumbar error. Values are Estimated Mean Difference; ±95% CI for Difference. CE – Constant Error, AE – Absolute Error, VE – Variable Error

Absolute error

No significant differences were noted in AE between upper and lower lumbar angle within any group or sub-group ($p>0.1$). There were no significant differences between no-LBP and NSCLBP sub-groups for the magnitude of AE difference between upper and lower lumbar angles ($p>0.2$).

Variable error

Significant differences were noted for VE between upper and lower lumbar angles for the extension sub-group ($p=0.024$) and the no-LBP group ($p<0.001$), but no difference between spine regions for the flexion sub-group. Estimated difference between regions are in Table 7-6. There were no differences between no-LBP and NSCLBP sub-groups for the magnitude of VE difference between upper and lower lumbar angles ($p>0.1$).

Area of pain

Significant differences were shown between sub-groups and area of pain ($\chi^2=5.32$, $p=0.030$), Table 7-2. With most flexion subjects experiencing pain localised to the lower lumbar spine and most extension subjects experiencing more widespread thoracolumbar pain.

7.6 DISCUSSION

This is the first study to investigate seated spinal repositioning error in adolescents, subgroups of NSCLBP or different lumbar spine regions.

Significant differences for accuracy (AE) were found between adolescents with (pooled) and without NSCLBP, a result similar to previous adult findings (Brumagne et al., 2000). However, no differences were found between adolescents with and without NSCLBP for either systematic bias (CE) or variability (VE). Previous adult studies have shown mixed results showing significant trends both for undershooting (Brumagne et al., 2000) and overshooting (Asell et al., 2006; Lam et al., 1999) the target position, while variability was shown to be greater in healthy adults than those with LBP (Brumagne et al., 2000).

The closest comparison to this adolescent data is with adult studies by Maffey Ward et al. and also Lam et al. who measured lumbar angle similarly. The magnitude of adolescent lumbar angle data (NSCLBP and no-LBP) is larger than previously reported adult findings (Lam et al., 1999; Maffey-Ward et al., 1996). Lower lumbar angle data (AE, CE, and VE) reported here is similar to that previously reported in adults for sacral tilt (Brumagne et al., 2000); with magnitudes for these measures being similar between adolescents and adults (Brumagne et al., 2000). It is difficult to make direct comparisons on the available evidence due to differences in protocol, angular measures and comparability of LBP groups (in terms of pain experience and maturation); with any one of these factors providing sufficient basis for noted differences. Combined with previous evidence for age-related refinement of proprioceptive control (Ashton-Miller et al., 1992; Assaiante, 1998; Goble et al., 2005; Largo et al., 2001a) these results support suggestions that the somatosensory system is not fully integrated during adolescence and that this period represents a transition in postural control (Assaiante, 1998; Viel et al., 2009). Whether immaturity is related to peripheral, central sensorimotor or cognitive processes (Goble et al., 2005) is not proven.

Results for AE and VE show a general pattern for less accuracy and greater variability in the flexion group compared to the extension or no-LBP groups (Table 7-5), being more evident in the lower than upper lumbar angle measures. This may be due to a greater concentration of pain in the lower lumbar spine with increased nociceptive ‘noise’ decreasing spinal repositioning acuity. Findings for poorer accuracy by the flexion sub-group are similar to a previous study of adults with flexion-pattern NSCLBP compared to healthy controls (O'Sullivan et al., 2003).

Whilst directional bias was small (<1.1º), there was significantly larger CE in the upper than lower lumbar spine in the flexion sub-group and no-LBP group (Table 7-6), with a pattern of undershooting the criterion position for the lower lumbar spine and overshooting in the upper lumbar spine (Table 7-4). Previous research on this cohort showed the flexion sub-group sat in a kyphotic lumbar position compared to those in the extension sub-group which sat with more lordosis than either other group (Astfalck et al., 2007). Further, it has been shown that lumbar spine repositioning sense decreases after slumping for as little as 5-minutes (Dolan & Green, 2006). Constant tension on soft tissues during slumped postures may alter muscle activity,

mechanoreceptor sensitivity and/or viscoelasticy (Dolan & Green, 2006), all contributors to proprioceptive acuity. Thus habitual posturing into lumbar flexion may lead to trunk proprioception deterioration and may partly explain tendencies for undershooting the target position in the flexion sub-group.

Regional differences for reduced variability in the low lumbar compared to the upper lumbar spine may reflect in the no-LBP group greater input from cutaneous afferents on the posterior thigh and buttocks contacting the seat and greater degrees of freedom to control in the upper lumbar spine. In the extension sub-group the increased variability in the upper lumbar spine may reflect the presence of pain in this region in combination with the previous factors. That no regional differences were seen in the flexion sub-group reflects the greater variability shown by this group, which is discussed above.

Clinical implications

It is arguable that the magnitudes of absolute error observed in this study (1.8–4.6º) represent potentially large enough error to increase strain on spinal structures when placed near end-of-range. Furthermore, deficits may be of greater significance under conditions of repetitive or prolonged loading of muscular, ligamentous and capsular tissue over longer durations (Dolan & Green, 2006); muscular fatigue; or loaded carrying (Chow et al., 2007) potentially imposing strain on the lumbar spine (Dolan & Green, 2006; O'Sullivan et al., 2003). These concepts are supported by previous studies identifying patients with flexion pattern displaying increased end-range lumbar flexion and rotation in adult cyclists with LBP (Burnett, Cornelius, Dankaerts, & O'Sullivan, 2004) and increased flexion loading in adolescent rowers with LBP (Perich et al., 2006). It may be that the greater repositioning errors identified in this sub-group renders the spine vulnerable to end-range flexion strain. Furthermore a recent intervention that trained spinal positioning sense and control in a group of adolescent female rowers, reduced the incidence of LBP across the rowing season (Perich, Burnett, O'Sullivan, & Perkin, 2007), highlighting that attending to these postural deficits may have clinical benefits in reducing LBP.

Research limitations

Test sensitivity may have been influenced by cutaneous mechanoreceptive feedback from contact with the stool (Lam et al., 1999) and tape securing the sensors and manual feedback by the tester between trials, however these were standard across comparisons, including prior adult studies (Lam et al., 1999). Similarly, superficial placement of sensors and skin movement during testing may have induced error (O'Sullivan et al., 2003) but the system has been shown to be a good estimate of vertebral body position during movement (Bryant, Reid, Smith, & Stevenson, 1989; Gracovetsky et al., 1995).

7.7 CONCLUSION

Differences were noted between adolescents with and without NSCLBP and sub-groups of NSCLBP for spinal repositioning directional bias, accuracy and variability. Adolescents with flexion-pattern NSCLBP had the lowest levels of spinal repositioning sense and demonstrated a tendency to undershoot the criterion position in the lower lumbar spine. Individuals with no-LBP or extension-pattern NSCLBP display greater variability in the upper lumber compared to the lower lumbar spine.

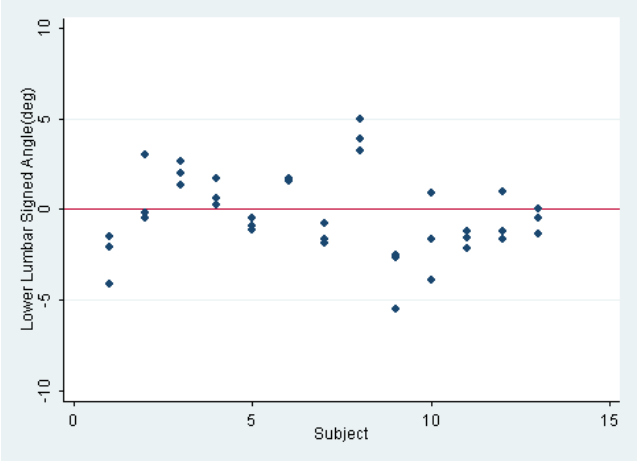

Figure 7-2A –Extension sub-group

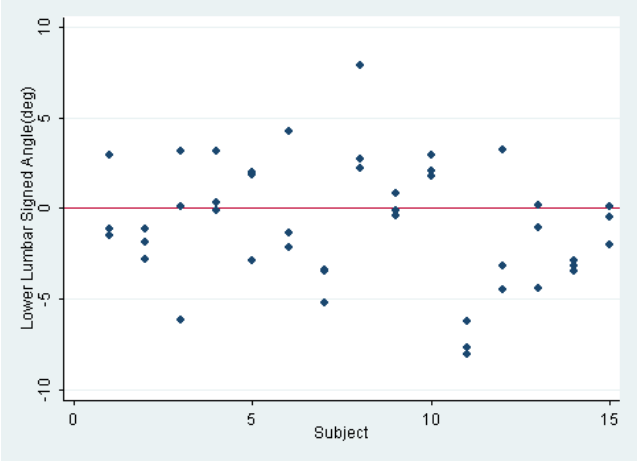

Figure 7-2B - Flexion sub-group

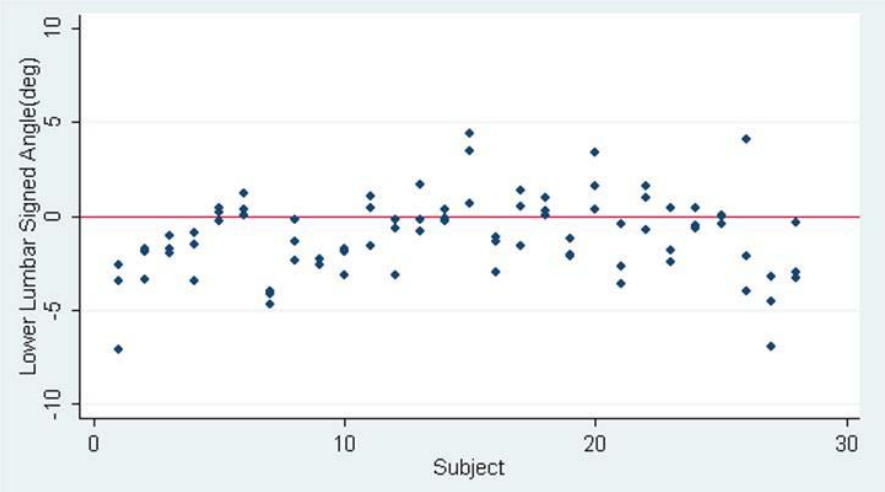

Figure 7-2C –No-LBP Group

Figures 7-2A-C–Constant Error for each trial and subject for lower lumbar angle

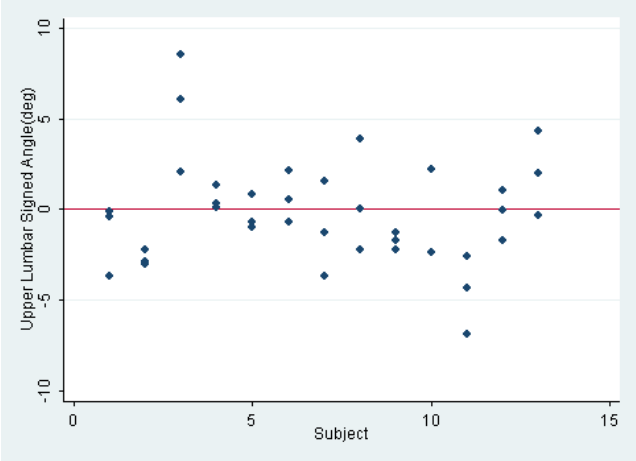

Figure 7-3A –Extension sub-group

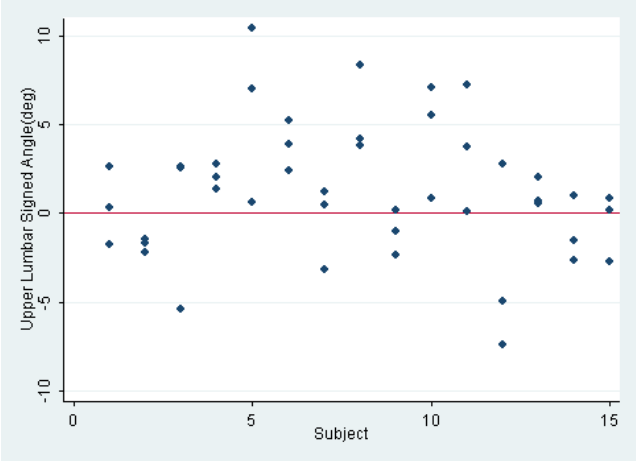

Figure 7-3B - Flexion sub-group

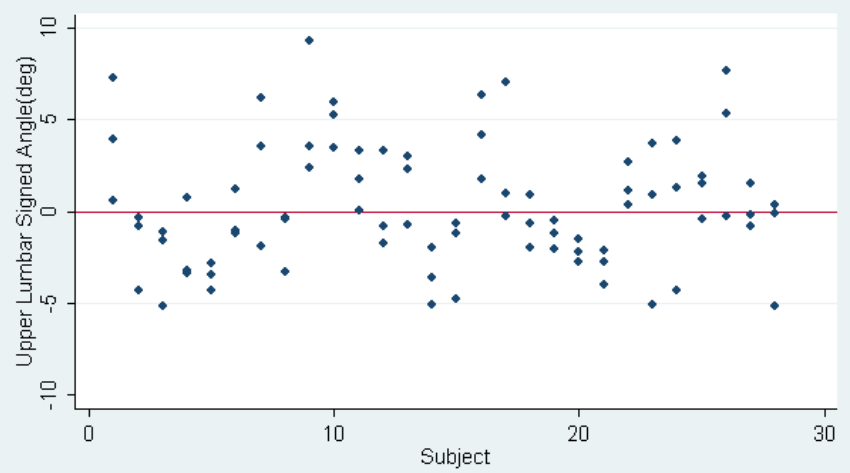

Figure 7-3C – No-LBP Group

Figures 7-3A-C– Constant Error for each trial and subject for upper lumbar angle

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CHAPTER 8– DISCUSSION

8.1 INTRODUCTION

Adolescence is a time of psychological, social and physical change. It is also a time where chronic health conditions often have a genesis or become exacerbated, increasing the risk for the existence of these conditions in adulthood (LeResche, Mancl, Drangsholt, Saunders, & Korff, 2005; Patton & Viner, 2007; Rhee, 2005; Steinberg & Morris, 2001; Steinhausen, Haslimeier, & Winkler Metzke, 2006). Included in this is the risk for suffering low back pain (LBP) (Harreby, Neergaard, Hesselsoe, & Kjer, 1995).

Much has been written concerning adult LBP, its causes and consequences. In spite of this, the puzzle of non-specific chronic LBP (NSCLBP) remains somewhat unresolved. Previous studies have investigated a variety of factors across the biopsychosocial dimensions and collectively suggest that NSCLBP is multifactorial in nature. Some of the recent research has identified a series of sub-groups based on both physical and psychosocial variables supporting that NSCLBP is not a homogenous group (Dankaerts et al., 2009; Leboeuf-Yde, Lauritsen, & Lauritzen, 1997; Linton, 2000; McCarthy, Arnall, Strimpakos, Freemont, & Oldham, 2004; P. O'Sullivan, 2005).

