Examining the role of sitting behaviour in non-specific chronic low back pain

by

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A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy at the University of Limerick

Supervised by Dr. Leonard O’Sullivan, Prof. Wim Dankaerts and Prof. Peter O’Sullivan

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Declaration

My submission as a whole is not substantially the same as any that I have previously made or currently am making, whether in published or unpublished form for a degree, diploma, or similar qualification at any university or similar institution. I am the author of this doctoral thesis and the principal author of the seven articles which form its core.

Signature: __________________

Kieran O'Sullivan
Abstract

Most chronic low back pain (CLBP) lacks a specific diagnosis, leading to it being labelled “non-specific” CLBP (NSCLBP). NSCLBP is a very common and costly musculoskeletal disorder, which is increasingly viewed as a multidimensional disorder, with contributing factors across the biopsychosocial spectrum. Many physical interventions for NSCLBP have demonstrated minimal effectiveness. Targeted management addressing the specific maladaptive physical and psychological behaviours among individuals with NSCLBP has been advocated.

One of the most commonly reported aggravating factors for NSCLBP is sitting. However, most existing research on sitting behaviour has been confined to laboratory settings, limiting the ability to analyse, or provide feedback on, sitting behaviour in real-world environments. Recent technological developments have made investigating sitting behaviour outside the laboratory possible.

This doctoral thesis examined the role of sitting behaviour in NSCLBP. In particular, this included the validation of a novel wireless posture monitor, investigating perceptions about sitting posture among clinicians and members of the community, and examining the effect of two specific interventions on sitting-related NSCLBP.

There are three main parts to this doctoral thesis, comprising seven studies. In the first part (Chapter 2 – three studies), a novel wireless method of analysing lumbo-pelvic posture was demonstrated to have very good reliability and concurrent validity. In the second part (Chapter 3 – two studies), perceptions of what constitutes good seated spinal posture were evaluated among both physiotherapists and members of the community, both with and without NSCLBP. These two studies showed that both physiotherapists and members of the community had a strong preference for lordotic postures of the lumbar spine. There were no significant differences in the perceptions of good sitting posture between those with and without NSCLBP. In the final part (Chapter 4 - two studies), the effect of two specific interventions for NSCLBP were examined. In a group of people with mild NSCLBP during sitting, postural biofeedback in isolation significantly reduced their NSCLBP during a 2-hour seated task. However, the magnitude of decrease was small, and there was no follow-up period. The second intervention study demonstrated that a multi-dimensional behavioural-based intervention improved pain and disability among people with more disabling NSCLBP. These improvements were maintained at clinically and statistically significant levels at follow-up three months later, with the improvements primarily related to changes in psychosocial measures rather than physical measures.

In conclusion, this doctoral thesis demonstrates that monitoring lumbo-pelvic posture can be done outside laboratory environments. Furthermore, while postural biofeedback may help reduce NSCLBP, physical factors such as sitting behaviour are only one component of the multi-dimensional problem that is NSCLBP. For more disabling NSCLBP, a multi-dimensional behavioural-based intervention demonstrates promising results at short-term follow-up.
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“Science is organised common sense where many a beautiful theory was killed by an ugly fact”

Thomas Huxley
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Back pain beliefs among Physiotherapists are more positive after biopsychosocially orientated workshops. O'Sullivan K, O'Sullivan P, O'Sullivan L, Dankaerts W. Physiotherapy Practice and Research. 2012. Accepted for Publication.


Author contribution to papers comprising the doctoral thesis.
List of Publications

Primary journal papers used in the main body of this doctoral thesis are as follows;

Part 1: Chapter 2

I The between-day and inter-rater reliability of a novel wireless system to analyse lumbar spine posture. O'Sullivan K, Galeotti L, Dankaerts W, O'Sullivan L, O'Sullivan P. Ergonomics. 2011. 54(1). 82-90


Part 2: Chapter 3


Part 3: Chapter 4


Secondary journal papers, that have been accepted for publication, which are summarised within the main body of this doctoral thesis and detailed in the appendices, are as follows;


Back pain beliefs among Physiotherapists are more positive after biopsychosocially orientated workshops. O'Sullivan K, O'Sullivan P, O'Sullivan L, Dankaerts W. Physiotherapy Practice and Research. 2012. Accepted for Publication.
Previously published studies mostly appear as they do in the relevant journal articles. However, minor changes have been made to some of these studies in the main thesis to enhance consistency across the thesis and to meet the submission requirements of the University of Limerick. This includes the labelling of figures and tables, the standardisation of abbreviations, and other minor grammatical changes.
List of Conference Presentations


O'Sullivan K, O'Sullivan P, O'Sullivan L, Dankaerts W. The back pain beliefs of physiotherapists are more positive after brief biopsychosocially orientated workshops. Oral Presentation. IFOMPT Congress, Quebec, October 2012.


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<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>AEP</td>
<td>active extension pattern</td>
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<tr>
<td>BBQ</td>
<td>back beliefs questionnaire</td>
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<td>BG</td>
<td>BodyGuard</td>
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<tr>
<td>BMI</td>
<td>body mass index</td>
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<tr>
<td>BSc</td>
<td>bachelor of science degree</td>
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<tr>
<td>C7</td>
<td>spinous process of 7th cervical vertebra</td>
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<tr>
<td>CFT</td>
<td>cognitive functional therapy</td>
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<tr>
<td>CI</td>
<td>confidence interval</td>
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<tr>
<td>CLBP</td>
<td>chronic low back pain</td>
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<td>cm</td>
<td>centimetres</td>
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<tr>
<td>CNS</td>
<td>central nervous system</td>
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<tr>
<td>CODA</td>
<td>cartesian optoelectronic dynamic anthropometer</td>
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<tr>
<td>CPM</td>
<td>continuous passive motion</td>
</tr>
<tr>
<td>d</td>
<td>mean difference between measures</td>
</tr>
<tr>
<td>DAP</td>
<td>dose-area product</td>
</tr>
<tr>
<td>DASS21</td>
<td>depression anxiety and stress scale (21 item version)</td>
</tr>
<tr>
<td>dGy/cm²</td>
<td>decigrays per square centimetre</td>
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<tr>
<td>DVF</td>
<td>digital videofluoroscopy</td>
</tr>
<tr>
<td>F</td>
<td>female</td>
</tr>
<tr>
<td>FABQ</td>
<td>fear-avoidance beliefs questionnaire</td>
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<tr>
<td>FB</td>
<td>forward bending</td>
</tr>
<tr>
<td>FP</td>
<td>flexion pattern</td>
</tr>
<tr>
<td>GA</td>
<td>graded activity</td>
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<tr>
<td>GXP</td>
<td>graded exposure</td>
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<tr>
<td>HCPs</td>
<td>health care professionals</td>
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<tr>
<td>Hz</td>
<td>hertz</td>
</tr>
<tr>
<td>ICC</td>
<td>intra-class correlation coefficient</td>
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<tr>
<td>kV</td>
<td>kilovolts</td>
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<td>kg</td>
<td>kilogram</td>
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<tr>
<td>kg/m²</td>
<td>kilogram per square metre</td>
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<tr>
<td>L1</td>
<td>spinous process of 1st lumbar vertebra</td>
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<td>L3</td>
<td>spinous process of 3rd lumbar vertebra</td>
</tr>
<tr>
<td>L5</td>
<td>spinous process of 5th lumbar vertebra</td>
</tr>
<tr>
<td>LBD</td>
<td>low back discomfort</td>
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<tr>
<td>LBP</td>
<td>low back pain</td>
</tr>
<tr>
<td>LED</td>
<td>light emitting diode</td>
</tr>
<tr>
<td>LOA</td>
<td>limits of agreement</td>
</tr>
<tr>
<td>LMM</td>
<td>lumbar motion monitor</td>
</tr>
<tr>
<td>M</td>
<td>male</td>
</tr>
<tr>
<td>MDC90</td>
<td>minimal detectable change at the 90% confidence level</td>
</tr>
<tr>
<td>MIC</td>
<td>minimally important change</td>
</tr>
<tr>
<td>MRI</td>
<td>magnetic resonance imaging</td>
</tr>
<tr>
<td>MSc</td>
<td>master of science degree</td>
</tr>
<tr>
<td>mSv</td>
<td>millisieverts</td>
</tr>
<tr>
<td>NA</td>
<td>not applicable</td>
</tr>
<tr>
<td>NPDs</td>
<td>non-pain developers</td>
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<tr>
<td>NRS</td>
<td>numeric rating scale</td>
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<tr>
<td>NSCLBP</td>
<td>non-specific chronic low back pain</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<td>---------</td>
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<tr>
<td>ODI</td>
<td>oswestry disability index</td>
</tr>
<tr>
<td>PCS</td>
<td>pain catastrophising scale</td>
</tr>
<tr>
<td>PDs</td>
<td>pain developers</td>
</tr>
<tr>
<td>PEDro</td>
<td>physiotherapy evidence database</td>
</tr>
<tr>
<td>PSEQ</td>
<td>pain self-efficacy questionnaire</td>
</tr>
<tr>
<td>PSIS</td>
<td>posterior superior iliac spine</td>
</tr>
<tr>
<td>r_s</td>
<td>spearmans rank correlation coefficient</td>
</tr>
<tr>
<td>r^2</td>
<td>coefficient of determination</td>
</tr>
<tr>
<td>R1-A</td>
<td>rater 1, 1st occasion</td>
</tr>
<tr>
<td>R1-B</td>
<td>rater 1, 2nd occasion</td>
</tr>
<tr>
<td>R2</td>
<td>rater 2</td>
</tr>
<tr>
<td>RCT</td>
<td>randomised controlled trial</td>
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<tr>
<td>ROM</td>
<td>range of motion</td>
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<td>s</td>
<td>seconds</td>
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<tr>
<td>S1</td>
<td>spinous process of 1st sacral vertebra</td>
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<tr>
<td>S2</td>
<td>spinous process of 2nd sacral vertebra</td>
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<tr>
<td>SD</td>
<td>standard deviation</td>
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<tr>
<td>SD diff</td>
<td>standard deviation of the mean difference</td>
</tr>
<tr>
<td>SEM</td>
<td>standard error of measurement</td>
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<td>SPSS</td>
<td>statistical package for the social sciences</td>
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<tr>
<td>TA</td>
<td>transversus abdominis</td>
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<td>US</td>
<td>usual sitting</td>
</tr>
<tr>
<td>3D</td>
<td>three-dimensional</td>
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CHAPTER 1: Introduction

The aim of this chapter is to review the scientific literature regarding sitting behaviour and non-specific chronic low back pain (NSCLBP). This includes providing a background to the problem of NSCLBP and the many different factors that are involved in it. Particular emphasis will be placed on the role of sitting behaviour in the development and maintenance of NSCLBP, and the role of conservative interventions aimed at altering sitting behaviour on NSCLBP. In addition, current concepts on what constitutes a good sitting posture will be reviewed, along with methods used to analyse spinal posture.
1.1 The biopsychosocial nature of chronic low back pain

Chronic low back pain (CLBP) is a very common and costly disorder, with effective treatments remaining elusive (Dagenais et al. 2008). With trends for increasing CLBP-related disability in recent decades, it has been proposed that the management of CLBP must be changed (Borkan et al. 2002; Deyo et al. 2009; O’Sullivan 2012). One key consideration in this management is that the vast majority of people with CLBP have no clearly identifiable pathology on spinal imaging which could explain their pain (Chou et al. 2009b). This has resulted in most CLBP being referred to as “non-specific” CLBP (NSCLBP). NSCLBP is viewed as a multidimensional disorder within a biopsychosocial framework with different factors possibly involved (Maniadakis and Gray 2000; Hansson et al. 2006; Linton et al. 2007; Schaafsma et al. 2010). For example, a wide range of physical (Hodges and Richardson 1996; Ferguson et al. 2004; Cholewicki et al. 2005; Marras et al. 2005; Shum et al. 2005; Dankaerts et al. 2009), psychosocial (Carroll et al. 2004; Jarvik et al. 2005; Main et al. 2010; Mitchell et al. 2010; Ramond et al. 2011), lifestyle (Onen et al. 2001; Chiu et al. 2005), genetic (Reichborn-Kjennerud et al. 2002; Battié et al. 2004) and neurophysiological (Apkarian et al. 2009; Wand et al. 2011b) factors appear to play a role in NSCLBP. In fact, there is emerging evidence that some of these factors are inter-related, rather than being completely distinct entities (Marras et al. 2000; Mannion et al. 2001b; Geisser et al. 2004; Moseley 2004a; Woby et al. 2007; Lewis et al. 2012).

Notwithstanding this range of factors in NSCLBP, many traditional interventions have focussed almost exclusively on addressing the physical dimension of NSCLBP (van Tulder et al. 2000; Assendelft et al. 2003; Furlan et al. 2005; Ferreira et al. 2007; Schaafsma et al. 2010), demonstrating only limited effectiveness. Numerous studies which have compared different physical interventions have shown similar, limited effectiveness for such interventions in NSCLBP (Cairns et al. 2006; Ferreira et al. 2007; Van Middelkoop et al. 2011). There is some evidence that interventions targeting psychosocial factors may be slightly more effective than physical interventions (van Tulder et al. 2001; Moseley 2002; Henschke et al. 2010;
Ryan et al. 2010), yet the long-term effectiveness of psychologically-based behavioural therapies is limited (Henschke et al. 2010). In line with studies of different physical interventions, the effectiveness of different behavioural therapies in isolation are also quite similar (Wetherell et al. 2011).

One possible reason for the poor effectiveness (Keller et al. 2007) of existing unidimensional interventions – physical or psychosocial - is the extensive central nervous system (CNS) reorganisation which takes place among people with NSCLBP (Wand et al. 2011b). NSCLBP is now known to be associated with a range of neurochemical, structural and functional changes within the CNS (Moseley 2003; Baliki et al. 2008; Wand et al. 2011b). These changes appear to lead to greater sensitivity of the CNS (“central sensitisation”) to peripheral nociceptive input, thus reducing the need for strong peripheral nociceptive input (e.g. from tissue damage) to generate the experience of NSCLBP (Butler 2000; Wand et al. 2011b). It also appears that the extent of these changes in the CNS differs between people with NSCLBP (Smart et al. 2010; O'Sullivan 2012). As such, the predominant pain mechanism of people with NSCLBP may be primarily related to peripheral nociceptive input, central sensitivity, or combinations of these mechanisms (Smart et al. 2010; O'Sullivan 2012).

There is considerable evidence that these CNS changes are closely related to a range of both psychological (Grachev et al. 2001; Grachev et al. 2002; Grachev et al. 2003; Lloyd et al. 2008) and physical (Tsao et al. 2008; Gwilym et al. 2010; Seminowicz et al. 2011) factors. These CNS changes also appear to manifest themselves in a variety of other clinically observable phenomena, including altered body schema (Bray and Moseley 2011) and tactile acuity (Wand et al. 2010), which appear to be related to abnormal movement behaviour (Luomajoki and Moseley 2011). Therefore, considering the myriad of factors which can impact on CNS sensitivity, it has consequently been proposed (Wand et al. 2011a; O'Sullivan 2012) that interventions which target multiple pain dimensions across the biopsychosocial spectrum (Gatchel et al. 2007; Campbell and Edwards 2009; Ramond et al. 2011; O'Sullivan 2012) should be further investigated in NSCLBP. It has also been proposed that a key part of such targeted
interventions would be the identification of specific subgroups within the broad NSCLBP population (Borkan et al. 2002; O'Sullivan 2012).

1.2 Subgrouping within the NSCLBP population
Within this multifactorial and multidimensional framework for NSCLBP disorders, it is increasingly recognised that specific subgroups exist which require targeted management addressing the specific mechanism underlying their NSCLBP (Boersma and Linton 2002; Borkan et al. 2002; McCarthy et al. 2004; Dankaerts et al. 2006b; Kent et al. 2009; Driessen et al. 2010). Several possible ways of subgrouping the NSCLBP population are currently being researched internationally. For example, several studies suggest that distinct subgroups of people with NSCLBP who share certain characteristics are at increased risk of chronicity or ongoing severe disability (Hill et al. 2008; Hockings et al. 2008; Melloh et al. 2009; Dunn et al. 2011; Westman et al. 2011; Beneciuk et al. 2012). Consequently, some subgrouping approaches use validated questionnaires to triage people with NSCLBP into groups of different risk categories, to attempt to prioritise those at greatest risk, as these typically consume most healthcare resources (Hockings et al. 2008; Hill et al. 2011). Other approaches include identifying subgroups based on patho-anatomical findings (Petersen et al. 2003), psychosocial characteristics (Westman et al. 2011; Hasenbring et al. 2012), and patient signs and symptoms such as evidence of altered movement behaviour (Sahrmann 2002) or the response to specific interventions (Delitto et al. 1995).

No specific classification system has so far been demonstrated to be superior (Fairbank et al. 2011). It would appear appropriate however, based on the importance of the CNS changes mentioned earlier, that NSCLBP subgrouping be based on an individual’s predominant pain mechanism. The classification of NSCLBP proposed by Peter O'Sullivan (O'Sullivan 2005) examines NSCLBP in terms of the primary pain mechanisms involved, and the relative contribution from different domains across the biopsychosocial spectrum. This subgrouping system has the advantage of considering several different contributing factors, allowing targeted interventions for each individual with NSCLBP. For example, it considers whether there is a greater
contribution from centrally mediated factors such as psychosocial factors, or peripherally mediated factors such as movement behaviour. Similarly, the directional nature of the maladaptive movement behaviour (as a physical factor) can be further subclassified.

Within this subgrouping framework, it is proposed that many NSCLBP patients display maladaptive movement behaviours which expose their spines to increased strain and contribute to their NSCLBP disorder (O’Sullivan 2012). Several studies support the existence of altered movement behaviours among people with NSCLBP (Burnett et al. 2004; Marras et al. 2005; Dankaerts et al. 2006a; Dankaerts et al. 2006b; Shum et al. 2007; Smith et al. 2008; Sheeran 2010; Sheeran et al. 2012). and modification of these movement behaviours has been associated with improved clinical outcomes (Van Dillen et al. 2003a; Dankaerts et al. 2007).

The nature of these maladaptive movement behaviours is variable (O’Sullivan 2005). For example, both increased (Vergara and Page 2002; Dankaerts et al. 2006b; Van Dillen et al. 2009) and decreased (Dankaerts et al. 2006b; Womersley and May 2006) lumbar lordosis has been documented among people with NSCLBP. It has therefore been proposed (O’Sullivan 2005) that optimal management would restore normal movement behaviours in everyday tasks according to the individual’s presenting maladaptive movement behaviour and individual aggravating factors, rather than advising all people with NSCLBP to assume a specific type of posture or movement behaviour.

It is however critical that such maladaptive movement behaviours are interpreted as just one aspect of each individual’s overall NSCLBP disorder, and given an emphasis in rehabilitation that reflects the predominant pain mechanism (O’Sullivan 2012). This is also consistent with the evidence of a close relationship between physical and psychosocial variables in NSCLBP (Marras et al. 2000; Mannion et al. 2001b; Geisser et al. 2004; Moseley 2004a; Woby et al. 2007; Sullivan et al. 2009; Lewis et al. 2012). Otherwise, it is likely that simplistic attempts to improve isolated physical factors such as sitting posture will display the limited effectiveness seen with other physical interventions (Keller et al. 2007; Driessen et al. 2010; Van Middelkoop et al. 2011).
The classification of NSCLBP proposed by O'Sullivan is based on findings from a comprehensive subjective interview and clinical examination, in combination with the interpretation of validated questionnaires (O'Sullivan 2012). This approach promotes targeted interventions based on an individual weighting of the possible contributing factors across the biopsychosocial spectrum for each person with NSCLBP. For example, a person with NSCLBP which is not mechanically provoked and whose symptoms are more closely linked to psychosocial factors (e.g. fear, anxiety, stress) may benefit from a greater emphasis on psychosocial factors in their rehabilitation. In contrast, a person with NSCLBP which is primarily mechanically provoked and whose symptoms are not closely linked to psychosocial factors may benefit from a greater emphasis on physical factors in their rehabilitation. Crucially, this approach acknowledges the co-existence of physical and psychosocial factors in NSCLBP and their inter-relationship, rather than viewing the physical and psychosocial factors as being mutually exclusive (O'Sullivan 2012). Despite the logical potential of such multidimensional intervention approaches, relatively few studies have examined matching NSCLBP rehabilitation to individual NSCLBP patient profiles in this context. A small number of initial studies which have used such approaches have shown encouraging findings (Asenlof et al. 2009; Sheeran 2010; Fersum et al. 2011; Hill et al. 2011), however more research is needed in this area.

1.3 The role of sitting and NSCLBP

Several studies have demonstrated that daily sitting duration does not appear to be a major contributing factor in developing NSCLBP (Hartvigsen et al. 2000; Lis et al. 2007; Roffey et al. 2010c). However, sitting is a commonly reported aggravating factor for people with NSCLBP (Williams et al. 1991; Dankaerts et al. 2006b; Wai et al. 2010c). There is also some evidence that assuming provocative postures which are closer to end-range may increase the risk of developing NSCLBP (Smith et al. 2008; Dolphens et al. 2012), although these studies examined standing posture rather than sitting posture. Therefore, addressing provocative, maladaptive spinal
postures is commonly advocated in NSCLBP management (O’Sullivan 2005; Poitras et al. 2005; Sheeran 2010).

There are several possible interpretations of the poor link between sitting duration and NSCLBP. Firstly, considering the multidimensional nature of NSCLBP already discussed, it appears unlikely that any one physical factor would display a strong, linear relationship with NSCLBP (Mitchell et al. 2010). This is supported by systematic reviews which have also reported a lack of convincing evidence of a clear relationship between NSCLBP and suspected physical contributing factors, such as awkward work postures (Roffey et al. 2010a), prolonged standing at work (Roffey et al. 2010d), occupational lifting (Wai et al. 2010c), occupational carrying (Wai et al. 2010b), occupational bending and twisting (Wai et al. 2010a), manual handling of materials or patients (Roffey et al. 2010e) or occupational pushing and pulling (Roffey et al. 2010b). Similar to sitting, many of these tasks are commonly reported aggravating factors (Dankaerts et al. 2006b; Sullivan et al. 2009), but these reviews demonstrate that they are not – at least in isolation – clear predictors of NSCLBP. Secondly, many studies have not controlled for the presence of the aforementioned subgroups within the NSCLBP population, and this has been shown to lead to a potential “wash-out” effect (Dankaerts et al. 2006b; Sheeran 2010) among people with NSCLBP. Thirdly, many NSCLBP field studies have simply considered the duration or frequency which different postures (e.g. sitting versus standing) are adopted (Roffey et al. 2010a; 2010c; 2010d; Wai et al. 2010c; Wai et al. 2010a), rather than reporting actual sitting behaviour. This has mainly been due to the technological limitations of measuring spinal sitting posture accurately outside the laboratory. In order to gain a better understanding of sitting behaviour in “real-world” environments, more sensitive, yet portable and minimally invasive methods of analysing spinal sitting behaviour are required.

1.4 Methods of analysing spinal sitting behaviour

A wide range of methods for analysing spinal sitting behaviour are available, from simple visual observation (Poirtrás et al. 2005), digital photography (Bell 2008; Smith et al. 2008) to sophisticated laboratory-based motion analysis.
systems (Pearcy and Hindle 1989; Schuit et al. 1997; Mannion and Troke 1999; Dankaerts et al. 2006b). Digital photography and video analysis are commonly used in field studies as relatively cheap, portable, reliable and non-invasive options (Spielholz et al. 2001; Straker et al. 2009). However, both approaches are limited as methods of “real-world” analysis by factors such as clothing and furniture, or the need to be physically present if the person being monitored moves to a different location. Furthermore, their ability to detect subtle regional changes in spinal posture reported in laboratory-based studies (Dankaerts et al. 2006b; Mitchell et al. 2008) may be limited (Elliott et al. 2007). Many laboratory-based methods have established reliability and validity (Pearcy and Hindle 1989; Schuit et al. 1997). Unfortunately, the ecological validity of these studies is limited as the methods and setting rarely reflect real-life environments, and long-term observation is rarely possible. Furthermore, laboratory systems are costly, complex and time-consuming to set up for analysis. In particular, the size of sensors and the relatively invasive marker placements required for most motion analysis systems makes spinal posture monitoring in the field very cumbersome.

The use of portable, minimally invasive posture monitors in “real-world” settings has been advocated (Hermens and Vollenbroek-Hutton 2008). In recent years, a number of such devices have been developed (Donatell et al. 2005; Dean and Dean 2006; Horton and Abbott 2008). Spinal posture analysis is now possible using accelerometers (Bazzarelli et al. 2001; Nevins et al. 2002; Wong and Wong 2008; Intolo et al. 2010), gyroscopes (Lee et al. 2003), fibre-optic goniometers (Bell 2008; Williams et al. 2010), inclinometers (Mork and Westgaard 2009), ultrasound (Wunderlich et al. 2011), strain gauges and/or optical sensors (Donatell et al. 2005; Dean and Dean 2006) and even sensing fabrics (Walsh et al. 2006). However, despite the potential of such devices, there is a lack of empirical data supporting their use (Wong et al. 2007; Hermens and Vollenbroek-Hutton 2008). Some of the devices are relatively large and invasive, and therefore cannot be concealed easily (Donatell et al. 2005; Magnusson et al. 2008), or can only be used under supervision (Magnusson et al. 2008). While several devices have at least some evidence of reliability and/or validity (Lee et al.
2003; Donatell et al. 2005; Intolo et al. 2010; Sheeran et al. 2010; Wunderlich et al. 2011; Williams et al. 2012a), this is not always the case (Dean and Dean 2006; Magnusson et al. 2008; Mork and Westgaard 2009). It is important that the desire to promptly use these devices in clinical trials is balanced against the need to adequately establish the scientific robustness of the device itself.

Each posture monitoring option has particular advantages and disadvantages. Inertial sensors such as accelerometers, gyroscopes and inclinometers are relatively small and provide minimal interference with function. Accelerometers (Intolo et al. 2010) and inclinometers (Mork and Westgaard 2009) can be used to analyse spinal and trunk angulation. However, they may interfere with normal use of a backrest when sitting unless they are not worn directly over the spine (Telfer et al. 2009; Wong et al. 2009), when their validity may not be as accurate. There are also established concerns about gyroscopic drift (Lee et al. 2003), although attempts to reduce this effect have been developed (Williams et al. 2012b). Both fibre-optic goniometers (Bell 2008; Williams et al. 2012a) and flexible electrogoniometers (Boocock et al. 1994; Bible et al. 2010) can provide angular data on dynamic spinal curvature. However, the option of providing biofeedback with these devices is often limited, their length can be exceeded during testing, their size may interfere with normal use of a backrest when sitting and they often require a relatively large data logger. This is even more relevant when such technologies are incorporated into larger exoskeletons which are attached to the trunk (Marras et al. 1992; Donatell et al. 2005). Combining different technologies has also been attempted (Vergara and Page 2000; Plamondon et al. 2007), and while such approaches provide more data, their increasing size questions whether participants are really moving in a typical manner while wearing such monitors. Simple strain gauges do not provide angular data, but are based on the varying distance between the skin overlying bony landmarks. They can be used to provide postural biofeedback. Their length can be exceeded during testing, and they may require calibration relative to static end-range postures. However, their small size suggests they currently present the least risk of interfering with typical backrest use during sitting.
The BodyGuard™ (Sels Instruments, Vorselaar, Belgium), a novel wireless method of measuring spinal sagittal plane posture using a simple strain gauge, has recently been developed. This device can monitor spinal posture in real-time without the need for cumbersome cables, thus facilitating more normal movement and function in a wide range of tasks compared to some other options (Donatell et al. 2005; Magnusson et al. 2008). The data is accessible for immediate presentation and analysis. Unlike many portable monitors which can either monitor posture or provide postural feedback (Dean and Dean 2006; Magnusson et al. 2008; Mork and Westgaard 2009; Bible et al. 2010), it can both monitor posture and provide immediate real-time postural biofeedback (audio or vibratory). The postural biofeedback offers the potential to modify movement behaviours among people with NSCLBP. While the BodyGuard™ device clearly demonstrates potential clinical utility, there is a need for preliminary reliability and validity studies before progressing to clinical studies.

1.5 What is a “good” sitting posture?

While different sitting postures have varying effects on trunk muscle activation and spinal loading (Adams and Hutton 1985; van Deursen et al. 1999; O'Sullivan et al. 2006a), it remains unclear what constitutes an optimal seated posture. Assuming (Gade and Wilson 2007) or sustaining (Dolan and Green 2006) end-range spinal flexion can impair spinal proprioception, and increase NSCLBP (Womersley and May 2006). Reducing spinal flexion sitting postures can reduce pain, with many authors recommending lordotic seated postures to reduce pain (Lander et al. 1987; Bennett et al. 1989; Williams et al. 1991; Vergara and Page 2002; Womersley and May 2006). In contrast, some studies report increased lordosis among some people with NSCLBP (Vergara and Page 2002; Van Dillen et al. 2003b; O'Sullivan 2005) and reduced pain among some people with NSCLBP during lumbar flexion (O'Sullivan 2005). While flexion in sitting has previously been proposed to increase disc compression, a recent review demonstrated no such effect (Claus et al. 2008). Lordotic sitting postures interspersed with movement are commonly advocated (Williams et al. 1991; van Deursen et al. 1999; Van Dieen et al. 2001; Womersley and May 2006; Ribeiro et al. 2011), however
lordotic sitting has also been associated with increased discomfort (Lander et al. 1987; Bennett et al. 1989; Vergara and Page 2002). While some of the contradictions within the literature may reflect the variation seen between different subgroups of people with NSCLBP (Dankaerts et al. 2009; Sheeran et al. 2012), developing a level of consensus regarding the sitting parameters which might be recommended to patients could be useful in the management of NSCLBP.

It has been proposed that an optimal sitting posture for people with NSCLBP who are sensitised to flexion or extension is a more “neutral” spine position involving slight lumbar lordosis and a relaxed thorax (O’Sullivan et al. 2006a). This would limit exposure to end-range postures associated with increased spinal stiffness and end-range strain (Scannell and McGill 2003; Beach et al. 2005), as well as facilitating low-level trunk muscle activation (O’Sullivan et al. 2006a; Claus et al. 2009a; O’Sullivan et al. 2012a). However, assuming such a posture may be difficult to achieve or sustain (O’Sullivan et al. 2012b), questioning its application in clinical practice. Furthermore no study has examined the perceptions of physiotherapists, or any healthcare profession, on what they would consider to be an optimum sitting posture. Considering the strong evidence that the beliefs of clinicians are closely related to the beliefs of people with NSCLBP (Darlow et al. 2012), assessing the beliefs of physiotherapists about what they consider to be an optimum sitting posture would be of interest. Similarly, the perceptions of members of the community on what they would consider to be an optimum sitting posture have not been examined. This could provide some insight into the postures observed in clinical practice among people with NSCLBP. For example, it is commonly reported that people with NSCLBP assume maladaptive postures, and appear to hold unhelpful beliefs about the need to “protect” a vulnerable spine (O’Sullivan 2005). It is possible that this reflects widespread beliefs in the community rather than being solely related to the presence of NSCLBP. Therefore, comparison of the perceptions on sitting posture between people with and without NSCLBP is necessary.
1.6 Interventions to change sitting behaviour in NSCLBP

In a series of systematic reviews performed as part of this doctoral thesis (Appendices I-IV), the evidence for specific interventions which aim to change sitting behaviour and which have been recommended for the management of NSCLBP were examined. One of the reviews has already been published (O'Sullivan et al. 2012e), two are currently under review, and one will shortly be submitted for publication. In all four reviews, electronic databases were searched independently by two reviewers, with eligible studies scored using the PEDro scale (Maher et al. 2003). The sitting interventions examined were dynamic sitting (Appendices I and II), using a chair backrest (Appendix III), and using chairs which involve less hip flexion in sitting (Appendix IV).

The aim of dynamic sitting devices, where the chair involves an increased degree of motion, is to continuously vary spinal loading and trunk muscle activation patterns. The specific devices included in the two reviews regarding dynamic sitting included motor-driven seats (van Deursen et al. 1999; Brumagne et al. 2000), dynamic office chairs with an adjustable seat, backrest and armrest (Van Dieen et al. 2001), an inflatable continuous passive motion (CPM) device placed behind the back (Dean and Dean 2006; Kernozek et al. 2006; Ribeiro et al. 2011), an inflatable ball (Gregory et al. 2006; McGill et al. 2006; Kingma and van Dieen 2009) and an inflatable cushion (O'Sullivan et al. 2006b) placed on the seat. Two separate reviews were conducted on the effectiveness of dynamic sitting; one focussing on low back pain (LBP) or low back discomfort (LBD) with the other review examining trunk muscle activation. In the review of LBP or LBD (O'Sullivan et al. 2012e), no randomised controlled trials (RCT) or longitudinal studies were found (Appendix I). Seven high-quality crossover studies were reviewed which examined the evidence that dynamic sitting as a stand-alone approach prevents or reduces LBP. Only three of the seven studies included participants with LBP. Overall, there was no evidence of reduced LBP or LBD with dynamic sitting interventions (O'Sullivan et al. 2012e). Similarly, no RCT or longitudinal studies were found on whether dynamic sitting significantly alters trunk muscle activation (O'Sullivan et al. 2012g). Six high-
quality crossover studies were eligible, however none of the six studies included participants with LBP. Similarly, there was no evidence of an effect on trunk muscle activation for dynamic sitting (Appendix II).