Juxtaposed against the adult literature concerning LBP, comparatively little detailed knowledge about this condition in adolescence exists. Of the relatively few detailed physical studies, investigations have considered factors such as standing posture, gross balance, trunk endurance and strength and flexibility (Andersen, Wedderkopp, & Leboeuf-Yde, 2006; Bernard et al., 2008; Biering-Sorensen, 1984; Jones, Stratton, Reilly, & Unnithan, 2005; Perry, Straker, O'Sullivan, Smith, & Hands, 2009; Sjolie & Ljunggren, 2001; Smith, O'Sullivan, & Straker, 2008). To date, most research has focussed attention on broad epidemiology studies investigating limited physical and psychosocial factors associated with LBP.

Given the large psychosocial and physical transformations that occur in adolescence it may not be appropriate to translate previous findings from adult research to an

adolescent population. Indeed it has been suggested that adolescents are involved in a learning process with regard to the expression of pain in an adequate and socially acceptable manner; and that the medicalisation of LBP in adolescence may not be appropriate (Balague, Dudler, & Nordin, 2003). This current belief regarding NSCLBP supports the conclusion of Burton and co-workers that '*much adolescent back pain, however, can be considered as a nonspecific disorder characterized by recurrent symptoms that are rarely disabling and, perhaps, should not be attributed undue significance… adolescent back pain may be considered a normal life experience'* (Burton, Clarke, McClune, & Tillotson, 1996). Further to this, the general consensus of previous research has been that LBP in young populations is most likely dominated by psychosocial rather than physical factors (Watson et al., 2003).

This dissertation challenges prior *beliefs* by demonstrating that NSCLBP in adolescence is not trivial or transitory. Rather it is multifactorial in nature and is related to a number of different physical aspects which can be sub-grouped. Some aspects of the adolescent presentation are similar to that previously documented in adult populations, although differences exist. Pragmatically, this research was restricted to a small sample size, despite this important information can be gleaned concerning the multifactorial nature of NSCLBP. The series of studies that constitute this doctoral thesis represents a detailed investigation of adolescent NSCLBP from a biopsychosocial perspective, with a particular emphasis on the assessment of motor control factors of the spine during functional postures and activities.

This chapter considers the results from the studies presented in this dissertation, in light of the current knowledge on adult and adolescent LBP. The limitations of this research are identified and recommendations for future research are made; and finally, implications for clinical practice arising from this study are presented.

8.2 ADOLESCENT LOW BACK PAIN IS A SIGNIFICANT DISORDER

This research demonstrates that NSCLBP in this small group of adolescents is not trivial, with teenagers suffering moderate levels of pain (>4/10) and kinesiophobia (>36/68) over considerable durations (>2 years). Pain levels reported in this study (Table 8-1) are similar to previous studies of adolescents with LBP (Masiero et al.

2008; Pellise et al. 2009; Perich et al. 2009) and suggest that this group of adolescents report clinically significant levels of pain. Findings by Ebrall that almost half of subjects with LBP having experienced pain for a year or more (Ebrall, 1994) is similar to evidence here for chronicity and supports that NSCLBP in adolescence is not transitory.

	Adolescent Data		Adult Data‡	
	Active-Extension Pattern (n=13)	Flexion/ Multidirectional Pattern (n=15)	Active-Extension Pattern (n=13)	Flexion Pattern (n=20)
Usual pain (VAS out of 10)	5.1 ± 1.3	3.8 ± 2.1	4.7 ± 1.1	4.1 ± 1.2
Pain duration (months)	24.8 ± 14.7	28.0 ± 8.7	58.8 ± 63.6	88.8 ± 63.6
Kinesiophobia (score out of 68)	35.5 ± 4.7	36.7 ± 8.8	41.3 ± 8.8	40.2 ± 8.2
Disability (%)	17.6 ± 7.9	18.2 ± 11.9	41.2 ± 14.2	36.6 ± 11.0
Gender				
Females	10 (77%)$	4 (27%)$	8 (62%)†	4 (20%)†
Males	3 (33%)$	11 (73%)$	5 (38%)†	16 (80%)†

Table 8-1 – Characteristics of pain sub-groups compared to previous adult data from the same capital city - Perth, Australia $ χ^2= 7.036$_2$, p=0.030 † χ^2= 6.4, p<0.05

‡ Adult data taken from Dankaerts et al 2006a and 2006b

Results for a comparable group of adults with NSCLBP – from the same capital city and sub-classified using the same clinical protocol (O'Sullivan, 2005) - showed similar pain levels but reported slightly higher levels of kinesiophobia and higher levels of disability levels - almost twice that of this adolescent group (Dankaerts, O'Sullivan, Burnett, & Straker, 2006b), see Table 8-1. This may be explained in part by the extended duration of pain amongst adults, with subjects suffering NSCLBP much longer than the current adolescent group. This was particularly so for duration of NSCLBP for the flexion sub-group which had experienced pain three times the duration of the comparable adolescent group. On the other hand, it may relate to differences in attitudes and beliefs regarding LBP and the associated coping strategies in response to it. Further, LBP in adults is likely to have different impacts

and ramifications, including on the ability to engage in employment and care for family.

Findings for low levels of documented disability (Table 8-1) were similar to results from Pellise and co-workers, using the Roland-Morris Questionnaire (Pellise et al., 2009); and also Perich and co-workers using the Oswestry Scale of Disability (Perich, Burnett, O'Sullivan, & Perkin, 2009). Whilst overall disability levels were low to moderate, sitting contributed most to the overall score of disability. On subjective questioning, sitting had an impact at school, with common reports of not being able to sit through a class without needing to stand up and move around; being especially uncomfortable on laboratory and art room stools; and not being able to sit on the floor with classmates during school assemblies. Given the large portion of each day that adolescents spend sitting in class (more than 5 hours for most students in Australia) and that they have homework commitments, again in sitting - the potential negative impact that LBP may have on educational outcomes in these individuals is significant. It has previously been shown that 44.2% of a large Australian adolescent male sample with LBP stated that LBP affected study or school (Ebrall, 1994); and is congruent with previous research showing poorer school performance amongst those school children that report LBP (Salminen, 1984).

Results for sitting as the most common aggravating factor are consistent with many previous adolescent studies (Salminen 1984; Balague et al. 1988; Nissinen et al. 1994; Troussier et al. 1994; Balague et al. 1999; Grimmer & Williams 2000; Geldhof et al. 2007). Specifically, it has been previously reported that those who spend more time flexed, or slumped, reported significantly more thoraco-lumbar pain (Salminen 1984; Geldhof et al. 2007; Murphy et al. 2007); and findings that LBP while sitting at school has been associated with twisted back postures and less than optimal ergonomics (Murphy, Buckle, & Stubbs, 2007).

Evidence for carrying school bags and participating in sporting activities also aggravating subjects with NSCLBP were found. Results presented in this research for school bags and LBP are similar to most previous adolescent studies (Grimmer & Williams 2000; Watson et al. 2002; Skoffer 2007; Haselgrove et al. 2008; Skoffer & Foldspang 2008). Previous findings showed increased risk for those who carry a

school bag over longer durations (>30 mins) (Haselgrove et al., 2008), carrying a backpack asymmetrically on one shoulder (Bejia et al., 2005; Murphy et al., 2007), or a heavy back pack for body size (Bejia et al., 2005; Korovessis, Koureas, & Papazisis, 2004). The noted frequency of sitting combined with carrying school bags daily to and fro and for some participation in sporting activities before, during and/or after school suggests that opportunities for aggravation for adolescents with NSCLBP are occurring regularly throughout each school day.

Summary

Defining the parameters of NSCLBP in adolescents helps to elucidate this pain experience. These findings support that rather than considering LBP in adolescents as transitory, insignificant and part of normal life experience (Burton et al., 1996), for those adolescents included in this research with NSCLBP, the disorder was a significant health issue of long duration.

8.3 ADOLESCENT NON-SPECIFIC LOW BACK PAIN IS MULTIFACTORIAL IN NATURE

This research supports previous evidence for NSCLBP in adolescence being multifactorial in nature (Balague, Troussier, & Salminen, 1999). In this small group of adolescents positive associations were found for NSCLBP (as a whole group and not sub-classified) with increased stressful life events; decreased trunk extensor and squat endurance; increased trunk extensor muscle activation in standing and decreased spinal repositioning error. When those with NSCLBP were sub-classified differences were noted between sub-groups of NSCLBP and healthy adolescent controls in usual and slump sitting postures, range-of-motion during forward bending, levels of trunk extensor muscle activation in forward bending and deficits in spinal repositioning error.

Observed differences between those adolescents with and without NSCLBP for the ‘number of life stress events’, suggest early life stress is associated with NSCLBP in this group. Findings in adolescents are similar to a recent study of female university nursing students (age 22.5 ± 4.5 years) which showed that stress was a factor associated with LBP and independent of anxiety and depression (Mitchell et al., 2009). The relationship between stress and LBP may be mediated via changes in the

central nervous system and hypothalamic-pituitary-adrenal (HPA) axis, potentially affecting tissue sensitivity thresholds to nociception, as well as influences on motor control patterns. Previously Marras and colleagues identified a pathway in adults between psychosocial stress, higher levels of muscle tension, spinal loading and increased risk of LBP (Marras, Davis, Heaney, Maronitis, & Allread, 2000). Stressful circumstances are also known to activate the HPA axis in adults and are linked with insufficient inhibition of inflammatory reactions, suppression of the immune system and when prolonged may have direct effects on muscle, bone and nerve tissue structures (Truchon, 2001). A recent evaluation of this 'stress process model' affirms the importance of life events in the development of disability in LBP (Truchon, Cote, Fillion, Arsenault, & Dionne, 2008). This does not suggest that chronic LBP (CLBP) is a disorder of psychogenic origin, but rather provides a relationship between biochemical changes and physical manifestations in response. Previous research identified that some adults with CLBP have dominant psychosocial factors and others do not (Dunn, Jordan, & Croft, 2006), suggesting different subgroups exist with NSCLBP. The current cohort may therefore represent a subgroup of the NSCLBP adolescent population with a lower prevalence of associated psychosocial factors.

The lack of statistically significant group differences across the broader range of psychosocial factors – behaviour, depression and family functioning – is in contrast to previous adolescent studies (Sjolie, 2002; Staes, Stappaerts, Lesaffre, & Vertommen, 2003; Watson et al., 2003). These studies showed associations for increased perceived stress (Diepenmaat, van der Wal, de Vet, & Hirasing, 2006), poor mood (Jones et al. 2003; Staes et al. 2003; Murphy et al. 2007), poor behaviour (Jones et al. 2003; Watson et al. 2003) and educational strain (Kristjansdottir & Rhee, 2002).

Differences between these results and previous research in adolescents may relate to the specific cohort studied which - to identify a group suitable for a detailed motor control investigation of NSCLBP - excluded certain individuals. This included those with: a BMI >28 kg/m^2 (required for successful surface EMG recording); co-morbidities influencing the spine or contributing to LBP, such as, neurological or metatastic disease; specific diagnoses associated with LBP, such as spondylolisthesis

or disc prolapse; and parents unsupportive of their child's participation or unwilling to organise transport to the university for testing. It is possible that psychosocial factors are more prevalent amongst those subjects excluded or who declined (30 potential subjects of the 153 individuals that were approached).

Previous reports have shown a dominance of psychosocial factors (Watson et al. 2003) related to NSCLBP in adolescence; however, psychosocial factors did not dominate the current findings. Rather the outlined evidence supports that for a sub-group of adolescents with NSCLBP the disorder is not dominated by psychosocial factors but rather physical factors. In this research, deficits in muscle endurance, altered trunk muscle activation, sitting postures, range-of-motion in forward bending and deficits in spinal repositioning error were noted. The basis of difference to previous research is likely to lie in the small sub-group of adolescents with NSCLBP studied here and that they may be representative of a sub-group of adolescents within the NSCLBP population. These findings are consistent with Dunn and co-workers who found a sub-group with ongoing LBP, moderate disability and an absence of dominant psychosocial factors (Dunn et al., 2006). Further studies with larger cohorts are required to investigate this hypothesis in adolescents and confirm the generalisability of these results from a relatively small sample.

Summary

This dissertation supports that NSCLBP in adolescents is multifactorial in nature with both physical and psychosocial aspects. The dominance of physical aspects in this research is in contrast to prior reports and may reflect both a previous lack of detailed physical examination of NSCLBP in adolescents; the possibility of different sub-groups that are yet to be fully investigated; or may reflect limited generalisability.

8.4 SUB-GROUPING IS IMPORTANT IN ADOLESCENT NON-SPECIFIC CHRONIC LOW BACK PAIN

The results from this doctoral research provide evidence for the existence of sub-groups of adolescents with NSCLBP. This is based both on the dominance of physical rather than psychosocial factors as well as posture and movement behaviour relating to pain. Evidence for the existence of sub-groups is further developed from

the previous section and discussed in terms of differences in physical activity levels, endurance, gender and trunk posture, kinematics and motor control during common tasks.

8.4.1 Physical activity and muscle endurance

The lack of differences in physical activity levels between those with and without NSCLBP in the current study is similar to some previous adolescent studies (Andersen et al., 2006; Harreby et al., 1999; Wedderkopp, Leboeuf-Yde, Andersen, Froberg, & Hansen, 2003; Widhe, 2001). However, other studies have shown both positive (Harreby et al. 1999; Grimmer & Williams 2000; Watson et al. 2002; Skoffer 2007; Sato et al. 2008; Skoffer & Foldspang 2008) and negative (Balague, Damidot, Nordin, Parnianpour, & Waldburger, 1993; Burton et al., 1996; Grimmer & Williams, 2000; Sjolie, 2004) associations with physical activity. Collectively these research reports support a U-shaped relationship with physical activity in adolescents; suggesting increased pain with too much or too little activity (Vikat et al. 2000). This finding would suggest that differences between studies, including the results presented here, are due to the different cohorts of adolescents studied; further reinforces the existence of different sub-groups of NSCLBP in adolescents across different domains; and suggests that research from specific sub-groups may not be generalisable to the wider adolescent population.

A recent study highlighted that adolescent female rowers had a higher prevalence of LBP than non-rowers (Perich, Burnett, & O'Sullivan, 2006) suggesting that the type of exercise is also a risk factor for LBP. The current adolescent group were all participants in physical activities, with some being involved at a highly competitive levels in their sporting pursuits. Additionally, they reported that various physical activities provoked their pain. The fact that the asymptomatic group were equally active suggests that other individual factors coupled with participation in sport may be associated with increased risk for NSCLBP. This research was not designed to detect these interactions or causation.