Using a chair backrest has been long recommended as a mechanism of supporting the back and reducing the muscle effort required in sitting (Andersson et al. 1974; Corlett 2006). In a systematic review (Appendix III) examining LBP and LBD as well as changes in trunk muscle activation, no RCT or longitudinal studies were found once again (O'Sullivan et al. 2012a). Seven crossover design studies comparing trunk muscle activation were eligible, with two of these also examining LBD. Only one of the seven studies included participants with LBP. All seven studies were of fair to high methodological quality. The results demonstrated that using a chair backrest significantly reduces paraspinal muscle activation, and reduces LBD to a small degree. However, larger prospective clinical trials involving people with LBP are required to confirm these findings.

Finally, chairs which involve less hip flexion, such as saddle stools, kneeler chairs or sit-to-stand chairs, have been recommended as a way to reduce the degree of lumbar flexion which occurs in sitting (Mandal 1981; Gadge and Innes 2007). 26 studies were included in this systematic review (O'Sullivan et al. 2012b), with 21 studies examining LBP, LBD or comfort, and 11 examining trunk muscle activation. Therefore, this was the largest amount of research evidence available across the four systematic reviews conducted, including three RCT’s. However, only seven of the 26 studies included participants with LBP, and only five of the 26 studies examined the effect of the modified chair over a period of time greater than one day. All 26 studies were of fair to high methodological quality. The overall results of the review were mixed (Appendix IV). There was no strong evidence that providing chairs which reduce hip flexion are an effective means of reducing LBP or LBD. In fact, the use of kneeler chairs was consistently associated with increased paraspinal muscle activation and discomfort. There was some limited evidence that integrating chairs which reduce seated hip flexion into an ergonomic workstation with higher, sloping desks could be of benefit, but most studies reported no significant effect. Interestingly, in most studies that asked about participant preference, chairs which reduced seated hip flexion
was preferred. Considering the limited, or negative, effect of these chairs on LBP and muscle activation, this is likely to reflect the novelty of the new chairs.

Overall, the evidence to support most of these seated interventions based on adjusting spinal sitting posture was weak. No clear conclusions about causality can be drawn, since the heterogenous nature of the studies, and the typically small sample sizes, did not allow a systemic evaluation of effects in the reviews. Most studies included only painfree participants, further limiting the clinical relevance of the findings. Only the use of a backrest demonstrated consistently positive results, and this was primarily regarding reduced paraspinal muscle activation in crossover design studies without a prolonged follow-up period. This suggests that encouraging backrest use during sitting could be advantageous, especially among those who present with NSCLBP related to high levels of paraspinal muscle activation in sitting (Dankaerts et al. 2006a; Sheeran et al. 2012). The limited effectiveness across these sitting interventions is again consistent with the limited effectiveness of unidimensional physical interventions for NSCLBP (Keller et al. 2007). None of the studies incorporated the altered sitting design into a multidimensional management plan for NSCLBP.

1.7 Postural biofeedback interventions for NSCLBP

There is evidence of altered proprioceptive awareness among people with NSCLBP (Brumagne et al. 2000; O'Sullivan et al. 2003; Sheeran et al. 2012). This may partly explain why people with NSCLBP assume provocative postures, and yet seem unaware they are doing so (Dankaerts et al. 2006b; Sheeran 2010). Similarly, there is evidence of an altered body schema among people with NSCLBP, such that they are less aware of their body shape, space and interaction with the surrounding environment (Bray and Moseley 2011; Moseley et al. 2012). A recent review (Ribeiro et al. 2011) highlighted the limited amount of evidence examining the provision of biofeedback in the management of NSCLBP. There is evidence that posture modification and postural awareness training may help normalise spinal motion (Dean and Dean 2006) and reduce spinal loading during lifting tasks (Kernozek et al. 2006). Furthermore, there is also some preliminary evidence
that biofeedback on postural movement behaviour may improve clinical outcomes in acute LBP (Horton and Abbott 2008) and NSCLBP (Magnusson et al. 2008; Sheeran 2010). The BodyGuard™ posture monitor may therefore also be useful as a feedback tool. It has the potential to provide patients with feedback regarding their movement patterns which may motivate patients (Horton and Abbott 2008), enhance exercise performance (Magnusson et al. 2008), reduce the link between pain and movement (Perry et al. 2008), and might decrease the costs associated with NSCLBP (Hermens and Vollenbroek-Hutton 2008). However, the role of this device as a biofeedback tool has not yet been investigated in any study.

1.8 A multi-dimensional intervention for NSCLBP: Cognitive Functional Therapy

Cognitive Functional Therapy (CFT) is a novel, person-centered intervention which addresses multiple dimensions in NSCLBP (O’Sullivan 2012). CFT combines a functional behavioural approach of retraining provocative postures and movements with cognitive reconceptualisation of the NSCLBP problem. As such, it aims to target the barriers to recovery across physical, lifestyle and psychosocial domains on an individual basis. In a RCT among people with mild-moderate NSCLBP, this approach was more effective than combining manual therapy and exercise (Fersum et al. 2011). However, this approach has not yet been evaluated among people with more disabling NSCLBP, who are the group who consume most healthcare resources (Hill et al. 2011). Therefore, it is appropriate that this intervention be trialled among more highly disabled people with NSCLBP. Since CFT has never been used before in studies involving people with higher levels of pain and disability, a multiple single-case design study could offer useful insights before progressing to RCT design studies. Multiple single-case designs are often used in the developmental stages of novel chronic pain interventions before progressing to RCT design studies (Boersma et al. 2004; Van De Meent et al. 2011). This allows interpretation of the changes which occur with rehabilitation, and facilitates fine-tuning of the intervention before performing an RCT.
1.9 Key points: Chapter 1

- NSCLBP is a complex multidimensional disorder, with contributions from physical, lifestyle, genetic, neurophysiological and psychosocial domains.
- Identifying subgroups within the NSCLBP population, based on the predominant pain mechanism associated with their disorder, has been proposed as a key strategy to facilitate targeted interventions for NSCLBP.
- While sitting is a common aggravating factor for NSCLBP, it does not cause NSCLBP in isolation. Postural advice is a common part of NSCLBP management, yet little is known about what physiotherapists, or indeed members of the community with and without NSCLBP, consider to be a good sitting posture.
- While many interventions to change sitting behaviour appear to display little effectiveness, little is known about the effectiveness of postural biofeedback as an intervention for NSCLBP.
- Previous methods to analyse spinal posture have involved sophisticated motion analysis systems in laboratory environments, or involved less sensitive methods of analysing spinal posture such as digital photographs outside the laboratory.
- Technological developments have facilitated the development of minimally invasive, portable posture monitors which can be used outside the laboratory during everyday tasks. One of these devices, the BodyGuard™, may allow enhanced understanding about sitting behaviour outside the laboratory. Before progressing to clinical trials, rigorous testing of this device is required.
- A multi-dimensional intervention for NSCLBP – Cognitive Functional Therapy – offers the possibility that multiple dimensions of NSCLBP can be addressed together during management. However, this intervention has never been tested among a group of people with highly disabling NSCLBP. Furthermore, it is not clear whether physical or psychosocial factors would be most influenced by such an intervention, or most related to improvements in pain and disability.
1.10 Aims of thesis

Reviewing the literature highlights that much remains unknown about the significance of sitting behaviour in NSCLBP, and the potential role of sitting interventions in the management of NSCLBP. This doctoral thesis aims to provide greater clarity on the importance of sitting behaviour in NSCLBP. This will be done in three parts;

2. Investigating the reliability and validity of a novel, minimally invasive posture monitor (BodyGuard\textsuperscript{TM}) which could analyse and provide feedback on spinal sitting behaviour outside the laboratory.

3. Investigating perceptions of sitting posture among physiotherapists, as well as among members of the community with and without NSCLBP.

4. Investigating the effectiveness of two different targeted interventions for NSCLBP. Firstly, the use of postural biofeedback as an intervention in isolation, and then the effectiveness of a multidimensional CFT intervention which addresses physical, lifestyle and psychosocial factors associated with NSCLBP.
CHAPTER 2: Investigating the validity and clinical applicability of a posture monitor

The overall layout of the three main parts of this doctoral thesis is illustrated in Table 1. This chapter contains three studies, each of which has already been published in the peer-reviewed literature (O'Sullivan et al. 2011a; O'Sullivan et al. 2012f; O'Sullivan et al. 2012k). The primary research questions for this chapter are illustrated in Table 1;

Table 1: Overview of the doctoral thesis and the research questions examined in each of the three main parts

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<tr>
<th>CHAPTER TITLE</th>
<th>QUESTIONS</th>
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<td>Investigating the validity and clinical applicability of a posture monitor</td>
<td>• Is this posture monitor reliable?</td>
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<td>• Is this posture monitor valid?</td>
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<td>• Can the posture monitor be used in clinical research?</td>
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<td>Perceptions of sitting posture</td>
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<td>Interventions to reduce seated low back pain</td>
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Study I: The between-day and inter-rater reliability of a novel wireless system to analyse lumbar spine posture


Abstract

Lumbar posture is commonly assessed in non-specific chronic low back pain (NSCLBP), although quantitative measures have mostly been limited to laboratory environments. The BodyGuard™ is a spinal posture monitoring device which can monitor posture in real-time, both inside and outside the laboratory. The reliability of this wireless device was examined in 18 healthy participants during usual sitting and forward bending, two tasks which are commonly provocative in NSCLBP. Reliability was determined using intra-class correlation coefficients (ICC), the standard error of measurement (SEM), the mean difference and the minimal detectable change (MDC90). Between-day ICC values ranged from 0.84 – 0.87, with small SEM (5%), mean difference (<9%) and MDC90 (<14%) values. Inter-rater ICC values ranged from 0.91 – 0.94, with small SEM (4%), mean difference (6%) and MDC90 (9%) values. Between-day and inter-rater reliability are essential requirements for clinical utility, and were excellent in this study. Further studies into the validity of this device, and its application in clinical trials in occupational settings are required.

Keywords: posture; back pain; reliability.
1. Introduction

Low back pain (LBP) is a very common and costly disorder that should be considered within a biopsychosocial framework (Maniadakis and Gray 2000; O'Sullivan 2005; Hansson et al. 2006; Linton et al. 2007). Most LBP lacks a specific radiological diagnosis, and has been termed non-specific chronic low back pain (NSCLBP) (Borkan et al. 2002; Dankaerts et al. 2006b). It is increasingly recognised that within the broad NSCLBP population, specific subgroups exist which require management addressing the specific mechanism underlying their NSCLBP (Boersma and Linton 2002; Borkan et al. 2002; McCarthy et al. 2004; Dunn and Croft 2005; O'Sullivan 2005; Kent et al. 2009). It has been proposed that in a subgroup of people with NSCLBP, the adoption of altered patterns of spinal movement and posture represents a primary mechanism for their NSCLBP disorder (O'Sullivan 2005). It has been proposed that these patients present with maladaptive spinal postures and movement patterns which expose their spines to increased loads and strain (O'Sullivan 2005). In line with this, spinal posture is considered by many in both clinical practice and research to be a factor in the development and maintenance of NSCLBP (Van Dillen et al. 2003b; Poitras et al. 2005; Dankaerts et al. 2006b; Womersley and May 2006; van Wyk et al. 2009). A number of studies now support the existence of these altered spinal postures among people with NSCLBP when examined in a laboratory environment (Burnett et al. 2004; Dankaerts et al. 2006a; Dankaerts et al. 2006b; Womersley and May 2006; Smith et al. 2008; Dankaerts et al. 2009), and modification of posture has been associated with improved clinical outcomes (Van Dillen et al. 2003a; Dankaerts et al. 2007).

There are numerous methods for analysing lumbar spine posture, from simple visual observation in clinical practice (Poitras et al. 2005), the use of photographic markers (Perry et al. 2008; Smith et al. 2008) to more complex laboratory-based motion analysis systems used in much NSCLBP research (Pearcy and Hindle 1989; Schuit et al. 1997; Mannion and Troke 1999; Dankaerts et al. 2006b). Many laboratory-based methods of analysing posture have been shown to be both reliable and valid (Pearcy and Hindle 1989; Schuit et al. 1997). Unfortunately, these systems are complex and time-
consuming to use, and cannot be easily used to analyse posture outside the laboratory setting.

The use of portable, minimally invasive methods of analysing posture in “real-world” settings has been advocated to provide a quantitative measurement of posture in the workplace (Hermens and Vollenbroek-Hutton 2008). In recent years a number of devices have been developed to analyse spinal posture outside the laboratory (Donatell et al. 2005; Dean and Dean 2006; Horton and Abbott 2008). Spinal posture analysis is now possible using accelerometers (Bazzarelli et al. 2001; Nevins et al. 2002; Wong and Wong 2008), gyroscopes (Lee et al. 2003), strain gauges and/or optical sensors (Donatell et al. 2005; Dean and Dean 2006) and even sensing fabrics (De Rossi et al. 2003; Walsh et al. 2006). Recent reviews have highlighted that, despite the potential of such devices, there is a lack of empirical data supporting their use (Wong et al. 2007; Hermens and Vollenbroek-Hutton 2008). Unfortunately some of the devices are relatively large and invasive, such that they cannot be concealed easily (Donatell et al. 2005; Magnusson et al. 2008), or only used under supervision (Magnusson et al. 2008). While some of these devices have at least some evidence of initial reliability and/or validity studies being completed (Donatell et al. 2005; Intolo et al. 2010), this is not the case with all devices (Dean and Dean 2006; Magnusson et al. 2008; Mork and Westgaard 2009). It is critical that the desire to promptly use these devices in clinical trials is balanced against the requirement to initially establish the scientific robustness of the device itself.

Another significant limitation of traditional laboratory-based motion analysis systems is that they cannot provide instantaneous postural feedback while the NSCLBP patient performs daily tasks. This shortcoming is significant considering the role reduced postural awareness and position sense may play in NSCLBP (O'Sullivan et al. 2003). In fact, recent studies demonstrate that provision of postural awareness training may help improve clinical outcomes in both acute LBP and NSCLBP (Horton and Abbott 2008; Magnusson et al. 2008)

The BodyGuard™ (Sels Instruments, Vorselaar, Belgium), a novel wireless method of measuring spinal sagittal plane posture, has recently been developed. This small device can monitor spinal posture in real-time without
the need for cumbersome cables, thus facilitating more normal movement and function in a wide variety of tasks compared to some existing options (Donatell et al. 2005; Magnusson et al. 2008). The data are accessible for immediate presentation and analysis. The BodyGuard™ device can also be used to provide immediate real-time postural biofeedback (audio or vibratory) with a view to modifying posture or movement patterns, and even enhancing the exercise performance of those using the device. While the BodyGuard™ device clearly demonstrates potential clinical utility, and could be trialled immediately in clinical trials as an intervention tool, we believe there is a clear need for robust scientific validation initially before progressing to clinical trials. Therefore a multi-stage investigation into the validity of this device for monitoring posture in NSCLBP patients has been outlined. This first study examines the between-day and inter-rater reliability of the device for analysing sagittal plane spinal posture during functional tasks. In order to minimise postural variation due to pain or external environmental factors, the reliability of the device will first be established among pain-free healthy control participants performing closely controlled postures and movements. Since forward bending and sitting are common aggravating factors in NSCLBP, and are commonly analysed in clinical practice and research (O'Sullivan et al. 2002; O'Sullivan 2005; Dankaerts et al. 2006b; Womersley and May 2006) they were deemed suitable for this reliability study.

The aim of the study was to establish the between-day and inter-rater reliability of the BodyGuard™ for monitoring these sagittal plane tasks.

2. Methods

2.1 Participants

Eighteen participants (4 males, 14 females) were recruited from within the university campus. These participants had a mean(SD) age of 21(2) years, height of 169(7) cm, mass of 65.4(6.9) kg and body mass index of 22.8(2.1) kg/m². Ethical approval from the local university research ethics committee (EHSREC 09-24) was obtained prior to the study. All participants provided written informed consent prior to participation. Participants were excluded if they were pregnant, aged less than 18 years, had current LBP, previous
NSCLBP for greater than three months, previous back surgery, a history of previous leg pain over the previous two years, previous postural education, or a known skin allergic reaction to tape.

2.2 Instrumentation
All posture measurements were performed with the BodyGuard™, which was adhered to the skin using adhesive tape (Figure 1). The BodyGuard™ incorporates a strain gauge that provides information about the relative distance between anatomical landmarks, estimating flexion/extension of the lumbar spine by the degree of strain gauge elongation. Elongation of the strain gauge alters its internal resistance, and therefore the voltage of the signal. This alteration in voltage occurs in a linear manner in response to elongation. Therefore, the voltage output is directly related to the length (flexion v extension) of the strain gauge. Postural data are recorded in real-time at 20Hz. Based on the elongation of the strain gauge, lower lumbar spine sagittal plane posture is expressed as a percentage of range of motion (ROM). Therefore, the degree of spinal flexion/extension is expressed relative to a referenced ROM, for example total lumbar flexion ROM, rather than being expressed in degrees (O'Sullivan et al. 2010b). This reflects the clinical assessment of patients where sitting posture is often considered relative to individual ROM. It is also similar to electromyography normalisation of muscle activity relative to maximal or sub-maximal voluntary contraction (Dankaerts et al. 2006a). The linearity of the BodyGuard™ has been established as excellent (correlation with digital callipers >0.99, mean difference <2.5% elongation). In comparison to other devices based on strain gauges (Donatell et al. 2005), the BodyGuard™ is very small, incorporating only a single strain gauge, with no other optical or inertial sensors being required. The device is operationally stable within a temperature range of 10-40°C. The BodyGuard™ has been validated as a measure of lumbo-pelvic posture and movement against a traditional flexible electrogoniometer (Biometrics), in both sitting (r=0.98) and standing (r=0.99) (O'Sullivan 2010).
2.3 Study Design
A between-day and inter-rater test–retest design was used. Two raters assessed participants on one day and one rater repeated the procedure on a second test day. The raters were a musculoskeletal physiotherapist with ten years clinical experience and an occupational therapist with three years clinical experience. Both raters agreed and practiced a procedure for palpation of the spine prior to testing. The BodyGuard™ was removed by each rater after testing, and re-applied by the other rater. Both raters were blind to previous results during testing. The mean(SD) number of days between testing was 5(2) days.

2.4 Experimental Protocol
2.4.1 Participant preparation
Participants removed their shoes and wore shorts during testing. The skin was cleaned with alcohol wipes prior to testing. The BodyGuard™ was positioned directly over the spine at the spinal levels of L3 and S1, as determined by palpation. These spinal levels were chosen as the lower lumbar spine is the most common area for people to report NSCLBP (Dankaerts et al. 2006b), and recent research suggests that the upper and lower lumbar spine regions
demonstrate functional independence (Dankaerts et al. 2006b; Mitchell et al. 2008). The BodyGuard™ was applied with participants sitting in a slouched position. Based on preliminary pilot testing, a 6cm strain gauge was used for all participants, and was secured with tape (Figure 1). Once the BodyGuard™ was positioned, participants stood up and performed repeated maximal flexion movements in standing to ensure the device was securely attached, and that its available length would not be exceeded during testing. Further, the BodyGuard™ was calibrated to full lumbar flexion ROM during standing flexion. To do this, each participant was first asked to maintain a relaxed standing position (Figure 2) which was set as 0% of their lumbar flexion ROM, and then to perform full flexion of the spine (“bend as far as possible towards your toes while keeping your knees straight”). This flexed position was set as 100% of their lumbar flexion ROM (Figure 3). Once this calibration procedure was completed, participants were asked to complete 3 repetitions of maximum ROM into full lumbar flexion in standing to ensure comfort and consistency of movement was possible while wearing the BodyGuard™. Participants then reassumed a seated position and were instructed in the tasks to be performed. All tasks were timed using an electronic clock. The following procedure was repeated in the same manner by both raters, on both test occasions.

Figure 2: Calibration to 0% flexion in standing
2.4.2 Forward Bending

For the forward bending (FB) task, participants were asked to bend forward in standing to touch a 45cm high target ("bend to touch the target while keeping your knees straight, and arms and fingers outstretched") (Figure 4). Foot position and distance from the target were standardised. To minimise the degree of natural variation in how participants performed the task, they were asked to perform it a few times for practice, taking breaks in between, until the rater was satisfied they were performing the task consistently. Participants then bent forward under verbal instruction, maintained this position for 5s, and then returned to their relaxed standing posture. This was performed three times.

2.4.3 Usual Sitting (US)

For the usual sitting (US) task, participants sat unsupported on a flat wooden 45cm high stool with their knees and ankles positioned at 90°, both feet flat on the ground, forearms over their thighs, while looking at a convenient fixed point straight ahead (Figure 5). In this position participants were asked to assume their usual sitting position ("sit as you usually do and look at the mark on the wall"). Similar to the FB task, participants adopted what they perceived as their US posture a few times for practice, until the tester was satisfied they were performing this consistently, to minimise the degree of natural variation.
Figure 4: Forward bending task

Figure 5: Usual sitting task
Participants were asked to remain in this position for 60s and this US posture was recorded once.

2.5 Data Analysis

Data were automatically uploaded to a Microsoft Excel file via a proprietary wireless signal developed by the manufacturers. For FB, the entire 5s of each sustained FB movement were analysed, and the average posture (expressed as %ROM) was used for comparison. For US, the entire 60s of data were analysed, and the average US posture was used for comparison. Data were then analysed using SPSS 15.0. The reliability analysis used in many studies (Troke et al. 1996; Schuit et al. 1997; Mannion and Troke 1999; Ng et al. 2001) has been criticised since the level of association between the data is assessed and no information on the level of agreement between measures is provided (Bland and Altman 1986; McGinley et al. 2009). To overcome this, it has been recommended that intra-class correlation coefficients (ICC) values are complemented with data that examines the level of agreement between measurements, for example using Bland and Altman methods (Bland and Altman 1986; Rankin and Stokes 1998). Therefore, for this study the association between values was analysed using one-way random (ICC_{2,1}) and two-way mixed (ICC_{3,2}) ICC’s, for between-day and inter-rater data respectively. In addition, Bland and Altman methods were used to determine the level of agreement between data (Bland and Altman, 1986). Finally, the standard error of measurement (SEM) and minimal detectable change at the 90% confidence level (MDC90) were calculated to provide an indication of the dispersion of the measurement error and the difference required between measurements to be considered real change. The mean difference, SEM and MDC90 values were all expressed as a percentage of flexion ROM.
3. Results

The mean(SD) posture during each task for each rater is displayed in Figure 6.

Figure 6: Mean(SD) lumbar posture during forward bending (FB) and usual sitting (US) for rater 1 on two occasions (R1-A and R1-B), as well as rater 2 (R2) on one occasion.

3.1 Between-day reliability

Between-day values displayed excellent association for both FB (ICC 2,1=0.87) and US (ICC 2,1=0.84) (Landis and Koch 1977). In addition, the between-day level of agreement was very good with mean difference values of 8.99% and 7.85% for FB and US respectively. The SEM was relatively small for both FB (5.91%) and US (4.78%). Finally, the MDC90 was 13.77% for FB and 11.14% for US (Table 2).

3.2 Inter-rater reliability

Inter-rater values also displayed excellent association for both FB (ICC 3,2=0.94) and US (ICC 3,2=0.91) (Landis and Koch 1977). In addition, the inter-rater level of agreement was very good with mean difference values of 6.31% and 6.17% for FB and US respectively. The SEM was again relatively small for both FB (4.16%) and US (3.87%). Finally, the MDC90 was 9.72% for FB and 9.03% for US (Table 2).
Table 2: Reliability of the wireless posture monitor

<table>
<thead>
<tr>
<th></th>
<th>ICC (95%CI)</th>
<th>d</th>
<th>95%CI for d</th>
<th>SD_diff</th>
<th>95%LOA</th>
<th>SEM</th>
<th>MDC90</th>
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<tbody>
<tr>
<td>FB-</td>
<td>0.87</td>
<td>8.99</td>
<td>5.1, 12.9</td>
<td>7.84</td>
<td>24.4, -6.4</td>
<td>5.9</td>
<td>13.8</td>
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<tr>
<td></td>
<td>(0.67,0.95)</td>
<td></td>
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<tr>
<td>FB-Inter</td>
<td>0.94</td>
<td>6.32</td>
<td>3.7, 9.0</td>
<td>5.29</td>
<td>16.7, -4.1</td>
<td>4.2</td>
<td>9.7</td>
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<tr>
<td></td>
<td>(0.84,0.98)</td>
<td></td>
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<tr>
<td>US-</td>
<td>0.84</td>
<td>7.85</td>
<td>5.6, 10.1</td>
<td>4.56</td>
<td>16.8, -1.1</td>
<td>4.8</td>
<td>11.1</td>
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<td></td>
<td>(0.57,0.94)</td>
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<tr>
<td>US-Inter</td>
<td>0.91</td>
<td>6.17</td>
<td>4.0, 8.4</td>
<td>4.47</td>
<td>14.9, -2.6</td>
<td>3.9</td>
<td>9.0</td>
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<tr>
<td></td>
<td>(0.77,0.97)</td>
<td></td>
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ICC= Intra class Correlation Coefficient; 95%CI= 95% confidence interval for the Intraclass Correlation Coefficient; ICC₂,₁ - used for between-day analysis; ICC₃,₂ - used for inter-rater analysis; d = mean differences between measures; expressed as %ROM; 95% CI for d = 95% confidence interval of the mean difference between measures, expressed as %ROM; SDdiff = standard deviation of the mean difference, expressed as %ROM; 95%LOA = 95% Limits of Agreement (calculated by d +/- [SD diff multiplied by 1.96]), expressed as %ROM; SEM = standard error of measurement, calculated as SD × \(\sqrt{(1 - ICC)}\); MDC90 = minimal detectable change at the 90% confidence interval; FB = Forward Bending; US = Usual Sitting.

4. Discussion

Good between-day and inter-rater reliability is a basic requirement for validity. Between-day reliability is important if the device is to be used as an outcome measure, while inter-rater reliability is important if different raters are to perform consistent measurements. The results indicate the reliability of the device for analysing lumbar spine posture during sagittal plane tasks is excellent. All ICC values were over 0.81 which has been described as “almost perfect” association between measurements (Landis and Koch 1977). Reliability of spinal posture measurement is critical to ensure that the presence or absence of an association between spinal posture and NSCLBP can be accurately estimated (Dartt et al. 2009). A high degree of measurement error could result in subtle alterations in posture going unnoticed, or indeed non-existent postural differences could be assumed on the basis of poor reliability.

The ICC values observed in this study for sagittal plane postural measurement using the BodyGuard™ are similar to those reported for
measurement of standing sagittal plane lumbar posture using laboratory motion analysis systems (Levine and Whittle 1996; Norton et al. 2002; Schuit et al. 2004; Troke et al. 2007), as well as simpler devices such as inclinometers (Ng et al. 2001). Furthermore, the ICC values are superior to those reported for digital photography for measurement of either standing or sitting lumbar sagittal plane postures (Dunk et al. 2004; Perry et al. 2008; Pownall et al. 2008). It is acknowledged that no study has previously examined the repeatability of the FB task performed in this study. However, the reliability of digital photography to measure lumbar flexion using a different standardised FB task was also slightly lower than that reported here (Corben et al. 2008). This, in addition to the fact that the device displays greater reliability during the sitting task compared to digital photography (Pownall et al. 2008) implies the device itself may be more reliable than digital photography. Overall, the ICC values were slightly better for inter-rater measurements, possibly due to these tests being conducted on the same day.

As previously mentioned, many reliability studies simply describe the association between measurements, but not the true level of agreement, which has been criticised (Bland and Altman 1986; McGinley et al. 2009). The mean differences obtained in this study, which varied between 6% and 9% of lumbar flexion ROM, appear to represent a relatively small amount of variation between testers. The SEM similarly varied between 4% and 6% for all measurements, and the MDC90 varied from 9%-14%. Ideally, the mean difference, SEM and MDC90 should be small and close to zero. It is difficult to estimate what is an acceptable level of difference between repeated measurements using the BodyGuard™ as this depends on the extent of the hypothesised postural differences between NSCLBP participants and matched controls, which is the scope of current further investigation. Since this discriminative validity of the device has not yet been fully investigated, this information is unknown. However based on NSCLBP research using angular measurements during laboratory testing (Dankaerts et al. 2006b), the degree of measurement error reported here for the BodyGuard™ appears to be acceptable. Therefore, based on previous research it appears the reliability of this postural monitoring device is as good as, or better than, other lumbar
posture measurement devices, either large laboratory-based systems or smaller, portable devices.

4.1 Applications and implications
The BodyGuard™ is a relatively simple, economical, and minimally-invasive postural monitoring system. It is considerably smaller than some alternative devices (Donatell et al. 2005), so that it should not interfere with normal movements and function. Many other similar-sized devices are based on overall trunk flexion rather than local spinal flexion (Intolo et al. 2010), which is a considerable disadvantage when addressing subtle local changes in lumbar spine posture. It is difficult to compare the output regarding spinal posture with the results of other devices as the output of this device is not expressed in degrees, and currently only measures sagittal plane motion. Despite this, research indicates that expressing lumbar posture relative to ROM (as the BodyGuard™ does) may be very useful, since postural differences between healthy controls and people with NSCLBP have been observed in laboratory settings (Dankaerts et al. 2006b). Only moderate human resources are needed for data collection and analysis, and very little training is required, reducing potential barriers to its application in practice.

This is the first in a series of studies planned to determine the clinical utility of the device for research in NSCLBP populations. While the device has been validated in simple sagittal plane postures and movements against an electrogoniometer, future studies will be performed to compare this device to a standard laboratory-based motion system, as well as digital videofluoroscopy, similar to the approach used with the validation of other motion analysis systems (Schuit et al. 1997; Mannion and Troke 1999; Bull and McGregor 2000; Ripani et al. 2008; Intolo et al. 2010).

Further studies are also required to determine if the device can discriminate between subgroups of people with NSCLBP and matched controls, similar to existing laboratory-based systems (Dankaerts et al. 2006b). Similarly, whether the provision of postural biofeedback via the BodyGuard™ improves outcomes in NSCLBP requires investigation. The potential to provide patients with biofeedback regarding the control of their
movement patterns may motivate patients (Horton and Abbott 2008), improve exercise performance (Magnusson et al. 2008), reduce the link between pain and movement (Zusman 2008), and might decrease the enormous rehabilitation costs associated with NSCLBP (Hermens and Vollenbroek-Hutton 2008).

As stated earlier, the use of spinal biofeedback to change motor patterns was supported in a recent study (Magnusson et al. 2008), and the BodyGuard™ is more portable and less-invasive than many existing devices. The BodyGuard™ may allow investigation of whether factors such as postural variability or prolonged exposure to near end-range postures are predictors of LBP, as detailed examination of these relationships in the past have been constrained by technological limitations. Currently digital photography and video analysis are commonly used in ergonomic research as they are the least invasive (Spielholz et al. 2001; Dartt et al. 2009; Straker et al. 2009). In future trials, the device may offer more specific assessment of postural exposure while still allowing maximal work productivity. Indeed, it is now possible to remotely monitor several people simultaneously and longitudinally using the BodyGuard™, so that the temporal relationship between postural exposure and musculoskeletal pain and discomfort can be studied in greater detail.

The device may also help bridge the gap between advice given to NSCLBP patients in the laboratory or clinic, and the challenges faced in implementing these postural changes into daily life.

4.2 Limitations

The sample size, although larger than some previous studies examining the reliability of lumbar posture and movement (Mannion and Troke 1999; Ng et al. 2001; Pownall et al. 2008), is small. Errors of palpation are always possible between raters; however every effort was made to ensure consistency of palpation technique between raters. The values obtained reflect those of two raters who practiced palpation and device application in advance, so that it is possible reliability would be lower for other raters. Inconsistent movement or postures by participants may explain some of the observed variation; however
this was minimised by giving clear instructions, along with time to practice each procedure. This study only evaluated the reliability of the BodyGuard™ for the lower lumbar spine during sagittal plane flexion tasks. The ability of the BodyGuard™ to monitor other spinal regions and planes of motion requires further study. The reliability of the BodyGuard™ in occupational environments, or when self-applied by the NSCLBP patient, has yet to be evaluated. Similar to all skin mounted spinal measurement systems, the BodyGuard™ may not reflect actual spinal motion, particularly as its output is related to linear strain gauge elongation and not angular displacement. The risk that motion in planes other than the sagittal plane (e.g. rotation or side-flexion) could compromise or contaminate the output must be examined in future validity studies. The limitations associated with not providing an angular output, and analysing only sagittal plane postures have already been highlighted. In future studies the calibration procedure may need to be specific to the task being analysed e.g. seated ROM if examining US task, however this was not deemed necessary for this initial study.

While there is emerging evidence that for subgroups of NSCLBP postural factors can be significant (Dankaerts et al. 2006b; 2007), it is acknowledged that there is still little agreement on what constitutes ideal posture (O'Sullivan et al. 2006a; Claus et al. 2009c; Reeve and Dilley 2009; O'Sullivan et al. 2010b). Further, it is acknowledged that NSCLBP is a multifactorial biopsychosocial disorder where numerous factors other than posture and movement patterns must be considered (McCarthy et al. 2004; Linton et al. 2007)

5. Conclusion
The results indicate that the BodyGuard™ has excellent reliability for analysis of lower lumbar spine sagittal posture, both between-days and between-raters. It has several potential advantages over existing methods of analysing spinal posture, although the lack of an angular output is a limitation. Further validation studies using this device are indicated before progressing to clinical trials.
Study II: Towards monitoring lumbo-pelvic posture in real-life situations: Concurrent validity of a novel posture monitor and a traditional laboratory-based motion analysis system


Abstract

Many factors are associated with non-specific chronic low back pain (NSCLBP), including provocative spinal postures. Consequently, lumbo-pelvic posture is commonly assessed in NSCLBP patients. A novel wireless monitor (BodyGuardTM) can monitor lumbo-pelvic sagittal plane movements reliably, and has demonstrated concurrent validity during non-functional tasks. This study evaluated the concurrent validity of this monitor during functional tasks, as a precursor to NSCLBP field studies. Twelve painfree participants performed a series of postural tasks (in sitting and standing) three times. Simultaneous postural measurements were obtained by the wireless monitor and a laboratory-based system (CODA™). Postural measurements were strongly correlated ($r_s=0.88$, $r^2=0.78$). The mean difference observed was small (<10% lumbo-pelvic ROM), however some tasks displayed greater error. The results support the concurrent validity of the wireless monitor for analysing lumbo-pelvic posture during functional tasks. Specific limitations of the monitor for certain postural tasks were identified, and should be considered before implementation in future field studies.