These results are in contrast with previous observations that regular sporting involvement is protective for LBP in adolescence (Grimmer & Williams 2000; Wedderkopp et al. 2009). Differences may be due to the nature and type of sporting

activity (e.g. rowing versus swimming) and the interaction of personal risk factors such as deficits in back muscle endurance. This hypothesis is supported by previous findings (Perich et al., 2006) demonstrating that female adolescent rowers with LBP had additional positive associations for more flexed sitting spinal postures, poor back and lower limb endurance compared to those adolescent female rowers without LBP. Similarly, Ng and colleagues (2008) reported that adolescent rowers with LBP postured their backs closer to end-range flexion than rowers without LBP during the drive phase on a rowing ergometer (Ng, Burnett, & O'Sullivan, 2008), suggesting that motor control factors while the spine is under load were associated with LBP during rowing and not just simply participating in the sport.

That this adolescent group displayed trunk and squat endurance deficits, is consistent with other adolescent findings (Andersen, Wedderkopp, & Leboeuf-Yde, 2006; Bernard et al., 2008; Biering-Sorensen, 1984; Luoto, Heliovaara, Hurri, & Alaranta, 1995; Perich et al., 2006; Sjolie & Ljunggren, 2001). Findings for muscle endurance deficits while maintaining high levels of physical activity is similar to a recent study of female adolescent rowers with LBP (Perich et al., 2006); and suggests that deficits in endurance are not simply related to deconditioning secondary to inactivity. The mechanism for deficits in back and lower limb endurance may relate to: lower pain thresholds in the NSCLBP pain group due to the ischaemic pain induced in a test to maximal fatigue; motivational factors; genetic influences; differences in proportion of type I or II muscle fibre types or underlying deficits in muscle endurance in the NSCLBP secondary to central changes induced via the HPA axis which has been shown to have potential impacts on muscle structure (Truchon, 2001). None of these hypotheses were proven by this cross-sectional research and require further investigation.

Findings for similar levels of physical activity between adolescents with and without NSCLBP, despite moderate levels of kinesiophobia, suggest that they are not activity avoidant despite reporting pain while undertaking physical activities. These results contrast to some adult literature where NSCLBP is considered to be associated with activity avoidance due to kinesiophobia and subsequent physical deconditioning leading to poor trunk and lower limb endurance (Vlaeyen & Linton 2000; Verbunt et al. 2003). Conversely, there is evidence for a sub-group of adults with NSCLBP that,

despite pain, continually engage in activity that leads to repetitive exposure, either centrally or peripherally, to pain generating stimuli and subsequent aggravation of symptoms (Hasenbring, Hallner, & Rusu, 2009; Karsdorp & Vlaeyen, 2009). Termed *excessive persistence* it is associated with low disability and positive mood (Hasenbring, Hallner, & Klasen, 2001; Hasenbring et al., 2009). The findings of this research in adolescents may support the presence of this sub-group although the study did not formally investigate this.

Further investigations with large cohorts are required to determine if other sub-groups - fear avoidance of activity, high association with psychosocial factors and/or more highly disabled – exist in the broader population of adolescents with NSCLBP. Some preliminary evidence suggests that such populations may exist in adolescents (O'Sullivan, Murray, & Myers, 2003b).

8.4.2 Clinical classification system

Three sub-groups, as outlined by O'Sullivan (2005) (Dankaerts, O'Sullivan, Straker, Burnett, & Skouen, 2006c), were identified in the current adolescent sample – extension, flexion and multidirectional patterns. By definition multi-directional patterns are sensitised to flexion and extension. For sitting and forward bending tasks the multidirectional sub-group was pooled with the flexion sub-group, as both groups during both tasks were similarly aggravated by lumbar spine flexion. In Chapters 4, 5 and 7 this group is called the flexion-pattern sub-group and in Chapter 6 the multidirectional sub-group. Herewith this is more accurately termed the flexion/multidirectional sub-group.

8.4.3 Gender

Findings for greater numbers of females in the extension sub-group and greater numbers of males in the flexion/multidirectional sub-group were very similar to previous research using O'Sullivan's classification system in adults (Dankaerts, O'Sullivan, Burnett, & Straker, 2006a), see Table 8-1. Why the clinical presentation in women would be different to men is unclear and requires further research, but it may be due to gender based morphological differences (such as pelvic shape and size), spinal structural differences, differences in trunk muscle endurance and/or a

psychological, social or cultural basis of preference for upright hyperlordotic postures in women and kyphotic slumped postures in men. While statistical analyses were adjusted for gender, this doctoral research did not consider comparisons based on gender. Further investigations are required that include larger sample sizes to allow determination of interaction effects between gender and sub-groups.

8.4.4 Posture, kinematics and trunk muscle activation during common tasks

Results from the laboratory-based aspects of this research also provide evidence that classifying adolescents with NSCLBP should be considered. Similar to studies by Dankaerts and colleagues (2009) this research investigated three common postures – usual sitting, slump sitting and standing – and one common dynamic task – forward bending. Due to the restricted nature of previous studies concerning posture kinematics and trunk muscle activation in adolescents with NSCLBP, in the main comparisons are made with previous adult literature. The exceptions to this are two adolescent studies, one of sitting and one of standing posture that are identified in the text. This doctoral research identified that differences in sitting posture and both range-of-motion and trunk muscle activation in forward bending between those adolescents with and without NSCLBP were only identified once sub-grouped. The discussion that follows outlines these results in more detail and discusses them compared to previous literature.

Posture

No statistically significant differences were noted between adolescents with and without NSCLBP during usual or slump sitting before being sub-grouped. This is comparable to finding from adult research using the same protocol (Dankaerts et al., 2006b). Previously, thoracolumbar pain has been associated with flexed or slumped postures in groups of *adolescents* with pooled LBP (Murphy, Buckle, & Stubbs, 2004), a finding not shown in this doctoral research. Differences are most likely due to either differences in measurement tools or age-related differences in spinal development with the study by Murphy and colleagues (2004) including a much younger sample, 11-14 years, than the current cohort.

Sub-group results in usual sitting (for the extension sub-group displaying increased lumbar lordosis and the flexion/multidirectional sub-group displayed a kyphotic lumbar spine in usual sitting (see Table 5-4A and Figure 5-2)) are similar to previous adult research (Dankaerts et al., 2006b). Findings in slump sitting for less posterior sacral tilt and increased lumbar lordosis in the extension sub-group compared to both the flexion/multidirectional sub-group and asymptomatic controls are also similar to previous comparable adult literature (see Table 5-4B and Figure 5-3). When results from both sub-groups were pooled, the equal and opposite results showed a *wash-out* effect (Dankaerts et al., 2006b), with no differences between those with and without NSCLBP being able to be detected.

The lack of findings in standing postures (Figure 6-3) between those without NSCLBP or sub-groups of NSCLBP are similar to a previous adult study (Dankaerts et al., 2009). This is in contrast to a recent large *adolescent* cohort study that was able to differentiate sub-groups of standing posture; with non-neutral postures linked with higher odds for LBP (Smith, O'Sullivan, & Straker, 2008). Differences between this and previous research could be due to differences in methodology. Angular measurements by Smith and colleagues (2008) used trunk angle (a measure of whole of trunk posture) and sway angle (a measure of trunk position over the ankle joint) in their cluster analysis to determine relationships between sub-group membership and LBP. Secondly, four sub-groups were identified in the cluster analysis which due to small group numbers wasn't possible with the current research.

Results for sitting posture support the need to consider the presence of sub-groups of NSCLBP to identify differences between those adolescents with and without pain. Previous results from adolescents in standing suggest that sub-groups may also exist during this activity although results from this doctoral research did not support this.

Trunk muscle activation in sitting and standing were non-discriminatory for sub-groups of NSCLBP in adolescents. In the comparable adult study muscle activation levels of lumbar multifidus, iliocostalis and internal oblique in sitting were found to be discriminatory for the extension sub-group compared to both the flexion sub-group and healthy controls (Dankaerts et al., 2006a). Differences are most likely due

to immaturity of the trunk motor control system and are discussed in detail latter in this discussion.

Forward bending

Similar to results in sitting, the findings in this doctoral research support that forward bending range-of-motion is not a sensitive marker for NSCLBP in adolescence unless those with pain are sub-classified. Trends in the adolescent data for reduced lower lumbar flexion (Figure 6-5) in the extension sub-group is similar to comparable data in adults that showed the active-extension sub-group did not move out of lower lumbar lordosis in forward bending (Dankaerts et al., 2009) while both the flexion sub-group and healthy controls achieved lower lumbar flexion. A comparison of mean differences in the current adolescent data indicates a likely effect of a large size decrease in lower lumbar flexion and a moderate sized decrease in upper lumbar flexion in the extension sub-group compared to both the flexion/multidirectional sub-group and healthy controls (Hopkins, 2007; Hopkins, Marshall, Batterham, & Hanin, 2009). The lack of statistical significance in this adolescent study most likely reflects a smaller effect size in this population. However, this would require an investigation with larger sample sizes to confirm this. The previous adult study did not report on differences in range-of-motion during forward bending restricting a comparison of results. However, noted differences in range-of-motion during forward bending support the requirement to sub-classify patients with NSCLBP in kinematic research.

In the previous comparable adult study activation levels of lumbar multifidus in the last quarter of forward bending discriminated between healthy controls and both sub-groups of NSCLBP (Dankaerts et al., 2009). This is at odds with current adolescent results where large sized increases in iliocostalis and thoracic erector spinae activation (Figures 6-6 & 6-7) during the second quarter of the return phase was the most substantive result between those with flexion-pattern NSCLBP and both those with extension-pattern NSCLBP and healthy adolescent controls. Similar to findings of posture and kinematics without sub-classification these differences could not be detected.

8.4.5 Spinal repositioning

This is the only study, adolescent or adult, to compare sub-groups of NSCLBP and in a test of spinal repositioning sense across the lumbar spine regions (see Tables 7-4 and 7-5). Reports for poorer accuracy and greater variability in the flexion/multidirectional sub-group compared to other groups are similar to a previous study of adults with flexion-pattern NSCLBP compared to healthy controls (O'Sullivan et al., 2003a). Less accuracy in this test was noted in the flexion/multidirectional sub-group compared to the extension-pattern or no pain group (see Table 7-5). Previously in adults it has been identified that repositioning acuity is poorer after lumbar flexion than extension or rotation (Asell, Sjolander, Kerschbaumer, & Djupsjobacka, 2006). That the flexion/multidirectional subjects spend most time in sitting in flexion may influence results for spinal repositioning.

8.4.6 Which classification system is best?

So far this discussion has considered that different sub-groups may be present in this population or that due to the limited sample the cohort may belong to a select sub-group of adolescents with NSCLBP. It is suggested that adolescent NSCLBP could be divided by: dominance or absence of psychosocial factors; high or low physical activity levels; being fear avoidant or excessively persistent; high or low disability levels; displaying kyphotic or lordotic sitting postures; showing increased or decreased lumbar ROM in forward bending; demonstrating greater or lesser muscle activation levels in returning from forward bending; having reduced or normal levels of trunk extensor or squat endurance levels; or demonstrating greater spinal repositioning error. Further, the literature would suggest that sub-groups may also be created by the influence of gender, age, pubertal stage and other lifestyle and physical factors not investigated here. These results suggest that adolescents with NSCLBP may be grouped in a variety of ways.

It is also apparent that different collections of these sub-groups and the multiple interactions between them may create different classes e.g. highly disabled, fear avoidant, low physical activity and scoring highly in psychosocial domains. It has long been noted that associations are known between emotion and posture (Atkinson, Dittrich, Gemmell, & Young, 2004; Marsden, 1982; Roether, Omlor, Christensen, &

Giese, 2009), hence, linkages are also likely to be found between psychosocial and biomechanical factors. These types of potential interactions underscore the important decision that despite the limited cohort size this research was conducted from a multifactorial biopsychosocial perspective. While the results are limited by generalisability this group of adolescents were characterised by relatively high physical activity and moderate disability levels and little to no avoidance behaviour. Those in the extension group had generalised lumbar pain, fewer stressful family life events and hyperlordotic lumbar sitting posture; those in the flexion/multidirectional group localised lumbar pain, greater numbers of stressful family life events and kyphotic lumbar sitting posture. Whether in this case stress and kyphotic sitting and low stress and hyperlordotic sitting are linked is undetermined and this research was not geared to determine such relationships, but it does reflect previous considerations between mood and posture (Atkinson et al., 2004; Marsden, 1982; Roether et al., 2009); and reinforces the need to study NSCLBP in a multifactorial manner.

The presence of different observable sub-groups and that a variety of interactions between these sub-groups may create different classes infers that different classification systems may be more or less appropriate when considering adolescent NSCLBP. This research used as its basis the O'Sullivan classification system for LBP, specifically that part of this system that deals peripherally mediated pain through localised mechanical provocation based on posture and movement behaviours. From the results of this research this system has shown good utility and suitability, is considered appropriate for the purpose, demonstrates face validity and is generalisable to the adolescent NSCLBP population (Buchbinder, Goel, Bombardier, & Hogg-Johnson, 1996). However, as no metanalysis has been conducted on the O'Sullivan classification system and the validity of one approach over the other has not been rigorously established, is this the only appropriate classification system that could be applied to this data?

Despite it's limitations in the psychosocial dimension the Sahrmann approach also focuses on classifying the movement disorder and treatment based on this classification. The five categories of the Sahrmann system are flexion, extension, rotation, rotation with flexion and rotation with flexion (Van Dillen et al., 2003). Three sub-groups were identified in this research using the O'Sullivan system

flexion, extension and multi-directional, see p 2-45 for descriptions. Two other patterns are defined in the O'Sullivan system flexion/lateral shifting and a differentiation between active and passive extension pattern. Pragmatically, due to numbers, subjects from the flexion and multi-directional group and both the active and passive extension subjects were pooled. At face value the pooled flexion and extension groups may be considered to be similar to the Sahrmann flexion and extension groups, and resultantly there may be similarities in treatment philosophies. However the identification of a distinct group of adolescents that displayed a motor control impairment of the lumbar spine of a multi-directional nature, with both flexion and extension provoking symptoms does not fit any category of the Sahrmann system and lends greater support to O'Sullivan's classification. A summary table of characteristics of each identified sub-group is at Table 8-2.