Keywords: posture; low back pain; validity.
1. Introduction

Non-specific chronic low back pain (NSCLBP) is a very common and costly musculoskeletal disorder (Woolf and Pfleger 2003), with many identified contributing factors including people adopting provocative spinal postures and movements (Pope et al. 2002; Scannell and McGill 2003; O'Sullivan 2005; Lis et al. 2007). Despite the significance of maladaptive postures in NSCLBP, most studies investigating posture have been confined to laboratories using traditional laboratory-based motion analysis systems (Dankaerts et al. 2006b; Mitchell et al. 2008). The ecological validity of these studies is limited as the methods and setting seldom approximate the real-life situation that is under investigation, and long-term observation is rarely possible. Furthermore, laboratory systems are costly, complex and time-consuming with limited ability to provide postural biofeedback during daily tasks, which is significant given the potential role of postural awareness and position sense in certain NSCLBP disorders (O'Sullivan et al. 2003).

Rather than reporting the actual lumbar spinal curvature, many NSCLBP field studies have simply considered the duration or frequency which different postures (e.g. sitting versus standing) are adopted for (Roffey et al. 2010a; 2010c; 2010d; Wai et al. 2010c; Wai et al. 2010a). Similarly, the measurement techniques used in previous occupational research have been constrained by technological limitations. Digital photography (Straker et al. 2009) and video analysis (Spielholz et al. 2001) have been commonly used as they are less invasive and less costly than three-dimensional (3D) motion analysis systems. However, their ability to detect regional changes in spinal posture reported in laboratory-based studies (Dankaerts et al. 2006b; Mitchell et al. 2008) is limited (Elliott et al. 2007).

In recognition of the importance of field-based posture recording, several portable, minimally-invasive methods of analysing posture in non-laboratory settings have recently been developed (Donatell et al. 2005; Dean and Dean 2006; Horton and Abbott 2008). Spinal posture analysis is now possible using accelerometers (Intolo et al. 2010), fibre-optic goniometers (Bell 2008), strain gauges and/or optical sensors (Donatell et al. 2005; Dean and Dean 2006), and gyroscopes (Lee et al. 2003). Despite their potential,
some devices are relatively large and cannot be concealed easily (Donatell et al. 2005; Magnusson et al. 2008), or can only be used under supervision (Magnusson et al. 2008). While the reliability (Donatell et al. 2005) and validity (Intolo et al. 2010) of some of these devices has been investigated, this is not the case with all devices (Dean and Dean 2006; Magnusson et al. 2008; Mork and Westgaard 2009). Other more simple devices can provide a snapshot of static spinal posture, but cannot analyse dynamic posture or provide postural biofeedback (Mannion et al. 2004; Sheeran et al. 2010). As a result of these limitations, there remains a need to develop and investigate methods of analysing spinal posture in a reliable, valid and sensitive manner outside the laboratory.

The BodyGuard™, a recently developed spinal posture monitoring device (Sels Instruments, Belgium), monitors sagittal spinal posture without cumbersome cables, facilitating more normal movement inside and outside the laboratory. While many portable monitors can either monitor posture or provide immediate real-time postural biofeedback (Dean and Dean 2006; Magnusson et al. 2008; Mork and Westgaard 2009; Bible et al. 2010), the BodyGuard™ can do both. While the BodyGuard™ has very good between-day and inter-rater reliability (O'Sullivan et al. 2011a), its validity is unclear. This study aimed to evaluate the concurrent validity of the BodyGuard™ by comparing lumbo-pelvic posture in painfree participants during a series of common functional tasks and postures (sitting and standing), as measured by the BodyGuard™, to a traditional laboratory-based motion analysis system.

2. Methods

2.1 Study design

A single session, concurrent validation study.

2.2 Participants

Twelve participants (9 female) were recruited via advertising within the local community. Participants’ mean(SD) age was 25.9(4.9) years, height was 169(4) cm, mass was 64.6(6.8) kg and body mass index (BMI) was 22.7(2.2) kg/m². Participants with current or previous NSCLBP, or who were pregnant
or aged <18 years were excluded. All participants provided written informed consent. Ethical approval was obtained from the local university Research Ethics Committee (Ref EHSREC 09-25).

2.3 Procedure

2.3.1 Instrumentation

The BodyGuard™ consists of a lightweight battery-powered processing unit and a strain gauge (Figure 7), and communicates via a proprietary wireless protocol with a computer as previously described (O'Sullivan et al. 2011a). It calculates spinal flexion/extension as a percentage of strain gauge elongation, so that posture is expressed relative to range of motion (ROM), rather than being expressed in degrees (O'Sullivan et al. 2010b). BodyGuard™ data were recorded in real-time at 20Hz. The Cartesian Optoelectronic Dynamic Anthropometer (CODA™) mpx64 (Charnwood Dynamics Ltd, Leicestershire UK) is a 3D pre-calibrated motion analysis system, which uses a laboratory-based coordinate system. The resolution of the system has been described previously (Richards 1999). CODA™ data were acquired and digitised at a sampling rate of 200Hz.

Figure 7: Participant in sitting with the BodyGuard™ posture monitor positioned using adhesive tape over the lower lumbar spine, at the levels of L3 and S2
2.3.2 Placement of spinal markers

A 6cm BodyGuard™ strain gauge was positioned over the lower lumbo-pelvic region with double-sided adhesive tape at the spinal levels of L3 and S2, since the upper and lower lumbar spine regions demonstrate functional independence and the lower lumbar spine is the most symptomatic region in NSCLBP (Dankaerts et al. 2006b; Mitchell et al. 2008). These levels were identified by manual palpation in a slightly flexed sitting posture. Two CODA™ cameras were placed 80cm apart, and approximately 2.2m posterolateral to the participants. CODA™ light emitting diode (LED) markers were positioned using double-sided adhesive tape on the skin surface over the following landmarks; right and left posterior superior iliac spine (PSIS), spinous process of L1, as well as bilaterally 5cm lateral to L3. In addition, three CODA™ markers were superimposed over the end-blocks of the strain gauge; one over L3 and two placed on the sacral attachment approximately 3.5cm apart (Figure 8). All placements were performed by a single investigator. Marker locations were reconstructed using customised CODA™ software and 3D rigid body segments were calculated during post processing, similar to previous research (Intolo et al. 2010). The lumbar rigid body was generated from the L1 and L3 markers (Y – axis) and L3 bilateral markers (second defining line and cross product with the Y axis used to create the X axis, and cross product of Y and X used to create the Z-axis). The pelvic rigid body was generated from the two markers overlying the sacrum (Y – axis), and the PSIS markers (second defining line: with remaining rigid body definition as outlined above). Lumbar rigid body motion relative to pelvic rigid body motion was calculated using a flexion–extension/abduction–adduction/internal–external rotation Cardan sequence of rotations in accordance with previous research (Intolo et al. 2010). The static accuracy of this CODA™ marker protocol was evaluated in advance, with the average static variation across five acquisitions <0.1°.
2.3.3 Calibration

The BodyGuard™ was calibrated relative to maximum ROM in both sitting and standing, with simultaneous CODA™ acquisition. For sitting, participants sat on an adjustable stool without back support, with their bare feet on the ground and their hips and knees flexed to 90°. Maximum anterior pelvic tilt was set as 0% ROM, and maximum posterior tilt was set as 100% ROM. For standing, participants stood in their bare feet with their feet shoulder width apart. In standing, anterior pelvic tilting and lumbar extension ROM was set as 0% ROM and full forward bending was set as 100% ROM. In both postures, participants practiced this calibration movement three times with manual and verbal facilitation before recording.

2.3.4 Reliability of the experimental setup

Despite both systems having established reliability (O'Sullivan et al. 2010a; O'Sullivan et al. 2011a), reliability was reassessed due to the altered marker placements required for simultaneous data acquisition. The first ten participants completed a range of sagittal plane sitting and standing tasks (usual sitting, usual standing, forward bending to knee, forward bending to lower leg) twice on one occasion. One-way random intra-class correlation
coefficient (ICC$_{1,1}$) values were all >0.73, with maximum mean differences of 1.4° for CODA™ and 1.4%ROM for the BodyGuard™, demonstrating very good reliability (Landis and Koch 1977).

2.4 Tasks performed
Participants completed tasks in both standing and sitting, including a mix of sagittal plane postures, as well as functional tasks which included varying degrees of movement into other planes. Each posture or task was performed for 30s, with 5s of data in the middle captured simultaneously by both systems. Postures and tasks were practiced three times before data collection.

2.4.1 Standing tasks
Participants assumed the following static postures; usual standing, forward bending to their knees (superior margin of patella) and forward bending to their lower leg (mid-level between lateral tibial plateau and floor). For forward bending tasks, participants bent forward with straight arms and touched an adjustable height surface with their fingertips, similar to previous research (Intolo et al. 2010). In addition, a number of common functional tasks were then completed. Participants were asked to lift and lower a box (mass=9.4kg) initially placed directly in front of them, and afterwards with the same box placed in front to the right hand side, to combine flexion with some trunk rotation. Other functional tasks involved wiping a bench placed at the height of the superior pole of the patella, sweeping the floor with a brush, and a sit-to-stand transfer, which were completed in any manner the participant wished.

2.4.2 Sitting tasks
The usual sitting posture of participants on a stool was first measured. Participants were then instructed to actively assume some altered sitting postures that were more flexed or extended than their usual posture. Finally, they were facilitated into a “neutral” sitting posture (O'Sullivan et al. 2010b). Three common daily seated tasks (typing on a laptop, reading a book, and writing in a notebook) were then completed in any manner the participant wished.
wished, provided they remained seated on the stool. Finally, participants were asked to remove and replace their left shoe, at a self-selected speed.

### 2.4.3 Non-sagittal plane movement

To investigate if BodyGuard™ accuracy was distorted by non-sagittal plane motion, all participants performed full bilateral trunk rotation and trunk side flexion, in both sitting and standing.

### 2.5 Data analysis

Following a residual analysis (Winter 1999), CODA™ data were low pass filtered at 16Hz using a fourth order Butterworth filter. Mean flexion data were exported for analysis, except for tasks where estimates of peak flexion were considered more clinically relevant, such as the bending and lifting tasks, and estimates for sit-to-stand transfers and putting on a shoe. Sitting data for one participant was lost, so that sitting data were available for only 11 participants. Since BodyGuard™ data are expressed as %ROM, CODA™ data were converted to %ROM to allow for easier comparison. Data were analysed using SPSS 16.0. Data were not normally distributed (Shapiro-Wilks; p<0.05). Therefore, overall agreement between BodyGuard™ and CODA™ data across all tasks for all participants was assessed using Spearman’s rank correlation coefficient ($r_s$), the coefficient of determination ($r^2$), and analysis of the mean difference (Bland and Altman 1986). Finally, clustering of data for many tasks meant correlations were not appropriate when analysing each task separately. As a result, agreement for each task was assessed using only the mean difference between BodyGuard™ and CODA™ data (Bland and Altman 1986). To accept the validity of the BodyGuard™ device, it must demonstrate a strong correlation ($r_s >0.8$) (Polgar and Thomas 2008). When assessing each task across all participants, differences >5° (13% of standing ROM, 19% of sitting ROM) were considered large errors, consistent with another validation study (Intolo et al. 2010).
3. Results
The ROM in standing and sitting, as calculated by the CODA™ system, is displayed in Table 3. All %ROM values presented refer to the posture relative to lumbo-pelvic ROM. There were strong positive correlations and small differences (approximately 3°) between the BodyGuard™ and CODA™ overall in sitting and standing (Table 4). Looking at the agreement for each participant separately, across all tasks in standing all participants had strong correlations ($r_s >0.8$), and 9/12 had overall mean differences of <10%ROM. Across all tasks in sitting, 9/11 participants had strong correlations of $>0.8$, yet only 6/11 had overall mean differences of <10%ROM.

Table 3: Mean(SD) total range of motion (ROM) in the lower lumbo-pelvic region, in standing and sitting, as calculated by the CODA™ motion analysis system

<table>
<thead>
<tr>
<th>Movement</th>
<th>Standing ROM (°)</th>
<th>Sitting ROM (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion / Extension</td>
<td>38.7(11.0)</td>
<td>25.1(6.3)</td>
</tr>
<tr>
<td>Rotation</td>
<td>12.9(5.0)</td>
<td>12.8(7.0)</td>
</tr>
<tr>
<td>Side Flexion</td>
<td>36.8(8.6)</td>
<td>23.6(9.8)</td>
</tr>
</tbody>
</table>

Table 4: The agreement between the BodyGuard™ and CODA™ motion analysis system across all tasks, for both sitting and standing.

<table>
<thead>
<tr>
<th>Position</th>
<th>$r_s$</th>
<th>$r^2$</th>
<th>$d$ (%ROM)</th>
<th>$d$ (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing</td>
<td>0.88</td>
<td>0.78</td>
<td>-7.91</td>
<td>3.06</td>
</tr>
<tr>
<td>Sitting</td>
<td>0.88</td>
<td>0.78</td>
<td>-9.53</td>
<td>2.39</td>
</tr>
</tbody>
</table>

$r_s$ = spearmans rank correlation coefficient; $r^2$ = coefficient of determination; $d$ = mean difference between measures; %ROM = percentage of range of motion.

3.1 Agreement during specific tasks
The agreement between BodyGuard™ and CODA™ data during each specific task, in sitting and standing, are summarised in Table 5. Overall, the mean difference varied considerably between tasks. The mean difference was small.
during simple forward bending (Figure 9) and many sitting tasks (Figure 10). However, the mean difference was higher during tasks such as sweeping the floor (Figure 11), and exceeded $5^\circ$ for two tasks when estimating peak flexion (Figure 12).

![Figure 9: Plot of peak flexion angle during flexion to the lower leg.](image)
The lines indicate the mean difference, and the 95% confidence interval (CI) of the mean difference. All values expressed in % of lumbo-pelvic ROM, where 0% = full extension and 100% = full flexion.

![Figure 10: Plot of mean posture during the typing task.](image)
The lines indicate the mean difference, and the 95% confidence interval (CI) of the mean difference. All values expressed in % of lumbo-pelvic ROM, where 0% = full extension and 100% = full flexion.
The mean difference between the BodyGuard™ device and the CODA™ system was small during both trunk rotation (<2°) and side-flexion (<4°) (Table 5).

3.2 Effect of non-sagittal plane movement

The mean difference between the BodyGuard™ device and the CODA™ system was small during both trunk rotation (<2°) and side-flexion (<4°) (Table 5).
Table 5: The agreement between the BodyGuard™ and CODA™ motion analysis system across a range of tasks in sitting and standing

<table>
<thead>
<tr>
<th>Task</th>
<th>d (% ROM)</th>
<th>d (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Usual Standing (mean)</td>
<td>-11</td>
<td>-4.3</td>
</tr>
<tr>
<td>Flexion to knees (peak)</td>
<td>-3</td>
<td>-1.2</td>
</tr>
<tr>
<td>Flexion to lower leg (peak)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lift box in front (peak)</td>
<td>-7</td>
<td>-2.7</td>
</tr>
<tr>
<td>Lower box in front (peak)</td>
<td>-8</td>
<td>-3.1</td>
</tr>
<tr>
<td>Lift box at angle (peak)</td>
<td>-6</td>
<td>-2.3</td>
</tr>
<tr>
<td>Lower box at angle (peak)</td>
<td>-9</td>
<td>-3.5</td>
</tr>
<tr>
<td>Wiping bench (mean)</td>
<td>-5</td>
<td>-1.9</td>
</tr>
<tr>
<td>Sweeping floor (mean)</td>
<td>-13</td>
<td>-5.0</td>
</tr>
<tr>
<td>Sit-to-stand extension (peak)</td>
<td>-9</td>
<td>-3.5</td>
</tr>
<tr>
<td>Sit-to-stand flexion (peak)</td>
<td>-16</td>
<td>-6.2</td>
</tr>
<tr>
<td>Standing rotation (mean)</td>
<td>5</td>
<td>1.9</td>
</tr>
<tr>
<td>Standing side-flexion (mean)</td>
<td>-10</td>
<td>-3.8</td>
</tr>
<tr>
<td><strong>Sitting</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Usual sitting (mean)</td>
<td>-3</td>
<td>-0.8</td>
</tr>
<tr>
<td>Instructed sitting postures (mean)</td>
<td>-14</td>
<td>-3.6</td>
</tr>
<tr>
<td>Neutral sitting (mean)</td>
<td>-3</td>
<td>-0.8</td>
</tr>
<tr>
<td>Typing (mean)</td>
<td>-7</td>
<td>-1.8</td>
</tr>
<tr>
<td>Reading (mean)</td>
<td>-6</td>
<td>-1.5</td>
</tr>
<tr>
<td>Writing (mean)</td>
<td>-4</td>
<td>-1.0</td>
</tr>
<tr>
<td>Putting on shoe (peak)</td>
<td>-23</td>
<td>-5.8</td>
</tr>
<tr>
<td>Sitting rotation (mean)</td>
<td>-1</td>
<td>-0.0</td>
</tr>
<tr>
<td>Sitting side-flexion (mean)</td>
<td>-12</td>
<td>-3.1</td>
</tr>
</tbody>
</table>

\(d = \text{mean difference between measures}; \ %\text{ROM} = \text{percentage of lumbo-pelvic range of motion.}\)
4. Discussion

The results of the current study further support the concurrent validity of the BodyGuard™ as a method of monitoring lumbo-pelvic posture relative to the CODA™ motion analysis system. Across a series of functional postures and tasks, strong correlations and high coefficients of determination were observed in both sitting and standing tasks (Polgar and Thomas 2008). Furthermore, the differences across all these tasks were small (maximum difference = 5.8°). When combined with previous data on reliability in non-functional tasks (O'Sullivan et al. 2011a), it appears the concurrent validity of the BodyGuard™ device is similar, or superior, to other posture monitors, both portable and laboratory-based (Thoumie et al. 1998; Perret et al. 2001; Friedrich 2002; Campbell-Kyureghyan et al. 2005; Guermazi et al. 2006; Bible et al. 2010; Intolo et al. 2010). For instance, a portable accelerometry-based device (Spineangel™) recently demonstrated moderate validity (r=0.38–0.93) for a variety of sitting and standing tasks when compared with 3D motion analysis (Intolo et al. 2010). Similar correlations and mean differences have been reported for other portable posture monitors (Stigant 2000; Vergara and Page 2000; Friedrich 2002), compared to 3D motion analysis systems or simple surface measures of spinal posture. Significantly, the postures and movements assessed in many of these other studies (Stigant 2000; Vergara and Page 2000; Friedrich 2002; Intolo et al. 2010) were closely controlled, and did not consider as wide a range of tasks and movements as the current study. This strengthens the validity of the BodyGuard™ as being suitable for monitoring complex postures and movements inside and outside the laboratory.

When the level of agreement is examined across each task separately (Table 5), it is clear that this varies considerably. Unsurprisingly, the strongest level of agreement was in controlled tasks, where there was little risk of bias due to coupled non-sagittal plane spinal motion or trunk lean. For example, the mean differences during forward bending to the knees and lower leg were <3%ROM. Other relatively static tasks with little non-sagittal plane movement such as usual sitting, typing, reading and writing also demonstrated small mean differences (Table 5).
In contrast, larger errors were observed during tasks involving considerable trunk leaning such as sweeping the floor, or when putting on a shoe (Table 5). Furthermore, it appears that estimates of peak spinal flexion angle during rapid movements may not be as accurate as estimates of mean posture during more sustained tasks and postures. Indeed the highest errors were evident in peak flexion estimates when participants performed movements which involved trunk flexion close to 100% of ROM, for example putting on a shoe. This is likely to reflect the fact that significant skin movement may occur during these tasks. As seen in Table 4, the margin of error across all tasks was broadly similar for sitting and standing (approximately 3°). While the BodyGuard™ is biased to some extent by non-sagittal movements and the addition of trunk rotation during a lifting task, this does not appear to be a very large source of error when comparing the values for lifting and lowering boxes at different angles (Table 5). It should also be acknowledged that measures of posture and movement commonly display considerable variation between different measurement systems (Gracovetsky et al. 1995; Assink et al. 2008). Since the difference was <5° with the exception of two estimates of peak flexion, the error in the current study is within levels of acceptability proposed in a previous similar study (Intolo et al. 2010).

Based on the results of the current study, a few issues are worthy of consideration before progressing to clinical trials using the BodyGuard™. Firstly, the BodyGuard™ tends to systematically underestimate lumbo-pelvic flexion to a slight degree, such that lumbo-pelvic flexion - in particular peak flexion - over a period of monitoring may be underestimated. However, this is not a major concern as long as variables known to confound surface-based motion analysis, such as BMI and age, are also controlled between populations. Secondly, the larger errors observed during tasks involving significant trunk leaning possibly reflects strain gauge elongation due to trunk lean and not just pure lumbo-pelvic flexion. As a result, the BodyGuard™ may be of most use in situations where significant trunk lean is not involved e.g. seated office workers. Alternatively, a method of controlling for the influence of trunk lean, for example synchronising accelerometry with data from the BodyGuard™, would allow interpretation of the bias due to trunk lean. Thirdly,
the error in sitting was greater when participants assumed postures other than their usual posture or a facilitated “neutral” posture. The reason for this is not entirely clear, although it may reflect participants using thoraco-lumbar motion, which was not captured by the BodyGuard™, rather than simply lumbo-pelvic motion to change their posture. Finally, it has not yet been investigated if the device can discriminate between subgroups of subjects with NSCLBP and matched controls (discriminative validity), although the error observed in the current study appears to be less than the between-group difference observed using laboratory-based systems (Dankaerts et al. 2006b; Luomajoki et al. 2008). Further studies in subjects with NSCLBP, and involving longer-term monitoring of lumbo-pelvic posture, are indicated.

There are several limitations to this study. The small sample size was not based on a power calculation, although it was consistent with previous validation studies (Schuit et al. 1997; Intolo et al. 2010). Placement of the strain gauge was based on manual palpation of spinal levels, which may involve some error. Participants were painfree, and primarily young and female, so that it is possible that validity may vary in different populations. Postural data were not expressed in degrees, although calculating posture relative to ROM is useful in NSCLBP research (Dankaerts et al. 2006b). Neither the BodyGuard™ nor CODA™ directly calculate spinal posture, however, the ROM data observed using CODA™ are similar to data on vertebral motion from L3-S1 in previous studies (Abbott et al. 2006). Obviously, many other tasks and postures are performed in daily life, however the wide range of tasks tested here is likely to reflect overall validity during normal everyday tasks. While posture and movement patterns may be significant in some people with NSCLBP (Dankaerts et al. 2006b), it is acknowledged that numerous other factors in NSCLBP must be considered within a biopsychosocial framework (McCarthy et al. 2004).

The simple, economical and minimally-invasive nature of the BodyGuard™ suggests it is a viable option for analysis of lumbo-pelvic sagittal plane posture and motion. It appears to be more sensitive to subtle postural alterations than digital photography and/or video assessments (Spielholz et al. 2001; Dartt et al. 2009; Straker et al. 2009) and has the advantage of directly measuring lumbo-pelvic posture, rather than simply overall trunk flexion (Intolo
et al. 2010). The BodyGuard™ can facilitate provision of real-time postural biofeedback (audio or vibratory) if a subject exceeds a pre-set threshold value of flexion or extension. Since posture modification and postural awareness training has been associated with improved clinical outcomes (Van Dillen et al. 2003a; Dankaerts et al. 2007; Horton and Abbott 2008; Magnusson et al. 2008; Luomajoki et al. 2010), the BodyGuard™ may therefore also be useful as a feedback tool.

5. Conclusion
The BodyGuard™ has concurrent validity as a means of assessing lumbo-pelvic posture and movement in the sagittal plane during a variety of functional tasks. It is a potentially useful tool for monitoring of lumbo-pelvic posture, in both laboratory and clinical settings. It requires further examination in clinical populations.
Study III: Validation of a novel spinal posture monitor: comparison with digital videofluoroscopy

Abstract
A novel, minimally invasive posture monitor which can monitor lumbar postures outside the laboratory has demonstrated excellent reliability, as well as concurrent validity compared to a surface marker-based motion analysis system. However, it is unclear if this device reflects underlying vertebral motion. Twelve participants performed full range sagittal plane pelvic tilting during sitting and standing. Their posture was measured simultaneously using both this device (BodyGuard™) and digital videofluoroscopy. Strong correlations were observed between the two methods (all rs >0.88). Similarly, the coefficients of determination were high (all r² >0.78). The maximum mean differences between the measures were located near the mid-range of motion and were approximately 3.4° in sitting and approximately 3.9° in standing. The BodyGuard™ appears to be a valid method of analysing vertebral motion in the sagittal plane and is a promising tool for long-term monitoring of spinal postures in laboratory and clinical settings in people with low back pain.

Keywords: low back pain; posture; validity; fluoroscopy; ergonomics
1. Introduction
Non-specific chronic low back pain (NSCLBP) is a very common and costly musculoskeletal disorder (Woolf and Pfleger 2003). Different contributing factors in NSCLBP have been proposed, including provocative spinal postures and movement patterns (Dankaerts et al. 2006b). While mechanical loads due to provocative postures and movement patterns do not in isolation cause NSCLBP (Roffey et al. 2010a; 2010c), assuming provocative postures may increase the risk of developing NSCLBP (Smith et al. 2008). Furthermore, static postures and dynamic tasks such as bending or lifting are common aggravating factors for NSCLBP subjects (Dankaerts et al. 2006b). As a result, avoiding provocative spinal postures is commonly advocated for NSCLBP (Smith et al. 2008).

The most common method of analysing spinal posture is using surface markers in laboratories (Dankaerts et al. 2006b). While such systems may not have the accuracy of radiographic imaging (Campbell-Kyureghyan et al. 2005), they involve no irradiation. Unfortunately, these systems are costly, complex, time-consuming and cannot be easily used in “real-world” settings. Many of these systems are also limited by their inability to provide instantaneous postural biofeedback while NSCLBP subjects perform daily tasks. This is significant considering the role reduced postural awareness may play in NSCLBP (O'Sullivan et al. 2003).

Many studies examining the role of posture in NSCLBP have simply considered the duration or frequency the posture is adopted, rather than actual spinal posture (Roffey et al. 2010a; 2010c). Similarly, the measurement techniques used in previous occupational research have been constrained by technological limitations. Digital photography and video analysis are commonly used in ergonomic research as relatively cheap, reliable and non-invasive options (Spielholz et al. 2001; Straker et al. 2009). However, both approaches are limited as methods of “real-world” analysis by factors such as clothing and furniture, or the need to be physically present if the person being monitored moves to a different location. To better evaluate the relationship between posture and NSCLBP, minimally invasive methods of monitoring lumbo-pelvic posture during daily tasks outside the laboratory are required.
Several portable, minimally invasive methods of analysing posture in “real-world” settings have recently been developed. Spinal posture analysis is now possible using devices based on accelerometers (Intolo et al. 2010), inclinometers (Mork and Westgaard 2009), gyroscopes (Lee et al. 2003), fibre-optics (Bell 2008), strain gauges and/or optical sensors (Donatell et al. 2005; Dean and Dean 2006) and ultrasound (Wunderlich et al. 2011). Despite their potential, some devices are relatively large and cannot be concealed easily (Donatell et al. 2005), or can only be used under supervision (Magnusson et al. 2008). While the reliability and/or validity of some of these devices has been investigated (Donatell et al. 2005; Intolo et al. 2010; Wunderlich et al. 2011), this is not the case with all devices (Dean and Dean 2006; Magnusson et al. 2008; Mork and Westgaard 2009). Other devices can provide a snapshot of static spinal posture, but cannot analyse dynamic posture or provide postural biofeedback (Mannion et al. 2004; Sheeran et al. 2010).

The “BodyGuard™” (Sels Instruments, Belgium) monitors spinal sagittal plane posture using a strain gauge. It has no cumbersome cables, facilitating normal movement in a variety of tasks both inside and outside the laboratory. Unlike many portable monitors which can either monitor posture or provide postural biofeedback (Dean and Dean 2006; Magnusson et al. 2008; Mork and Westgaard 2009; Bible et al. 2010), it can both monitor posture and provide immediate real-time postural biofeedback (audio or vibratory). The between-day and inter-rater reliability of the device in measuring lumbo-pelvic posture is excellent (O’Sullivan et al. 2011a). Its potential as a clinical tool capable of providing both spinal postural analysis and biofeedback has recently been demonstrated in a field study of cyclists with NSCLBP (Van Hoof et al. 2012). Furthermore, it has recently been validated as a measure of lumbo-pelvic posture and movement in a range of seated and standing functional tasks (O’Sullivan et al. 2012f). However, to facilitate analysis of complex movement tasks, the study (O’Sullivan et al. 2012f) simply compared the BodyGuard™ to a surface marker-based system (CODA™). Therefore, it is unclear if the BodyGuard™ truly reflects underlying vertebral alignment and motion. This study aimed to investigate the validity of the BodyGuard™ device.
as a measure of underlying vertebral alignment and motion, using digital videofluoroscopy (DVF) as the reference standard.

2. Materials and Methods

2.1 Participants

Twelve participants (six female) were recruited from within a university community. Participants’ mean(SD) age was 22(1) years, height was 176(10) cm, mass was 71(11) kg and body mass index was 23(3) kg/m$^2$. Participants with current or previous NSCLBP, previous spinal surgery, serious health problems, who were aged <18 years or were pregnant were excluded. All participants provided written informed consent. Ethical approval was obtained from a local university Research Ethics Committee (S52189).

2.2 Instrumentation

The BodyGuard™ consists of a lightweight battery-powered processing unit and a strain gauge, which communicates via a proprietary wireless protocol with a computer (Figure 13). Posture is expressed as a percentage of strain gauge elongation, so that the degree of flexion/extension is expressed relative to range of motion (ROM), rather than being expressed in degrees. DVF is a motion X-ray recording of the spine, combining video technology with traditional fluoroscopy. DVF images at 25Hz were obtained with a Philips Diagnost Super 80CP system (1,024 x 1,024 image resolution) (Philips Medical Systems, Best, The Netherlands). The image intensifier was positioned to the side of the participant’s lumbo-pelvic region, so that the field of view could capture all lumbo-pelvic motion performed. The radiograph beam field of the videofluoroscopy unit was collimated to obtain optimal sharpness of the image. Exposure parameters were 80 kV. The average fluoroscopy time per participant was approximately 20s with a mean dose-area product (DAP) of 28 dGy/cm$^2$. The estimated effective dose for the whole procedure was 0.22mSv, which is lower than the effective dose of a single plain radiograph of the lumbar spine (0.39mSv). Radiation parameters were reviewed with a radiation physicist before the study to ensure that radiation exposure was minimised. The environmental temperature was within the
acceptable range for the BodyGuard™. Pilot testing (n=4) confirmed that the best DVF images of the lumbo-pelvic region were obtained by performing lumbo-pelvic flexion/extension as a pelvic tilt. Otherwise, image quality deteriorated as participant movement during forward bending shifted them out of the centre of the image intensifier’s field of view. Although some previous studies (Wong et al. 2006) have overcome this issue by stabilising the pelvis within the DVF unit while participants perform spinal flexion/extension, this may not reflect natural spinal motion, especially at the lower lumbar levels.

Figure 13: Participant in sitting with the BodyGuard™ posture monitor positioned using adhesive tape over the lower lumbar spine, at the levels of L3 and S2.

2.3 Calibration

A 6cm BodyGuard™ strain gauge was positioned using adhesive tape over the spinal levels of L3 and S2, using manual palpation of the posterior superior iliac spine (PSIS) to locate S2 (Figure 13). Calibration of the BodyGuard™ relative to maximum ROM was then performed in both sitting and standing. For sitting, the participants sat in the DVF unit (no back support) with their feet supported, and their knees and hips flexed to 90°. Participants performed flexion and extension of the lower lumbar spine by performing a pelvic tilt. After three practice attempts, participants sustained full anterior pelvic tilt for 3s, and this was set as 0% ROM. Maximum lumbar flexion was set as 100% ROM by sustaining full posterior pelvic tilt in a similar manner.
(Figure 14). For standing, participants stood upright in the DVF, barefoot with their knees extended. Similar to sitting, participants performed a pelvic tilting manoeuvre in standing to calibrate the lower lumbar position relative to standing ROM (Figure 15).

Figure 14: Participant performing full anterior and posterior pelvic tilt in sitting.
This movement was used for initial calibration of full range of movement, and then as the actual movement during testing.

Figure 15: Participant performing full anterior and posterior pelvic tilt in standing.
This movement was used for initial calibration of full range of movement, and then as the actual movement during testing.
2.4 Experimental protocol
First, participants performed maximal pelvic tilt (from anterior to posterior) in sitting, as described earlier. Two trials were performed, whereby movement of the spine was captured in a synchronised manner by the BodyGuard™ (20Hz) and the DVF (25Hz). Secondly, participants performed maximal pelvic tilt in standing, once again in the same manner as was performed for the calibration. Data were averaged for the two trials in each position.

2.5 Data analysis
Data of 23 sitting and 24 standing trials were analysed. One dataset (sitting) was lost because of a software error. Synchronised BodyGuard™ and DVF data were analysed at 5Hz. DVF data were analysed semi-automatically. Anatomical landmarks (corners of the vertebrae) were first manually marked and digitised on the DVF footage. Subsequently, the digitised data were analysed using an in-house custom-made software program. Lumbar lordosis was measured by calculating the angle between lines perpendicular to the midline of L3 and the cranial side of the sacrum (Figure 16). The reliability of this approach was assessed for two different raters using a single pilot data set. Both intra-rater and inter-rater intra-class correlation coefficients (ICC) were >0.97, while the mean difference between all measurements reached a maximum of 5.4°. This demonstrates a very good level of reliability, similar to previous DVF studies (Lee et al. 2002).

DVF data were converted to %ROM, relative to the calibration movements, for comparison with the BodyGuard™ data. Data were non-normally distributed (Shapiro-Wilks, p<0.05). The correlation between BodyGuard™ data and DVF data were assessed separately for sitting and standing across all subjects using Spearman’s rank correlation coefficient (rₛ), and the coefficient of determination (r²). To accept the validity of the BodyGuard™ device, it must demonstrate a strong correlation (rₛ >0.8) (Polgar and Thomas 2008). Furthermore, to assess the effect of position within the ROM on the relationship between the BodyGuard™ and DVF, BodyGuard™ data were segmented into bands of 10% of ROM based on DVF %ROM values for each measurement. Average BodyGuard™ values of each
10% band were calculated and the mean difference between BodyGuard™ and DVF data was assessed. When assessing the mean difference from DVF values, differences >5° (approximately 13% of sitting ROM and 17% of standing ROM) were considered large errors, consistent with another validation study (Intolo et al. 2010). An independent t-test examined for significant differences between genders, and a paired t-test compared sitting and standing ROM. Data were analysed using SPSS 15.0.

Figure 16: Illustration of the method used to calculate the lumbo-pelvic angle on digital videofluoroscopy.

Corners of the vertebrae marked, with perpendicular lines (solid) used to calculate the complementary angle (dotted line)

3. Results

Since the calibration procedures differed, results for sitting and standing are presented separately. Strong correlations were observed in both sitting ($r_s=0.94$) and standing ($r_s=0.88$). Similarly, coefficients of determination were high for sitting ($r^2=0.88$) and standing ($r^2=0.78$). The mean differences (as %ROM) between DVF and BodyGuard™ values throughout the full ROM are displayed in Error! Reference source not found.. The maximum mean difference was 9.1% in sitting, and 12.9% in standing. The differences were
greatest close to mid-ROM, occurring between 31-40%ROM for standing and 51-60%ROM for sitting. A representative scatter plot of values for one participant during standing is illustrated in Figure 18, where the slight underestimation of flexion by the BodyGuard™ can be seen near mid-range. When converting these percentages into angles, based on mean ROM in each test position, these maximum mean differences were 3.4° and 3.9°, in sitting and standing, respectively. The ROM (mean+SD) in sitting (37.3+11.2°) was significantly larger than in standing (30.2+10.4°) (p=0.03). There was no statistically significant difference in the ROM (mean+SD) between male (32.8+11.1°) and female (34.5+11.5°) participants (p=0.61).

![Figure 17: Mean differences between digital fluoroscopy and BodyGuardTM measurements in sitting and standing through every 10% of range of motion (ROM).](image)

0% = maximum lower lumbar extension; 100% = maximum lower lumbar flexion.
4. Discussion

This study examined the validity of a novel spinal posture monitoring device (BodyGuard™) by comparing lumbo-pelvic posture during sagittal plane pelvic tilting with simultaneous DVF measurements. Overall, the two methods displayed strong correlations and high coefficients of determination. Furthermore, the mean differences between the two measurements of lumbo-pelvic posture were not large, particularly approaching end-range motion, suggesting the BodyGuard™ device is a valid measure of underlying lumbo-pelvic vertebral motion. It is noteworthy that these results are very consistent with previous data examining the concurrent validity of this posture monitor during seated and standing functional tasks, although that study (O’Sullivan et al. 2012f) simply used a surface marker system for comparison. These two validation studies together suggest the BodyGuard™ is a valid measure of lumbo-pelvic sagittal plane posture.

Establishing the validity of any spinal posture monitor is critical before it can be recommended for use in clinical trials. While absolute agreement between any skin-mounted posture monitor and measurement of underlying vertebral posture and motion is unrealistic, these results suggest the validity of the BodyGuard™ device is similar, or indeed superior, to that of other posture...
monitors (Thoumie et al. 1998; Perret et al. 2001; Guermazi et al. 2006; Bible et al. 2010). Both a small flexible electrogoniometer (Biometrics™) and a larger electrogoniometer (OSI CA-6000) have demonstrated similar mean differences, but poorer correlations, compared to X-ray measurement of lumbar posture and/or ROM (Schuit et al. 1997; Thoumie et al. 1998; Bible et al. 2010). Similarly, a monitor which combines electrogoniometry with pelvic inclinometry and chair-backrest contact data (Rachimetre™) and another method of analysing static spinal posture (Spinal Mouse™) were strongly correlated to overall lumbar ROM (Perret et al. 2001; Guermazi et al. 2006), without examining through-range accuracy. Furthermore, many other portable posture monitors (Bell 2008; Intolo et al. 2010; Wunderlich et al. 2011) have simply been validated against surface marker systems rather than methods such as DVF, X-ray or MRI. It is noteworthy that the validity of the BodyGuard™ device as a measure of lumbar curve is actually superior to the lumbar motion monitor (LMM™), which is commonly used in occupational analysis (Campbell-Kyureghyan et al. 2005).

When data were partitioned into 10% intervals of ROM (based on DVF data), there was slightly greater error in mid-range. This was expected, since the BodyGuard™ device was calibrated at end-range flexion and extension. The BodyGuard™ appears to slightly, and consistently, underestimate lumbo-pelvic flexion through range compared to the DVF, particularly in standing. However, the maximum differences were still only 3.4° (9.1% ROM) and 3.9° (12.9% ROM) in sitting and standing respectively. While any degree of error in estimation of underlying posture and motion is undesirable, the current degree of error probably reflects the difficulty of interpreting vertebral motion using any surface-marker approach. For example, the current degree of error is in line with the error reported by other skin-mounted posture monitors (Bible et al. 2010).

The ROM obtained in sitting was significantly larger than in standing, possibly due to greater ease facilitating pelvic motion in sitting due to direct contact with the stool. The ROM obtained is broadly in line with data on segmental vertebral motion from L3 to S1 (Abbott et al. 2006).
4.1 Implications
The results of this study, when combined with previous studies (O'Sullivan et al. 2011a; O'Sullivan et al. 2012f), suggest that the BodyGuard™ device is a reliable and valid means of measuring lumbo-pelvic sagittal plane posture and movement. It is a simple, economical and minimally invasive postural monitoring system that should allow normal movement and function in “real-world” settings. The small size and ease of use of the BodyGuard™ may allow field-based studies to investigate in detail the role of posture and lumbo-pelvic movement patterns in NSCLBP. Further discriminative validity studies are required to determine if the device can discriminate between subgroups of subjects with NSCLBP and matched controls, similar to existing laboratory-based systems (Dankaerts et al. 2006b). Modification of spinal posture has been associated with improved clinical outcomes (Dankaerts et al. 2007), and recent studies demonstrate that provision of postural awareness training may help normalise spinal motion (Dean and Dean 2006), reduce spinal loading during lifting tasks (Kernozek et al. 2006) and improve clinical outcomes in both acute and chronic presentations (Horton and Abbott 2008; Magnusson et al. 2008). The potential to provide patients with biofeedback regarding the control of their lumbo-pelvic movement patterns via the BodyGuard™ requires further clinical investigation.

4.2 Limitations
The sample size was small to limit the number of participants exposed to irradiation, but was similar to previous validation studies (Schuit et al. 1997). The device has only been validated in the sagittal plane, which reflects the way in which the device is used. While the device does not provide an angular value for lumbo-pelvic posture, research indicates that expressing lumbar posture relative to ROM may be very useful (Dankaerts et al. 2006b). Limiting motion to pelvic tilting may not truly reflect sagittal plane lumbo-pelvic motion during routine daily tasks; however concurrent validity during complex functional tasks involving forward bending has already been established (O'Sullivan et al. 2012f). In addition, the study has demonstrated that the BodyGuard™ is a valid measure of underlying spinal motion, so that it is
unlikely that this differs significantly in forward and backward bending of the trunk. Furthermore, this approach allowed simultaneous measurement of lumbo-pelvic motion, unlike previous research (Schuit et al. 1997). Similar to all skin-mounted posture monitors, variations in body mass index may affect accuracy. It should also be acknowledged that NSCLBP is a complex biopsychosocial disorder where analysis of multiple factors other than lumbo-pelvic posture and movement patterns is warranted (McCarthy et al. 2004).

5. Conclusion
The BodyGuard™ device provides a valid assessment of lumbo-pelvic motion in the sagittal plane. The minimally invasive nature of the device may be appropriate for use in “real-world” settings outside the laboratory when detailed assessment of lumbo-pelvic posture is required. Future studies on its clinical utility for people with NSCLBP, are indicated.
Key points: Chapter 2

The general aim of the three studies discussed in Chapter 2 was to examine the reliability and validity of the BodyGuard™ device to facilitate refinement of the device before progressing to clinical trials. The results demonstrated excellent reliability of the BodyGuard™ device, both between-days and between-raters. The BodyGuard™ device also demonstrated good concurrent validity in a range of tasks of daily living, both compared to a traditional motion analysis system and DVF. Overall, the reliability and validity of the BodyGuard™ device is similar, or indeed superior, to that of several other posture monitors. The use of multiple validation comparisons during a range of different tasks, and using comprehensive statistical analysis, enhances the rigour of the findings. The BodyGuard™ device therefore has several distinct advantages as a method of analysing spinal posture outside the laboratory. For example, it is a low cost and minimally invasive device compared to some existing options (Campbell-Kyureghyan et al. 2005; Donnell et al. 2005). It is simple to collect and analyse data with the device. It allows for participants to wear their usual clothing, and perform daily tasks in a relatively unconstrained manner compared to some other devices (Campbell-Kyureghyan et al. 2005). Its placement directly over the spine allows measurement of lumbo-pelvic posture, rather than simply overall trunk flexion (Intolo et al. 2010). While it does not provide an angular value for spinal posture, expressing lumbar posture relative to ROM may be very useful, since postural differences between healthy controls and NSCLBP subjects have been observed in laboratory settings (Dankaerts et al. 2006b). While there was a trend for underestimation of spinal flexion, especially in mid-range which may affect the ability to accurately reflect spinal loads, this did not bias the data to a large extent.

Some specific limitations of the device, and considerations for field testing, were established. The most important of these were that:

- Validation was only investigated for the sagittal plane. While trunk rotation and side-flexion do not appear to bias the signal of the monitor to a significant degree, the validity of the device to monitor movements in these other planes has not been established.
The extent of strain gauge elongation is greater during activities in standing than during sitting. This reflects the greater skin movement associated with increased hip flexion in standing ROM. This additional strain gauge elongation requires that separate calibrations are used for sitting and standing tasks. In turn, this requires a method of measuring overall body posture (sitting versus standing) to be used simultaneously, as the BodyGuard™ device cannot differentiate between sitting and standing tasks. Therefore, a simple ActivPal™ accelerometer will be placed on participant’s thighs to provide information on overall body posture so that their postural data can be expressed relative to the appropriate sitting or standing ROM calibration.

Trunk lean, especially when it varies rapidly during a task, appears to bias the output of the BodyGuard™ posture monitor. This was seen during several tasks of daily living, and is likely to reflect skin movement causing strain gauge elongation. As a result, the BodyGuard™ may be most useful in situations with minimal trunk lean e.g. seated office workers. Certain tasks involving rapid or quickly varying degrees of trunk lean may be less measurable (O’Sullivan et al. 2012f). Despite some initial efforts, a satisfactory method of controlling for the influence of trunk lean on BodyGuard™ output was not possible. Therefore, there is a risk that data will be somewhat contaminated by varying degrees of trunk lean which are not quantifiable outside the laboratory.

Based on these results, application to clinical investigations of seated postural behaviour using the BodyGuard™ device was considered appropriate. The next chapter asks, before progressing to the clinical interventions, what current perceptions about what constitutes a good sitting posture are.
CHAPTER 3: Perceptions of sitting posture

This chapter contains two studies. Both studies examined what is considered to be a good sitting posture. Firstly, the perceptions of physiotherapists were examined. Thereafter, the perceptions of members of the community, with and without NSCLBP, were examined. The first study (among physiotherapists) has already been published in the peer-reviewed literature (O'Sullivan et al. 2012i), and the second paper is currently undergoing peer-review. The primary research questions for this chapter are illustrated in Table 6.

Table 6: Overview of the doctoral thesis and the research questions examined in each of the three main parts

<table>
<thead>
<tr>
<th>CHAPTER TITLE</th>
<th>QUESTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigating the validity and</td>
<td>•What do physiotherapists perceive to be the best sitting posture?</td>
</tr>
<tr>
<td>clinical applicability of a posture</td>
<td>•What do members of the community perceive to be the best sitting posture?</td>
</tr>
<tr>
<td>monitor</td>
<td>•Do perceptions of good sitting posture vary between those with and without NSCLBP?</td>
</tr>
<tr>
<td>Perceptions of Sitting Posture</td>
<td></td>
</tr>
<tr>
<td>Interventions to reduce seated low</td>
<td></td>
</tr>
<tr>
<td>back pain</td>
<td></td>
</tr>
</tbody>
</table>
Study IV: What do physiotherapists consider to be the best sitting spinal posture?


Abstract

While sitting is a common aggravating factor in non-specific chronic low back pain (NSCLBP), the best sitting posture remains unclear. This study investigated the perceptions of 295 physiotherapists in four different European countries on sitting posture. Physiotherapists selected their perceived best sitting posture from a sample of nine options that ranged from slumped to upright sitting, as well as completing the back beliefs questionnaire (BBQ). 85% of physiotherapists selected one of two postures as best, with one posture being selected significantly more frequently than the remainder (p<0.05). Interestingly, these two most frequently selected postures were very different from each other. Those who selected the more upright sitting posture had more negative beliefs on the BBQ (p<0.05). The choice of best sitting posture also varied between countries (p<0.05). Overall, disagreement remains on what constitutes a neutral spine posture, and what is the best sitting posture. Qualitative comments indicated that sitting postures which matched the natural shape of the spine, and appeared comfortable and/or relaxed without excessive muscle tone were often deemed advantageous. Further research on the perceptions of people with NSCLBP on sitting posture is indicated.

Keywords: posture; back pain; physiotherapy; sitting
1. Introduction

Despite the large amount of research undertaken on non-specific chronic low back pain (NSCLBP), it remains a very common and costly musculoskeletal disorder (Woolf and Pfleger 2003). It is now widely acknowledged that NSCLBP is a complex disorder, with numerous contributing factors, including physical (Mitchell et al. 2010), biological (Moseley 2007) and psychosocial factors (Jarvik et al. 2005; Campbell and Edwards 2009), as well as genetic and environmental interactions (Reichborn-Kjennerud et al. 2002).

One of the most common strategies used by physiotherapists in the management of NSCLBP is providing advice on spinal postures (Poitras et al. 2005). Prolonged sitting periods, for example periods exceeding 30 minutes, are a common aggravating factor for many subjects with NSCLBP (Williams et al. 1991; O’Sullivan 2005). There is evidence that the sitting spinal posture of some NSCLBP subjects differs to that of matched controls (Dankaerts et al. 2009), and that addressing these postures may help reduce NSCLBP (Dankaerts et al. 2006b; Womersley and May 2006). While there is no clear evidence that prolonged sitting in isolation is a significant risk factor for developing NSCLBP (Lis et al. 2007; Roffey et al. 2010c), combined exposure to prolonged sitting, awkward postures and vibration may increase the risk of developing NSCLBP (Lis et al. 2007). Considering the large amount of time spent sitting in modern society, assuming seated spinal postures which are non-provocative may be helpful as part of NSCLBP management.

What constitutes the best seated lumbar posture remains widely debated (Claus et al. 2009b; Claus et al. 2009c; Dankaerts et al. 2009; O’Sullivan et al. 2010b). While sitting involves more lumbar flexion than standing (Scannell and McGill 2003; Dunk et al. 2009; De Carvalho et al. 2010), it is not clear what constitutes an optimal amount of lumbar flexion in sitting (Claus et al. 2009c; O’Sullivan et al. 2010b). Increased lumbar flexion in sitting, for example during slumped sitting postures, has traditionally been considered problematic, since sitting in lumbar flexion can increase NSCLBP symptoms (Womersley and May 2006). Reducing such flexed sitting postures can reduce NSCLBP, such that many authors recommend lordotic seated postures (Williams et al. 1991; Lengsfeld et al. 2000; Womersley and May
2006; Bettany-Saltikov et al. 2008; Claus et al. 2009c). In direct contrast however, increased lordosis has also been reported in NSCLBP subjects (Christie et al. 1995; Vergara and Page 2002; Dankaerts et al. 2006b; Van Dillen et al. 2009), with relief of pain reported by some NSCLBP subjects in more flexed postures (O'Sullivan 2005). In addition, lordotic lumbar postures which are associated with higher levels of paraspinal muscle activation may increase fatigue and discomfort (Lander et al. 1987; O'Sullivan et al. 2006a; Claus et al. 2009c).

As a result, while it is clear that sitting postures do not all have the same effect on spinal load and trunk muscle activation (O'Sullivan et al. 2002; O'Sullivan et al. 2006a; Claus et al. 2009c; Reeve and Dilley 2009; O'Sullivan et al. 2010b), there is little consensus on the best sitting posture. In recent years, there has been an increased emphasis on adopting “neutral” lumbar spine postures, to avoid potentially painful end-range positions (Scannell and McGill 2003), and facilitate activation of key trunk muscles (O'Sullivan et al. 2006a; Claus et al. 2009a).

Interestingly, no study has asked physiotherapists, or any other group of healthcare professionals, about what they perceive as the best sitting posture. There is strong evidence that the beliefs of healthcare professionals strongly influence their NSCLBP management approach (Darlow et al. 2012). Consequently, the beliefs of physiotherapists about sitting postures, and the importance they attach to it, might also influence the advice they provide on spinal sitting posture. For example, we hypothesised that those physiotherapists who select more upright lumbar sitting postures may hold more negative beliefs about NSCLBP, indicating a perceived vulnerability of the lumbar spine to mechanical loads among patients with NSCLBP.

Therefore, the aims of this study were to investigate the perceptions of physiotherapists on the best sitting posture, how these perceptions vary in four different European countries, what characteristics physiotherapists associate with good seated posture, and whether their beliefs about NSCLBP are related to their perceptions on spinal sitting posture.
2. Methods

2.1 Participants

A total of 296 physiotherapists who attended continuing professional development workshops on NSCLBP in four countries (Ireland; n=111, England; n=88, Germany; n=41 and the Netherlands; n=56) participated in this study prior to the workshops commencing. Ethical approval was obtained from a university Research Ethics Committee (Ref EHSREC 09-116).

2.2 Generating photographs of sample postures

A 29 year-old female with no history of NSCLBP and adequate flexibility to assume a variety of spinal postures acted as a model for the generation of the seated posture photographs. The model wore shorts and her bra, and sat on a flat wooden stool without back support. Her knees and ankles were positioned at 90°, with her wrists positioned palms-downward on her thighs. Photo-reflective markers were placed overlying the spinous processes of C7, T12, L3 and S2 using hypoallergenic adhesive tape. These markers facilitate calculation of sagittal-plane angles for the thoracic (C7-T12-L3), lumbar (T12-L3-S2), and overall thoraco-lumbar (C7-T12-S2) regions using a LABVIEW programme. As such, these angles represent simple sagittal-plane spinal flexion, rather than forward tilt or lean of the trunk. The digital camera (Panasonic Lumix TZ3) was positioned on a tripod 80cm from the floor and 250cm from the model. The model was aligned such that she was facing perpendicular to the camera (Straker et al. 2009). After consultation with professional colleagues, a range of postures observed in clinical practice between slumped and upright sitting were chosen, including some postures with varying cervical, thoracic and lumbar spine angles, as well as varying degrees of trunk lean. The model was assisted into each of these postures using manual and verbal facilitation, and then maintained each posture for 10s while the photograph was taken. Three images were taken in each posture, and the one which best reflected each target posture was used for the study. No single posture was considered to constitute the best posture. It was hypothesised that such a mix of postures may facilitate the participating physiotherapists having to prioritise their concepts of optimal sitting. For
example, the most lordotic lumbar posture involved significant thoracic flexion along with considerable relaxation of the neck and shoulders. The actual spinal angles associated with each posture are displayed in Table 7.

Table 7: Spinal angles for each of the selected photographs

<table>
<thead>
<tr>
<th>Posture</th>
<th>Thoraco-lumbar (C7-T12-S2)</th>
<th>Thoracic (C7-T12-L3)</th>
<th>Lumbar (T12-L3-S2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>32.7</td>
<td>28.9</td>
<td>7.6</td>
</tr>
<tr>
<td>2</td>
<td>-16.5</td>
<td>-7.0</td>
<td>-16.3</td>
</tr>
<tr>
<td>3</td>
<td>24.8</td>
<td>21.4</td>
<td>6.9</td>
</tr>
<tr>
<td>4</td>
<td>10.4</td>
<td>9.5</td>
<td>1.7</td>
</tr>
<tr>
<td>5</td>
<td>2.1</td>
<td>4.0</td>
<td>-3.4</td>
</tr>
<tr>
<td>6</td>
<td>30.6</td>
<td>26.9</td>
<td>7.5</td>
</tr>
<tr>
<td>7</td>
<td>14.0</td>
<td>21.9</td>
<td>-16.6</td>
</tr>
<tr>
<td>8</td>
<td>18.3</td>
<td>15.5</td>
<td>5.4</td>
</tr>
<tr>
<td>9</td>
<td>18.8</td>
<td>23.7</td>
<td>-10.6</td>
</tr>
</tbody>
</table>

C7 - Spinous process of 7th cervical vertebra; T12 – Spinous process of 12th thoracic vertebra; L3 - Spinous process of 3rd lumbar vertebra; S2 – Positioned in midline between both posterior superior iliac spines; positive values indicate flexion; negative angles indicate extension; all values in degrees.

2.3 Data Collection

After explaining the study to participants, and obtaining written informed consent, the nine photographs were displayed in colour via digital projection, prior to the commencement of each workshop. The postures were randomly numbered from one to nine, starting in the top left hand corner (Figure 19). The model’s face was obscured in each photograph. Participants were also given a black/white paper copy of the photographs. They were asked to view all nine postures, and then select the best posture, justifying their selection with some comments on the relative advantages and disadvantages of the selected postures. The specific instruction to participants was to “select the best posture for the spine as a whole, especially the lumbar spine”. Participants were asked about their level of experience, qualifications, area of expertise and work location. In addition, all participants, with the exception of those in the Netherlands, completed the Back Beliefs Questionnaire (BBQ) (Buchbinder and Jolley 2005). Finally, participants were asked to rate how important they thought spinal posture was in the management of NSCLBP on
a scale of 0-10, where 0 = very unimportant and 10 = very important. Participants were given approximately 10 minutes to complete this task.

Figure 19: The nine sitting posture options, numbered according to the descriptions in the main text.

2.4 Data analysis

Data were analysed using SPSS 19.0. Chi-square analysis was used to examine if there were significant differences in the frequency with which specific postures were selected, and if this varied significantly between countries. The qualitative comments justifying their selection of each posture as the best sitting posture were categorised into common themes, divided into both positive and negative aspects of each posture. To examine differences in the characteristics of physiotherapists selecting the most common postures, Mann-Whitney U-tests were used for interval data and chi-square was used for categorical data. The level for statistical significance was set at p<0.05, and was adjusted appropriately using a Bonferroni correction for multiple comparisons.
3. Results

3.1 Characteristics of participating physiotherapists

Only one physiotherapist (in Ireland) stated that there was no best sitting posture, stating that all postures were acceptable options. The remaining 295 physiotherapists completed the questionnaire, and their primary characteristics are displayed in Table 8. 85% worked primarily in musculoskeletal physiotherapy, and 89% worked primarily in clinical practice. The highest degree obtained by participants was most commonly a BSc (59%), followed by an MSc (39%).

Table 8: Mean(SD) experience of participants and their rating of the importance of posture in the management of non-specific chronic low back pain

<table>
<thead>
<tr>
<th></th>
<th>England (n=88)</th>
<th>Ireland (n=110)</th>
<th>Netherlands (n=56)</th>
<th>Germany (n=41)</th>
<th>Overall (n=295)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experience (in years)</td>
<td>12.8(8.2)</td>
<td>7.6(7.8)</td>
<td>15.5(11.6)</td>
<td>16.4(6.6)</td>
<td>11.9(9.3)</td>
</tr>
<tr>
<td>Importance of posture (rated 0-10)</td>
<td>7.4(2.7)</td>
<td>7.4(2.7)</td>
<td>6.1(3.7)</td>
<td>6.5(2.4)</td>
<td>7.0(2.9)</td>
</tr>
</tbody>
</table>

3.2 The best sitting posture

The percentage of physiotherapists who selected each sitting posture option as the best sitting posture is displayed in Table 9. Two postures – posture 9 (n=162, 54.9%) and posture 5 (n=94, 30.5%) - were most commonly selected as the best sitting posture. Posture 9 involved a relatively neutral spine sitting posture with lordosis mainly in the lumbar spine and with relaxation of the thoracic spine, while posture 5 involved extension in both the lumbar and thoracic regions, as well as some forward trunk lean. Posture 9 was significantly more popular than posture 5; $\chi^2(1, n=252) = 20.57$, $p<0.001$. Furthermore, posture 5 in turn was significantly more popular than both of the next most commonly selected postures; posture 2; $\chi^2(1, n=106) = 51.66$, $p<0.001$, and posture 4; $\chi^2(1, n=106) = 51.66$, $p<0.001$. 

73
Table 9: Percentage of physiotherapists who selected each posture as the best sitting posture in each country, along with the mean value across all countries

<table>
<thead>
<tr>
<th>Posture</th>
<th>England (n=88)</th>
<th>Ireland (n=110)</th>
<th>Germany (n=41)</th>
<th>Netherlands (n=56)</th>
<th>Overall (n=295)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1.1</td>
<td>6.4</td>
<td>12.2</td>
<td>5.4</td>
<td>5.4</td>
</tr>
<tr>
<td>3</td>
<td>1.1</td>
<td>0</td>
<td>2.4</td>
<td>1.8</td>
<td>1.0</td>
</tr>
<tr>
<td>4</td>
<td>4.5</td>
<td>3.6</td>
<td>7.3</td>
<td>8.9</td>
<td>5.4</td>
</tr>
<tr>
<td>5</td>
<td>28.4</td>
<td>26.4</td>
<td>48.8</td>
<td>28.6</td>
<td>30.5</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>1.8</td>
<td>0</td>
<td>1.8</td>
<td>1.0</td>
</tr>
<tr>
<td>8</td>
<td>1.1</td>
<td>0</td>
<td>2.4</td>
<td>5.4</td>
<td>1.7</td>
</tr>
<tr>
<td>9</td>
<td>63.6</td>
<td>61.8</td>
<td>26.8</td>
<td>48.2</td>
<td>54.9</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

3.3 Qualitative comments on the postures selected

To summarise the comments on the selected postures, the major themes identified with the two most commonly selected postures are described here, along with the number of physiotherapists who made similar comments. The main positive theme identified for posture 9 was that the lumbar (n=150) and thoracic (n=34) regions were described as being moderately lordotic and kyphotic respectively, without approaching end-range. This was often described in terms of being advantageous as it “matches the natural shape of the spine”. Further positive themes were how the posture appeared “comfortable” and/or “relaxed” (n=48), and did not require too much muscle tone (n=14). The main negative themes identified for posture 9 were that the head was positioned excessively forward with too much cervical extension (n=70), that it involved excessive thoracic kyphosis (n=35) and excessive shoulder protraction (n=23). The major positive theme identified for posture 5 was that the lumbar region appeared moderately lordotic, and not “end-range” (n=65). Furthermore, it looked “comfortable” and/or “relaxed” (n=24), involved good head/neck alignment (n=28) and good thoracic posture (n=11). The main negative themes identified for posture 5 were that it involved “too much forward trunk lean” (n=25), and did not involve sufficient lumbar lordosis and/or anterior pelvic tilt (n=24). It was also thought to involve excessive muscle tone (n=20) and excessive thoraco-lumbar extension (n=20).
3.4 Variations between countries
In all countries, postures 5 and 9 were the two most popular choices. However, the ratio at which these two sitting posture were selected as best in the four countries was significantly different; $\chi^2(3, n=252) = 13.50, p= 0.004$. Posture 9 was most commonly selected by physiotherapists in Ireland (n=68, 62%), England (n=56, 64%) and the Netherlands (n=27, 48%), whereas in Germany posture 5 (n=20, 49%) was most commonly selected.

3.5 Factors associated with choice of best sitting posture
While posture 5 was most commonly chosen in Germany, where the mean experience of physiotherapists was the highest, there were no significant differences in the experience, qualifications, area of expertise, work location or perceived importance of posture between those who selected postures 9 and 5 ($p>0.05$). However, those who selected the more upright posture 5 had significantly more negative beliefs about NSCLBP than those who selected posture 9 (mean difference = 1.5 points, $p=0.045$).

4. Discussion
There is very little data available on the perceptions of physiotherapists regarding what is the best sitting posture. The results of the current study indicate that physiotherapists believe that spinal sitting posture is important in the management of NSCLBP. Thereafter, the results are partly contradictory. On one hand, there is considerable agreement among physiotherapists on what constitutes a good sitting posture, with 85% picking one of the two most common postures as the best sitting posture. However, another interpretation is that the two most commonly selected postures are actually very different when analysed quantitatively. As a result, it appears that while most physiotherapists picked one of these two postures, there is still considerable disagreement on what is the best sitting posture.

While posture 5 involved less lumbar lordosis than posture 9, it also involved considerably greater thoracic extension and forward trunk lean. Therefore, posture 5 is likely to be associated with higher levels of muscle activation, particularly of muscles such as thoracic erector spinae, iliostalis
longissimus pars thoracis and external oblique (O'Sullivan et al. 2006a; Claus et al. 2009a; Reeve and Dilley 2009). As a result, posture 5 may be associated with greater fatigue and potential discomfort (Lander et al. 1987). In contrast, posture 9 was the closest approximation to a neutral sitting posture, and was not an end-range posture, being the third most lordotic in the lumbar region, the third most kyphotic in the thoracic region, and the fourth most kyphotic in overall thoraco-lumbar curvature. This is consistent with physiotherapist descriptions of it as a comfortable and relatively natural spinal posture. On the other hand, posture 5 was the second most extended posture for the thoracic spine and thoraco-lumbar regions overall, and the fourth most extended in the lumbar region, suggesting it does not reflect a relaxed, mid-range or neutral spine. The authors agree with the majority of physiotherapists surveyed that posture 9 has several potential advantages. This is not to suggest that posture 9 should automatically be considered the best sitting posture. Indeed, the qualitative comments highlight several aspects of posture 9 that the physiotherapists did not like, especially regarding the cervical, thoracic and shoulder region. In addition, it is important to highlight that there is no evidence that assuming any specific static sitting posture is effective in the management of NSCLBP.

It is noteworthy that while only four of the nine sitting postures had lordotic lumbar angles, these four postures comprised 91.8% of the best postures selected. This suggests that there is a strong tendency among physiotherapists to select lordotic sitting postures, which is likely to influence their clinical practice. This is consistent with much of the published literature on the proposed benefits of lordotic sitting (Pynt et al. 2008), despite a lack of evidence for clear superiority of lordotic sitting over other sitting postures for NSCLBP. Interestingly, while the most popular posture involved significant lumbar lordosis, other postures (postures 2 and 7) which involved even greater lumbar lordosis were selected very infrequently. These data, supported by the qualitative comments, suggest that while physiotherapists believe lordosis is beneficial and/or necessary in the lumbar spine, the relationship of the lumbar region to the rest of the spine is also considered to be important. Posture 2 involved extension into the thoracic spine, while posture 7 involved an extreme kypho-lordotic posture along with some forward
trunk lean which, while maintaining lumbar lordosis, could require far greater paraspinal muscle activation. The fact that physiotherapists avoided selecting these postures, along with the qualitative comments provided, suggest physiotherapists weigh up the relative merits of different sitting postures. This may include balancing the desire for maintaining lumbar lordosis with the aim of selecting a posture which does not require large amounts of muscle activation, and appears relatively relaxed and comfortable. This is supported by the fact that twice as many physiotherapists described posture 9 as comfortable and/or relaxed compared to posture 5.

As hypothesised, those who selected the more upright posture 5 had more negative NSCLBP beliefs than those who selected the more relaxed posture 9. Selecting the more upright posture 5 perhaps reflects concern among these physiotherapists about the need to support and protect a vulnerable spine among patients with NSCLBP, although this is merely speculation. From this perspective, it would be interesting to assess whether patients with NSCLBP who assume more tense or upright sitting postures have more negative or fearful NSCLBP beliefs.