Extension	Flexion/Multidirectional
Generalised lumbar pain (above and below L3)	Localised lumbar pain (below L3)
Numbers of stressful life events is not discriminatory compared to adolescents with no LBP but fewer than the flexion/multidirectional sub-group	Numbers of stressful life events are more common than in the extension sub-group or adolescents with no LBP
Hyperlordotic lumbar posture in usual sitting with a reduced thoracic kyphosis	Kyphotic lower and upper lumbar spine during usual sitting with posterior pelvic tilt compared to adolescents with extension-pattern disorder. An increased upper kyphosis is discriminatory when comparing to adolescents with no LBP
Maintenance of lower lumbar lordosis in slump sitting	Slump sitting postures are more kyphotic than those with extension-pattern disorder, but no different to adolescents with no LBP
Reduced lower lumbar range-of-movement in forward bending	Similar to adolescents with no-LBP, those with flexion/multidirectional disorder are able to fully flex the lumbar spine in forward bending and have greater lower lumbar range-of-movement than those with extension-pattern disorder
Reduced levels of timed trunk extensor and squat endurance compared adolescents with no LBP	High levels of trunk extensor muscle activation, particularly for Iliocostalis and Thoracic Erector Spinae, activation during the return phase of forward bending
Common Characteristics	
Similar levels of usual pain	
Common aggravating factors - sitting, sport and carrying school bag	
High levels of physical activity, no avoidance behaviour. †	

Table 8-2– Characteristics of sub-groups of NSCLBP in adolescents

† Caution should be applied to this characteristic as it is most likely that the current sample were active copers and at the upper end of the physical activity/LBP curve.

Summary

Postural, kinematic, trunk muscle activation and spinal repositioning accuracy differences lend support, using O'Sullivan's classification system, to the existence of sub-groups in adolescents with NSCLBP (O'Sullivan, 2004, 2005). These sub-groups, while showing similarities to adult sub-groups also differ. Further, the findings support the need to sub-classify patients with NSCLBP as pooled data resulted in a 'wash out' effect (Dankaerts et al., 2006b). Table 8-2 summarises characteristics expected for each sub-group of adolescents with NSCLBP. These characteristics include the impairments associated with sub-groups of NSCLBP and thus allow for more targeted intervention. It is recognised that these findings are preliminary and should additionally be considered in the wider context of other suggested classification systems for NSCLBP.

8.5 REGIONAL DIFFERENCES

Thus far in this discussion evidence is provided for differences between this doctoral research of adolescents with NSCLBP and previous adult findings for disability, kinesiophobia, duration of pain, trunk endurance and trunk muscle activation in forward bending. Results between those with and without NSCLBP for sitting posture and spinal repositioning error suggest similarities with the adult literature, there are differences based on spinal regional differences.

Spinal posture in sitting

In adults, posture of the lower lumbar spine in usual sitting was found to be most discriminatory between groups (Dankaerts et al., 2006b), whereas in this adolescent study upper lumbar angle was the only angle to discriminate between each of the three possible comparisons. Further, in adults the flexion sub-group was able to be differentiated from the extension sub-group and healthy controls during usual sitting by sacral and lower lumbar angles (Dankaerts et al., 2006b); whereas, in this adolescent study, the only comparison to discriminate between the flexion/multidirectional sub-group and controls was upper lumbar angle.

Differences in slump sitting between the extension sub-group and both other groups (see Table 5-4) were shown for sacral, lower lumbar and upper lumbar angle. Results

are similar to previous adult research except that no differences were found between groups in the upper lumbar spine (Dankaerts et al., 2006b). No statistical differences were noted between the flexion/multidirectional sub-group and healthy controls achieving a comparably kyphotic posture in slump sitting (see Figure 5-3) a result also found in adult data (Dankaerts et al., 2006b). This finding could be due to low statistical power and if true differences exist, research with greater numbers in each group will be required to detect these.

Results for regional differences support those of Mitchell and co-workers who, reported differences based on posture and movement between lumbar regions (Mitchell, O'Sullivan, Burnett, Straker, & Smith, 2008). Previous studies from other authors have investigated the lumbar spine as a singular functional unit. Findings from this doctoral research combined with adult findings by Dankaerts et al. (2006a, 2006b, 2009) and Mitchell and colleagues (2008) would suggest that considering the lumbar spine as two distinct regions, upper and lower lumbar, is important for future research investigating either adult or adolescent NSCLBP.

Results for both usual and slump sitting posture suggest that regional lumbar spine differences may exist between adolescents and adults with NSCLBP. In adolescents, NSCLBP was more consistently associated with changes in upper lumbar spine posture, while in adults, lower lumbar spine posture was most discriminatory (Dankaerts et al., 2006b). Regional spinal differences may be due to the ongoing development of sagittal spinal curves in the adolescent group (Cil et al., 2005).

Spinal repositioning

In the flexion/multidirectional sub-group lower spinal repositioning accuracy was noted in the lower than upper lumbar spine. Results for area of NSCLBP from body charts suggest that pain in the flexion/multidirectional sub-group is localised to the lower lumbar spine (lower than L3) while the extension sub-group displayed more generalised lumbar pain. Decreased spinal repositioning acuity in the lower lumbar spine in flexion/multidirectional sub-group suggests that the greater concentration of pain in this region may influence accuracy.

Summary

In this study of adolescents the upper lumbar spine was most discriminatory spinal region in usual and slump sitting and the lower lumbar spine was most discriminatory during tests of spinal repositioning. The noted differences in adult and adolescent studies may be due to differences in spinal morphology in a still maturing adolescent spine.

8.6 DIFFERENCES IN MOTOR CONTROL BETWEEN ADOLESCENTS AND ADULTS WITH NON-SPECIFIC CHRONIC LOW BACK PAIN

This part of the discussion compares those results that suggest that differences in underlying motor control factors between adults and adolescents with NSCLBP exist. Whilst there were broad base similarities in results of posture and kinematics between current adolescent and previous adult samples, there were also differences. It is of interest to understand if similarities and differences exist as this will inform the suitability of transferring previous research information concerning LBP in adults to adolescents. Results are considered from the laboratory-based studies.

Posture and kinematics

In standing no differences were shown between those with and without NSCLBP and sub-groups of NSCLBP in either group. In usual and slump sitting, in both groups, differences in posture were only noted once sub-classified. The direction of results for sub-groups in both adults and adolescents would suggest that those with flexion/multidirectional disorder sit in more slumped postures while those with extension pattern disorder sit in hyperlordotic postures, maintaining lordosis when attempting to move into slump sitting.

There were, however, noted differences. Results for a lack of difference in range-of-motion between usual and slump sitting for any comparison is at odds with previous adult data (Dankaerts et al., 2006b). The prior adult study showed that both NSCLBP sub-groups moved through less range of both sacral tilt and lower lumbar flexion when moving into slump sitting (Dankaerts et al., 2006b); whereas this doctoral research of NSCLBP in adolescence showed no range-of-motion deficits in sitting either when considered as a whole or sub-classified (Table 5-4C). Similarly, no differences were shown in kinematics during forward bending or at end-range in

adolescents with and without NSCLBP, yet previous adult research would indicate differences should exist (Dankaerts et al., 2009; Esola, McClure, Fitzgerald, & Siegler, 1996; McClure, Esola, Schreier, & Siegler, 1997; Paquet, Malouin, & Richards, 1994; van Wingerden, Vleeming, & Ronchetti, 2008). Further, and as mentioned earlier, regional spinal differences exist between these current adolescent and previous adult findings.

The observed differences between adolescents and prior adult studies may relate to differences in the cohorts studied such as levels of impairment or kinesiophobia or differences in spinal or neuromuscular maturity. Previous studies have identified differences in spinopelvic morphology between healthy young adolescents and young adults, including, an increased lumbar lordosis compared to adolescents (Vedantam et al. 1998; Mac-Thiong et al. 2004; Poussa et al. 2005; Mac-Thiong et al. 2007). Dissimilar results between adolescents and adults for posture and kinematics may be due to these spinal maturational differences. An alternative hypothesis would be that the observed effect size in this adolescent population may be less than that previously shown in adult studies. If real but small postural and kinematic differences exist in the lower lumbar spine in sitting, during standing or end-range forward bending in the adolescent population, studies with increased group sizes, and greater power, will be required to detect these.

Trunk muscle activation

In comparison to studies of posture with demonstrated similarities and differences between the current adolescent and prior adult studies investigation of trunk muscle activation was clearly different. Differences were shown between the current doctoral research of adolescents and previous adult studies in sitting, standing, forward bending, in sub-groups of NSCLBP and in measures of the flexion-relaxation phenomenon.

Levels of trunk muscle activation in adolescents during sitting, standing and forward bending were variable and largely non-discriminatory between adolescents with and without NSCLBP or sub-groups of NSCLBP. The exceptions, where differences were noted between those with and without NSCLBP, were: a decrease in internal oblique activation during usual sitting; an increase in iliocostalis activation during

quiet standing; and between the flexion/multidirectional sub-group and both the extension sub-group and healthy adolescent controls increases in iliocostalis and thoracic erector spinae activation during return from forward bending. These differences were not shown in previous adult studies in sitting and standing (Ahern, Follick, Council, Laser-Wolston, & Litchman, 1988; Arena, Sherman, Bruno, & Young, 1989, 1991; Cassisi, Robinson, O'Conner, & MacMillan, 1993; Dankaerts et al., 2006a; Geisser et al., 2005; Hoyt et al., 1981; Kaigle, Wessberg, & Hansson, 1998; Miller, 1985; Pope, Bevins, Wilder, & Frymoyer, 1985; Sherman, 1985; Watson, Booker, Main, & Chen, 1997). No previous adult study has investigated trunk muscle activation in the return phase from forward bending, the most discriminatory time epoch of the forward bending cycle in the current adolescent group.

In their study of adults Dankaerts and colleagues identified that the extension sub-group had greater activation during both usual and slump sitting in lumbar multifidus and iliocostalis compared to both healthy adult controls and the flexion sub-group (Dankaerts et al., 2006a). As no differences for an increase in activation in the extension sub-group were shown in this doctoral research of adolescents, the question arises as to what motor control strategy the adolescents with extension pattern NSCLBP employ to sit. It may be that spinal postural muscles not measured in this study are being utilised to maintain the upright postures such as deep fibres of lumbar multifidus, quadratus lumborum or iliopsoas.

The flexion-relaxation phenomenon was seen in adolescents with NSCLBP during usual to slump sitting and was non-discriminatory between adolescents with and without NSCLBP during forward bending with almost all subjects exhibiting a flexion-relaxation response. This result is at odds with research in adults where absence of flexion-relaxation during forward bending is a consistent indicator of the presence of LBP (Paquet et al. 1994; Sihvonen 1997; Watson et al. 1997; Kaigle et al. 1998; McGorry et al. 2001). Flexion-relaxation has also been shown in adults during usual to slump sitting (Callaghan & Dunk, 2002; O'Sullivan et al., 2006). Ironically flexion-relaxation was absent in adolescents with no history of LBP, a finding contrary to previous adult studies.

Visual analysis of the adolescent data in sitting and forward bending showed a highly variable flexion-relaxation response across NSCLBP and asymptomatic groups, between subjects and within subject trials and may reflect a immaturity of spinal motor control in adolescents. The highly variable response would explain differences between this adolescent group and previous adult findings and suggests that if real differences exist effect sizes are likely to be smaller in the adolescent population. Results support that stereotypical patterns of motor control observed in adults are absent in adolescents.

With the comparable adult group having experienced NSCLBP over longer durations and the adolescent group still participating in physical activity despite pain provocation, an alternate hypothesis is that spinal motor control system in adolescents is yet to be altered by the presence of LBP. Hence some subjects with NSCLBP displayed a flexion-relaxation response while others did not and may help to explain some of the noted variability in the data. Comparative studies between adolescent and adults are needed to identify any real differences.

Spinal repositioning

In contrast to previous reports in adults for increased variability (VE) in those with LBP (Brumagne, Cordo, Lysens, Verschueren, & Swinnen, 2000) no differences were shown between adolescents with and without NSCLBP. Results for greater accuracy (AE) in healthy controls compared to those with NSCLBP is similar to previous adult findings (Brumagne et al., 2000).

Research by Maffey Ward and co-workers (1996) and Lam and colleagues (1999) most closely represent comparable studies in adult LBP populations. Both these studies measured lumbar angle error similar to this study and employed a very similar repositioning task – usual to slump sitting and return. The magnitude of the current adolescent lumbar angle data is larger for both groups than those previously reported in adults, see Table 8-3 (Maffey-Ward et al. 1996; Lam et al. 1999). Measures in this current study for lower lumbar angle (AE, CE, and VE) are similar to previous adults research for sacral tilt (Brumagne et al., 2000), with magnitudes being similar. However, caution must be drawn for these comparisons as the task

direction prior to repositioning was opposite to the current study of adolescents which may obscure direct comparisons.

Evidence for greater inter-subject variability in AE (as evidenced by the SD of the AE) in adolescents compared to adults, particularly with NSCLBP, suggests that this group was more variable in their ability to reposition the spine. Combined with previous evidence for age-related refinement of proprioceptive control (Ashton-Miller et al. 1992; Assaiante 1998; Largo et al. 2001; Goble et al. 2005) these results support suggestions that the somatosensory system may not be fully integrated during adolescence and that this period represents a transition in postural control (Assaiante 1998; Viel et al. 2009). Whether the noted immaturity is related to peripheral, central, sensorimotor or cognitive processes (Goble, Lewis, Hurvitz, & Brown, 2005) is not proven by this research.

Authors	Group	Constant Error	Absolute Error	Variable Error	Sensor Position	Task Direction
Maffey-Ward et al 1996	No-LBP		2.6±1.2 (3.1±1.3)		S2-T10†	Flexion
Lam et al 1999	LBP		2.3±0.9 (4.1±2.3)		S2-T10†	Flexion
Brumagne et al 2000	No-LBP	-0.6±1.0 (-1.1±1.8)	1.6±0.6 (1.8±1.3)	1.7±0.7 (1.2±0.8)	S2‡	Extension
	LBP	-2.5±2.5 (-0.6±2.4)	4.3±1.0 (2.3±1.5)	3.3±1.4 (1.6±1.2)	S2‡	

Table 8-3 – Repositioning errors previously documented in comparable adult research – for easy comparison adolescent data is included in parentheses below each value

Values are mean and standard deviation. Subject group's - age, gender, inclusion and exclusion criteria - differ between studies. Comparable adult studies were chosen based on measurement of two dimensional sagittal angular repositioning error during an unsupported sitting task. † Sensor position makes measurement most comparable to lumbar angle measurements, ‡ Sensor position makes measurement most comparable to lower lumbar angle measurement

Summary

In comparing the current results of adolescents with and without NSCLBP to previous adult studies differences in posture and kinematics align broadly, however, specific variables and regions varied. In comparison to kinematic measures, results for trunk muscle activation are very different between adolescents and adults during sitting, standing and forward bending. Evidence is presented that there are

differences most likely due to immaturity of trunk motor control system and still developing spino-pelvic morphology. For these reasons caution must be heeded in directly transferring previous results from adult research concerning trunk posture, kinematics and motor control and LBP to adolescent populations. Comparative studies are required to confirm these hypotheses.

8.7 LIMITATIONS OF PRESENT RESEARCH

While the current study provided an insight into the multiple dimensions of small group of adolescents with NSCLBP, specifically the physical domain, the following is a summary of identified limitations with the present research.