It would be interesting to further evaluate what physiotherapists interpret as “neutral” and “not end-range”, as many physiotherapists considered posture 5 to be comfortable and/or relaxed. It would appear that physiotherapists differ on whether a neutral spine is in fact straight or curved in the “natural shape of the spine”. Firstly, a neutral sitting posture is likely to be different to neutral standing posture, such that neutral sitting should involve greater posterior pelvic tilt and flexion that standing (Scannell and McGill 2003; Dunk et al. 2009; De Carvalho et al. 2010). A key consideration is what position in the available seated range of motion (ROM) constitutes the neutral position. Posture is influenced by a wide range of factors including genetics (Seah et al. 2011), gender (Dunk and Callaghan 2005), physical factors such as body mass index (Smith et al. 2011) and muscle endurance (Smith et al. 2010), as well as psychosocial factors (O’Sullivan et al. 2011b). Furthermore, we know that an individual’s neutral position is influenced by their static posture (Scannell and McGill 2003). ROM is highly variable between individuals, as well as being influenced by factors such as age (Kuo et al. 2009) and pathology (McGregor et al. 1997). In this regard, examining how
close to their end-range an individual sits may be as useful as examining the specific spinal angle they assume in sitting (Dankaerts et al. 2006b), and comparison to their habitual standing posture may also be worthy of investigation. An individual with greater thoracolumbar flexion ROM could require higher levels of trunk muscle activation to maintain the same neutral spinal angle as someone with less flexion ROM. The flexion moment of the spine which must be counterbalanced by such muscle activation is also influenced by individual stature. Furthermore, since painfree people tend to vary their posture during prolonged sitting rather than choose a single static posture (Callaghan and McGill 2001), whereas people with NSCLBP assume more static postures with only large, infrequent shifts in posture (Vergara and Page 2002; Telfer et al. 2009), the ability to vary posture easily and regularly may be as important as maintaining any specific postural angle. In contrast, in the event of a specific directional sensitivity to movement (Williams et al. 1991; O’Sullivan 2005), adopting a posture involving more or less spinal flexion may then be indicated. As a result, the best sitting posture for any specific individual with NSCLBP may need to consider all these factors, rather than adhering rigidly to any specific prescribed angle of spinal curvature. For example, individual variations in specific aggravating/easing factors which take into account the presence of any underlying pathology should be used to discriminate between adaptive and maladaptive postures among those with NSCLBP (O’Sullivan 2005; Dankaerts et al. 2009). Thereafter, it is the contention of the authors that once a posture is not maintained too close to an individual’s end-range, does not involve inappropriately high levels of muscle activation, and allows for movement and variation in posture, that several seated postures may be acceptable. This multitude of considerations may partly explain the variation seen between physiotherapists, along with the aforementioned variation in beliefs between the participating physiotherapists.

The differences between countries are interesting but difficult to explain. The proportions in England and Ireland who selected the neutral sitting posture as the best posture were very similar, with the Netherlands selecting this posture slightly less frequently. In contrast, physiotherapists in Germany preferred the more upright posture 5. While the physiotherapists in Germany were the most experienced, there was no difference in experience
across countries between those selecting these two postures. One possible explanation is that physiotherapists in Germany simply place a greater emphasis on extension of the trunk as a whole, which is partly supported by the observation that physiotherapists in Germany selected an extremely upright posture (posture 2) as the best sitting posture more than twice as often as the other countries selected it. While variation across countries may reflect differences in undergraduate or postgraduate training, this cannot be confirmed based on the current data.

There are several limitations to this study. Posture was only considered during static sitting, and confined to a sagittal plane view, although other sitting postures and observational views are obviously possible. Other seated postures, such as squatting and cross-legged sitting on the floor, are common in some countries and were not considered in this study. Prolonged standing is also a common aggravating posture, and perceptions of the best standing posture should also be conducted. Physiotherapists may have selected different postures for a male model, based on gender differences in sitting posture (Dunk and Callaghan 2005; Smith et al. 2010). Similarly, the posture selected may have differed for an older model, especially considering changes in ROM which occur with age (Kuo et al. 2009). All postures involved unsupported sitting to allow clear visualisation of the spine, such that perceptions of optimal sitting might have been different for supported sitting. This is particularly relevant since there is evidence that the use of backrests can reduce muscle activation and discomfort in sitting (Andersson et al. 1979; Vergara and Page 2002). The degree of trunk lean relative to the vertical varied between the different posture options, but was not quantified. The instructions to “select the best posture for the spine as a whole, especially the lumbar spine”, may have influenced the results, as there is evidence that lumbar posture influences the posture and muscle activation of other spinal regions (Falla et al. 2007; Caneiro et al. 2010). Participating physiotherapists were not given any information about the pain status of the model, or the presence of any particular spinal pathology, and it would be interesting to evaluate how such information would influence the findings. While the beliefs of health care professionals strongly influence their management approach (Darlow et al. 2012), the posture selected may not truly reflect the posture
actually prescribed to NSCLBP patients. Clearly, since NSCLBP is a multidimensional problem (Campbell and Edwards 2009), management must consider multiple aspects other than sitting posture. Future studies investigating the perceptions of people with NSCLBP on good sitting posture are planned, and may shed more light on this area.

5. Conclusion
Most physiotherapists consider sitting spinal posture important for the management of NSCLBP. The majority (85%) of physiotherapists in four European countries selected one of two postures as the best sitting posture. However, these two sitting postures were very different from each other, indicating a lack of agreement. The choice of best sitting posture varied between countries, and was related to the NSCLBP beliefs of the physiotherapists. Overall, there remains disagreement on what constitutes the best sitting posture, and on interpretation of neutral posture. Further research on the effect of different sitting postures on NSCLBP, and the perceptions of people with NSCLBP on good sitting posture, is indicated.
Study V: Perceptions of sitting posture among people with and without non-specific chronic low back pain


Abstract
Due to the reported aggravation of non-specific chronic low back pain (NSCLBP) in sitting, advice on sitting postures is commonly provided by physiotherapists in the management of NSCLBP, although the best sitting posture remains unclear. This study investigated perceptions of sitting posture among people with (n=120) and without (n=235) NSCLBP. From a sample of nine photographs (ranging from slumped to upright sitting), participants selected their perceived best and worst sitting posture. Participants with NSCLBP reported thinking about their posture significantly more frequently than those without NSCLBP (p<0.001). 54% of all participants selected a “neutral” lordotic sitting posture as their best posture, and this was selected significantly more frequently than any other posture (p<0.001). Qualitative comments indicated that sitting postures which were “straight”, and were perceived to keep the head, neck and shoulders in good alignment were deemed advantageous. However, what people considered straight varied considerably. 78% selected a slumped sitting posture as their worst posture, and this was selected significantly more frequently than any other posture (p<0.001). The choice of best sitting posture was influenced by gender (p=0.032), but not by the presence of NSCLBP (p=0.167). Interestingly, a very upright sitting posture was the second most popular selection as both the best (19%) and worst (15%) posture. Overall, lordotic lumbar postures were strongly favoured over flexed lumbar postures among people with and without NSCLBP. However, the degree of spinal extension which was considered optimal varied, with considerable conflict on the benefit of very upright postures. The perceptions of members of the community are broadly in line with those reported for physiotherapists. Future research on how accurately people with NSCLBP can detect their own sitting posture is indicated.

Keywords: posture; back pain; perceptions; sitting
1. Introduction

Non-specific chronic low back pain (NSCLBP) is a complex musculoskeletal disorder, with numerous contributing factors across the biopsychosocial spectrum (Reichborn-Kjennerud et al. 2002; Jarvik et al. 2005; Moseley 2007; Campbell and Edwards 2009). While increased sitting duration does not appear to increase the risk of developing NSCLBP (Roffey et al. 2010c), sitting is a very commonly reported aggravating factor (Dankaerts et al. 2006b; Womersley and May 2006). Due to this reported aggravation of NSCLBP in sitting, and the increased sitting time in modern society, providing advice on sitting postures is commonly used by physiotherapists in the management of NSCLBP (Poitras et al. 2005).

Recent research has highlighted inconsistencies on what constitutes an optimal seated lumbar posture (Pynt et al. 2001; Claus et al. 2009c; Reeve and Dilley 2009; O'Sullivan et al. 2010b). While some reduction in lumbar lordosis occurs during sitting (Scannell and McGill 2003; Dunk et al. 2009; De Carvalho et al. 2010), a large degree of lumbar flexion in sitting is often suggested to be unhelpful (Williams et al. 1991; Pynt et al. 2001; Womersley and May 2006). Sitting posture also varies with gender (Dunk and Callaghan 2005; Smith et al. 2010). Furthermore, people with NSCLBP appear to present with variable provocative sitting postures, which can be near end-range flexion (kyphotic) or near end-range extension (lordotic) (Dankaerts et al. 2006b).

The belief that lordotic sitting postures are optimal was reflected in a recent study among physiotherapists where lordotic sitting postures were more frequently selected as ideal sitting postures than flexed sitting postures (O'Sullivan et al. 2012i). The most commonly selected posture involved a relatively “neutral” sitting posture with moderate lumbar lordosis and a relaxed thorax (O'Sullivan et al. 2012i). The physiotherapists highlighted the trade-off between proposed advantages of upright sitting postures such as supporting spinal structures and maintaining the “natural shape of the spine”, and the costs in terms of increased muscular effort and spinal loading (Lander et al. 1987; O'Sullivan et al. 2006a; Claus et al. 2009c). Differences also existed
between the physiotherapists regarding the optimal degree of spinal extension which should be maintained in sitting.

No previous study has examined the perceptions of members of the community about sitting postures. This is significant considering perceptions about optimal sitting posture are likely to influence how people load their spine in daily seated tasks. It is hypothesised that members of the community will also select lordotic sitting postures as optimal, similar to physiotherapists. However, it is unclear whether these vary between those with and without NSCLBP, and between genders. Therefore, the aims of this study were to investigate the perceptions of members of the community on the best and worst sitting posture, and whether perceptions differ between people with and without NSCLBP.

2. Methods

2.1 Participants
A total of 355 (132M/223F) members of the community participated in this study, including 120 reporting NSCLBP (>three months duration) in the previous year and 235 control participants not reporting NSCLBP. Ethical approval was obtained from both a local university Research Ethics Committee (EHSREC 09-116) and a local hospital Research Ethics Committee.

2.2 Photographs of posture
Photographs of nine different sitting postures which assessed the perceptions of physiotherapists on sitting posture in a previous study (O'Sullivan et al. 2012i) were used. Detail regarding the setup for these photographs has been published previously (O'Sullivan et al. 2012i), such that only the main details are provided here. A 29 year-old female without NSCLBP was used as a model. Spinal markers facilitated calculation of sagittal-plane angles for the thoracic (C7-T12-L3), lumbar (T12-L3-S2), and overall thoraco-lumbar (C7-T12-S2) regions. The nine options included a range of postures observed in clinical practice between slumped and upright sitting, including some postures with varying cervical, thoracic and lumbar spine angles, as well as varying
degrees of trunk lean. No single posture was considered to constitute the best posture. The postures were randomly numbered from one to nine, starting in the top left hand corner (Figure 20). The model’s face was obscured in each photograph. It was hypothesised that such a mix of postures may facilitate the participants having to prioritise their concepts of optimal sitting. For example, the most lordotic lumbar posture involved significant thoracic flexion along with considerable relaxation of the neck and shoulders. The actual spinal angles associated with each posture are displayed in Table 10.

Figure 20: The nine sitting posture options, numbered according to the descriptions in the main text.

2.3 Data Collection
Participants were recruited from local pain medicine and physiotherapy clinics, as well as from within the local community. After obtaining informed consent, participants viewed the nine photographs either electronically (colour format) or in paper format (A4 black and white). They were asked to view all nine postures, and then select both their perceived best and worst posture, justifying their selection with some comments on the relative advantages and
disadvantages of the selected postures. The specific instruction was to “select the best posture for the spine as a whole, especially the lumbar spine”. Participants were asked to rate on 5 point Likert scale both how important they thought spinal posture was in the management of NSCLBP (very important to unimportant), and how often they considered their own spinal posture (always to never). People with NSCLBP rated their pain severity using the average of the four (maximum, minimum, average, now) numeric rating scales (NRS) of the Brief Pain Inventory (Wand et al. 2011a). They also completed the Oswestry Disability Index (ODI) (Fairbank and Pynsent 2000), the physical activity subscale of the Fear-avoidance beliefs questionnaire (FABQ) (Waddell et al. 1993) and the Back Beliefs Questionnaire (BBQ) (Buchbinder and Jolley 2005).

Table 10: Spinal angles for each of the selected photographs

<table>
<thead>
<tr>
<th>Posture</th>
<th>Thoraco-lumbar (C7-T12-S2)</th>
<th>Thoracic (C7-T12-L3)</th>
<th>Lumbar (T12-L3-S2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>32.7</td>
<td>28.9</td>
<td>7.6</td>
</tr>
<tr>
<td>2</td>
<td>-16.5</td>
<td>-7.0</td>
<td>-16.3</td>
</tr>
<tr>
<td>3</td>
<td>24.8</td>
<td>21.4</td>
<td>6.9</td>
</tr>
<tr>
<td>4</td>
<td>10.4</td>
<td>9.5</td>
<td>1.7</td>
</tr>
<tr>
<td>5</td>
<td>2.1</td>
<td>4.0</td>
<td>-3.4</td>
</tr>
<tr>
<td>6</td>
<td>30.6</td>
<td>26.9</td>
<td>7.5</td>
</tr>
<tr>
<td>7</td>
<td>14.0</td>
<td>21.9</td>
<td>-16.6</td>
</tr>
<tr>
<td>8</td>
<td>18.3</td>
<td>15.5</td>
<td>5.4</td>
</tr>
<tr>
<td>9</td>
<td>18.8</td>
<td>23.7</td>
<td>-10.6</td>
</tr>
</tbody>
</table>

C7 - Spinous process of 7th cervical vertebra; T12 – Spinous process of 12th thoracic vertebra; L3 - Spinous process of 3rd lumbar vertebra; S2 – Positioned in midline between both posterior superior iliac spines; positive values indicate flexion; negative angles indicate extension; all values in degrees.

2.4 Data analysis

Data were analysed using SPSS 19.0. People with and without NSCLBP were compared for gender (chi-square - $\chi^2$), as well as age and number of pain sites (Mann-Whitney U test). The frequency with which specific postures were selected as the best and worst postures was examined using Chi-square ($\chi^2$). Chi-square ($\chi^2$) was also used to compare the frequency with which the two most commonly selected postures for both best and worst sitting postures
varied according to NSCLBP status, gender, frequency of thinking about their posture, and number of pain sites (none versus at least one). Finally, chi-square ($\chi^2$) analysis compared the selection of best and worst postures between those above/below the median value for age, pain, functional disability, fear-avoidance and back beliefs. All qualitative comments justifying selection of best and worst sitting posture were categorised into common themes by one author (KOS), for both people with and without NSCLBP. Another author (MOK) then screened all qualitative comments and verified the major themes identified. The level for statistical significance was set at $p<0.05$.

3. Results

3.1 Characteristics of participants

Participant characteristics, including data regarding the pain intensity, functional disability and beliefs of those with NSCLBP, are displayed in Table 11. 98% of people with NSCLBP, and 96% of controls, thought spinal posture was important or very important in the management of NSCLBP ($p>0.05$). There was no significant difference in age ($p=0.163$) or gender distribution ($p=0.433$) between those with and without NSCLBP. However, people with NSCLBP had a significantly higher number of total pain sites ($p<0.001$). Participants most commonly reported that they thought about their spinal posture “occasionally” (41%), followed by “very frequently” (23%) and “rarely” (22%). Those with NSCLBP stated that they thought about their spinal posture significantly more frequently than those without NSCLBP ($\chi^2 (4, n=355) = 40.397, p<0.001$).

3.2 The best sitting posture

The percentage of people, both with and without NSCLBP, who selected each sitting posture option as the best sitting posture is displayed in Table 12. Posture 9 was most commonly selected as the best sitting posture, followed by posture 2 in both people with and without NSCLBP. Posture 9 involved a relatively neutral spine sitting posture with lordosis mainly in the lumbar spine and with relaxation of the thorax, while posture 2 involved a large degree of
extension in both the lumbar and thoracic regions. Posture 9 was significantly more popular than posture 2; \( \chi^2 (1, n=258) = 61.54, p<0.001 \). Furthermore, posture 2 in turn was significantly more popular than posture 5, which was the next most commonly selected best posture; \( \chi^2 (1, n=104) = 7.54, p=0.006 \).

Table 11: Participant characteristics, for people with non-specific chronic low back pain (NSCLBP) and controls

<table>
<thead>
<tr>
<th>NSCLBP</th>
<th>Controls</th>
<th>p values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age#</td>
<td>31(22-48)</td>
<td>29(22-41)</td>
</tr>
<tr>
<td>Gender (F/M)</td>
<td>72/48</td>
<td>151/84</td>
</tr>
<tr>
<td>Number of pain sites#</td>
<td>3(2-4)</td>
<td>0(0-1)</td>
</tr>
<tr>
<td>NRS</td>
<td>3.9(2.3)</td>
<td>NA</td>
</tr>
<tr>
<td>ODI</td>
<td>24.0(15.8)</td>
<td>NA</td>
</tr>
<tr>
<td>BBQ</td>
<td>24.6(7.2)</td>
<td>NA</td>
</tr>
<tr>
<td>FABQ#</td>
<td>14(10-18)</td>
<td>NA</td>
</tr>
</tbody>
</table>

Data expressed as mean(SD), except where data non-normally distributed and expressed as median(interquartile range), as indicated by #; * - statistically significant; F – female; M – male; NRS – numeric rating scale; ODI – oswestry disability index; BBQ – back beliefs questionnaire; FABQ – physical activity subscale of the fear-avoidance beliefs questionnaire; NA - not applicable.

Table 12: Percentage of people, with and without non-specific chronic low back pain (NSCLBP), who selected each posture as the best and sitting posture

<table>
<thead>
<tr>
<th>Posture Selected</th>
<th>Best</th>
<th>Worst</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NSCLBP (n=120)</td>
<td>Controls (n=235)</td>
<td>NSCLBP (n=120)</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>78.3</td>
</tr>
<tr>
<td>2</td>
<td>19.2</td>
<td>18.3</td>
<td>14.2</td>
</tr>
<tr>
<td>3</td>
<td>0.8</td>
<td>0</td>
<td>1.7</td>
</tr>
<tr>
<td>4</td>
<td>9.2</td>
<td>6.0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>15.8</td>
<td>8.1</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0.4</td>
<td>5.8</td>
</tr>
<tr>
<td>7</td>
<td>0.8</td>
<td>1.7</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>7.5</td>
<td>7.6</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>46.7</td>
<td>57.8</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>'100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>
3.3 The worst sitting posture
The percentage of people, both with and without NSCLBP, who selected each sitting posture option as the worst sitting posture is displayed in Table 12. Posture 1 was most commonly selected as the worst sitting posture, followed by posture 2. Posture 1 involved a slumped sitting posture, with posterior pelvic tilt and relaxation of the trunk muscles, while posture 2 involved a large degree of extension in both the lumbar and thoracic regions. Posture 1 was selected significantly more frequently as the worst posture than posture 2; $\chi^2 (1, n=330) = 154.78, p<0.001$. Furthermore, posture 2 in turn was selected significantly more frequently than posture 6, the next most frequently selected as the worst posture; $\chi^2 (1, n=70) = 16.51, p<0.001$.

3.4 Factors influencing selection of best and worst postures
Despite some variation regarding best sitting posture (Table 12), there was no significant difference between those with and without NSCLBP for either the best ($\chi^2 (1, n=355) = 10.39, p=0.167$) or worst ($\chi^2 (1, n=355) = 0.748, p=0.945$) sitting posture. There was a significant difference between genders for the best posture ($\chi^2 (1, n=355) = 15.34, p=0.032$), with females picking posture 9 in proportionately greater numbers whereas males picked postures 2, 4, 5 and 8 in proportionately greater numbers. This gender effect was not seen for selecting the worst posture ($\chi^2 (1, n=355) = 3.012, p=0.556$). How often participants thought about their posture was not significantly related to their choice of best ($\chi^2 (1, n=257) = 2.85, p=0.584$) or worst ($\chi^2 (1, n=329) = 7.92, p=0.095$) sitting posture. Age was not significantly related to their choice of best ($\chi^2 (1, n=253) = 1.114, p=0.291$) or worst ($\chi^2 (1, n=324) = 0.123, p=0.725$) sitting posture. Similarly, the presence of pain at any site was not significantly related to their choice of best ($\chi^2 (1, n=256) = 0.032, p=0.857$) or worst ($\chi^2 (1, n=326) = 0.798, p=0.372$) sitting posture. Finally, among those with NSCLBP, the choice of best and worst sitting postures did not vary significantly according to their pain intensity, functional disability, back beliefs or fear-avoidance beliefs (all $p>0.05$).
3.5 Qualitative comments on the postures selected

To summarise the comments on the selected postures, the major themes identified with the two most commonly selected postures for both best and worst sitting posture are described here, along with the number of participants who made similar comments. The comments of both people with and without NSCLBP were very similar, such that they have been discussed together. The main positive themes identified for posture 9 were the importance of being (i) straight or upright (n=144), and maintaining the (ii) shoulders (n=44), or (iii) head and neck (n=27) in good alignment. Interestingly, the main positive themes identified for posture 2 were also being (i) straight or upright (n=36), and maintaining good alignment of the (ii) shoulders (n=18), as well as (iii) the head and neck (n=18). Consistent with this, the main negative themes identified for posture 1 were (i) not being straight enough (n=250), (ii) poor shoulder alignment (n=20), (iii) poor head and neck alignment (n=26), and (iv) perceived pressure or compression on the spine (n=31). Interestingly, the main negative themes identified for posture 2 were quite different, such as being (i) too stiff or rigid (n=24), (ii) too curved or upright (n=21), (iii) uncomfortable (n=9) and (iv) unnatural or awkward (n=5).

4. Discussion

This is the first study to evaluate the perceptions of people in the community about sitting posture. An overwhelming majority (96%) believed that spinal sitting posture is important or very important in the management of NSCLBP. Lordotic sitting postures were strongly favoured among participants, although the type of lordotic posture which was preferred was variable. The perceptions of members of the community on sitting postures were broadly in line with those previously reported for physiotherapists (O'Sullivan et al. 2012i). While only four of the nine sitting postures had lordotic lumbar angles, these four comprised 88% of the best postures selected, which again is consistent with the percentage (92%) reported among physiotherapists (O'Sullivan et al. 2012i). The fact that they were straight or upright sitting postures was the most common stated reason for preferring postures 9 and 2, and avoiding
posture 1. This likely reflects the fact that most recommendations on sitting posture favour lordotic sitting (Harrison et al. 1999; Pynt et al. 2001), despite a lack of evidence for clear superiority of lordotic sitting over other sitting postures for NSCLBP.

Posture 9 was most commonly chosen (54%) as the best posture, which is almost identical to data among physiotherapists (55%) (O'Sullivan et al. 2012i). Posture 9 is a relatively “neutral” rather than “end-range” sitting posture, in that it is the third most lordotic in the lumbar region, the third most kyphotic in the thoracic region, and the fourth most kyphotic in overall thoraco-lumbar curvature. While the second most popular posture (posture 2) was also a “lordotic” posture for the lumbar region, it is actually very different to posture 9. For example, it is the most extended posture for the thoracic spine and thoraco-lumbar regions overall, and the second most extended in the lumbar region. It also involves a considerable amount of forward trunk lean. Therefore, posture 2 is likely to be associated with far higher levels of paraspinal muscle activation (O'Sullivan et al. 2006a; Claus et al. 2009a; Reeve and Dilley 2009), and greater potential for fatigue and discomfort (Lander et al. 1987).

The greater frequency with which posture 2 was selected as the best sitting posture in the current study (19%) is the biggest contrast with the data from physiotherapists, where only 5% selected it as the best sitting posture (O'Sullivan et al. 2012i). This is not to suggest, however, that posture 2 was a very popular choice of posture among participants, since almost as many (15%) participants selected this posture as the worst sitting posture on the basis of the effort involved in sustaining it, and its unnatural, awkward or uncomfortable appearance. This contrast possibly reflects discussions in the scientific literature on weighing up the proposed benefits of upright sitting with the effort involved in sustaining it (O'Sullivan et al. 2006a; Claus et al. 2009a). This may explain why posture 9 was described as relaxed (n=15) or comfortable (n=12), whereas posture 2 was never described in such terms by participants.

The reason for the difference in perceptions between genders is unclear. While both genders most frequently picked posture 9 as the best posture, a greater proportion of males selected postures which involved more
spinal extension (postures 2, 4, 5 and 8) as their best posture. There is evidence that lumbar posture differs between genders (Dunk and Callaghan 2005; Smith et al. 2010), and that body-image awareness is heightened in females (Muth and Cash 1997). However, this is the first study to demonstrate that perceptions of good sitting posture differ between genders.

While most participants only occasionally thought about their own posture, participants with NSCLBP thought about their posture more frequently than those without NSCLBP. The increased frequency of thinking about posture among people with NSCLBP is consistent with descriptions of hypervigilance among people with NSCLBP (Peters et al. 2002). However, the increased focus on their own posture does not seem to have significantly affected their perception of good sitting posture. This lack of a difference in perceptions of good posture between people with and without NSCLBP is intriguing. Considering the reported difficulties among people with NSCLBP in assuming neutral postures (O'Sullivan 2005; Dankaerts et al. 2006b; Sheeran et al. 2012), in repositioning to a neutral sitting posture (Brumagne et al. 2000; O'Sullivan et al. 2003; Sheeran et al. 2012), in perceiving their own body movement and body space (Bray and Moseley 2011; Luomajoki and Moseley 2011; Moseley et al. 2012), and evaluating the perceived harm of tasks using photographs (Leeuw et al. 2007b; Trost et al. 2009), it was hypothesised that people with NSCLBP would demonstrate an altered perception of what constitutes good sitting posture. However, their perceptions were not significantly different to people without NSCLBP. Nor were perceptions of sitting posture significantly different among those with higher levels of disability, even though the back beliefs of physiotherapists were related to their perceptions of good sitting posture (O'Sullivan et al. 2012i). The lack of difference may indicate that people with NSCLBP have the same postural beliefs as people without NSCLBP, yet display a specific deficit in determining their own posture due to mechanisms such as altered proprioception, body schema and cortical processing (Brumagne et al. 2000; Bray and Moseley 2011; Luomajoki and Moseley 2011; Wand et al. 2011b; Moseley et al. 2012; Sheeran et al. 2012). To determine this, further studies investigating the perceived ability of people with NSCLBP to detect their own posture would be of interest. For example, it is possible that the posture selected by people with
NSCLBP as the best posture may differ from the posture they would assume if asked to achieve such a posture, considering deficits in their body schema and movement awareness (Bray and Moseley 2011; Luomajoki and Moseley 2011; Moseley et al. 2012).

It is important to highlight that no specific static sitting posture has been shown to effectively prevent or reduce NSCLBP. While posture 9 may have some advantages, a more relevant consideration in advising patients with NSCLBP on posture is likely to be their personal aggravating and easing factors and underlying pain mechanisms (O'Sullivan 2005; Dankaerts et al. 2009). The reason is that a specific directional sensitivity to movement (Williams et al. 1991; O'Sullivan 2005) may determine whether more or less seated spinal flexion is indicated. In fact, the ability to gradually vary posture in sitting may be as important as maintaining any specific static posture (Callaghan and McGill 2001; Vergara and Page 2002; Telfer et al. 2009). Therefore, for peripherally-maintained NSCLBP which is provoked in sitting, once a posture is not maintained too close to end-range, does not involve inappropriately high levels of muscle activation, and allows for gentle movement and variation in posture, several seated postures may be acceptable. Even more importantly, the multidimensional nature of NSCLBP (O'Sullivan 2012) illustrates the need for clinical management to consider multiple aspects across the biopsychosocial spectrum which may be significant for each individual with NSCLBP, rather than focussing solely on sitting posture. For example, pain in sitting may primarily reflect underlying sensitisation of the central nervous system (CNS) which does not have a postural basis, rendering specific postural advice meaningless.

There are several limitations to this study. Only static, unsupported, sagittal plane postures were considered, and other seated postures are clearly possible. Several other postures and tasks, such as standing and bending, are also common aggravating factors for NSCLBP, and were not considered. Participants were not given any information about the pain status of the model, and were not specifically asked to relate it to their own pain or discomfort if they had NSCLBP. All participants were offered the same range of photographs, to simplify data collection and analysis, and minimise the influence of other confounding variables. The posture selected may have
varied with a model of a different gender (Dunk and Callaghan 2005; Smith et al. 2010) or body mass index (Smith et al. 2010). Several factors which could influence posture were not examined in this study such as thoughts and affect (Wilson and Peper 2004; Briñol et al. 2009), inter-personal communication (Mehrabian 1968), and psychosocial factors such as self-efficacy (O'Sullivan et al. 2011b). No information on age (Kuo et al. 2009) or pathology (McGregor et al. 1997), both of which could influence range of motion, was provided. Only unsupported sitting postures were used in order to allow clear visualisation of the spine, and participant selections may have differed for supported sitting since using a backrest can influence muscle activation and seated discomfort (Andersson et al. 1979; Vergara and Page 2002).

5. Conclusion

Members of the community consider sitting spinal posture to be important for the management of NSCLBP, yet only occasionally think about their own posture. The majority of participants selected lordotic sitting postures as being optimal, with flexed postures being seen as disadvantageous. Perceptions on sitting posture differed between genders, but not according to NSCLBP status. In particular, the extent of spinal extension which was considered optimal varied, with considerable conflict on the benefit of very upright postures. The perceptions of members of the community are broadly in line with those reported for physiotherapists. Further research on the effect of different sitting postures on NSCLBP, and on how accurately people with NSCLBP can detect their own sitting posture is indicated.
Key points: Chapter 3

The aim of this chapter was to examine perceptions of sitting posture among physiotherapists, as well as members of the community with and without NSCLBP. The results indicate that both physiotherapists and members of the community have a very strong preference for lordotic sitting postures. In particular, a “neutral” lordotic sitting posture was most commonly considered the best posture by both groups. Consistent with this, a slumped sitting posture was most commonly considered the worst posture by members of the community, although this was not examined among physiotherapists. An interesting dimension is the fact that in both physiotherapists and the wider community, alternative methods of sitting “upright” involving significant thoracic extension were also popular, despite involving very different spinal curvatures, trunk muscle activation patterns and spinal loads. This suggests that both groups prioritise lordosis in sitting, and consider several different ways of avoiding slump sitting to be acceptable.

The best posture selected by physiotherapists was influenced by their personal back beliefs, with physiotherapists who have a more pessimistic view of the prognosis for NSCLBP selecting more upright postures. This effect was not seen among the wider community however. While perceptions on sitting posture differed between genders, they were not significantly influenced by the presence of NSCLBP. The lack of a difference between those with and without NSCLBP was somewhat surprising, but may reflect the difference between looking at photographs of posture and actually assessing awareness of one’s own sitting posture. Further study examining the ability of people with NSCLBP to detect their own posture may clarify this.

Both groups expressed a degree of concern about the feasibility of maintaining upright or straight sitting postures, with very upright postures being criticised by some for the effort and strain associated with them. It seems that both physiotherapists and members of the community favour upright lordotic sitting postures. Furthermore, the accuracy and ease of positioning people in a “neutral” sitting posture has also been questioned (Claus et al. 2009c). For this reason, we conducted some related studies which have been added to the appendices (Appendices V-VII). Firstly, we
demonstrated that positioning pain-free participants in a neutral sitting posture can be done easily and reliably, even by student physiotherapists (O'Sullivan et al. 2010b) (Appendix V). Secondly, we demonstrated that the effort of maintaining a neutral sitting posture can be significantly reduced through simple modification of the sitting surface, such as by using a dynamic, forward-inclined chair (O'Sullivan et al. 2012c) (Appendix VI). Thirdly, we demonstrated that using the same dynamic, forward-inclined chair during typing can increase lumbar lordosis while reducing paraspinal muscle activation (O'Sullivan et al. 2012d) (Appendix VII). Therefore, it would appear that facilitation of neutral, upright spinal postures is possible without requiring excessive muscle activation. Taken in conjunction with the findings from the earlier systematic review which showed that using a backrest can reduce paraspinal muscle activation (Appendix III) (O'Sullivan et al. 2012a), it would appear that there are several ways of reducing the effort of maintaining an upright neutral posture.

Some specific limitations of the studies in this chapter, and their clinical implications, are worthy of consideration. The most important of these included the fact that;

- Despite the popularity of upright sitting, no specific static sitting posture has been shown to effectively prevent or reduce NSCLBP, including “neutral” upright sitting. While this posture may have some mechanical advantages, it may be more important to consider the personal aggravating and easing factors of people with NSCLBP (O'Sullivan 2005; Dankaerts et al. 2009; Sheeran 2010), and their underlying pain mechanism (O'Sullivan 2005), to determine if a specific directional sensitivity to movement exists (Williams et al. 1991; O'Sullivan 2005). In the event that a directional preference exists, reduction of spinal loading in the painful direction may help, and that may not always involve a strictly “neutral” posture. In fact, considering the frequency with which increased lordosis (Dankaerts et al. 2006b) and increased paraspinal muscle activation (Geisser et al. 2004; Geisser et al. 2005; Dankaerts et al. 2006a; Lewis et al. 2012) are reported in people with NSCLBP, it may often involve assuming more relaxed, less lordotic sitting postures, in direct contrast to the perceptions of the majority of both physiotherapists and members of the community.
• The actual ability of people with NSCLBP to detect their own posture accurately was not examined, although such a study is planned.

• Considering the evidence discussed earlier on the presence of subgroups, it is possible that people with mechanically-provoked NSCLBP may respond better to postures other than a neutral posture, according to their own directional sensitivity (Dankaerts et al. 2006b). For that reason, attempts to change posture should be closely linked to the pain response of the person with NSCLBP.

• Sitting posture is related to a range of factors, modifiable and non-modifiable, which were not considered in these studies including genetic (Seah et al. 2011), gender (O’Sullivan et al. 2011b), psychosocial (Wilson and Peper 2004; O’Sullivan et al. 2011b) and lifestyle (O’Sullivan et al. 2011b) factors. For that reason, attempts to change sitting posture may need to consider these other factors, rather than examining sitting posture in isolation.