- The cross-sectional study design did not allow identification of cause and effect of the various identified factors. Thus, neither the development of deficits associated with NSCLBP, or the progression of the disorder from adolescence to adulthood could be determined.
- The current cohort is likely to represent a sub-group of the adolescent population with NSCLBP with low psychosocial factors and findings here may not be generalisable to the whole population.
- While adequately powered to detect moderate effects based on estimates for previous adult studies, the study was not able to detect smaller effect sizes, especially with the increased variability of these measures in adolescents.
- It is acknowledge that the high number of variables and repeated measures increases the risk of type 2 error due to multiple comparisons. However, findings were consistent with previous research suggesting that they are not likely to be spurious.
- Other than adjusting for gender in group comparisons, sufficient numbers of each gender were not present in each sub-group to allow determination of interaction effects.
- Trunk muscle activity in this research was only recorded for superficial muscles; prior adult studies have also considered the contribution and role of deeper trunk muscles on posture and function and the effect of LBP (Claus, Hides, Moseley, & Hodges, 2009).

- This study did not consider longer sitting or standing tasks where effects of fatigue are likely to be more dominant. This is an important consideration given longer duration tasks show greater differences in reported pain provocation in adults (Gregory & Callaghan, 2008; Lis, Black, Korn, & Nordin, 2007).

8.8 IMPLICATIONS FOR CLINICAL PRACTICE

NSCLBP in adolescence is a significant public health issue and multifactorial in nature. Evidence from this dissertation suggests that physical factors are important in the development and aggravation of NSCLBP in this group of adolescents and conflicts with previous suggestions that the disorder is predominately influenced by psychosocial factors. The identification of distinct sub-groups based on pain area and behaviour, body posture, movement patterns and repositioning error suggests that these need to be determined on examination. Clinical examination of adolescent patients with NSCLBP needs to investigate across multiple domains. This new knowledge has implications both for thorough examination and may have implications for the effective clinical management of sub-groups of adolescent patients with motor control disorders.

This research highlights that a battery of measures may be required to document and discriminate adolescents with and without NSCLBP and commonly identified sub-groups of NSCLBP. The differences between the extension and flexion/multidirectional sub-groups outlined in Table 8-2 suggest that the follow measures are required:

- distribution of pain (body chart);
- common aggravating factors;
- number of stressful life events;
- levels of physical activity;
- timed trunk extensor and squat endurance;
- kinematic analysis of provocative postures and movements – specifically usual and slump sitting and forward bending;
- trunk extensor activation in returning phase of forward bending; and
- measures of spinal repositioning acuity.

Comparisons to previous literature would suggest that the group of adolescents investigated in this dissertation may belong to a sub-group with high physical activity levels, active coping and low fear avoidance behaviour; although it is suggested that there are sub-groups with different clusters of factors likely to be present in the wider adolescent NSCLBP population. While not found to be discriminatory in this doctoral research, the following measures hold utility for future investigations and clinical practice in quantifying impairments and screening for psychosocial factors.

- levels of usual pain (VAS);
- Oswestry scale of disability;
- Tampa scale of kinesiophobia;
- Child behaviour checklist;
- Becks depression inventory; and
- McMaster scale of family functioning.

It is acknowledged that more appropriate tools may exist for use in adolescents with NSCLBP. It may be that patient specific scales to measure disability could be more valid. For students these scales should focus on sitting, sport and bag carrying. Using such an extensive battery of tests is not likely to be feasible for most clinicians and broad based tests, such as the Balanced Inventory for Spinal Disorders (Svensson, Schillberg, Kling, & Nystrom, 2009), may be more suited as initial screening tools. These hypotheses need further investigation in adolescents.

A multi-dimensional approach to management has recently been shown to be successful in reducing the incidence of LBP, pain and disability in a group of adolescent female rowers across a rowing season based on this classification system (Perich et al., 2009). This approach addresses the impairments outlined in this doctoral research, such as deficits in trunk and lower limb muscle endurance as well as addressing motor control issues relating to spine position sense, and the control of static postures and pain provocative movements. The research by Perich and colleagues (2009) suggests that these factors are modifiable, can influence pain and may be related to the aetiology of the disorder. The fact that results for kinematics were more discriminatory than results for trunk muscle activation may support functional kinematic approaches to management rather than muscle focussed

approaches. Further research is required to validate these management approaches to broader groups of adolescents with NSCLBP.

The evidence within this thesis for relationships between NSCLBP in adolescents and stressful life experiences suggests that even in this group of 'active-copers' consideration of the psychosocial domain is important in clinical practice. In adults, a biopsychosocial approach to pain management is suggested to address multiple factors – biological, psychological and social – simultaneously (Gatchel & Rollings, 2008). In this spectrum cognitive behavioural therapy (CBT) has been shown to be effective in addressing the psychosocial dimensions of CLBP in adults (Gatchel & Rollings, 2008; Hoffman, Papas, Chatkoff, & Kerns, 2007). CBT approaches are designed to help patients identify maladaptive patterns and acquire, develop and practice more adaptive ways of responding and are considered an important complement to more traditional medical treatment approaches for CLBP (Turk, 2003).

In adolescents there is strong evidence that psychological treatments, are highly effective in reducing the severity and frequency of chronic pain in adolescents (Eccleston, Morley, Williams, Yorke, & Mastroyannopoulou, 2002). Specifically, CBT has been shown to be effective in the treatment of adolescents with chronic pain (Merlijn et al., 2005; Wicksell, Melin, & Olsson, 2007). While CBT approaches have not been specifically studied in adolescents with CLBP, results from groups of adolescents with chronic musculoskeletal pain (Eccleston, Malleson, Clinch, Connell, & Sourbut, 2003) suggest that CBT is likely to be effective.

Evidence of the efficacy of multidisciplinary rehabilitation in the treatment of adults with CLBP suggests that intensive (>100 hours of therapy) rehabilitation programs which focus on functional restoration produces greater improvements in pain and function than less intensive multidisciplinary or non-multidisciplinary rehabilitation or usual care (Guzman et al., 2001). Multidisciplinary approaches must, however, be tailored to the identified impairments (biological, psychological and social) of each patient (Gatchel & Rollings, 2008). For those adolescents with more dominant psychosocial factors a multidisciplinary clinical approach including a strong cognitive behavioural component is likely to be required.

8.9 RECOMMENDATIONS FOR FURTHER RESEARCH

In consideration of the research findings presented in this thesis and the above acknowledged limitations the following recommendations are made to further understand the complexities of adolescent NSCLBP.

- A larger study with greater power is required to confirm the preliminary findings presented here both to further strengthen evidence for difference and to make more concrete determinations of no difference between those with and without NSCLBP (when sub-grouped and considered as a whole).
- Future research with larger cohort numbers may need to consider a higher alpha value for significance to adjust for multiple comparisons.
- Findings highlight the importance of identifying sub-groups of NSCLBP in the examination, clinical management and scientific investigation of the disorder (Dankaerts et al., 2009; O'Sullivan, 2005). Future research should also consider the presence and effects of specific sub-groups of NSCLBP in adolescents across a broader representation of the adolescent population; this will require studies with greater numbers in each sub-group.
- Further studies of differences in posture and kinematics in adolescents with NSCLBP are likely to be most useful in elucidating differences. While studies of superficial trunk muscle activation are likely to be less discriminatory in studies of adolescents with and without NSCLPB (when sub-grouped and considered as a whole).
- Future research should consider the contribution of deep trunk muscles, such as deep multifidus, quadratus lumborum and iliopsoas, and of other global postural control muscles, such as the gluteals and hamstrings; their influence on motor control of the trunk; and relationships with NSCLBP in adolescence.
- To help inform the development of targeted interventions, further research should investigate whether previously documented clinical management strategies for different sub-groups of NSCLBP in adults (O'Sullivan, 2004, 2005) are suitable for adolescents with NSCLBP.

- Valuable information would be gleaned from a comparative study between adolescents and adults with NSCLBP.
- Finally, future studies should determine the longitudinal time course of documented differences shown in adolescent NSCLBP as they develop towards adulthood. This could include examination of trunk muscle activation; relationships between developmental spinal morphology, posture; the development of spinal proprioceptive acuity; and interactions with NSCLBP.

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CHAPTER 9 – CONCLUSIONS

Adolescence is a period of rapid physiological, physical, psychological and social growth resulting in considerable morphological, structural and functional changes (Viel, Vaugoyeau, & Assaiante, 2009). This period is also a stage of development linked with genesis or exacerbation of many chronic health conditions (Patton & Viner, 2007) and harbours many challenges (especially for social, emotional and psychological health) (Waylen & Wolke 2004; Short & Rosenthal 2008). Adolescence also presents great opportunity for preventative medicine and interventions aimed at health, well being (Kleinert, 2007) and correction of maladaptive behaviours and beliefs.

While there is a wealth of information concerning adult LBP, the puzzle that is non-specific chronic low back pain (NSCLBP) remains somewhat unresolved. Previous research has identified that populations of individuals with NSCLBP are not homogenous and can be sub-grouped (Dankaerts et al., 2009; Leboeuf-Yde, Lauritsen, & Lauritzen, 1997; Linton, 2000; O'Sullivan, 2005). Previously, it was unknown whether results from adult literature concerning NSCLBP were suitable for transference to adolescent sufferers of NSCLBP. Consequently, the general aim of this research dissertation was to investigate and document the biopsychosocial factors of NSCLBP in adolescents and investigate the presence of sub-groups based on O'Sullivan's classification system in a population of adolescents with NSCLBP.

The current findings challenge previous beliefs that LBP in adolescence is dominated by psychosocial factors. Findings in those with NSCLBP (both considered as a whole and sub-grouped) for increased stressful life events, postural and kinematic changes in spinal posture, differences in trunk muscle activation and impairments in spinal repositioning compared to asymptomatic controls suggest that multifactorial associations and differences exist. This research demonstrates for the first time that for a small group of adolescents with NSCLBP the disorder is not dominated by psychosocial factors but rather physical factors with a minor influence from the psychosocial domain.

From the results of this dissertation the following conclusions can be drawn:

- This research outlines that NSCLBP in adolescence is a significant health disorder with significant pain levels and associated impact.
- Findings across a broad range of biopsychosocial factors, indicates that, similar to the adult disorder, NSCLBP in adolescents is multifactorial in nature.
- In this small group of adolescents with NSCLBP the disorder was dominated by physical rather than psychosocial factors.
- NSCLBP in adolescence is not a homogenous group, but, rather different sub-groups exist based on spinal posture, kinematics, spinal repositioning acuity, physical activity levels, trunk extensor and squat endurance and psychosocial factors. These finding broadly reflects previous observations in populations of adult with NSCLBP.
- The classification of adolescents with NSCLBP is likely to be important both in research practice and for successful clinical intervention.
- Studies of superficial trunk muscle activation during common tasks did not discriminate groups. This is likely to be due to the large inter-individual variability in adolescent muscle activity levels. These findings are at odds to previous reports in adult NSCLBP populations possibly reflecting immaturity of the motor system in adolescents.
- Despite variability in accuracy, tests of spinal repositioning error discriminated between those with and without NSCLBP and sub-groups of NSCLBP.
- Differences were shown between sub-groups of NSCLBP in adolescents in tasks of spinal repositioning and in different spinal regions. Consideration of sub-groups of NSCLBP for future spinal repositioning research is important.

- Differences between the current research and adult literature would suggest that adolescent NSCLBP is not the same as adult NSCLBP, especially in terms of trunk muscle activation and the accuracy of spinal repositioning. In this regard findings from previous adult literature cannot be directly transferred to the adolescent population. NSCLBP in adolescence requires further investigation.

This dissertation supports that NSCLBP in adolescence is a significant health disorder and multifactorial in nature. Whilst this doctoral research was of a small group of adolescents with NSCLBP, hence it has low generalisability, results do support broad postural and kinematic findings from prior studies of adults. NSCLBP in adolescence, like in adults, is not homogenous, but rather can be considered a series of sub-groups with different clusters of factors from physical, psychological and social domains. This investigation of NSCLBP provides a contribution towards understanding the disorder in adolescence and may help inform the development of targeted interventions. Early interventions during adolescence may help to decrease the large social cost and burden of adult LBP.

9.1 REFERENCES (IN ALPHABETICAL ORDER)

Dankaerts, W., O'Sullivan P, B., Burnett, A., Straker, L., Davey, P., & Gupta, R. (2009). Discriminating healthy controls and two clinical subgroups of nonspecific chronic low back pain patients using trunk muscle activation and lumbosacral kinematics of postures and movements - a statistical classification model. *Spine, 34*(15), 1610-1618.

Kleinert, S. (2007). Adolescent health: an opportunity not to be missed. *Lancet, 369*(9567), 1057-1058.

Leboeuf-Yde, C., Lauritsen, J. M., & Lauritzen, T. (1997). Why has the search for causes of low back pain largely been nonconclusive? *Spine, 22*(8), 877-881.

Linton, S. J. (2000). A review of psychological risk factors in back and neck pain. *Spine, 25*(9), 1148-1156.

O'Sullivan, P. (2005). Diagnosis and classification of chronic low back pain disorders: maladaptive movement and motor control impairments as underlying mechanism. *Manual Therapy, 10*(4), 242-255.

Patton, G. C., & Viner, R. (2007). Pubertal transitions in health. *Lancet, 369*(9567), 1130-1139.

Viel, S., Vaugoyeau, M., & Assaiante, C. (2009). Adolescence: a transient period of proprioceptive neglect in sensory integration of postural control. *Motor Control, 13*(1), 25-42.

APPENDIX 1 – INFORMATION AND CONSENT FORMS

Lumbo-pelvic Motor Control in Adolescents With and Without Low Back Pain

Parent information sheet

Dear Parent/Caregiver

Thank you for considering allowing your child to participate in this study. We would like to take the opportunity to investigate how young adolescents use their bodies in a variety of simple functional tasks and compare how this differs between those with and without low back pain (LBP). We know in adults that such differences exist. We further know that correcting the way people use their bodies is important in treating adult patients with low back pain. Little knowledge is known about LBP in adolescents, the importance of postures that they naturally choose in sitting and standing and patterns of movement during simple tasks.

Why now?

Early adolescence is a time when LBP starts to become noticeable in the population. It is valuable to identify the differences that exist in those who are starting to develop symptoms of LBP with those who have no symptoms. This should provide a better understanding of the development of LBP in adolescence.

What will be measured?

A test battery has been developed that will investigate different aspects of motor control. It is aimed to find differences between groups of adolescents with and without LBP. The tests are predominately concerned with control of the low back. However, there are few tests that will provide information on whether differences are localised to the low back or affect the body more globally.

What equipment will be used?

Information about the muscles of the back will be collected through the use of **surface EMG**. Electrodes will be attached to the skin over 4 back and 4 abdominal muscles. These electrodes will detect electrical activity from the muscles as they turn on and off.