• The multidimensional nature of NSCLBP requires that clinical management consider multiple aspects across the biopsychosocial spectrum, rather than focusing solely on sitting posture. In many cases, posture and other physical factors may be closely linked to psychosocial factors (Geisser et al. 2004; Lewis et al. 2012). Considering the limited evidence for seated interventions already identified in chapter 1, it would appear unlikely that postural biofeedback would greatly reduce the pain and disability associated with complex, disabling NSCLBP. For example, where the underlying pain mechanism is primarily linked to central sensitisation, postural interventions may be ineffective and even inappropriate.

Based on the results of this chapter, targeted interventions among people with NSCLBP appear justified. The next chapter asks whether simple postural biofeedback intervention can reduce seated discomfort, and whether a multidimensional, behavioural-based intervention can help reduce pain and disability among people with disabling NSCLBP.
CHAPTER 4: Interventions to reduce seated low back pain

This chapter contains two studies, both of which examined the effect of interventions for NSCLBP. The first study investigated using simple postural biofeedback to reduce seated LBP in a single-session among people with mild NSCLBP whose pain was aggravated by prolonged sitting. The second study examined the medium-term (3 months) effect of a multi-dimensional intervention on pain and disability among people with more disabling NSCLBP. The primary research questions for this chapter are illustrated in Table 13.

Table 13: Overview of the doctoral thesis and the research questions examined in each of the three main parts

<table>
<thead>
<tr>
<th>CHAPTER TITLE</th>
<th>QUESTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigating the validity and clinical applicability of a posture monitor</td>
<td></td>
</tr>
<tr>
<td>Perceptions of sitting posture</td>
<td></td>
</tr>
<tr>
<td>Interventions to reduce seated low back pain</td>
<td>• Can a simple postural biofeedback intervention reduce seated low back discomfort?</td>
</tr>
<tr>
<td></td>
<td>• Can a multi-dimensional intervention reduce the pain and disability associated with NSCLBP?</td>
</tr>
<tr>
<td></td>
<td>• If a multidimensional intervention is effective, what factors are changed using such an intervention?</td>
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Study VI: Investigating the effect of real-time spinal postural biofeedback on seated discomfort in people with non-specific chronic low back pain


Abstract

Sitting is a common aggravating factor in non-specific chronic low back pain (NSCLBP). 24 participants with NSCLBP sat for two hours while their seated posture and discomfort were analysed. 16 pain developers (PDs), defined as an increase in low back discomfort (LBD) of at least 2 points on the numeric rating scale, repeated the procedure one week later, while receiving real-time postural biofeedback. PDs were significantly older (p=0.018), more disabled (p=0.021) and demonstrated greater postural variability (p<0.001) than the other participants. The ramping up of LBD during sitting was significantly less (p=0.002) on retesting, when sitting posture was significantly less end-range (p<0.001), and less variable (p=0.032) than during initial testing. The results demonstrate that seated LBD is related to a range of factors, including modifiable characteristics such as sitting behaviour. In a specific sitting-related subgroup of people with NSCLBP, the ramping up of seated LBD was reduced by modifying sitting behaviour using real-time postural biofeedback. The magnitude of change, while statistically significant, was relatively small and no follow-up of participants was completed. Further research should examine the integration of postural biofeedback into comprehensive management strategies for NSCLBP addressing multiple factors involved in NSCLBP across the biopsychosocial spectrum.

Keywords: posture; low back pain; biofeedback; sitting
1. Introduction

Chronic low back pain (CLBP) is a very common and costly musculoskeletal disorder (Woolf and Pfleger 2003). Despite increased access to advanced spinal imaging in recent decades, the vast majority of people with CLBP demonstrate no relevant, identifiable pathology (Chou et al. 2009b), resulting in most CLBP being labelled “non-specific” CLBP (NSCLBP). It has been proposed that identification of specific subgroups within the NSCLBP population may help improve treatment outcomes, through the targeting of specific interventions (Borkan et al. 2002; O’Sullivan 2012).

Sitting commonly aggravates NSCLBP (Womersley and May 2006), yet does not cause NSCLBP in isolation (Roffey et al. 2010c). Little is known about why people report increasing low back discomfort (LBD) during sitting. It appears that people with NSCLBP adopt a “dynamic” sitting behaviour and use a large seated range of motion (ROM) whereas painfree participants assume a more “static” sitting behaviour (Dunk and Callaghan 2010). Studies among painfree participants in both sitting (Vergara and Page 2002; Telfer et al. 2009) and standing (Lafond et al. 2009; Gallagher et al. 2011) support the hypothesis that pain developers (PDs) do more fidgeting in static postures than non-pain developers (NPDs), such that large postural variation is an indicator of sitting discomfort. Increased trunk, and in particular hip, muscle co-activation (Nelson-Wong et al. 2008; Marshall et al. 2011) has also been linked to LBD during prolonged standing. Interestingly, these neuromuscular differences are present before the development of LBD (Gregory and Callaghan 2008; Nelson-Wong et al. 2008; Nelson-Wong and Callaghan 2010c), suggesting they may be maladaptive (provocative) rather than adaptive. However, reduced postural variation has also been reported among people with LBD (Bell 2008), highlighting a lack of clarity on the relationship between sitting behaviour and LBD. Age, body mass index (BMI) and physical activity levels do not appear to be different between people who do, and do not, develop LBD during prolonged static postures (Nelson-Wong and Callaghan 2010b; 2010a; 2010d), although further studies among people with NSCLBP are required.
Postural advice is commonly used in managing NSCLBP (Poitras et al. 2005), particularly among NSCLBP subgroups presenting with altered motor control (Dankaerts et al. 2006b). In particular, “neutral” sitting postures which avoid end-range flexion or extension are commonly advocated (O'Sullivan et al. 2012i). It would appear that differences in posture among people with NSCLBP are only evident when subgrouping of NSCLBP populations is performed based on the direction of pain provocation in patients with mechanically-provoked NSCLBP (Dankaerts et al. 2006b; Sheeran 2010). However, while some evidence demonstrates that altering sitting posture can reduce seated discomfort (Williams et al. 1991), most research suggests that changing sitting posture or chair design (Koskelo et al. 2007; Saarni et al. 2009; O'Sullivan et al. 2012e), does not significantly help NSCLBP. The strong evidence of neurophysiological changes among people with NSCLBP (Wand et al. 2011b) suggests that NSCLBP during sitting may in fact be multidimensional, with sitting posture being just one contributing factor to the overall NSCLBP disorder (O'Sullivan 2012).

Attempting to change sitting posture is challenging for several reasons. Firstly, posture is influenced by non-modifiable factors including genetics (Seah et al. 2011) and gender (Dunk and Callaghan 2005), as well as a range of psychosocial and lifestyle factors (O'Sullivan et al. 2011b). Secondly, trying to improve sitting posture may be complicated by the presence of altered proprioceptive awareness (Brumagne et al. 2000; O'Sullivan et al. 2003; Sheeran et al. 2012) and changes in body schema (Bray and Moseley 2011; Moseley et al. 2012) among people with NSCLBP, such that people with NSCLBP appear to adopt maladaptive, provocative postures without awareness of this (Dankaerts et al. 2006b; Sheeran et al. 2012).

A recent review (Ribeiro et al. 2011) demonstrated the potential of, and yet currently limited evidence for, biofeedback in NSCLBP management. Various forms of biofeedback have been used in the management of NSCLBP, with some evidence of effectiveness (Magnusson et al. 2008; Sheeran 2010). There is some preliminary evidence that biofeedback may help normalise spinal motion (Schön-Ohlsson et al. 2005; Dean and Dean 2006; Kernozek et al. 2006), and enhance clinical outcomes in acute low back pain (LBP) (Horton and Abbott 2008) and NSCLBP (Magnusson et al. 2008;
Sheeran 2010; Van Hoof et al. 2011). However, other studies have demonstrated little benefit from using biofeedback for NSCLBP (Bush et al. 1985; Stuckey et al. 1986). There is a lack of studies which have examined the effect of providing postural biofeedback during a standardised sitting task in specific NSCLBP subgroups.

Therefore this study investigated how sitting behaviour is related to seated LBD, and whether using postural biofeedback can reduce NSCLBP among people who experience LBD during a standardised seated task.

2. Methods
2.1 Study design
A repeated measures study design was used. All participants completed the same protocol on day one. Participants who developed LBD (see section 2.6) on day one repeated the procedure with postural biofeedback approximately one week later. Ethical approval was obtained from both university (EHS10-20) and hospital Research Ethics Committees. Written informed consent was obtained from all participants.

2.2 Participants
24 (14F/10M) participants were recruited from within the local community, and from a local pain medicine clinic. Participants’ mean(SD) age was 24.7(8.4) years, height was 174(9) cm, mass was 74.3(12.3) kg and BMI was 24.5(2.4) kg/m².

2.3 Eligibility Criteria
Participants were aged >18 years, and had experienced NSCLBP for at least three months, including the two weeks prior to testing. They had to report aggravation of their NSCLBP when sitting for longer than one hour. Participants were excluded if they were pregnant or reported neurological symptoms, a specific spinal pathology or previous spinal surgery. Participants were further classified into two NSCLBP subgroups; (i) active extension pattern (AEP) (n=14), and (ii) flexion pattern (FP) (n=10), as detailed in Table 14 and in greater detail elsewhere (O'Sullivan 2005).
### Table 14: Primary features of the two non-specific chronic low back pain (NSCLBP) subgroups

<table>
<thead>
<tr>
<th></th>
<th>Active Extension Pattern (AEP)</th>
<th>Flexion Pattern (FP)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Common Features</strong></td>
<td>• Primary pain is NSCLBP</td>
<td>• Predominantly report symptom aggravation during flexion movements e.g. slump sitting, bending, dressing and lifting activities</td>
</tr>
<tr>
<td></td>
<td>• Localised pain with or without referral</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Absence of a specific spine pathology</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Their maladaptive movement behaviour stresses their pain sensitive tissue</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Often appear to be unaware of their maladaptive movement behaviour</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• No impaired movement in direction of pain</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• While psychosocial factors and central sensitisation may be present, they are not considered to be the primary driver of the person’s pain</td>
<td></td>
</tr>
<tr>
<td><strong>Discriminatory features</strong></td>
<td>• Predominantly report symptom aggravation during extension movements e.g. standing, fast walking, running, swimming and overhead activities</td>
<td>• Movements involving spinal extension such as standing and walking are pain easing</td>
</tr>
<tr>
<td></td>
<td>• Movements involving relaxed spinal flexion are pain easing (e.g. relaxed sitting against a backrest)</td>
<td>• Reduced lumbar lordosis at the symptomatic region</td>
</tr>
<tr>
<td></td>
<td>• Increased lumbar lordosis at the symptomatic region</td>
<td>• Tendency to hold their pelvis in posterior pelvic tilt</td>
</tr>
<tr>
<td></td>
<td>• Tendency to hold their pelvis in anterior pelvic tilt</td>
<td></td>
</tr>
</tbody>
</table>

### 2.4 Outcome measures

Participants completed the numeric rating scales (NRS) of the Brief Pain Inventory (Wand et al. 2011a), the physical activity subscale of the Fear-Avoidance Beliefs Questionnaire (FABQ) (Waddell et al. 1993) and the Oswestry Disability Index (ODI) (Fairbank and Pynsent 2000). Participant’s mean(SD) pain was 1.5(1.3), fear-avoidance was 5.9(6.3), and functional disability was 10.8(12.7)%. 

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2.5 Posture monitoring

Lumbo-pelvic posture was measured using the BodyGuard™ (Sels Instruments, Vorselaar, Belgium). The BodyGuard™ is a wireless sagittal plane lumbo-pelvic posture monitor which can provide real-time postural biofeedback (audio or vibratory). The device has acceptable reliability (O'Sullivan et al. 2011a) and concurrent validity (O'Sullivan et al. 2012f; O'Sullivan et al. 2012k). Recent studies demonstrate that the device can detect differences in lumbo-pelvic posture between cyclists with and without NSCLBP (Van Hoof et al. 2012) (Appendix VIII), and reduce NSCLBP in a single case-study during cycling (Van Hoof et al. 2011) (Appendix IX). A 6 cm strain gauge, whose length during sagittal spinal motion modifies the device’s output, was positioned over the spinal levels of L3 and S2 (Figure 21). Calibration relative to maximum seated lumbo-pelvic ROM was then performed so that subsequent lumbo-pelvic posture could be expressed as a percentage of total lumbo-pelvic ROM. Maximum anterior pelvic tilt was set as 0% ROM, and maximum posterior pelvic tilt was set as 100% ROM (O'Sullivan et al. 2012c). Data were sampled at 20Hz and exported to Microsoft Excel. Postural variation was expressed as the standard deviation (SD) of lumbo-pelvic posture.

Figure 21: Participant in sitting with the BodyGuard™ posture monitor positioned using adhesive tape over the lower lumbar spine, at the levels of L3 and S2
2.6 Procedure
During testing, participants sat on a height-adjustable stool with a flat, leather seatpan without a backrest. They wore shorts and no shoes, with their hips and knees flexed to 90°. A television screen was placed directly in front of participants, with the bottom of the monitor at approximately eye level. They were instructed to “sit as you normally would” while watching a DVD for two hours. No breaks were provided during the two hours of testing. All relevant participants completed the full two hours of testing on both days. At baseline, every 15 minutes during testing, as well as six and 24 hours later, participants rated their discomfort levels in 12 body parts using the Body Part Discomfort Scale (BPDS) (Corlett and Bishop 1976). In this study a version using an 11 point scale was used (Vergara and Page 2002), where 0 = ‘no pain or discomfort’, 10 = ‘worst pain imaginable’. Both LBD and other body discomfort (OBD) were monitored, since changing sitting posture may affect LBD and OBD differently (Gadge and Innes 2007). For each test, LBD was rated using a single score, while OBD comprised the mean rating of the other 11 sites (O’Sullivan et al. 2012d). After testing, participants categorised as PDs were invited back for retesting. PDs were participants (n=16) whose LBD increased during testing by at least 2/10 from baseline (Ostelo et al. 2008; Ikeda and McGill 2012). NPDs (n=8) were discharged from the study.

2.7 Provision of postural biofeedback on retesting
The mean(SD) duration between tests was 6.5(2.8) days, which was performed at the same time of day (+/- one hour). For each participant, a threshold for their biofeedback was first established. This threshold position was set in a more flexed position for the AEP group and in a more extended position for the FP group. The exact %ROM used as the threshold varied pragmatically for each participant, taking into account their gender, available ROM, and difficulty assuming a neutral posture. The rationale for changing their posture, based on their aggravating factors and their baseline posture values, was explained to participants. Participants were advised to move through full ROM intermittently while sitting, but to then relax in a posture which did not exceed their threshold. The BodyGuard™ device vibrated when
participants assumed a posture beyond their individual threshold. On completion of retesting, participants were asked whether they found the biofeedback comfortable and/or helpful.

2.8 Data Analysis
Data were analysed using SPSS 19.0. Data were checked for normality of distribution (Shapiro-Wilks, p<0.05). Where data were non-normally distributed, non-parametric statistics were used. Postural data were analysed in 15 minute segments for each test day, as well as across the full duration of testing (two hours), in line with previous research (Van Hoof et al. 2012). A mixed-model ANOVA examined the effect of time (within-subjects) and pain development (between-subjects) on mean posture. Changes in LBD, OBD, and postural variation over time during both tests were analysed using Friedman’s test. Mean posture across the two hours, postural variation across the two hours, LBD and OBD were compared between groups using independent t-tests or Mann-Whitney U tests, and between tests using paired t-tests or Wilcoxon Signed-Ranks tests.

3. Results
3.1 Baseline testing (T1)
PDs were significantly older (Z=-2.363, p=0.018) and more disabled (Z=-2.314, p=0.021) than NPDs, with no significant differences for BMI (t=-1.250, p=0.481), NSCLBP duration (t=0.825, p=0.257), pain intensity (t=1.276, p=0.337) or fear-avoidance (Z=-0.625, p=0.532).

3.1.1 Discomfort
Both LBD ($\chi^2(10, n=24) = 115.592, p<0.001$) and OBD ($\chi^2(10, n=24) = 48.814, p<0.001$) increased significantly during T1 across all 24 participants. 16 participants (8AEP/8FP) were PDs (Table 15). While LBD increased to a significantly greater degree among PDs (Z=-4.051, p<0.001), there was no difference in OBD between the PD and NPD groups (Z=-0.278, p=0.787).
Table 15: Low back discomfort (LBD) and other body discomfort (OBD)

<table>
<thead>
<tr>
<th></th>
<th>PD (n=16)</th>
<th>NPD (n=8)</th>
<th>All (n=24)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBD – T1*#</td>
<td>2.00(2.00-4.00)</td>
<td>0.00(0.00-0.75)</td>
<td>2.0(0.25-3.00)</td>
</tr>
<tr>
<td>OBD – T1*</td>
<td>0.32(0.09-0.52)</td>
<td>0.27(0.11-0.45)</td>
<td>0.27(0.09-0.45)</td>
</tr>
<tr>
<td>LBD – T2*†</td>
<td>1.00(0.00-1.75)</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>OBD – T2*</td>
<td>0.18(0.00-0.36)</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

PD – pain developer; NPD – non-pain developer; T1 – test 1; T2 – test 2; * - significant increase within testing session; # - significant difference between PD and NPD groups during test 1; † - significantly smaller increase than during test 1; NA – not applicable; all data expressed as median(Interquartile range).

3.1.2 Posture

There was no significant main effect on mean posture for time (F=1.299, p=0.275), PD status (F=0.221, p=0.608), nor the interaction (F=0.698, p=0.603) between them. Mean posture across the entire two hours of T1, for PD (85.5%) and NPD (78.7%) groups is illustrated in Table 16. Since mean posture did not change significantly during T1, other mean posture data were analysed across the entire two hours.

Postural variation increased during T1 ($\chi^2= 33.006$, p<0.001). Mean postural variation across the two hours was significantly greater (t=3.043, p=0.006) among PDs (17.7%) than NPDs (10.4%).

Mean posture was significantly different (t=4.504, p<0.001) between the AEP (66.1%) and FP (107.1%) subgroups during T1 (Figure 22), unlike postural variation (t=0.330, p=0.745) between the AEP (14.8%) and the FP (15.9%) subgroups.

Table 16: Mean(SD) lumbo-pelvic posture among pain developers and non-pain developers, stratified by non-specific chronic low back pain (NSCLBP) subgroup, during test 1

<table>
<thead>
<tr>
<th></th>
<th>PD (n=16)</th>
<th>NPD (n=8)</th>
<th>All (n=24)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEP</td>
<td>61.4(11.5) %</td>
<td>72.3(21.9) %</td>
<td>66.1(18.3) %</td>
</tr>
<tr>
<td>FP</td>
<td>109.5(27.1) %</td>
<td>97.6(10.4) %</td>
<td>107.1(26.5) %</td>
</tr>
<tr>
<td>All</td>
<td>85.5(32.1)%</td>
<td>78.7(24.1) %</td>
<td>83.2(29.9)%</td>
</tr>
</tbody>
</table>

3.2 Effect of biofeedback on PDs during test 2 (T2)

3.2.1 Discomfort

LBD during T2 was significantly reduced compared to T1 (Z=-3.107, p=0.002) (Figure 23), however OBD was not significantly different (Z=-1.305, p=0.192) during T2 (Table 15). Although the increase was smaller than during T1, both LBD ($\chi^2(10, n=16) = 126.604, p<0.001$) and OBD ($\chi^2(10, n=16) = 69.640, p<0.001$) still increased significantly during T2 (Table 15).

Figure 22: Lumbo-pelvic posture for both non-specific chronic low back pain (NSCLBP) subgroups during both test days

T1 – baseline test; T2 – repeat test for pain developers; FP – flexion pattern subgroup; AEP – active extension pattern subgroup; times 1-8 were the average posture for every 15 minutes over the two hour test; %ROM – percentage of lumbo-pelvic range of motion.
3.2.2 Posture

Mean posture during T2 (80.8%) was not significantly different (t=0.436, p=0.669) from T1 across the entire NSCLBP population (85.4%). However, the NSCLBP subgroups were provided with biofeedback which changed their mean posture in different directions. When values for change in mean posture were all expressed as positive to account for the two subgroups, there was a significant difference (Z=-3.516, p<0.001) in mean posture between tests. During T2 there was no longer a significant difference (t=-1.101, p=0.290) in mean posture between the AEP (85.2%) and the FP (76.4%) subgroups.

A significant main effect on postural variation for time ($\chi^2= 36.25$, p<0.001) was present during T2, with greater postural variation later during testing again. Postural variation among the PD group was significantly reduced (t=2.358, p=0.032) during T2 (14.9%) compared to T1 (17.7%). Similar to T1, there was no significant difference (t=-0.145, p=0.887) in postural variation between the AEP (15.2%) and the FP (14.6%) subgroups during T2.
3.2.3 Participant comments on biofeedback

All participants reported that the device was comfortable and the biofeedback helped their postural awareness. One participant commented that the vibration might not be sufficiently noticeable during a more dynamic task.

4. Discussion

This study demonstrated that providing postural biofeedback significantly reduced seated LBD by facilitating a more neutral and less variable sitting posture, suggesting a potential role for biofeedback in NSCLBP management.

Increased postural variability associated with discomfort has previously been reported among people with NSCLBP during sitting (Dunk and Callaghan 2010), and among painfree participants in both sitting (Vergara and Page 2002; Telfer et al. 2009) and standing (Lafond et al. 2009; Gallagher et al. 2011). The fact that postural variability increased during testing on both days, among both PDs and NPDs, could be interpreted as an adaptive attempt to reduce seated discomfort through varying spinal postures and loads. However, the increased postural variability among PDs during T1 suggests this is a maladaptive sitting behaviour rather than a beneficial, adaptive response to pain. This is further supported by the fact that assuming a less variable posture during T2 was associated with reduced LBD. This behaviour is also consistent with reports of increased muscle co-activation (Nelson-Wong et al. 2008, Nelson-Wong and Callaghan 2010c, Gregory and Callaghan 2008) and postural fidgeting (Gallagher et al. 2011) before the onset of LBD in standing among PDs. This pre-existing increased postural variability among PDs may partly explain the poor evidence for “dynamic” chairs in the management of NSCLBP (O'Sullivan et al. 2012e) as they may actually reinforce this behaviour.

The data regarding mean posture were not discriminative unless NSCLBP subgroups were considered. While the AEP and FP subgroups were significantly different, the lack of a significant difference in mean posture between the PDs and NPDs during T1 possibly reflects a “wash-out” effect between heterogenous subgroups (Dankaerts et al. 2006b; Sheeran 2010). Given the small numbers involved in each subgroup – for example only two of
the FP subgroup were NPDs – further statistical analysis was not performed on that data. However, assuming a less end-range posture, away from their provocative position, for both subgroups resulted in reduced LBD during T2.

The decision to facilitate a less end-range posture, with less variability, was based both on recommendations within the literature, as well as the baseline data from T1. Neutral postures have been linked to less risk of NSCLBP (Smith et al. 2008; Dolphins et al. 2012), possibly by reducing nociceptive input from prolonged end-range loading of spinal structures and facilitating low-level trunk muscle activation (O'Sullivan et al. 2006a). While assuming static postures has been criticised (van Deursen et al. 1999), taking regular breaks from sitting and then returning to relaxed, neutral sitting may be more appropriate than ongoing postural fidgeting in sitting.

Despite the perceived importance of seated posture in NSCLBP management (O'Sullivan et al. 2012i), there remains a lack of strong evidence that attempts to change sitting posture help prevent or reduce NSCLBP (Saarni et al. 2009; O'Sullivan et al. 2012e). Both electromyographic and postural real-time biofeedback could address documented deficits in proprioception (O'Sullivan et al. 2003; Sheeran et al. 2012) and body schema (Bray and Moseley 2011; Moseley et al. 2012) in NSCLBP management. Considering the time and expense which can be involved with biofeedback, clear supporting evidence is warranted before it is advocated for retraining maladaptive provocative sitting postures. However, many biofeedback studies have demonstrated changes in secondary measures such as muscle activation, without improving pain or disability (Peck and Kraft 1977; Nouwen 1983; Asfour et al. 1990). Some single case-studies or uncontrolled, preliminary studies (Neblett et al. 2003, Horton and Abbott 2008, Van Hoof et al. 2012) have demonstrated the potential of biofeedback to reduce pain or disability in NSCLBP. Biofeedback also appears to help when used as an additional intervention (Magnusson et al. 2008). However, more rigorous controlled studies disagree on whether biofeedback is better than (Nouwen and Solinger 1979; Flor et al. 1986) or no better than (Bush et al. 1985; Stuckey et al. 1986) either a placebo or no intervention. In a similar vein, whether biofeedback is as effective as, or better than, a range of interventions including cognitive-behavioural therapy (CBT), education or relaxation training.
is still not fully understood (Stuckey et al. 1986; Flor and Birbaumer 1993; Donaldson et al. 1994; Newton-John et al. 1995).

Several factors may explain the effectiveness of biofeedback in the current study. The biofeedback was matched to participant postural needs based on their NSCLBP subgroup. This has only been done in two previous studies, both of which also reported positive results (Sheeran 2010; Van Hoof et al. 2012). Therefore, rather than providing generic postural advice or biofeedback, these may be more effective when matched to an individual’s NSCLBP presentation (Sheeran 2010). The controlled task studied was a primary aggravating factor for every participant, increasing the clinical relevance of the biofeedback. Also, participants had a relatively low level of disability, and their predominant pain mechanism was likely to be a peripheral nociceptive one (Smart et al. 2010) based on the inclusion criteria. While the results support the hypothesis that sagittal plane kinematics can contribute to NSCLBP, postural biofeedback may be less effective among people with more severely disabling NSCLBP disorders, whose pain is primarily driven by central sensitisation (Smart et al. 2010). While postural factors may be significant for NSCLBP subgroups, NSCLBP is a multidimensional disorder where physical (Hodges and Richardson 1996; Hides et al. 2008; Dankaerts et al. 2009), psychosocial (Carroll et al. 2004; Jarvik et al. 2005; Main et al. 2010; Mitchell et al. 2010; Ramond et al. 2011), lifestyle (Onen et al. 2001; Chiu et al. 2005), genetic (Reichborn-Kjennerud et al. 2002; Battie et al. 2004) and neurophysiological (Apkarian et al. 2009; Wand et al. 2011b) factors are often relevant. It is unlikely that postural biofeedback, or any one-dimensional physical or ergonomic intervention, would significantly reduce disabling NSCLBP in the long-term. However, even in NSCLBP subjects with high levels of fear, stress or anxiety, facilitation of less painful sitting postures may help as part of a comprehensive functional rehabilitation programme (Geisser et al. 2004; Lewis et al. 2012), especially if the patient is given insight into their pain mechanisms, and given strategies to control their NSCLBP.

Limitations and recommendations
The selection of a two point increase for categorising participants as PDs was somewhat arbitrary, but reflects the minimally important change (MIC) for the
NRS (Ostelo et al. 2008), and the value used in previous similar research (Ikeda and McGill 2012). While biofeedback reduced LBD, both LBD and OBD still increased significantly over time on both days, suggesting any sustained static seated posture still aggravates NSCLBP, and intermittent periods of physical activity may be needed. This is also consistent with the multidimensional nature of NSCLBP, where central sensitising factors are also implicated (Apkarian et al. 2009; O’Sullivan 2012). The magnitude of decrease (1.7 points on NRS) was relatively small, and less than the recommended MIC value (Ostelo et al. 2008). It is however greater than the within-session decrease in LBP reported using approaches such as mirror feedback (Wand et al. 2012). Since PDs reported significantly greater disability than NPDs, it suggests that PDs had greater central sensitisation (Butler 2000). This baseline sensitivity is also likely to have contributed to the increased LBD reported during T1, rather than purely sitting behaviour.

It is unclear what form of biofeedback is most effective (e.g. visual using mirrors, verbal, auditory etc..) (Sheeran 2010; Wand et al. 2012), or even whether this will be the same for all people with NSCLBP. It is possible that combining different forms of biofeedback and awareness training may be even more useful (Moseley and Wiech 2009). Several other approaches may help reduce LBD during static tasks, including ergonomic interventions (Nelson-Wong and Callaghan 2010b) and exercise programmes (Nelson-Wong and Callaghan 2010a). Many different postures are provocative for NSCLBP, including dynamic tasks such as bending and lifting. These are worthy of further study, although it appears that neuromuscular patterns among PDs in static postures are predictive of altered neuromuscular control in dynamic tasks like bending (Nelson-Wong et al. 2012) and trunk loading (Gregory et al. 2008). No follow-up of the participants was included, such that it is unclear if the reduced LBP was maintained. However, within-session changes in LBP, as seen in this study, appear to indicate a likelihood of responding to rehabilitation (Cook et al. 2012). The novel, innovative nature of the postural biofeedback makes participant blinding almost impossible, and raises the possibility of an enhanced placebo effect. Longer sitting durations are worthy of investigation. Using a stool without a backrest does not reflect the type of seat most commonly used. However, it was considered
advantageous in this study to remove use of the backrest as a confounding variable (Gregory et al. 2006), and pilot testing suggested this increased the likelihood of participants experiencing a sufficient increase in LBD within two hours. It is possible that discomfort may have been reduced simply due to task familiarity (Nelson-Wong and Callaghan 2010a). Future research using postural biofeedback which is not matched to NSCLBP subgroups could clarify whether matching the direction of biofeedback to the person’s NSCLBP subgroup is required. Other potentially relevant parameters such as muscle activation were not measured. The assessor of seated discomfort was not blinded. Angular data is not provided with the posture monitor, and increased forward lean can result in data exceeding the calibration value of 100%ROM.

5. Conclusion
LBD was significantly reduced using real-time postural biofeedback to facilitate a more neutral, less variable, sitting posture. Postural and/or ergonomic interventions which are targeted to the specific aggravating factors, and clinical presentations, of people with NSCLBP may be useful in the management of NSCLBP. Nevertheless, NSCLBP is a multi-dimensional biopsychosocial disorder, where addressing mechanical factors such as seated posture are only one aspect of management.
Study VII: The effect of a multidimensional cognitive functional therapy intervention on people with non-specific chronic low back pain: a case-series


Abstract

Cognitive Functional Therapy (CFT) is a behavioural intervention which aims to address multiple dimensions across the biopsychosocial spectrum in the management of non-specific chronic low back pain (NSCLBP). CFT combines a behavioural approach of retraining provocative postures and movements with cognitive reconceptualisation of the NSCLBP problem, while also targeting psychosocial barriers to recovery. This study aimed to examine the effectiveness of CFT for people with disabling NSCLBP on a waiting list for a specialist medical consultant, using a multiple case-series (n=26) design consisting of 3 phases (A1-B-A2). Measurement phase A1 was a baseline phase during which pain and functional disability were collected on three occasions over two months for all participants. During phase B, participants entered a CFT intervention program, involving approximately eight treatments over an average of 12 weeks. Finally, phase A2 was a no-treatment follow-up period lasting three months. A general linear model repeated measures ANOVA (post-hoc Bonferroni) compared functional disability and pain across the five time intervals – three baselines, immediately post-intervention, and three months later. Statistically significant improvements in both functional disability (p<0.001) and pain (p<0.001) were observed immediately post-intervention, and three months later compared to baseline measurements. The effect sizes were large, and reached clinical significance for both disability (41% decrease) and pain (31% decrease). Several secondary outcomes were significantly (p<0.01) improved after the intervention, including depression, back beliefs, fear of physical activity, catastrophising and self-efficacy. These promising results suggest that CFT should be compared to other conservative
interventions for the management of disabling NSCLBP in large randomised clinical trials.

**Keywords:** low back pain; rehabilitation; behaviour; physiotherapy;
1. Introduction

Non-specific chronic low back pain (NSCLBP) remains a common and costly musculoskeletal disorder, with effective treatments remaining elusive (Dagenais et al. 2008). While the movement behaviours and body schema of people with NSCLBP differ from painfree controls (Lewis et al. 2012, Bray and Moseley 2011, Dankaerts et al. 2009), most physical interventions demonstrate limited effectiveness (van Tulder et al. 2000, Furlan et al. 2005, Assendelft et al. 2003, Ferreira et al. 2007, Schaafsma et al. 2010). There is growing evidence that a range of psychosocial factors including depression, anxiety, fear, low self-efficacy, catastrophising, distress, negative beliefs and maladaptive coping are associated with disabling NSCLBP disorders (Carroll et al. 2004; Jarvik et al. 2005; Gatchel et al. 2007; Leeuw et al. 2007a; Main et al. 2010; Mitchell et al. 2010; Ramond et al. 2011). In light of this knowledge, educational and/or psychosocial interventions have been employed which appear to be slightly more effective than traditional physical interventions (van Tulder et al. 2001; Moseley 2002; Henschke et al. 2010; Ryan et al. 2010). This is supported by reports that reduced disability after rehabilitation is primarily related to improvements in fear, distress, catastrophising and self-efficacy (Mannion et al. 2001b; Woby et al. 2007). However, systematic reviews reveal that the effect size of educational and psychologically-based behavioural therapies remains relatively small, with limited long-term effectiveness (Keller et al. 2007; Henschke et al. 2010). Further, with several behavioural therapies available, no specific type appears to be more effective than another (Wetherell et al. 2011).

The evidence suggests that maladaptive movement behaviours in NSCLBP subjects are associated with increased levels of fear (Geisser et al. 2004) and catastrophising (Sullivan et al. 2009), highlighting close body-mind interactions. Given the inter-related multi-dimensional nature of disabling NSCLBP, interventions which target multiple dimensions associated with a person’s pain disorder have been advocated (Wand et al. 2011a; O’Sullivan 2012). The few trials employing targeted behavioural approaches to managing NSCLBP have shown encouraging findings (Asenlof et al. 2009; Fersum et al. 2011; Hill et al. 2011).
Cognitive Functional Therapy (CFT) is a novel, person-centered behavioural intervention which addresses multiple dimensions in NSCLBP (O’Sullivan 2012). CFT combines a functional behavioural approach of retraining provocative postures and movements with cognitive reconceptualisation of the NSCLBP problem. In a randomised controlled trial (RCT) among people with mild-moderate NSCLBP, this approach was more effective than combining manual therapy and exercise (Fersum et al. 2011). However, this approach has not yet been evaluated among people with higher levels of disabling NSCLBP, a group who consume most healthcare resources (Hill et al. 2011).