As well as muscle activity we are interested in knowing what position the spine is in during most of the tests. Small sensors are taped to the skin over 4 spinous processes (1 on the pelvis, 2 on the low back, and one at the base of the neck) and for one test the forehead and arm. The position of these sensors will be very precisely measured through the test battery using an electromagnetic field. Neither EMG nor the tracking device is invasive, nor have either been associated with any side effects. Subjects will be attached to both EMG and Fastrak for the duration of testing.

While a lot of precise information is learnt from this, observing the quality of movement is also important for some tests. Subjects will be **video** taped for tasks 1-5, 8 & 9. This will be taken so that the face cannot be seen.

What is involved?

Those adolescents that have been identified **with LBP** will be required to be screened by a qualified physiotherapist to ensure that the type of LBP is suitable for the study. This will occur independently to the data collection session. Those participants that indicate they have **no LBP** will be required to attend for the data collection session only.

Before data collection - Each subject will have their spine assessed on the day of testing to ensure that they can complete the test battery. The assessor will be a qualified physiotherapist with relevant experience.

Setting up - For EMG to be collected successfully the contact between the electrodes and the skin must be good. Before adhering the electrodes the skin will be shaved (if required) and alcohol will be used to clean the skin, the electrodes stick to the skin similar to a band-aid and are easily removed. Similarly the Fastrak sensors will be taped to the skin with hypoallergenic tape.

What to wear - The researchers will need to visualise the trunk through testing. For this reason it is important that subjects be in a state of semi-undress and expose their backs. A pair of shorts that can be positioned on the waist will be required and additionally for girls a crop top or bathers top would be ideal. Discretion will be provided to every subject and his or her dignity will be considered at all times. Only two female research staff, the subject and parent/caregiver will be allowed to be in the room during testing.

What happens through the test battery - Subjects will be asked to undertake the following, each test will be repeated 2-3 times:

1. Sit unsupported on a stool in usual posture
2. Move from their usual sitting posture to slumped sitting and return
3. Move from upright sitting, flex and extend the low spine and return to upright sitting
4. Stand in usual posture
5. Stand on one leg with and without their eyes closed
6. Bend forward and return to standing
7. Bend backwards and return to standing
8. In standing trace a line with their hand and point at a target
9. Rotate their head left and right and return to their natural head posture
10. Assume a semi-squat position for as long as they are able
11. Assume an unsupported trunk position over the edge of a bed for as long as able

Tests 10 and 11 are tests of maximal effort; they are designed to fatigue the trunk and thigh muscles. Some subjects will notice symptoms of fatigue and post exercise soreness in these muscles for 48-72 hours. This is not expected to last or exacerbate any LBP symptoms.

Subjects and their parents/caregivers will be encouraged to ask questions as they arise through testing. Subjects will be free to withdraw from the study at any time either through their own desire or that of their parent/caregiver. The researcher will cease testing if any of the test battery aggravates or creates unwelcome symptoms for the subject.

How long will this take?

Clinical screening for subjects with LBP will take half an hour. The data collection session will take approximately 2 hours.

How will this information be used?

This information will be analysed to determine differences between the adolescents with and without LBP. It will provide valuable insight into motor control of the lumbar spine at a critical time of development. The results of the study will be published, names or identifying information would not be published regarding any participant. Long-term it is hoped the information can be used to determine how best to treat adolescents with LBP, however this would need to be subject to further research.

We would like you to feel free to ask any questions you may have about any aspect of the study. It is important that you understand why we are asking you to allow your child to participate in this study. The first point of contact in this regard is Ms Roz Astfalck, her details are below.
We would like to assure you that all information we collect is strictly confidential. Curtin University and its researchers are bound by the Privacy Act 1988 and abides by this at all times. If you have any concerns or complaints regarding the way this study is being conducted you can direct enquiries to the Secretary of the Human Research Ethics Committee Curtin University, Ms Sinead Darley on 08 9266 2784.
Thank you again for considering this important research.

Dr Peter O'Sullivan	Dr Leon Straker	Roz Astfalck
Senior Lecturer	Associate Professor	Doctoral Student
(08) 9266 3629	(08) 9266 3634	(08) 9266 3660
		0421 330 613

School of Physiotherapy
Curtin University of Technology

Lumbo-pelvic Motor Control in Adolescents With and Without Low Back Pain

Adolescent information sheet

Dear

Thanks for thinking about being in this study. We want to know how teenagers use their bodies when you sit, stand and do simple tasks. We want to know how this is different between those of you who have back pain and those who don't. It may not sound too exciting, but we're hoping it will provide some great information and help us understand teenage bodies with back pain better.

Why now?

A fairly large number of you start to notice you have low back pain (LBP) in your early teenage years. For some this will be mild for others it can stop you doing the things you like to do. It's important for us researchers to test your bodies when you are starting to develop some of the symptoms of LBP, so we can understand better how it develops.

What will be measured?

A series of tests has been developed that will investigate different aspects of how you control your body. Most tests look just at the low back but some look at how you use your whole body.

What equipment will be used?

Information about the muscles of the back will be collected through the use of surface EMG. Electrodes will be attached to the skin over 4 back and 4 tummy muscles. These electrodes will detect electrical activity from the muscles as they turn on and off. As well as muscle activity we are interested in knowing what position the spine is in during most of the tests. This will be measured by placing small sensors over the spine, forehead and arm. None of this usually creates any discomfort. While a lot of precise information is provided by EMG and the position sensors, observing how you move is also important for some tests. You will be **video** taped for some tasks. Don't worry this will be taken so that your face cannot be seen, so no one will know it is you!

What is involved? - Those of you that have been identified **with LBP** will be required to be tested by a physiotherapist to make sure that you're suitable for the study. You would also need to turn up to another session to collect the data. Those that are lucky enough **not to have LBP** will be required to attend just for data collection..

Before data collection - Each subject will have their spine assessed on the day of testing to ensure that they have no abnormal pain or tenderness and that they have normal range of joint and muscle movements.

Setting up - For EMG to be collected successfully the contact between the electrodes and the skin must be good. If you are hairy the skin will be shaved where we need to put the electrodes and alcohol will be used to clean the skin, the electrodes stick to the skin similar to a band-aid and are easily removed. The movement sensors will be taped to the skin.

What to wear - We'll need to see your back through the tests. So we'll ask you to expose your back. A pair of shorts that can be positioned on the waist would be best and additionally for girls a crop top or bathers top would be ideal. Only two female research staff, you and parent/caregiver will be allowed to be in the room during testing. Well try as best as we can to make you feel comfortable.

What happens through the test battery - You will need to do each of the following tests 2-3 times, we will tell what and how to do them, none of them are too hard:

1. Sit unsupported on a stool in your usual posture
2. Move from your usual sitting posture to slumped sitting and return
3. Move from upright sitting, flex and extend the low spine and return to upright sitting
4. Stand in your usual posture
5. Stand on one leg with and without your eyes closed
6. Bend forward and return to standing

7. Bend backwards and return to standing
8. In standing trace a line with your hand and point at a target
9. Rotate your head left and right and return to your natural head posture
10. Assume a semi-squat position for as long as you are able
11. Assume an unsupported trunk position over the edge of a bed for as long as you are able

Tests 10 and 11 are tests of maximal effort; they are designed to fatigue (tire) the trunk and thigh muscles. Some of you will notice symptoms of tiredness and soreness in these muscles for 48-72 hours. This is not expected to last or make your LBP worse if you have any.

While we are testing you will be able to ask as many questions as you like. You can pull at any time. We will cease testing if any of the tests give you unwelcome symptoms.

How long will this take?

Clinical screening for those with LBP will be about half an hour. The data collection session will take about 2 hours.

How will this information be used?

We'll see what's different between those of you with LBP and those who don't. We'll publish the results in scientific journals (magazines) but don't worry no names will be given, and no one will know you've been a part of the research. With some more research we might be able to work out how to treat teenagers with LBP better.
If you have any questions you are welcome to ring us, or ask your Mum, Dad or Caregiver to. Ring Roz first, her number is below.
Thanks for considering being a part of our research.

Dr Peter O'Sullivan
Senior Lecturer
(08) 9266 3629

Dr Leon Straker
Associate Professor
(08) 9266 3634

Ms Roz Astfalck
Doctoral Student
(08)9266 3660
0421 330 613

School of Physiotherapy
Curtin University of Technology

Lumbo-pelvic Motor Control in Adolescents With and Without Low Back Pain

Parent Consent Form

I, _____ have read the Parent Information Sheet explaining the study on low back pain in adolescents . Any questions asked have been answered to my satisfaction.
Withdrawal from the study at any stage will be possible and will not interfere with access to routine care.
I agree that the research data gathered from the results of this study may be published, provided that names are not used.
I understand that it will involve:

- Physical examination of the low back
- The attachment of electrodes and sensors to the skin of their back abdomen and arm, to collect muscle activity and movement information

I agree to my son/daughter _____ participating in the following parts of the study:

- Simple movement tasks in sitting and standing **yes** **no**
- An endurance test of the back muscles **yes** **no**
- An endurance test of the thigh muscles **yes** **no**

I agree to my son/daughter _____ being video taped during some of the posture and movement tests.

yes **no**

It is my understanding that my son/daughter's face will not be able to be identified from any video footage collected.

Dated _____ day of _____ 20 _____

Signed _____ (Parent/Guardian)

I, _____ have explained the above study to the signatory who states that he/she understand the same.

Signed _____ (Investigator)

Lumbo-pelvic Motor Control in Adolescents With and Without Low Back Pain

Subject Consent Form

I, _____ have read the Parent Information Sheet explaining the study on low back pain and motor control in adolescents . Any questions asked have been answered to my satisfaction.

Withdrawal from the study at any stage will be possible and will not interfere with access to routine care.

I agree that the research data gathered from the results of this study may be published, provided that names are not used.

I understand that it will involve:

- Physical examination of the low back; and
- The attachment of electrodes and sensors to the skin of their back abdomen and arm, to collect muscle activity and movement information

I agree to participate in the following parts of the study:

- Simple movement tasks in sitting and standing **yes** **no**
- An endurance test of the back muscles **yes** **no**
- An endurance test of the thigh muscles **yes** **no**

I agree to being video taped during some of the posture and movement tests. **yes** **no**

I understand that my face will not be able to be identified from any video footage collected.

Dated _____ day of _____ 20 _____

Signed _____

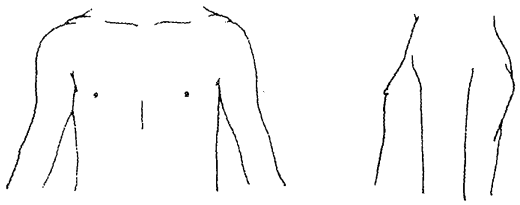
I, _____ have explained the above study to the signatory who states that he/she understand the same.

Signed _____ (Investigator)

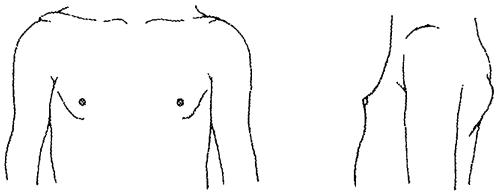
APPENDIX 2 – TANNER SCALE OF PUBERTAL DEVELOPMENT

The drawings on this page show different stages of development of the breasts. A female passes through each of the five stages shown by these drawings. Please look at each drawing then choose the one closest to your stage of development by placing an X in the corresponding box.

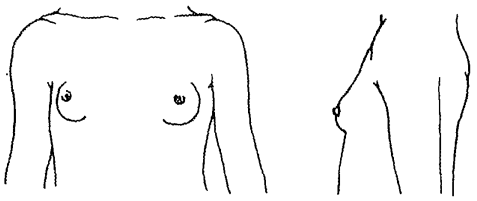
Breast Development



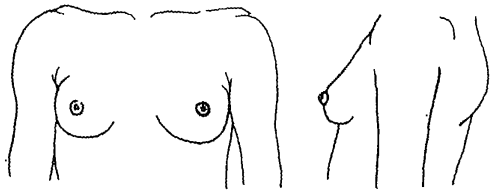
Stage 1 – prepubertal ☐



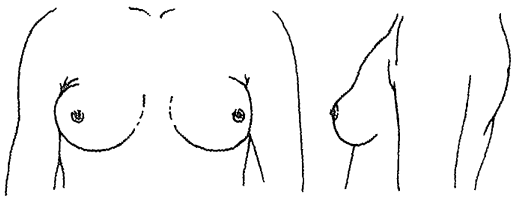
Stage 2 – elevation of breasts and papilla ☐



Stage 3 – further elevation and areola but no separation of contours ☐

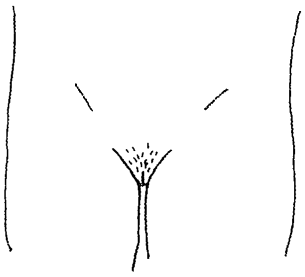


Stage 4 – areola and papilla form a secondary mound above level of the breast ☐

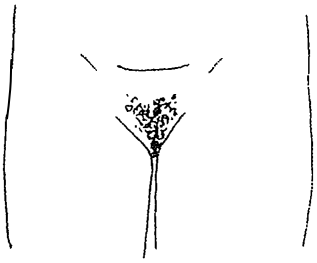


Stage 5 – areola recesses to the general contour of the breast ☐

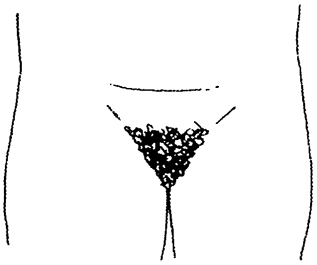
The drawings on this page show different amounts of female pubic hair. A girl passes through each of the four stages shown by these drawings. Please look at each drawing then choose the one closest to your stage of development by placing an X in the corresponding box.



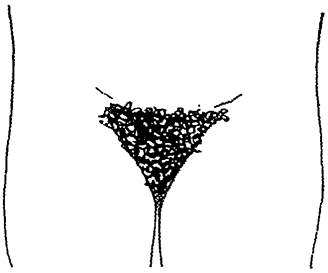
Pubic Hair Stage 2 ☐



Pubic Hair Stage 3 ☐



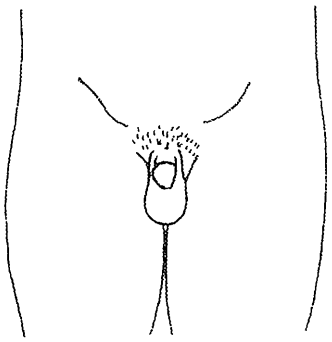
Pubic Hair Stage 4 ☐



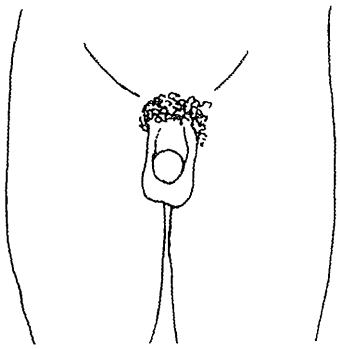
Pubic Hair Stage 5 ☐

The drawings on this page show different amounts of male pubic hair and stages of development of the testes, scrotum and penis. A boy passes through each of the four stages shown by these drawings. Please look at each drawing then choose the one closest to your stage of development by placing an X in the corresponding box.