Multiple single-case designs are advocated in the developmental stages of novel chronic pain interventions before progressing to RCT design studies (Boersma et al. 2004; Van De Meent et al. 2011). This allows interpretation of the changes which occur with rehabilitation, and fine-tuning of the intervention before a RCT. Therefore, this study examined the role of CFT in a multiple single-case design, using repeated measurements of the primary outcomes at baseline in a group of patients with disabling NSCLBP. Secondary outcomes were assessed by a range of questionnaires along with novel, minimally invasive, “real-world” methods of analysing physical factors relevant to NSCLBP such as posture and physical activity.

2. Methods
2.1 Study Design
A multiple single-case design consisting of three phases (A1-B-A2) was used. Phase A1 (duration three months) was a baseline measurement phase during which no new intervention took place. During this phase, self-reported baseline measures of pain and functional disability (see section 2.3) were collected for all participants on three occasions six weeks apart. In addition, a range of other secondary outcome measures (see section 2.3) were collected once at the start of this stage. During phase B, participants started the CFT intervention. The length of this intervention phase varied in a pragmatic manner based on the progress of the participants, but had a minimum duration of 6 weeks. At the end of phase B, all outcome measures (primary
and secondary) were completed once again. Formal treatment was withdrawn in Phase B, but participants were expected to continue their behavioural-based modification program independently using the strategies developed during the intervention period for the duration of phase A2, which lasted three months. At the end of phase A2 primary outcome measures for self-reported pain and functional disability were completed once more. Data were collected over a period of 11 months. Ethical approval for this study was obtained from two local hospital Research Ethics Committees.

2.2 Participants

Participants were recruited from three local medical consultant clinics (two chronic pain centres, one rheumatology centre). All participants were on the public health service waiting lists, either awaiting appointment with the medical consultant, or awaiting a medical intervention after their initial appointment. To be eligible for inclusion, participants had to report NSCLBP for at least six months, their NSCLBP had to be present in the previous week and the lower back had to be reported as their primary pain location. The NSCLBP must have interfered with their function, such that they reported reduced activity levels, or required treatment or medication, in the previous year (Mitchell et al. 2010). Participants had to be aged between 18 and 65 years of age, be independently mobile, and capable of participating in a rehabilitation programme incorporating an exercise component. They had to report their NSCLBP was aggravated by changes in posture, movement or physical activity. Participants were excluded if they had evidence of specific spinal pathology (such as malignancy, fracture, infection, spinal stenosis, spondylolisthesis, or inflammatory joint or bone disease), were pregnant or < six months postpartum, had evidence of neurological compromise or had undergone a pain-relieving medical procedure (e.g. facet or sacroiliac joint injection, myofascial trigger point injection, denervation procedure) in the previous three months. A total of 47 potential participants from the medical consultant waiting lists were contacted. 11 people did not meet the criteria, while another nine people declined participation (Figure 24). The remaining 27 people fulfilled all criteria, and were invited to participate in the study. One
Figure 24: Flowchart of participant progress through the study
NSCLBP – non-specific chronic low back pain; ITT – intention-to-treat analysis
participant then withdrew before starting the study, due to difficulty organising transport to attend. The remaining 26 people provided written informed consent, and entered the study.

### 2.3 Outcome measures

Participants provided a range of demographic information, including age, height, weight, NSCLBP duration, and the number of pain sites throughout their body during the last 12 months using the Nordic Musculoskeletal Questionnaire (Kuorinka et al. 1987).

The primary outcomes were (1) functional disability using the Oswestry Disability Index (ODI) (Fairbank and Pynsent 2000) and (2) pain severity, scored using the average of the four (maximum, minimum, average, now) numeric rating scales (NRS) of the Brief Pain Inventory (Wand et al. 2011a).

A range of secondary outcome measures were also collected. Depression, anxiety and stress were analysed using the subscales of the DASS21 (Lovibond and Lovibond 1995). Participants beliefs and thoughts about NSCLBP were analysed using the back beliefs questionnaire (BBQ) (Buchbinder and Jolley 2005), the physical activity subscale of the Fear Avoidance Beliefs Questionnaire (FABQ) (Waddell et al. 1993) and the pain catastrophising scale (PCS) (Sullivan 2004). Self-efficacy was assessed using the pain self-efficacy questionnaire (PSEQ) (Nicholas 2007), while the STarT Back screening tool, which is a predictor of outcome (Hill et al. 2008), was also completed. All these questionnaires have appropriate psychometric properties for use in NSCLBP research.

Usual daily physical activity over approximately one week was analysed using an accelerometer (ActivPal™) placed on the thigh (Ryan et al. 2009). Usual seated lumbo-pelvic posture (mean and SD) was evaluated during a representative day outside the laboratory using a wireless posture monitor (BodyGuard™) placed on the lower lumbar spine. This wireless posture monitor has established reliability and validity for monitoring lumbo-pelvic posture (O'Sullivan et al. 2011a; O'Sullivan et al. 2012f; O'Sullivan et al. 2012k). Lower lumbar spine posture during the three longest sitting periods on each day was extracted for analysis. Finally, lumbo-pelvic repositioning error
(constant error) during a neutral sitting posture repositioning task was evaluated as previously described (O'Sullivan et al. 2003) using the same posture monitoring device both in phase A1 and after treatment (end of phase B).

2.4 Clinical Assessment

After all baseline measurements were completed, all participants underwent a comprehensive interview and physical examination by one of the authors (KOS), who is a specialist musculoskeletal physiotherapist with 13 years experience. The aim of this interview was to let participants tell their story regarding their pain disorder and the impact it had on their life. During this interview participants provided information about their history of pain, pain area and nature, pain behaviour (aggravating/easing movements and activities), their primary functional impairments, disability, activity levels, lifestyle behaviours and sleep patterns. Inquiries were also made regarding their level of fear of pain and any avoidance of activities, work and social engagement. Their degree of pain focus, pain coping strategies, stress responsiveness and its relationship to pain and their pain beliefs were also questioned, as was any history of anxiety and depression. Finally their beliefs and goals regarding management of their disorder were ascertained. The physical examination involved analysis of the subject's primary reported functional impairments (pain provocative movements and functional tasks), in order to identify maladaptive movement and muscle guarding behaviours (pain behaviours). They were also assessed regarding their level of body control and awareness (body schema), their ability to relax their trunk muscles and normalise their movement behaviours, and the effect this had on their pain (O'Sullivan 2005).

2.5 Intervention

Formal treatment was provided in an outpatient university setting, typically once per week and reducing gradually to once every two weeks. Each patient received a specific targeted intervention directed at changing their individual cognitive, movement and lifestyle behaviours considered to be provocative for
their disorder (O'Sullivan 2005; Dankaerts et al. 2007; Lewis et al. 2012). There were four main components to the intervention. Details of the different components involved in the CFT intervention are described in detail in Table 17. These were; (1) a cognitive component focussed on pain mechanisms and the factors identified from the examination that were considered to contribute to their pain disorder; (2) functional movement training which involved a behavioural modification approach to rehabilitation where subjects were taught strategies aiming to enhance their body awareness and control in order to relax and modify postures and tasks they reported as being pain provocative; (3) functional integration of these exercises in activities of daily life which they reported that they avoided or which provoked their pain and (4) restoration of relaxed, comfortable physical activity levels (Table 17). Participants were requested to practice these strategies at home, and to become increasingly aware of both physical and cognitive dimensions to their pain, both during the treatment period (phase B), as well as after the cessation of formal treatment (phase A2).
Table 17: Detailed description of the four stages involved in the Cognitive Functional Therapy (CFT) Intervention

<table>
<thead>
<tr>
<th>Stages</th>
<th>Components</th>
<th>Details</th>
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<tr>
<td>1. Cognitive training</td>
<td>Changing perception of pain as “harm” and education regarding the multidimensional nature of chronic pain: A contemporary view of chronic pain physiology was presented. This emphasised how chronic pain more accurately reflects nervous system sensitivity than harm or structural damage, and that multiple factors across the biopsychosocial spectrum are relevant in the development and management of chronic pain. This integrated the biopsychosocial model for NSCLBP and outlined maladaptive cognitions and maladaptive behaviours as part of NSCLBP.</td>
<td>All participants watched an online video regarding chronic pain (<a href="http://www.youtube.com/watch?v=4b8oB757DKc">http://www.youtube.com/watch?v=4b8oB757DKc</a>) at the first session. This video was used to address commonly held beliefs that pain is an accurate indicator of the health of spinal tissues. The manner in which negative beliefs about pain, fear of movement, increased focus on pain, low mood, poor pacing, “protective” movement behaviours and muscle guarding can feed a “vicious cycle” of pain was outlined in a diagram. This cycle was based on findings from the interview, the clinical examination and completion of their questionnaires. The specific factors discussed varied for each participant and included psychosocial factors such as pain interpretation, beliefs about NSCLBP, fear, anxiety, worry, depression, stress, hypervigilance, guilt, grief, anger and stressful or traumatic life events. This process was openly discussed and participants were invited to consider how they might be able to break their cycle and set their own goals for management. These functional goals formed the basis on which the individual management plan was developed and targeted.</td>
</tr>
<tr>
<td></td>
<td>Interpretation of radiological findings: If participants had previously undergone spinal imaging, or were considering further imaging, this was discussed.</td>
<td>Participants were informed about the poor correlation of radiological findings with their clinical presentation. They fact that such radiological findings are common in painfree subjects, and generally correlate poorly with levels of pain and disability, was also discussed. They were educated about the strong, robust nature of the spine in dealing with movement and mechanical loads. Participants were asked to interpret weekly fluctuations in their pain in relation to events (physical, psychological, social) which occurred during their week. Prior to discharge, acute exacerbation management planning was discussed with each participant in order to promote an active/confrontational approach to ongoing pain management.</td>
</tr>
<tr>
<td></td>
<td>Management of fluctuations in pain and acute exacerbations: The overall emphasis of this component was to change the way the person with NSCLBP conceptualised their problem</td>
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on a long-term basis.

All other stages of the intervention (stages 2 – 4) had a strong cognitive focus with an emphasis on reflective communication, self-management practices, functional enhancement and goal orientation.

2. Functional movement training

**Re-education of normal postural and movement behaviour:**

This stage aimed to normalise movement behaviour, using a graduated exposure model where participants were exposed to previously pain provocative tasks, but in a non-provocative manner through modification of their movement behaviour, and their perception of the meaning of pain.

All participants received targeted functional movement training based on the specific tasks that they avoided due to pain, or that provoked their pain, or both.

The emphasis was on facilitating awareness of how their “protective” pain-related movement behaviour could maintain pain. Simple non-threatening low load exercises were gradually progressed towards higher load and more complex functional exercises, as participants gained confidence and control in performing the tasks. For example, if a participant was initially unable to relax their trunk muscles, they were initially taught diaphragmatic breathing in relaxed postures such as lying, sitting and standing. Once this was achieved, participants progressed to performing more challenging tasks in a relaxed, mindful and controlled manner. Pain behaviours such as grimacing, breath-holding, muscle guarding, propping with hands or avoidance such as asymmetrical loading were identified and abolished with practical demonstration by the therapist. This was augmented by the use of videos and mirrors so they could view their own spines to enhance body schema awareness, written instructions and stick body diagrams (outlining the “old” versus the “new” way of sitting, standing, bending, lifting and moving). No more than 3 or 4 exercises were given at a time.

3. Functional integration into each participant’s nominated pain-

Participants nominated specific tasks that provoked their pain. These tasks were rehearsed with the therapist, so that participants became more confident.
Integration provocative tasks: The exercises from stage 2 were integrated functionally into problematic daily tasks, specific to each participant’s functional impairments. The aim was to restore normal functional movement capacity and enhance body awareness, while reducing avoidance, pain behaviours and fear by means of pain control and confrontation in daily life.

4. Physical activity training Gradual increase in physical activity: Participants were encouraged to perform some form of physical exercise 3-5 times a week if they were not previously doing so. The duration for this was initially based on the participants exercise tolerance and gradually increased to 20-40 minutes duration.

and mindful of normalising their movement behaviours whilst performing these tasks. If the participant reported tasks they avoided, these were rehearsed and they were encouraged to confront these tasks (without protective pain behaviours) and include them in their daily life. In this manner, the aim was to increase functional capacity and participants were challenged to perform the tasks in a normal, painfree and controlled manner. For example, if a participant reported pain with, and/or fear of, lifting, a graded series of lifting tasks were rehearsed with feedback from the therapist. The re-emergence of maladaptive physical and psychological behaviours during such tasks was closely monitored and discussed with participants. The difficulty of these tasks was gradually increased in conjunction with participants. Where the participant’s functional goals required it, this was progressed into a conditioning program to build strength and endurance within these functional tasks.

No specific form of exercise was prioritised, with the emphasis instead being placed on performing exercise in a relaxed, mindful manner to facilitate normal movement. The type of physical activity was directed by participant preference, the availability of space and resources, and their symptoms during specific activities.
2.6 Data Analysis

The thigh accelerometer which collected physical activity data was worn for a mean(SD) of 5.6(1.3) days before and 5.8(1.2) days after treatment. This physical activity data were analysed as steps per day for each participant. The spinal posture monitor was worn for a mean(SD) duration of 341(123) minutes on one day during phase A1 and again for 243(96) minutes after treatment. Sitting periods while wearing the posture monitor were identified using the accelerometer placed on the thigh. Seated posture data for the three longest sustained sitting periods were then identified for each participant. The mean(SD) duration of each sitting period exported was 26(11) minutes and 25(13) minutes before and after treatment respectively.

All statistical analyses were carried out with SPSS 19.0. The reliability of the primary outcome measures (NRS and ODI) were assessed across the three baselines using the intra-class correlation coefficient (ICC) (two-way mixed), analysis of the standard error of measurement (SEM) and the minimal detectable change at the 90% confidence interval (MDC90). Data were tested for sphericity and normality of distribution. Mauchly’s test indicated that the assumption of sphericity had been violated for both disability and pain, such that degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity. ODI data were not normally distributed and were transformed using a natural log transformation in SPSS. Drop-outs were controlled for on an intention-to-treat basis, using the last observation carried forward. A general linear model repeated measures ANOVA was used to compare the primary outcomes (ODI and NRS) across the five time intervals – three baselines, immediately post-intervention, as well as the three-month follow-up period. Post-hoc Bonferroni tests were used when significant differences were observed. Statistical significance for these primary outcome measures was set as p<0.05. Effect sizes for the primary outcome measures were calculated using partial eta squared ($\eta^2$), and interpreted as small ($\eta^2$>0.01), medium ($\eta^2$ >0.06) or large ($\eta^2$>0.14) (Cohen 1988). The number of participants whose disability and pain remained at least 30% lower three months after the intervention was also evaluated, as this is considered the minimally important change (MIC) (Ostelo et al. 2008). The secondary outcome measures were
compared at baseline and immediately post-intervention using (depending on normality of distribution) a Wilcoxon-signed ranks test or a paired t-test. The effect size of the secondary outcome measures was expressed as $r^2$, and interpreted as small ($r^2>0.01$), medium ($r^2>0.09$) or large ($r^2>0.25$) (Cohen 1988). All p values for these secondary outcome measures were adjusted for multiple comparisons to p<0.0041.

3. Results
The 26 participants (14 female) had a mean(SD) age of 44.3(9.7) years, height of 171(10) cm, mass of 88.3(18.7) kg and body mass index of 30.1(5.3) kg/m². Their mean(SD) NSCLBP duration was 141(120) months, and number of pain sites was 4.3(1.9). Based on their STarT Back screening score, 14 were “high risk”, 8 were “moderate risk” and 4 were “low risk” at baseline. Two participants did not complete the programme; one participant was involved in a road traffic accident after entering the study and was unable to attend for further treatment, while another participant was offered a pain-relieving medical intervention during the study such that she was no longer eligible for participation. One further participant did not complete the three month follow-up. The mean(SD) number of treatment sessions was 7.7(2.5), provided over 12.0(3.5) weeks, with each session lasting 60.0(6.6) minutes.

3.1 Reliability of baseline measures
ODI values showed excellent association (ICC=0.86) between measurements, with small values for both the SEM (3.4) and MDC90 of 9.5. The reliability of the NRS was moderate, with an ICC of 0.67, while the SEM was 0.7 and the MDC90 was 2.0 (Table 18).

Table 18: The reliability of the primary outcome measures over the three repeated baselines

<table>
<thead>
<tr>
<th></th>
<th>ICC (95%CI)</th>
<th>SEM</th>
<th>MDC90</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODI</td>
<td>0.84(0.72-0.92)</td>
<td>3.4</td>
<td>9.5</td>
</tr>
<tr>
<td>NRS</td>
<td>0.67(0.47-0.82)</td>
<td>0.7</td>
<td>2.0</td>
</tr>
</tbody>
</table>

ODI – Oswestry Disability Index; NRS – numeric rating scale; ICC – intra-class correlation coefficient; CI – confidence interval; SEM - standard error of measurement; MDC90 - minimal detectable change at the 90% confidence interval.
3.2 Effect of CFT intervention

Functional disability was significantly reduced after the intervention, F(1.82, 45.6) = 17.550, p< 0.001. Post-hoc Bonferroni tests demonstrated that ODI values immediately after treatment and at 3 months follow-up were significantly different (p<0.05) to all three baseline measurements, with no other significant differences present (all p>0.05) (Figure 25). This effect size was large ($\eta^2=0.412$). Compared to mean ODI values across the three baselines, ODI values were 15.7% lower after treatment, and 16.3% lower 3 months later. 17 of the 24 participants who completed the intervention reported a reduction in functional disability greater than 30% three months after the intervention was ended.

Pain was also significantly reduced after the intervention, F(2.85, 71.2) = 8.466, p<0.001. Post-hoc Bonferroni tests demonstrated that NRS values immediately after treatment and at 3 months follow-up were significantly different to the middle one of the three baseline measurements (p<0.05). However, this reduction in NRS values did not reach statistical significance (p>0.05) for the other two baseline measurements, with no other significant differences present (all p>0.05) (Figure 26). This effect size was large ($\eta^2 =0.253$). Compared to average NRS values across the three baselines, NRS values were 1.6 points lower after treatment, and 1.5 points lower 3 months later. 12 of the 24 participants who completed the intervention reported a reduction in pain greater than 30% three months after the intervention was ended.
Figure 25: Functional disability (ODI) at each stage of the study
Times 1-3 were the three repeated baseline measurements each taken six weeks apart; time 4 was immediately after the intervention was completed (mean 12 weeks later); time 5 was three months after completing the intervention; ODI – Oswestry disability index; * - statistically significant decrease from all three baseline measurements (times 1, 2 and 3); all data expressed as mean(SD).

Figure 26: Pain intensity (NRS) at each stage of the study
Times 1-3 were the three repeated baseline measurements each taken six weeks apart; time 4 was immediately after the intervention was completed (mean 12 weeks later); time 5 was three months after completing the intervention; NRS – numeric rating scale; * - statistically significant decrease from second baseline measurement (time 2); all data expressed as mean(SD).

3.3 Secondary measures
The values for the secondary measures at baseline and immediately after the intervention are displayed in Table 19. There were statistically significant
(p<0.0041) improvements in depression, back beliefs, fear of physical activity, catastrophising, self-efficacy as well as the STarT Back risk score. The effect sizes for these measures were large (r²>0.25) with the exception of depression, which displayed a moderate effect size (r²=0.22). Further, there was a non-significant trend towards a reduction of anxiety and stress after the intervention. There were no significant changes (all p>0.05) in any of the physical measures including the number of steps per day, usual sitting posture, variation in sitting posture and lumbar repositioning error.

Table 19: Secondary outcome measures at baseline and after the CFT intervention

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Baseline</th>
<th>After</th>
<th>Effect size (r²)</th>
<th>Risk at baseline</th>
<th>Risk after</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depression</td>
<td>13(0-38)</td>
<td>4(0-34)</td>
<td>0.22</td>
<td>16</td>
<td>9</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Anxiety</td>
<td>7(0-36)</td>
<td>3(0-30)</td>
<td>0.09</td>
<td>12</td>
<td>8</td>
<td>0.03</td>
</tr>
<tr>
<td>Stress</td>
<td>16(0-38)</td>
<td>8(0-36)</td>
<td>0.13</td>
<td>12</td>
<td>8</td>
<td>0.01</td>
</tr>
<tr>
<td>BBQ</td>
<td>23(11-39)</td>
<td>38(19-45)</td>
<td>0.32</td>
<td>12</td>
<td>3</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>FABQ</td>
<td>16(1-24)</td>
<td>3.5(0-17)</td>
<td>0.31</td>
<td>15</td>
<td>5</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>PCS</td>
<td>29.5(3-51)</td>
<td>4.5(0-32)</td>
<td>0.35</td>
<td>10</td>
<td>1</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>PSEQ</td>
<td>32(9-59)</td>
<td>51(21-60)</td>
<td>0.34</td>
<td>6</td>
<td>0</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>STarT Back</td>
<td>6(2-9)</td>
<td>2.0(0-7)</td>
<td>0.32</td>
<td>14</td>
<td>4</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Physical activity (steps/day)</td>
<td>7045(2603)</td>
<td>7260(2786)</td>
<td>0.004</td>
<td>NA</td>
<td>NA</td>
<td>0.77</td>
</tr>
<tr>
<td>Usual sitting posture</td>
<td>73.5(42.2)</td>
<td>76.0(40.3)</td>
<td>0.005</td>
<td>NA</td>
<td>NA</td>
<td>0.76</td>
</tr>
<tr>
<td>Variation in sitting posture</td>
<td>11.3(2.2-47.3)</td>
<td>23.3(2.3-68.4)</td>
<td>0.04</td>
<td>NA</td>
<td>NA</td>
<td>0.15</td>
</tr>
<tr>
<td>Reposition Error</td>
<td>2.2(7.5)</td>
<td>3.1(12.9)</td>
<td>0.004</td>
<td>NA</td>
<td>NA</td>
<td>0.81</td>
</tr>
</tbody>
</table>

Data expressed as median (range) except for physical activity, usual sitting posture and reposition error which are expressed as mean(SD) and indicated by #; BBQ - back beliefs questionnaire; FABQ - physical activity subscale of the Fear Avoidance Beliefs Questionnaire; PCS – pain catastrophising scale; PSEQ - pain self-efficacy questionnaire; * statistically significant difference (p<0.0041); posture and reposition error expressed as a percentage of range of motion (%ROM); physical activity expressed as steps per day; “at risk” refers to the number of participants considered at high risk based on their scores on the relevant questionnaires; NA – not applicable.
4. Discussion

This multiple single-case design study demonstrated that CFT, a novel person-centred multidimensional behavioural-based intervention significantly reduced functional disability and pain among a group of people with disabling NSCLBP. Furthermore, these improvements were maintained three months after the intervention. The absence of a control group did not allow for comparison of effectiveness to another intervention. However, the significant improvement from repeated baseline measurements suggests natural recovery is unlikely to have been a major factor in this study.

On average the reduction in functional disability of approximately 16 points (40% reduction from baseline average) after the intervention and three months later exceeded the proposed MIC value reported in the literature of 30% (Ostelo et al. 2008), with 17/24 who completed the study meeting this criterion. The average reduction in functional disability also exceeded the MDC90 of 9.5 points based on the variation in ODI scores observed over the three repeated baselines.

On average the reduction in pain of approximately 1.5 points (31% reduction from baseline average) after the intervention and three months later met the proposed MIC reduction of 30% (Ostelo et al. 2008), with 12/24 who completed the study meeting this criterion. However, the reduction in pain did not exceed the MDC90 of 2 points based on the variation in NRS scores observed over the three repeated baselines.

Overall, the reductions in functional disability and pain were both statistically and clinically significant. The effect size was larger for functional disability than for pain, as is commonly observed with interventions for NSCLBP (Guzmán et al. 2001; Lambeek et al. 2010), and also reflects greater variation in the repeated baseline pain measurements.

Analysis of the secondary outcome measures after the intervention provides some insight into the possible mechanisms associated with the CFT intervention. The majority of the psychosocial outcome measures demonstrated significant improvement, with mostly large effect sizes, after the intervention. In contrast, none of the physical outcome measures (usual sitting posture, variation in sitting posture, repositioning error, daily physical activity
levels) were significantly different after treatment. This is notable considering that the CFT intervention included instruction on gradually increasing levels of physical activity, and on assuming relaxed, non-provocative postures in sitting and during other functional tasks.

These results could suggest that physical factors are less relevant in this subgroup of NSCLBP, since addressing psychosocial factors seems to be more important in reducing disability. Previous research has however demonstrated that seemingly quite different interventions such as cognitive behavioural therapy (CBT) and various forms of physical exercise appear to have their effect on NSCLBP disability by reducing psychosocial factors such as catastrophising, distress, fear and self-efficacy (Mannion et al. 2001a; Spinhoven et al. 2004; Smeets et al. 2006b; Leeuw et al. 2007a; Woby et al. 2007). This hypothesis of indirectly influencing psychosocial factors through physical rehabilitation is further supported by studies demonstrating that physical rehabilitation programmes appear to be as successful as interventions like CBT at changing psychosocial factors such as catastrophising (Mannion et al. 2001b; Smeets et al. 2006b). The exact reasons for this are unclear. It is known that physical factors such as increased back muscle activity are closely related to psychosocial factors (Geisser et al. 2004; Lewis et al. 2012). Assessment of the trunk muscles, such as examination of the flexion-relaxation phenomena (Geisser et al. 2005), may be a more sensitive physical measure to assess these changes, especially considering the high baseline levels of muscle activation noted on clinical examination. One of the aims of CFT is to teach patients to perform painful or physically impaired activities in a less painful manner, which may reduce the threat value of pain, provide hope, reassurance and encourage participation in rehabilitation (Mannion et al. 2001b; Smeets et al. 2006b). Alternatively, it has been suggested that all conservative interventions, whether focussed on physical or psychosocial factors, act through a similar mechanism by decreasing central nervous system sensitivity (Wand and O'Connell 2008). This would explain how several different forms of exercise may help NSCLBP, without demonstrating clear exercise-specific effects (Steiger et al. 2012).
The magnitude of improvement on several of the psychosocial secondary outcome measures in this study (Table 19) was greater than that observed with a range of other interventions used among people with NSCLBP, including CBT, educational approaches and various forms of physical exercise. This includes the effect of rehabilitation programmes on catastrophising (Spinhoven et al. 2004; Smeets et al. 2006b), back beliefs (Symonds et al. 1995, Burton et al. 1999, George et al. 2009), pain self-efficacy (Williams et al. 1996; Woby et al. 2007), fear (Mannion et al. 2001b; Woby et al. 2008) and depression (Della-Posta and Drummond 2006). Several of the secondary outcome measures have proposed cut-off values for risk or clinical significance applied to them. Using these recommended cut-off values, the number of participants at “risk” based on their STarTBack (Hill et al. 2008), catastrophising (Sullivan 2004), depression (Lovibond and Lovibond 1995), anxiety (Lovibond and Lovibond 1995), stress (Lovibond and Lovibond 1995), pain self-efficacy (Nicholas 2007) and fear-avoidance (Poiraudreau et al. 2006) scores reduced after the intervention (Table 19). While no cut-off value for the BBQ has been published, the number of participants scoring below the median baseline value (21.5) reduced after the intervention (Table 19). Furthermore, the post-intervention values obtained on measures such as the PSEQ (Nicholas 2007), STarT Back (Hill et al. 2008) and FABQ (Leeuw et al. 2007a) have been associated with maintenance of rehabilitation gains, increased return to work rates, decreased risk of chronicity and reduced use of healthcare resources. The magnitude of these changes in a wide range of psychosocial factors suggests the CFT intervention impacts upon several relevant psychosocial factors effectively. The smaller effect on stress and anxiety is interesting, and may represent a greater resistance to modification of these factors (Linton 2001; Henningsen et al. 2003), or an inadequate emphasis on these factors in rehabilitation which should be considered for future studies.

One of the key features of CFT is the tailoring of a behavioural-based intervention to each individual with NSCLBP. This is done by targeting specific physical (e.g. aggravating postures and activities) and related psychosocial (e.g. the person’s experience of pain to their own thoughts, emotions, beliefs and life events) behaviours. The few studies which have examined the
Tailoring of rehabilitation to individual patient profiles across multiple domains have shown some encouraging findings (Asenlof et al. 2009; Fersum et al. 2011; Hill et al. 2011). Simply combining conservative interventions (physical and psychosocial) may be no more effective than either intervention provided in isolation (Smeets et al. 2006a). In fact, there is some evidence that simply adding physical exercise to an existing neurophysiology education approach actually reduces rehabilitation effectiveness (Ryan et al. 2010). Therefore, the benefit from an integrated behavioural-based CFT approach may not be from simply combining different interventions, but from linking these different physical and psychosocial interventions to develop a greater insight into pain among patients. This aims to facilitate mindful physical activity with enhanced pain control. This interlinking of contributing factors reflects their physiological interaction (Lewis et al. 2012). The aim is to challenge behaviours as a means of changing beliefs regarding the threat of pain. While several dimensions are involved in the CFT intervention, all aspects were provided by a single therapist, which may reduce the risk of contradictory advice being received from different health care professionals.

Since only 4 participants were rated “low risk” on the STarT Back, most participants probably required a multidimensional intervention incorporating a behavioural-based approach, including a large psychosocial component. CFT rehabilitation can emphasise physical or psychosocial factors according to the person’s primary contributing factors. For example, CFT has been used with a greater emphasis on addressing physical behaviours when indicated (Thorpe et al. 2010; Perich et al. 2011). It is unclear if the broad CFT intervention used in this study is required in all people with NSCLBP, or whether more simple physical approaches (Van Hoof et al. 2012) can be effective in other populations, depending on their predominant pain mechanism (Smart et al. 2011).

There were several limitations to this study. This was not a blinded RCT. Only a small sample of participants with NSCLBP from one region were included. However, the study was still able to demonstrate treatment effects that were both statistically significant and clinically relevant. Posture was only analysed as seated posture on a single day. Several other physical factors were not examined or controlled for, including seating design while wearing
the posture monitor and trunk muscle activation. Not measuring these physical factors may explain the lack of physical changes at follow-up. Further long-term follow-up is required. The outcome assessor was not blinded to treatment, although the primary outcomes were self-reported. Secondary outcome measures were not assessed after three months, but will be assessed again after six and 12 months. Delivery of individualised treatment is time-consuming and potentially costly. Consequently, class-based versions of CFT or once-off interventions based on CFT may be worth investigating, although the effect sizes of once-off interventions are typically small (Liddle et al. 2007). The design of the current study did not allow evaluation of whether the benefit obtained was dependent on treatment being individualised to each person’s pain mechanism, and this is an area worthy of further study. The study was designed as a preliminary study to determine the potential utility of CFT in NSCLBP patients with moderate to high levels of disability. A RCT, where CFT is compared to another management approach, using a blinded assessor, is now needed.
Key points: Chapter 4

The general aim of the two studies discussed in Chapter 4 was to examine the effect of two quite different interventions among two different subgroups of people with NSCLBP. The results of Study VI demonstrated that using a simple intervention like postural biofeedback can significantly reduce seated LBD among people with NSCLBP. The biofeedback facilitated a less end-range, and less variable, sitting posture. These results must been interpreted in the context of the research design and its limitations; the effectiveness of the biofeedback was only examined in a single-session with no follow-up period. Furthermore, there was no control group, and the disability of the people involved was mild (Tonosu et al. 2012).

In contrast to Study VI, Study VII involved people with far greater disability. Offering these participants the same postural biofeedback intervention would have provided a useful comparison with data from the less disabled participants in Study VI. However, this would be hard to justify considering the evidence that addressing psychosocial factors plays a large role in the resolution of disabling NSCLBP (Mannion et al. 2001b; Smeets et al. 2006b). Therefore, a multidimensional intervention – CFT – was used with this more disabled group of people with NSCLBP. Both pain and disability were reduced to statistically and clinically significant levels after the intervention and three months later. Interestingly, while both physical and psychosocial contributing factors were considered in the CFT intervention, analysis of the secondary outcome measures suggests that it was primarily psychosocial factors which changed with the CFT intervention, rather than kinematic sitting behaviour.

The results from these two intervention studies could be viewed as contradictory, in that Study VI showed sitting behaviour is relevant in NSCLBP, while in Study VII people with NSCLBP reported reduced pain and disability despite no significant change in sitting behaviour. However, they are consistent with the hypothesis outlined in Chapter 1 that NSCLBP is a multidimensional disorder, with contributions from biological, psychological and social domains (O'Sullivan 2012). Furthermore, the hypothesis that the importance of each of these domains could vary between NSCLBP subgroups
is partially supported by these results (O'Sullivan 2012). For example, participants with NSCLBP in Study VI were specifically aggravated by prolonged sitting, and the biofeedback specifically tried to make their sitting behaviour less provocative, such that it was less end-range and less variable. In contrast, participants with NSCLBP in Study VII had much higher levels of pain, disability and fear, such that they would appear unlikely to respond to a simple postural biofeedback intervention. A multidimensional CFT intervention addressing the breadth of contributing factors in their NSCLBP disorder was therefore more likely to be effective.