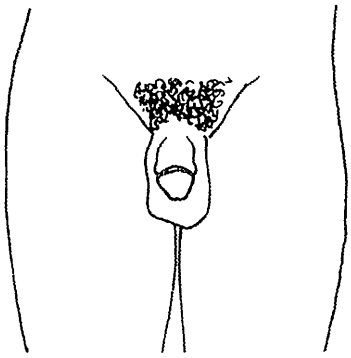
Genital and Pubic Hair Stages



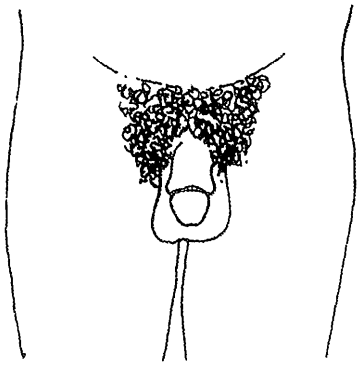
Genital 2/Pubic Hair 2 ☐



Genital 3/Pubic Hair 3 ☐



Genital 4/Pubic Hair 4 ☐



Genital 5/Pubic Hair 5 ☐

APPENDIX 3 – ETHICS APPROVALS

To	A/Professor Leon Straker Physiotherapy
From	Dr Stephan Millett, Executive Officer, Human Research Ethics Committee
Subject	Protocol Approval **HR 84/2005**
Date	21 June 2005
Copy	

Office of Research and Development

Human Research Ethics Committee

TELEPHONE 9266 2784
FACSIMILE 9266 3793
EMAIL s.darley@curtin.edu.au

Thank you for your application submitted to the Human Research Ethics Committee (HREC) for the project titled *"Spinal pain development in adolescence"*.

Your application has been reviewed by members of the HREC reviewing panel who have recommended that your application be **APPROVED**.

- You are authorised to commence your research as stated in your proposal.
- The approval number for your project is **HR 84/2005**. *Please quote this number in any future correspondence.*
- Approval of this project is for a period of twelve months **21/06/2005** to **20/06/2006**.

If you are a Higher Degree by Research student, data collection must not begin before your Application for Candidacy is approved by your Divisional Graduate Studies Committee.

Applicants should note the following:

- It is the policy of the HREC to conduct random audits on a percentage of approved projects. These audits may be conducted at any time after the project starts. In cases where the HREC considers that there may be a risk of adverse events, or where participants may be especially vulnerable, the HREC may request the chief investigator to provide an outcomes report, including information on follow-up of participants.
- All recommendations for approval are referred to the next meeting of the HREC for ratification. In the event the Committee does not ratify the recommendation, or would like further information, you will be notified. **The next meeting of the HREC is on 23/08/2005.**

The attached **FORM B** is to be completed and returned as soon as possible to the Secretary, HREC, C/- Office of Research & Development:

- When the project has finished, or
- If at any time during the twelve months changes/amendments occur, or
- If a serious or unexpected adverse event occurs.

Please find attached your protocol details together with the application form/cover sheet.

SDarley.

Dr Stephan Millett
Executive Officer
Human Research Ethics Committee

Please Note: The following standard statement must be included in the information sheet to participants:
This study has been approved by the Curtin University Human Research Ethics Committee. If needed, verification of approval can be obtained either by writing to the Curtin University Human Research Ethics Committee, c/- Office of Research and Development, Curtin University of Technology, GPO Box U1987, Perth, 6845 or by telephoning 9266 2784.

Department of Health
Government of Western Australia

Women's & Children's Health Service

Dr Garth Kendall
Raine Study
Institute for Child Health Research
SUBIACO WA 6008

Dear Dr Kendall

REGISTRATION NUMBER: **1172/EP**

TITLE: **Physical, lifestyle and psychosocial determinants of spinal pain development in adolescence**

REFERENCE NUMBER: **EC05-84.2**

MEETING DATE: **15 September 2005**

The Ethics Committee has recommended approval be given for you to undertake the abovenamed research study. This recommendation has been ratified by the Women's and Children's Health Service.

The Ethics Committee does however wish to be informed immediately of:

I. any untoward effects experienced by any participant in the trial where those effects in degree or nature were not anticipated by the researchers, and steps taken to deal with these,

II. substantial changes in the research protocol together with an indication of ethical implications, and

III. other unforseen events.

The Ethics Committee has been charged with the responsibility of keeping the progress of all approved research under surveillance. A copy of the final result must be forwarded to the Committee upon completion of the research or if the research is not completed within twelve months you are asked to submit a progress report and annually thereafter. This information should include:

a) The status of the project (completed/in progress/abandoned/not commenced). In the event that a project does not commence within 12 months of being approved by the Ethics Committee the study must be resubmitted to the Committee for approval.

b) Compliance with conditions of ethical approval, including security of records and procedures for consent.

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374 Bagot Road
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PO Box 134
Subiaco WA 6904
Tel: (08) 9340 2222
Fax: (08) 9388 1780

Princess Margaret Hospital for Children
Roberts Road
Subiaco WA 6008
GPO Box D184

c) Compliance with any special conditions stated by the Ethics Committee as a condition of approval.

d) Results from the study to date, including outcome.

Please note that approval for studies is for three years and the research should be commenced and completed within that period of time. Projects must be resubmitted if an extension of time is required. In the event that a project does not commence within 12 months of being approved by the Ethics Committee the study must be resubmitted to the Committee for approval.

Please quote the above registration number on all correspondence.

Yours sincerely

Dr Geoff Masters
Executive Director
Medical Services

22 September 2005

cc Assoc Professor Leon Straker

- **The Ethics Committee is constituted, and operates in accordance with the National Health and Medical Research Council's National Statement on Ethical Conduct in Research Involving Humans**

APPENDIX 4 – VISUAL ANALOGUE SCALE

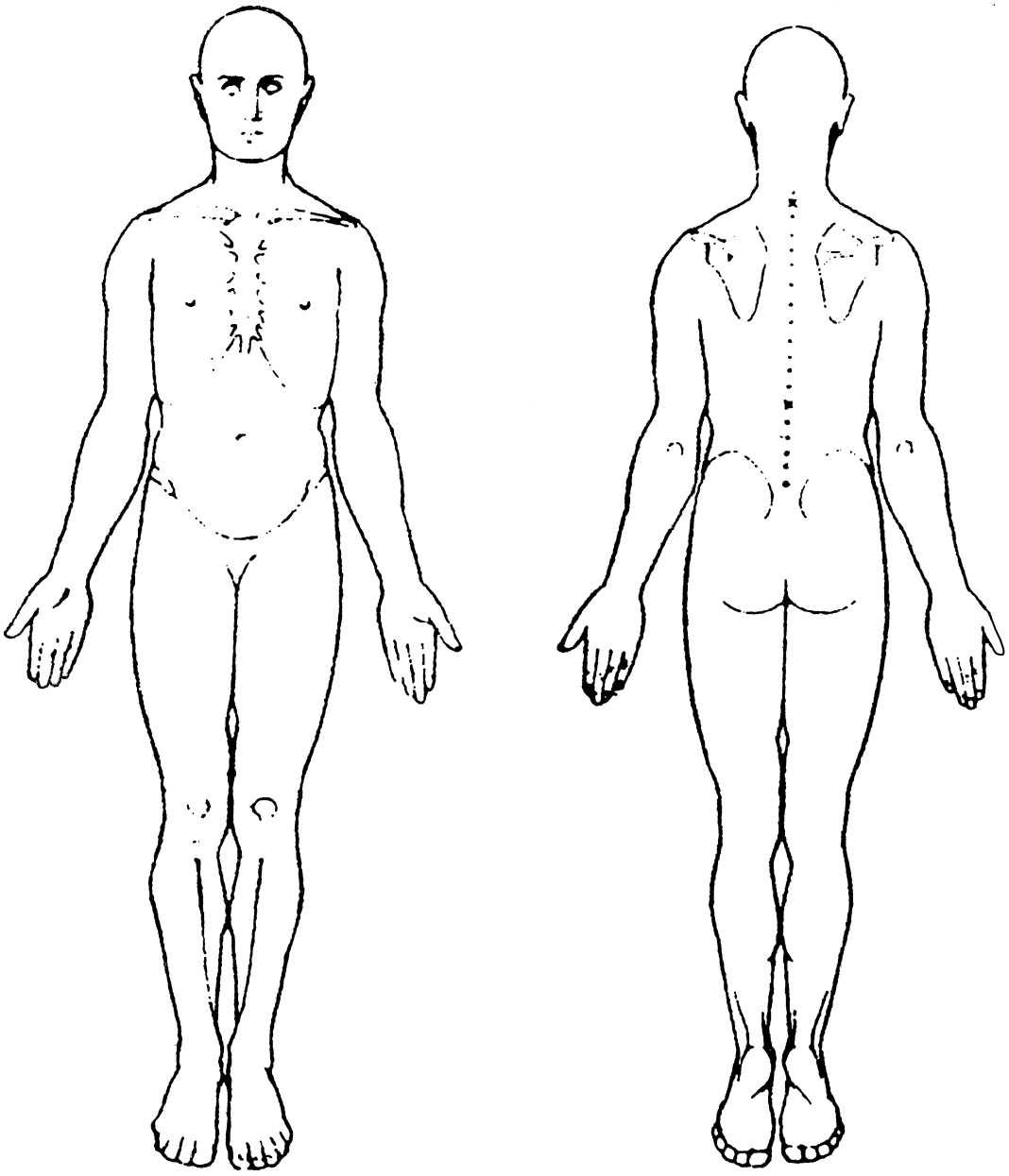
This scale was explained to each subject as follows:

“I want you to tell me how back your pain is on a usual day by placing a mark on the following the line. The left hand side of the line indicates you have no pain, the right hand pain as bad as you can possibly imagine it to be.”

NO Pain _____Pain as bad as it could be

APPENDIX 5 – BODY CHART

Subjects were given this chart and asked to colour in where on the chart where they experience pain. This was not specified as low back pain.



APPENDIX 6 – MODIFIED OSWESTRY DISABILITY QUESTIONNAIRE

This questionnaire has been designed to provide information on how your back pain has affected you ability to manage in everyday life. Please answer every section, and mark in each section only the ***one box*** which applies to you. We realise you may consider that two of the statements in any one section relate to you, but please **just *mark the box which closely describes your problem***.

Modified from original questionnaire outlined in Fairbank JC, Couper J, Davies JB, O'Brien JP. The Oswestry low back pain disability questionnaire. Physiotherapy 1980; 66(8): 271-3.

Section 1 – Pain Intensity

- ☐ I can tolerate the pain I have without having to use pain killers
- ☐ The pain is bad but I manage without taking pain killers
- ☐ Pain killers give complete relief from pain
- ☐ Pain killers give moderate relief from pain
- ☐ Pain killers give very little relief from pain
- ☐ Pain killers have no effect on the pain and I do not use them

Section 2 – Personal Care (Showering, Dressing etc)

- ☐ I can look after myself normally without causing extra pain
- ☐ I can look after myself normally but it causes extra pain
- ☐ It is painful to look after myself and I am slow and careful
- ☐ I need some help but manage most of my personal care
- ☐ I need help every day in most aspects of self care
- ☐ I do not get dressed, wash with difficulty and stay in bed

Section 3 – Lifting

- ☐ I can lift heavy weights without extra pain
- ☐ I can lift heavy weights but it gives extra pain
- ☐ Pain prevents me from lifting heavy weight off the floor, but I can manage if they are conveniently positioned, eg on a table
- ☐ Pain prevents me from lifting heavy weights but I can manage light to medium weights if they are conveniently positioned
- ☐ I can lift only very light weights
- ☐ I cannot lift or carry anything at all

Section 4 – Walking

- ☐ Pain does not prevent me walking any distance
- ☐ Pain prevents me walking more than 800m
- ☐ Pain prevents me walking more than 400m
- ☐ Pain prevents me walking more than 200m
- ☐ I can only walk using a stick or crutches
- ☐ I am in bed most of the time and have to crawl to the toilet

Section 5 – Sitting

- ☐ I can sit in any chair as long as I like
- ☐ I can only sit in my favourite chair as long as I like
- ☐ Pain prevents me from sitting more than 1 hour
- ☐ Pain prevents me from sitting more than ½ hour
- ☐ Pain prevents me from sitting more than 10 mins
- ☐ Pain prevents me from sitting at all

Section 6 – Standing

- ☐ I can stand as long as I want without extra pain
- ☐ I can stand as long as I want but it gives me extra pain
- ☐ Pain prevents me from standing for more than 1 hour
- ☐ Pain prevents me from standing for more than 30 mins
- ☐ Pain prevents me from standing for more than 10 mins
- ☐ Pain prevents me from standing at all

Section 7 – Sleeping

- ☐ Pain does not prevent me from sleeping well
- ☐ I can sleep well only by using tablets
- ☐ Even when I take tablets I have less than six hours sleep
- ☐ Even when I take tablets I have less than four hours sleep
- ☐ Even when I take tablets I have less than two hours sleep
- ☐ Pain prevents me from sleeping at all

Section 8 – Social Life

- ☐ My social life is normal and gives me no extra pain
- ☐ My social life is normal but increases the degree of pain
- ☐ Pain has no significant effect on my social life apart from limiting my more energetic interests, e.g. dancing , sport
- ☐ Pain has restricted my social life and I do not go out as often
- ☐ Pain has restricted my social life to home
- ☐ I have no social life because of pain

Section 9 – Travelling

- ☐ I can travel anywhere without extra pain.
- ☐ I can travel anywhere but it gives me extra pain
- ☐ Pain is bad but I manage journeys over two hours
- ☐ Pain restricts me to journeys of less than one hour
- ☐ Pain restricts me to short necessary journeys under 30 minutes
- ☐ Pain prevents me from travelling except to the doctor or hospital

APPENDIX 7 - TAMPA SCALE FOR KINESIOPHOBIA

Here are some of the things which other patients have told us about their pain. For each statement please circle any number from 1 to 4 to signify whether you agree or disagree with the statement.

	Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree
1. I'm afraid that I might injure myself if I exercise.	1	2	3	4
2. If I were to try to overcome it, my pain would increase.	1	2	3	4
3. My body is telling me I have something dangerously wrong.	1	2	3	4
4. My pain would probably be relieved if I were to exercise.	1	2	3	4
5. People aren't taking my medical condition seriously.	1	2	3	4
6. My accident has put my body at risk for the rest of my life.	1	2	3	4
7. Pain always means I have injured my body.	1	2	3	4
8. Just because something aggravates my pain does not mean it is dangerous.	1	2	3	4

9. I am afraid that I might injure myself accidentally.	1	2	3	4
10. Simply being careful that I do not make any unnecessary movements is the safest thing I can do to prevent my pain from worsening.	1	2	3	4
11. I wouldn't have this much pain if there weren't something potentially dangerous going on in my body.	1	2	3	4
12. Although my condition is painful, I would be better off if I were physically active.	1	2	3	4
13. Pain lets me know when to stop exercising so that I do not injure myself.	1	2	3	4
14. It's really not safe for a person with a condition like mine to be physically active.	1	2	3	4
15. I can't do all the things normal people do because it's too easy for me to get injured.	1	2	3	4
16. Even though something is causing me a lot of pain, I don't think it's actually dangerous.	1	2	3	4
17. No one should have to exercise when he/she is in pain.	1	2	3	4

Reprinted from *Pain*, 62: 363-372 with permission from Elsevier Science.
Vlaeyen J, Kole-Snijders A, Boersen R, van Eek H. (1995) Fear of movement/(re)injury in chronic low back pain and its relation to behavioural performance.

APPENDIX 8 - TELEPHONE QUESTIONS

Both Groups

Would you be willing to be involved in some research to find out more about low back pain in teenagers?	Yes/No
How tall are you? How much do you weigh? (TAB 11 - BMI SCALE)	
Are you able to sit, stand, stand on one leg, or move between sitting and standing without any problems?	Yes/No Yes/No Yes/No Yes/No
Has a doctor every told you that you have anything wrong with your back? Do you know what they said was wrong? Do you know what type of doctor they were?	Yes/No
Have you ever had any surgery on your back? If so, what and when?	Yes/No
Have you had surgery on your feet or legs in the last 2 years?	Yes/No
Have you hurt your legs, neck or arms recently? If so, when and how does it affect you?	Yes/No Yes/No Yes/No
Do you every get pain in your tummy or pelvis?	
If female, Do you ever have period pain that makes your back ache? If yes, has this troubled you recently?	Yes/No Yes/No
If female, Is there any possibility that you could be pregnant or have you had a baby in the past six months?	Yes/No
What language do you speak at home and at school?	
If not English, can you read and write in English?	Yes/No

Pain Group (Only)

	Inclusion	**Exclusion**
How long have you had your back pain?		
	≥3/12	<3/12
Where do you feel your back pain?		
	T12-Gluteal Folds	Widespread
Do you ever feel your pain in your legs? or in the top half of your back?	Yes/No Yes/No	
How bad does your back pain get?		
If you had to measure this out of 10 (ten) where 10 was the worst pain you could imagine what number would you score it on most days?	≥3/10	<3/10
What score would you give your back pain on its worst days?		
What activities make your back pain worse? and what makes if feel better?		
Does sitting make your back feel worse or better?	Worse/Better	
Does standing make your back feel worse or better?	Worse/Better	
Does walking make your back feel worse or better?	Worse/Better	
Do you do any exercise? What type of exercise?	Yes/No	
Does this make your back feel worse or better?	Worse/Better	
Does your back pain stop you doing anything? What?		
Does your back pain make anything difficult to do? What?		
What medication are you taking?		
	Pain killers/ NSAIDS	Meds for excluded conditions

Pain Group (only)

Do you have back pain at the moment?	Yes/No
Have you ever had back pain?	Yes/No
If yes, Where did you feel your back pain? How long did it last? How painful was your back pain? (1-10) Have you felt this pain more than once? Did it stop you doing any activities?	

Parent/Guardian (only)

Can your son/daughter easily sit, stand, stand on one leg and move easily between positions?	Yes/No Yes/No Yes/No Yes/No
Have they every been diagnosed with a specific cause of back pain? If yes, can you remember what this was? (scoliosis, spondylolisthesis, disc prolapse, inflammatory disorders, Schermmans disease, neurological or metatastic disease involving the spine)	Yes/No
Does your son/daughter have any neurological deficits?	Yes/No
Have they ever had surgery involving the spine?	Yes/No
Has your son/daughter had surgery to either leg or foot in the last two years?	Yes/No
Do they have a current leg or foot injury?	Yes/No
Have they had any health problem involving their pelvis or abdomen including ongoing pain in the last 12 months?	Yes/No
If daughter, Is there any possibility that your daughter could be currently pregnant or has she had a baby within the previous six months?	Yes/No
Is there any reason that you believe that your son/daughter would have difficult understanding and responding to written or spoken directions given in English?	Yes/No

APPENDIX 9 – CHILD BEHAVIOUR CHECKLIST

ID

SECTION 2
SOME QUESTIONS ABOUT YOUR BEHAVIOUR

Below is a list of items that describe adolescents. For each item that describes you **now or with the past 6 months**, please select **2** if the item is **very true or often true** of you. Select the **1** if t item is s **omewhat or sometimes true** of you. If the item is **not true** of you then select **0**. Plea answer all items as well as you can, even if some do not seem to apply to you.

0 = Not true 1 = Somewhat or sometimes true 2 = Very true or often true

1.	I act too young for my age	○0 ○1 ○2
2.	I have an allergy	○0 ○1 ○2
3.	I argue a lot	○0 ○1 ○2
4.	I have asthma	○0 ○1 ○2
5.	I like the opposite sex	○0 ○1 ○2
6.	I like animals	○0 ○1 ○2
7.	I brag	○0 ○1 ○2
8.	I have trouble concentrating or paying attention	○0 ○1 ○2
9.	I can't get my mind off certain thoughts	○0 ○1 ○2
10.	I have trouble sitting still	○0 ○1 ○2
11.	I am too dependant on adults	○0 ○1 ○2
12.	I feel lonely	○0 ○1 ○2
13.	I feel confused or in a fog	○0 ○1 ○2
14.	I cry a lot	○0 ○1 ○2
15.	I am pretty honest	○0 ○1 ○2
16.	I am mean to others	○0 ○1 ○2
17.	I day dream a lot	○0 ○1 ○2
18.	I deliberately try to hurt or kill myself	○0 ○1 ○2
19.	I try to get a lot of attention	○0 ○1 ○2
20.	I destroy my own things	○0 ○1 ○2
21.	I destroy things belonging to others	○0 ○1 ○2
22.	I disobey my parents	○0 ○1 ○2
23.	I disobey at school	○0 ○1 ○2

ID

0 = Not true 1 = Somewhat or sometimes true 2 = Very true or often true

24.	I don't eat as well as I should	○0 ○1 ○2
25.	I don't get along with other kids	○0 ○1 ○2
26.	I don't feel guilty after doing something I shouldnt	○0 ○1 ○2
27.	I am jealous of others	○0 ○1 ○2
28.	I am willing to help others when they need help	○0 ○1 ○2
29.	I am afraid of certain animals, situations or places other than school	○0 ○1 ○2
30.	I am afraid of going to school	○0 ○1 ○2
31.	I am afraid I might think or do something bad	○0 ○1 ○2
32.	I feel that I have to be perfect	○0 ○1 ○2
33.	I feel that no one loves me	○0 ○1 ○2
34.	I feel that others are out to get me	○0 ○1 ○2
35.	I feel worthless or inferior	○0 ○1 ○2
36.	I accidentally get hurt a lot	○0 ○1 ○2
37.	I get in many fights	○0 ○1 ○2
38.	I get teased a lot	○0 ○1 ○2
39.	I hang around with kids who get in trouble	○0 ○1 ○2
40.	I hear sounds or voices that other people think arent there	○0 ○1 ○2
41.	I act without stopping to think	○0 ○1 ○2
42.	I would rather be alone than with others	○0 ○1 ○2
43.	I lie or cheat	○0 ○1 ○2
44.	I bite my fingernails	○0 ○1 ○2
45.	I am nervous or tense	○0 ○1 ○2
46.	Parts of my body twitch or make nervous movements	○0 ○1 ○2
47.	I have nightmares	○0 ○1 ○2
48.	I am not liked by other kids	○0 ○1 ○2
49.	I can do certain things better than most kids	○0 ○1 ○2
50.	I am too fearful or anxious	○0 ○1 ○2

ID

0 = Not true 1 = Somewhat or sometimes true 2 = Very true or often true

51.	I feel dizzy	○0 ○1 ○2
52.	I feel too guilty	○0 ○1 ○2
53.	I eat too much	○0 ○1 ○2
54.	I feel overtired	○0 ○1 ○2
55.	I am overweight	○0 ○1 ○2
56.	Physical problems without known medical cause:	
	a. Aches or pains (not headaches)	○0 ○1 ○2
	b. Headaches	○0 ○1 ○2
	c. Nausea, feel sick	○0 ○1 ○2
	d. Problems with eyes	○0 ○1 ○2
	e. Rashes or other skin problems	○0 ○1 ○2
	f. Stomach-aches or cramps	○0 ○1 ○2
	g. Vomiting, throwing up	○0 ○1 ○2
	h. Other (describe): _____	○0 ○1 ○2
57.	I physically attack people	○0 ○1 ○2
58.	I pick my skin or other parts of my body	○0 ○1 ○2
59.	I can be pretty friendly	○0 ○1 ○2
60.	I like to try new things	○0 ○1 ○2
61.	My school work is poor	○0 ○1 ○2
62.	I am poorly coordinated or clumsy	○0 ○1 ○2
63.	I would rather be with older kids than kids my own age	○0 ○1 ○2
64.	I would rather be with younger kids than kids my own age	○0 ○1 ○2
65.	I refuse to talk	○0 ○1 ○2
66.	I repeat certain actions over and over	○0 ○1 ○2
67.	I run away from home	○0 ○1 ○2
68.	I scream a lot	○0 ○1 ○2
69.	I am secretive or keep things to myself	○0 ○1 ○2
70.	I see things that other people think aren't there	○0 ○1 ○2

ID

0 = Not true 1 = Somewhat or sometimes true 2 = Very true or often true

71.	I am self-conscious or easily embarrassed	○0 ○1 ○2
72.	I set fires	○0 ○1 ○2
73.	I can work well with my hands	○0 ○1 ○2
74.	I show off or clown around	○0 ○1 ○2
75.	I am shy	○0 ○1 ○2
76.	I sleep less than most kids	○0 ○1 ○2
77.	I sleep more than most kids during the day and/or night	○0 ○1 ○2
78.	I have a good imagination	○0 ○1 ○2
79.	I have a speech problem	○0 ○1 ○2
80.	I stand up for my rights	○0 ○1 ○2
81.	I steal at home	○0 ○1 ○2
82.	I steal from places other than home	○0 ○1 ○2
83.	I store things up I dont need	○0 ○1 ○2
84.	I do things other people think are strange	○0 ○1 ○2
85.	I have thoughts that other people would think are strange	○0 ○1 ○2
86.	I am stubborn	○0 ○1 ○2
87.	My moods or feelings change suddenly	○0 ○1 ○2
88.	I enjoy being with other people	○0 ○1 ○2
89.	I am suspicious	○0 ○1 ○2
90.	I swear or use dirty language	○0 ○1 ○2
91.	I think about killing myself	○0 ○1 ○2
92.	I like to make others laugh	○0 ○1 ○2
93.	I talk too much	○0 ○1 ○2
94.	I tease others a lot	○0 ○1 ○2
95.	I have a hot temper	○0 ○1 ○2
96.	I think about sex too much	○0 ○1 ○2
97.	I threaten to hurt people	○0 ○1 ○2
98.	I like to help others	○0 ○1 ○2

ID

0 = Not true 1 = Somewhat or sometimes true 2 = Very true or often true

99.	I am too concerned about being neat or clean	○0 ○1 ○2
100.	I have trouble sleeping	○0 ○1 ○2
101.	I skip classes or wag school	○0 ○1 ○2
102.	I don't have much energy	○0 ○1 ○2
103.	I am unhappy, sad or depressed	○0 ○1 ○2
104.	I am louder than other kids	○0 ○1 ○2
105.	I use alcohol or drugs for non-medical purposes	○0 ○1 ○2
106.	I try to be fair to others	○0 ○1 ○2
107.	I enjoy a good joke	○0 ○1 ○2
108.	I like to take life easy	○0 ○1 ○2
109.	I try to help other people when I can	○0 ○1 ○2
110.	I wish I were of the opposite sex	○0 ○1 ○2
111.	I keep from getting involved with others	○0 ○1 ○2
112.	I worry a lot	○0 ○1 ○2

APPENDIX 10 – BECKS DEPRESSION INVENTORY

Here is a list of things that happen to people and that people think or feel. Please read each statement carefully, and thinking over the last two weeks, select the number that tells the best how you feel about each statement. There are no right or wrong answers.

0 = Never
1 = Sometimes
2 = Often
3 = Always

1.	I think that my life is bad	○0 ○1 ○2 ○3
2.	I have trouble doing things	○0 ○1 ○2 ○3
3.	I feel that I am a bad person	○0 ○1 ○2 ○3
4.	I wish I were dead	○0 ○1 ○2 ○3
5.	I have trouble sleeping	○0 ○1 ○2 ○3
6.	I feel no one loves me	○0 ○1 ○2 ○3
7.	I think bad things happen because of me	○0 ○1 ○2 ○3
8.	I feel lonely	○0 ○1 ○2 ○3
9.	My stomach hurts	○0 ○1 ○2 ○3
10.	I feel like bad things happen to me	○0 ○1 ○2 ○3
11.	I feel like I am stupid	○0 ○1 ○2 ○3
12.	I feel sorry for myself	○0 ○1 ○2 ○3
13.	I think I do things badly	○0 ○1 ○2 ○3
14.	I feel bad about what I do	○0 ○1 ○2 ○3
15.	I hate myself	○0 ○1 ○2 ○3
16.	I want to be alone	○0 ○1 ○2 ○3
17.	I feel like crying	○0 ○1 ○2 ○3
18.	I feel sad	○0 ○1 ○2 ○3
19.	I feel empty inside	○0 ○1 ○2 ○3
20.	I think my life will be bad	○0 ○1 ○2 ○3

APPENDIX 11 - MCMASTER FAMILY ASSESSMENT DEVICE

Q86. This is called the Family Assessment Device; it was developed to give an idea of how families work together. *(Please circle one answer only for each item)*

Item 1
Below are statements about families and family relationships. Circle the category which best describes your family - the people living in your house.

	Strongly Agree	Agree	Disagree	Strongly Disagree
a. Planning family activities is difficult because we misunderstand each other	3	2	1	0
b. In times of crisis we can turn to each other for support	3	2	1	0
c. We cannot talk to each other about sadness we feel	3	2	1	0
d. Individuals (in the family) are accepted for what they are	3	2	1	0
e. We avoid discussing our fears and concerns	3	2	1	0
f. We express feelings to each other	3	2	1	0
g. There are lots of bad feelings in our family	3	2	1	0
h. We feel accepted for what we are	3	2	1	0
i. Making decisions is a problem in our family	3	2	1	0
j. We are able to make decisions about how to solve problems	3	2	1	0
k. We don't get on well together	3	2	1	0
l. We confide in each other	3	2	1	0