Some specific limitations of the studies in this Chapter, and their clinical implications, are worthy of consideration. The most important of these included the fact that;

- Study VI did not include a control group, and did not involve a follow-up period. It is therefore possible that any intervention would have reduced LBD on retesting, or that the significant within-session effect would not result in a meaningful reduction in disability. It is not suggested in any way that postural biofeedback is the only suitable intervention for the NSCLBP participants included in Study VI, merely that it is a potentially valid and useful option for this NSCLBP subgroup. Further research should evaluate the effectiveness of postural biofeedback for this subgroup of people with NSCLBP compared to other interventions.

- Study VII also did not contain a control group. The use of a repeated measures baseline approach controls for natural recovery, but does not control for a possible placebo effect. The magnitude of the improvements in pain and disability suggest that the CFT intervention was more effective than a placebo intervention, however the possibility cannot be discounted. Given the multitude of RCT’s among people with NSCLBP showing negligible differences between interventions (Fersum et al. 2010), such preliminary studies are valuable to determine the mechanisms through which interventions act, and to allow refinement of the intervention (Boersma et al. 2004). Further RCT studies in similar, highly disabled populations are required to build on these findings.
In study VII, sitting behaviour was not significantly different after the CFT intervention. It is important to highlight that other postures and tasks such as forward bending which are commonly provocative in NSCLBP were also practiced during the CFT intervention. These postures may have been performed significantly differently afterwards, but they were not analysed as it is not currently possible to identify such data from the BodyGuard™ output. Other physical factors such as trunk muscle activation may also have changed after the intervention, but were not analysed in the current study. It is also possible that the CFT intervention applied in study VII did not sufficiently emphasise the physical domain, and that addressing these factors could further reduce the residual pain and disability reported.

The next, and final, chapter discusses the results from all studies, and relates the findings from this doctoral thesis overall to the existing literature.
CHAPTER 5: Discussion

The aim of Chapter 5 is to review the studies from each chapter in this doctoral thesis, and link the findings to the current scientific literature regarding sitting behaviour and NSCLBP. Furthermore, this chapter will examine how this doctoral thesis builds on current knowledge regarding the presence of biopsychosocial subgroups within the NSCLBP population, including the role of pain mechanisms in NSCLBP. Finally, the primary limitations and implications of this doctoral thesis will be discussed.
5.1 Summary of Findings

NSCLBP is a complex and potentially disabling disorder, with contributing factors across the biopsychosocial spectrum. Sitting is a commonly reported aggravating factor, and a significant cause of disability, among people with NSCLBP. However, a series of systematic reviews completed as part of this doctoral thesis (Appendices I-IV) demonstrated that there is little evidence to support seated interventions as a stand-alone intervention for NSCLBP. The strongest, and still limited, evidence available was that using a chair backrest reduces back muscle activity and may help reduce seated discomfort. However, these seated interventions had not been investigated among specific subgroups of people with NSCLBP, or used as part of a multidimensional intervention for NSCLBP.

The three studies in Chapter 2 examined the validity and clinical applicability of a novel posture monitor. They demonstrated excellent between-day and inter-rater reliability for the BodyGuard™ device, in addition to good concurrent validity during a range of daily postures and tasks. Overall, the reliability and validity of the BodyGuard™ device was as good as, or even better than, that of several other small and/or portable posture monitors (Thoumie et al. 1998; Perret et al. 2001; Guermazi et al. 2006; Bible et al. 2010; Williams et al. 2012a). It has certain advantages such as its low cost, small size, minimal interference with normal daily tasks and the simplicity of data analysis. While some specific limitations of the device are noteworthy, and discussed later on in Chapter 5, at the conclusion of Chapter 2 the device was deemed suitable for use in clinical investigations of seated postural behaviour.

The two main studies in Chapter 3 examined perceptions of “good” sitting posture among both physiotherapists and members of the community. The results indicated a strong preference for lordotic sitting postures among both groups. In particular, a “neutral” lordotic sitting posture involving moderate lumbar lordosis with thoracic relaxation was most commonly considered optimal. Concerns that this posture would be difficult to assume were addressed by the results of another study indicating that this neutral posture can be facilitated reliably (O'Sullivan et al. 2010b) (Appendix V), even
by student physiotherapists. Consistent with the preference for lordotic sitting, a slumped sitting posture was most commonly considered the “worst” posture by members of the community, although this was not examined among physiotherapists. Male members of the community were more likely to select postures involving greater thoracic extension, although there was no significant difference in perceptions between people with and without NSCLBP. The main criticism of upright sitting postures, among both physiotherapists and members of the community, was the potential effort associated with maintaining them. However, the effort of maintaining a neutral upright sitting posture (O'Sullivan et al. 2012c) (Appendix VI) and performing seated office tasks in such a posture (O'Sullivan et al. 2012d) (Appendix VII) was significantly reduced by modifying chair design in two studies of painfree participants.

The two main studies discussed in Chapter 4 examined the effect of two quite different interventions among people with NSCLBP. In Study VI it was demonstrated that postural biofeedback significantly reduced seated LBP among people with NSCLBP. As such, Study VI is the first study to show that changing sitting behaviour using real-time postural biofeedback reduces seated LBP during a prolonged sitting task in a single session. The biofeedback facilitated a less end-range, and a less variable, sitting posture. Therefore, the results of Study VI suggest sitting behaviour can play a role in the development and management of mildly disabling NSCLBP. In Study VII, the effect of a multidimensional CFT intervention was examined among people with more disabling NSCLBP. Both pain and disability were reduced to statistically and clinically significant levels after the intervention and at a three month follow-up. Large changes were evident among the psychosocial outcome measures after the intervention, rather than physical outcome measures such as sitting behaviour. Therefore, the results of Study VII suggest changes in kinematic sitting behaviour, as measured in this study, were not a major contributor to the improvements observed among people with highly disabling NSCLBP.

This contradiction between Studies VI and VII on the importance of sitting behaviour in NSCLBP relates to a key hypothesis regarding NSCLBP (O'Sullivan 2005). Specifically, it has been proposed that patients with
NSCLBP are heterogenous, consisting of subgroups with different underlying mechanisms driving their pain and disability (O’Sullivan 2005). Several different approaches to identifying subgroups within the NSCLBP population have been proposed, including approaches based on patho-anatomical findings (Petersen et al. 2003), psychosocial characteristics (Westman et al. 2011), and patient signs and symptoms such as evidence of altered movement behaviour (Sahrmann 2002) or the response to specific interventions (Delitto et al. 1995). While no specific classification system has been demonstrated to be superior (Fairbank et al. 2011), it is logical that NSCLBP sub grouping be based on pain mechanisms, given the increased emphasis placed on the significance of neurophysiological changes in the development and maintenance of NSCLBP (Butler 2000; Smart et al. 2010).

The multidimensional classification of NSCLBP proposed by O’Sullivan examines NSCLBP in terms of the primary pain mechanisms involved, and the relative contribution from different domains across the biopsychosocial spectrum (O’Sullivan 2005). This sub grouping system has the advantage of considering several different contributing factors, allowing targeted interventions for each individual with NSCLBP. For example, it considers whether there is a greater contribution from centrally mediated factors, such as psychosocial factors, or peripherally mediated factors, such as movement behaviour. The inter-relationship between these peripheral and central factors (Marras et al. 2000; Mannion et al. 2001b; Geisser et al. 2004; Moseley 2004a; Woby et al. 2007; Sullivan et al. 2009; Lewis et al. 2012) is also considered within the framework. Similarly, the directional nature of the maladaptive movement behaviour (as a physical factor) can be further subclassified. In terms of the seeming contradiction between Studies VI and VII, the participants in Study VI had a NSCLBP disorder which was primarily mechanically provoked, with low levels of psychosocial factors. In contrast, participants in Study VII reported more psychosocial factors, experienced greater levels of NSCLBP during certain physical activities including sitting, and had a more widespread pain disorder. This suggests they had a mixed pain mechanisms profile, with contributions from both central sensitising and peripheral nociceptive factors. Consequently, it seems logical that the contribution of specific sitting postures in the subjects of Study VII to their
NSCLBP disorder, or its resolution, would be much less than among the participants in Study VI. The role of kinematic sitting behaviour, and the hypothesis of both physical and psychosocial factors contributing to NSCLBP through their influence on central sensitisation and peripheral nociception, will now be discussed in greater detail.

5.2 The role of sitting behaviour in NSCLBP
As described earlier in Chapter 1, there is no evidence that daily sitting duration is a major contributing factor in developing NSCLBP (Hartvigsen et al. 2000; Lis et al. 2007; Roffey et al. 2010c). However, sitting is a commonly reported aggravating factor for people with NSCLBP (Williams et al. 1991; Dankaerts et al. 2006b; Womersley and May 2006), as it was for participants in both Studies VI and VII. Since sitting involves more lumbo-pelvic flexion than standing, the greater flexion involved is often proposed as a reason for the aggravation of NSCLBP in sitting (Dunk et al. 2009; De Carvalho et al. 2010). This may explain the strong preference seen among both physiotherapists and members of the community (Studies IV and V) for lordotic sitting postures. However, in Study VI, PDs were not on average more flexed than the NPDs when considered as a homogenous NSCLBP population. Furthermore, while biofeedback significantly reduced LBP on retesting, it did not reduce flexion across the entire NSCLBP population, but instead was used to increase spinal flexion in some participants and reduce spinal flexion in others. Therefore, the findings do not support the contention that NSCLBP develops, or is increased, during prolonged sitting because of excessive lumbo-pelvic flexion across the entire NSCLBP population. This is also consistent with the systematic review of chairs that reduce seated hip flexion (Appendix IV) demonstrating they do not appear to significantly reduce NSCLBP, despite their ability to increase seated lumbar lordosis.

There is a risk that such findings could be interpreted as suggesting sagittal plane kinematics are irrelevant in NSCLBP. The lack of difference across the entire group of NSCLBP participants in Study VI is actually consistent with previous data, where the presence of heterogeneous NSCLBP subgroups has been shown to lead to a “wash-out” effect (Dankaerts et al.
2006b; Sheeran et al. 2012). In fact, analysis of the two NSCLBP subgroups separately showed that PDs tended to assume more end-range postures than their NPD counterparts, and that this involved either more flexion (FP) or more extension (AEP). This is consistent with existing reports in the literature of both increased (Vergara and Page 2002; Dankaerts et al. 2006b; Van Dillen et al. 2009) and decreased (Dankaerts et al. 2006b; Womersley and May 2006) lumbar lordosis among some people with NSCLBP. These findings are consistent with previous data, based on spinal posture, trunk muscle activation and spinal proprioception, on the presence of the same distinct subgroups within the NSCLBP population (Dankaerts et al. 2006a; Dankaerts et al. 2006b; Dankaerts et al. 2009; Sheeran et al. 2012). Furthermore, while reducing lumbo-pelvic flexion prevented the gradual ramping up of LBP among the FP subgroup, increasing flexion prevented this ramping up of LBP among the AEP subgroup. In other words, the ramping up of LBP was not always controlled by reducing lumbo-pelvic flexion. The findings are also in agreement with the contention that non-neutral postures are more likely to lead to the development and aggravation of NSCLBP in specific patients, rather than purely flexed postures (Smith et al. 2008; Dolphens et al. 2012). It is also consistent with data that mid-range loading patterns and spinal stiffness through ROM may be more relevant than end-range kinematics among some people with LBP (Shum et al. 2010).

Others have proposed that the static nature of sitting is a primary contributor to the development of NSCLBP (Bell 2008), and that interventions to increase seated mobility may be beneficial (Van Deursen et al. 2000; Van Dieen et al. 2001). However, systematic reviews completed as part of this doctoral thesis (O’Sullivan et al. 2012e; O’Sullivan et al. 2012g) (Appendices I and II) demonstrate that there are no clear benefits from the use of dynamic sitting approaches in isolation. Firstly, when one considers the clear importance of psychosocial factors for a significant group of people with disabling NSCLBP (Gatchel et al. 2007; Leeuw et al. 2007a; Linton et al. 2011), this is unsurprising. However, the findings of Study VI provide another reason why dynamic sitting is likely to be of limited benefit for people with NSCLBP as a stand-alone intervention. Specifically, study VI showed that, among participants with NSCLBP, PDs were even more variable in their sitting
behaviour than NPDs. This is in line with previous findings of increased postural variability among PDs in both sitting (Vergara and Page 2002; Telfer et al. 2009; Dunk and Callaghan 2010) and standing (Lafond et al. 2009; Gallagher et al. 2011). Consequently, it seems logical that dynamic chairs which further increase seated postural variability are unlikely to be of significant benefit in isolation for many people with NSCLBP, if increased movement among people with NSCLBP is associated with increased pain.

The findings on kinematic sitting behaviour in Study VI are consistent with the hypothesis that movement behaviour among people with NSCLBP is often maladaptive, and contributes to NSCLBP, rather than being protective (O’Sullivan 2005). For example, mean posture of the PD and NPD groups did not differ significantly over time, such that PDs did not gradually assume a maladaptive posture more than the NPDs, but rather assumed the provocative posture at the start of testing. Similarly, the increased postural variability among PDs is likely to be a maladaptive sitting behaviour, since it was present at the start of testing before there was a difference in LBP intensity between PDs and NPDs. This is also consistent with increased muscle co-activation (Gregory and Callaghan 2008; Nelson-Wong et al. 2008; Nelson-Wong and Callaghan 2010c) and postural fidgeting (Gallagher et al. 2011) being reported among PDs at the start of a prolonged standing period. Assuming a less end-range, less variable posture on retesting reduced the ramping up of LBP during prolonged sitting, again suggesting the initial sitting behaviour was maladaptive. During initial testing, PDs appeared to be unable to modify this behaviour, despite increasing their postural variability over time. This inability to modify their sitting behaviour may be related to deficits in proprioception (Brumagne et al. 2000; O’Sullivan et al. 2003; Sheeran et al. 2012) and body schema (Bray and Moseley 2011; Moseley et al. 2012) reported among NSCLBP patients. Consistent with this, another study we recently completed demonstrated proprioceptive deficits among a FP subgroup of NSCLBP patients (O’Sullivan et al. 2012j) (Appendix X), which may explain why postural biofeedback reduced LBP on retesting.

Using postural biofeedback to change seated behaviour was effective at reducing NSCLBP in Study VI. While this is consistent with some other studies using biofeedback in NSCLBP (Neblett et al. 2003; Horton and Abbott
2008; Magnusson et al. 2008; Van Hoof et al. 2012), the overall evidence on the effectiveness of biofeedback from other studies is underwhelming (Nouwen and Solinger 1979; Bush et al. 1985; Flor et al. 1986; Stuckey et al. 1986; Flor and Birbaumer 1993; Donaldson et al. 1994; Newton-John et al. 1995). In fact, Study VI was the first study to show that facilitating a different sitting posture using biofeedback reduces seated LBP during prolonged sitting on a single day. It was the first to examine the sitting behaviour during prolonged sitting, of a specific subgroup of people with NSCLBP who were specifically aggravated by sitting, and match their biofeedback to specifically change their movement behaviour. As acknowledged earlier on, Study VI included several limitations such as not having a control group and not including a follow-up period. Therefore, although modification of movement behaviour has previously been associated with improved clinical outcomes in other preliminary studies (Van Dillen et al. 2003a; Dankaerts et al. 2007; Sheeran 2010) in line with the findings of Study VI, it is important to recognise the effectiveness of modifying movement behaviour with biofeedback may often be less pronounced. In particular, biofeedback may be less effective in other NSCLBP subgroups where sitting behaviour is not a primary driver of their NSCLBP disorder, where the biofeedback is not matched to their directional movement behaviour, or where the role of central sensitising factors is greater than that of peripheral nociceptive factors. For this reason, postural biofeedback was not used as a stand-alone intervention among the participants in Study VII, as it was deemed unlikely to provide a clinically meaningful improvement in their more complex NSCLBP disorder.

Therefore, despite the perceived importance of posture in the management of NSCLBP (O'Sullivan et al. 2012i), the findings of this doctoral thesis, and the existing literature (Burton et al. 2006), suggest that no uniform sitting posture is likely to effectively prevent, or reduce, NSCLBP. A “neutral” upright posture may have some possible advantages in some people with NSCLBP where there is a clear directional pain provocation pattern, in that it is not an end-range posture, and may therefore not place as much stress on pain sensitive structures (Solomonow et al. 2003). In addition, it does not involve as much trunk muscle activation as some other upright sitting postures (O'Sullivan et al. 2006a; Reeve and Dilley 2009), which is relevant since even
slightly elevated levels of muscle activation have been linked to the development of seated LBP (Lander et al. 1987; Gregory et al. 2006). The importance of avoiding high levels of trunk muscle activation is probably reflected in the fact that using a backrest to reduce paraspinal muscle activation was the only seated intervention which had some supporting evidence available in the four systematic reviews performed as part of this doctoral thesis (O'Sullivan et al. 2012a) (Appendix III). Considering that increased trunk muscle co-contraction and increased spinal stiffness are commonly reported among people with LBP during a range of daily tasks (Marras et al. 2001; Ferguson et al. 2004; Marras et al. 2005; Shum et al. 2007; Dankaerts et al. 2009; Shum et al. 2009; Shum et al. 2010), postures which are less-end range and involve less effort may be advantageous. However, given the weak relationship between changes in LBP and changes in parameters such as muscle activation and spinal posture (Linton et al. 1994; Koskelo et al. 2007), interventions to change sitting behaviour should be justified on clinically meaningful changes in LBP rather than secondary outcome measures such as posture or muscle activation.

While the adoption of a less end-range posture using postural biofeedback reduced seated LBP in Study VI, a key part of the benefit may have been the matching of postural correction with the individual aggravating and easing factors of the participants with NSCLBP (O'Sullivan 2005; Dankaerts et al. 2009; Sheeran 2010). Considering the frequency with which increased lordosis (Dankaerts et al. 2006b) and increased paraspinal muscle activation (Geisser et al. 2004; Geisser et al. 2005; Dankaerts et al. 2006a; Lewis et al. 2012; Sheeran et al. 2012) are reported in people with NSCLBP, the fact that some participants with NSCLBP report less pain in flexion should not be surprising. In addition, the greater change in psychosocial factors among participants in Study VII probably reflects the significance of central sensitising factors in their NSCLBP disorder. In fact, even the less end-range posture facilitated in Study VI varied between participants, and on average it was more flexed than the “neutral” posture preferred in Studies IV and V. Therefore, while most current recommendations and guidelines advocate significant seated lordosis as the natural, and best, sitting posture (Pynt et al. 2001; Pope et al. 2002), these may need to be re-evaluated, on the basis that
no specific spinal angle is likely to be the optimum for all people. Instead, posture should be matched to the clinical presentation, pain response and type of people with NSCLBP, so that interventions can be more targeted (Dankaerts et al. 2007; Sheeran 2010). For example, another study we recently completed demonstrated that a FP subgroup of people with NSCLBP reported less LBP during a prolonged sitting task when they sat on a forward inclined chair which facilitates lumbar lordosis (O'Keeffe et al. 2012) (Appendix XI). This is consistent with reports that subgroup-matched postural interventions are more effective, at least in the short-term, than generic postural advice (Sheeran 2010). Finally, the posture advocated should take into account the myriad of factors which could affect seated posture, both modifiable and non-modifiable including genetic (Seah et al. 2011), gender (O'Sullivan et al. 2011b), psychosocial (O'Sullivan et al. 2011b) and lifestyle (O'Sullivan et al. 2011b) factors.

In conclusion, the existing evidence demonstrates that while sitting commonly aggravates symptoms, several factors other than sitting duration are clearly involved in NSCLBP (Roffey et al. 2010c). Despite the widespread belief that lordotic sitting postures are better than slumped sitting postures, there is no evidence that lordotic sitting postures prevent or reduce NSCLBP (Bell 2008). A series of systematic reviews, as discussed in Chapter 1, demonstrated the weak evidence for many seated interventions in the management of NSCLBP. The poor evidence for most of the seated interventions probably reflects the fact that there may be a need to match seated interventions to specific NSCLBP subgroups, as seen in Study VI. In addition, the poor evidence for most of the seated interventions probably also reflects the fact that NSCLBP is not a purely mechanical disorder where only physical factors are relevant, as seen in Study VII. However, when sitting behaviour is closely controlled, as in Study VI, in a subgroup whose NSCLBP is specifically aggravated and relieved by specific sitting postures, sitting behaviour appears to contribute to the aggravation of NSCLBP. Furthermore, when the seated intervention (postural biofeedback) is matched to specific NSCLBP subgroups, modification of sitting behaviour is relevant in the management of NSCLBP. In contrast, when physical factors are only a minor contributing factor in a patient with NSCLBP, sitting behaviour in isolation is
unlikely to be a major contributing factor. It is acknowledged that several other physical factors associated with sitting behaviour, including trunk muscle activation, were not analysed in study VII and could have been altered during rehabilitation. Overall though, while Studies VI and VII appear to disagree on whether sitting behaviour is important in NSCLBP, this is likely to relate to differences between the relative contribution of central sensitisation and peripheral nociception to each subgroup. Therefore, it is appropriate to reflect on how this relates to current concepts regarding the biopsychosocial nature of NSCLBP.

5.3 The biopsychosocial nature of NSCLBP

As described in Chapter 1, NSCLBP is viewed in the contemporary literature as a multidimensional disorder with contributions from multiple domains across the biopsychosocial spectrum (Maniadakis and Gray 2000; Hansson et al. 2006; Linton et al. 2007; Schaafsma et al. 2010). It is important at this stage to reflect on how interventions can be tailored to improve NSCLBP, based on the strong evidence, as discussed in Chapter 1, that NSCLBP is associated with a range of neurochemical, structural and functional changes within the CNS (Moseley 2003; Baliki et al. 2008; Wand et al. 2011b).

The neurophysiological changes evident in chronic pain disorders (affecting sensory, motor, sympathetic and immune systems) reduce the need for strong peripheral nociceptive input (e.g. from tissue damage) to generate the experience of NSCLBP (Butler 2000). These changes also seem to explain recovery from LBP, and responses to interventions. A recent longitudinal study (Baliki et al. 2012) demonstrated, based on functional MRI scanning, that increased neural connectivity in pathways related to the emotional and behavioural responses to pain are predictive of acute LBP disorders becoming NSCLBP. The benefits obtained from placebo interventions also appear to reflect such neurophysiological changes (Wager et al. 2004), suggesting central changes in pain sensitivity are critical in understanding NSCLBP. Considering the very poor ability of physical factors or spinal imaging to delineate factors which discriminate between those who
do, and do not, recover from NSCLBP, this further highlights the key role of CNS physiological processes in NSCLBP generation and maintenance.

The complexity of these CNS changes, however, should be viewed as just one component of the NSCLBP disorder. For example, there is no evidence that such neurophysiological changes are present before the onset of NSCLBP (Wand et al. 2011b), or that they are irreversible (Wand et al. 2011b). In fact, considerable research in recent years on pain disorders other than NSCLBP, such as phantom limb pain and complex regional pain syndrome, has demonstrated that a range of novel interventions which target cortical function can reverse these CNS changes, and relieve pain and disability (Wand et al. 2011b). This includes graded motor imagery (Moseley 2004b; 2005a; Moseley 2006), visual feedback using mirrors (McCabe et al. 2003; Chan et al. 2007; Mercier and Sirigu 2009) and sensory discrimination training (Flor et al. 2001; Moseley et al. 2008; Moseley 2008; Moseley and Wiech 2009). More recently, preliminary studies have investigated the use of such approaches in NSCLBP specifically, and the results have been somewhat encouraging (Wand et al. 2011a; Wand et al. 2012). However, the use of other direct brain stimulation techniques such as repetitive transcranial magnetic stimulation have yet to demonstrate conclusive effectiveness for NSCLBP (O'Connell et al. 2010).

There is strong evidence that CNS changes are correlated with psychosocial factors such as depression (Grachev et al. 2003), anxiety (Grachev et al. 2001; Grachev et al. 2002) and distress (Lloyd et al. 2008), and that the CNS changes are not explained by either pain or psychosocial factors alone (Seminowicz et al. 2011). Education about pain neurophysiology changes CNS activation during a motor task (Moseley 2005b), and it is likely that several educational, cognitive-behavioural and psychosocial interventions influence NSCLBP through their effect on CNS sensitisation (Henschke et al. 2010; Louw et al. 2011; Brown and Jones 2012).

The decreased requirement for a strong peripheral nociceptive input to cause NSCLBP, in an individual with a highly sensitised CNS, could be interpreted as indicating that traditional physical interventions for NSCLBP have limited long-term efficacy (Butler 2000; Wand and O'Connell 2008). However, physical factors such as impaired trunk muscle activation patterns
are closely related to parameters of CNS sensitisation (Tsao et al. 2008). For example, motor cortical representation of the transversus abdominis (TA) muscle is shifted and enlarged among people with recurrent NSCLBP and the extent of the changes is related to altered TA recruitment patterns (Tsao et al. 2008). Furthermore, TA muscle training can – at least partially – normalise neuronal networks, although it is not clear whether such normalisation improves pain and disability more than any other conservative intervention (Tsao et al. 2010). Other physical or peripherally orientated interventions such as surgery and injections also appear to result in normalisation of these neurophysiological changes within the CNS in people with NSCLBP (Seminowicz et al. 2011), and in other chronic pain conditions such as hip osteoarthritis (Gwilym et al. 2010). Therefore, it would appear that interventions which are effective at reducing pain and disability, by acting at peripheral or central levels, can normalise the neurophysiological changes seen in chronic pain conditions such as NSCLBP. Therefore, it is likely that a range of interventions may be of benefit if they target the presumed pain generators involved in, or contributing to, NSCLBP. This includes a potential role for interventions which target the drivers of peripheral nociceptive pain and/or central sensitisation.

The findings from this doctoral thesis support the multidimensional nature of NSCLBP disorders with the potential for contributions from multiple domains across the biopsychosocial spectrum (Maniadakis and Gray 2000; Hansson et al. 2006; Linton et al. 2007; Schaafsma et al. 2010). The findings support the hypothesis that the contribution from different domains may differ between different NSCLBP subgroups. For example, peripheral nociception was implicated among participants in Study VI, where increasing LBP was related to increased postural variability and the assumption of sitting postures which were closer to end-range. In addition, baseline disability, which probably reflects CNS sensitisation, was also linked to the development of LBP, highlighting the role of both domains in the development of LBP. Consistent with this proposed role for physical factors acting as peripheral nociceptive drivers, assuming a more relaxed, less end-range and less variable posture reduced the ramping up of LBP among these participants. The short-term mechanism of effect is therefore likely to have been reduced
peripheral nociceptive input through reducing passive tissue strain and muscle tension, although these were not measured directly. It is hoped that in the medium-term such postural interventions would enhance postural awareness in daily tasks, and address alterations in proprioception (Brumagne et al. 2000; O’Sullivan et al. 2003; Sheeran et al. 2012) and body schema (Bray and Moseley 2011; Moseley et al. 2012) reported among NSCLBP patients. In turn, the experience of reduced LBP could enhance perceptions of control and self-efficacy, and reduce fear, such that reductions in NSCLBP can be maintained, although no follow-up was performed in Study VI.

In contrast, psychosocial factors were more strongly implicated in Study VII where the improvements in pain and disability after CFT were overwhelmingly related to improvements in psychosocial factors rather than physical factors as measured in the study. This supports that the primary mechanism underlying the intervention was improvement among factors linked to central sensitisation such as depression, fear, catastrophising, pessimistic beliefs about pain, and self-efficacy. Such findings are once again consistent with the biopsychosocial framework. The lack of change in physical measures such as kinematic sitting behaviour demonstrates that the biggest change among these participants was not physical. It is however possible that the lack of change in physical factors explains the residual pain and disability reported by participants. It is also possible, as already mentioned, that other physical factors were modified through rehabilitation, but were not analysed e.g. trunk muscle activation.

Consequently, the findings of this doctoral thesis suggest that attempts to categorise NSCLBP into either a purely “physical” or “psychosocial” disorder are inappropriate. Instead, these domains should be viewed as potential pain generating, or pain sensitising, factors, the significance of which may vary between individuals and over time. This is consistent with evidence that both patho-anatomical and psychosocial factors appear to be important in NSCLBP (Peters et al. 2005). Figure 27 attempts to illustrate this concept of NSCLBP being the result of interplay, to varying degrees, between potential peripheral and central contributions. For someone with no pain, and little or no central sensitisation, their threshold for pain may allow large physical loads (moderate to large peripheral input) to be placed on the spine without
experiencing pain. In contrast, people with NSCLBP who are highly centrally sensitised may experience pain doing only slightly physically demanding tasks (minor peripheral input). As well as varying between individuals, it is likely that CNS sensitivity varies within individuals over time, in line with fluctuations occurring in factors such as stress, anxiety, depression, sleep and hormonal levels (Riley et al. 1999; Onen et al. 2001; Chiu et al. 2005).

![Diagram of NSCLBP](image)

**NSCLBP**

<table>
<thead>
<tr>
<th>Central sensitising factors</th>
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<tr>
<td>This includes chronic stress, acutely stressful or traumatic life events, depression, anxiety, fear, catastrophising, poor coping, poor self-efficacy, pessimistic beliefs, hypervigilance, physical inactivity, poor general health, poor sleep, poor diet, smoking, lack of vitality, hormonal, endocrine and sympathetic factors, and genetic factors.</td>
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<table>
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<tr>
<th>Peripheral nociceptive factors</th>
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<tr>
<td>This includes pathology, local inflammation, maladaptive postures and movement behaviours, increased muscle tension, reduced proprioception, altered body schema, faulty biomechanics and poor ergonomics.</td>
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Figure 27: Framework for the interaction between central sensitising and peripheral nociceptive factors in non-specific chronic low back pain (NSCLBP)

Importantly, this framework allows for consideration of the potential contribution of peripheral nociceptive drivers of pain, in relation to the other dimensions known to be important factors in NSCLBP. So, while findings of "pathology" on spinal MRI are not strongly related to NSCLBP (Chou et al. 2009b; Chou et al. 2011), this framework allows for the limited evidence that more significant pathologies (Jensen et al. 2008; Hancock et al. 2011;
Hancock et al. 2012) and associated local inflammatory responses (Burke et al. 2002) can contribute to greater pain and disability by increasing peripheral nociceptive drive. It also explains the lack of a strong relationship between NSCLBP and formerly suspected physical contributing factors such as prolonged sitting, standing, lifting, bending, twisting, carrying, manual handling, pushing and pulling (Roffey et al. 2010a; 2010d; 2010e; 2010b; Wai et al. 2010c; Wai et al. 2010b; Wai et al. 2010a; Kwon et al. 2011) when they are considered in isolation. However, it also allows room for considering maladaptive movement behaviours (O'Sullivan 2005; Shum et al. 2005; Shum et al. 2007), sustained or repeated spinal loading (Marras et al. 2004; Sbriccoli et al. 2004; Le et al. 2007), or inappropriate spinal ergonomics (Pope et al. 2002; McGill 2009) as relevant contributors to NSCLBP.

It is important also that the central sensitising factors and the peripheral nociceptive factors are not seen as separate, mutually exclusive aspects of the NSCLBP disorder. In many cases, there are close links between these peripheral and central factors (Marras et al. 2000; Mannion et al. 2001b; Geisser et al. 2004; Moseley 2004a; Woby et al. 2007; Sullivan et al. 2009; Lewis et al. 2012), with “physical” interventions perhaps having their effect through reducing psychosocial factors (Mannion et al. 2001b; Smeets et al. 2006b). There is evidence that the transition from local, acute pain to chronic, widespread pain is influenced by a wide range of factors across the biopsychosocial spectrum, including demographic (age and gender), psychosocial and physical factors (Larsson et al. 2012). Furthermore, the term “biopsychosocial” in itself can be misleading. The “bio” aspect is typically used to refer to mechanical factors (sitting posture, lifting, spinal loads), and patho-anatomical or patho-physiological (e.g. disc prolapse, inflammation) processes. However, as the framework outlined in this doctoral thesis highlights, the “psychosocial” element acts via its effect on CNS biology. In other words, NSCLBP is entirely a biological disorder, as long as one understands that the biology is influenced by a range of factors, including physical, psychological, social, genetic, environmental and lifestyle factors.

This framework is consistent with the limited effectiveness, and potential mechanisms, of several interventions for NSCLBP. For example, the fact that the effect sizes for many psychosocial and educational interventions
are only moderate in the long-term (Keller et al. 2007; Henschke et al. 2010) may be partly explained by their lack of attention to possible peripheral nociceptive contributors to NSCLBP, or not integrating the various factors together for patients with NSCLBP. Similarly, the limited effectiveness of many traditional physical interventions used in the management of NSCLBP (van Tulder et al. 2000; Assendelft et al. 2003; Furlan et al. 2005; Ferreira et al. 2007; Keller et al. 2007; Schaafsma et al. 2010), as well as the seated interventions systematically reviewed in this doctoral thesis (O'Sullivan et al. 2012e) (Appendices I - IV) may be partly explained by their lack of attention to central sensitising factors. Therefore, it becomes clear how quite different interventions can display similar magnitudes of effect, with physical interventions helping NSCLBP by addressing the peripheral pain generating source (Furlan et al. 2002; Seminowicz et al. 2011). In contrast, psychosocial and educational interventions may help NSCLBP by primarily addressing the central sensitising factors (Moseley et al. 2004; Henschke et al. 2010). Notwithstanding the aforementioned interplay between physical and psychosocial factors (Marras et al. 2000; Mannion et al. 2001b; Geisser et al. 2004; Moseley 2004a; Woby et al. 2007; Sullivan et al. 2009; Lewis et al. 2012), many of these approaches may not target both components optimally.

Therefore, it is proposed that sitting behaviour, and other physical movement behaviours, play some role in the development, and management of NSCLBP. Furthermore, other factors which have the potential to increase peripheral nociceptive drive such as significant local pathology and local inflammation are of relevance in NSCLBP. However, such factors should be considered as only one component of a person’s NSCLBP disorder, and given an emphasis in rehabilitation that reflects their contribution to the overall NSCLBP disorder (O'Sullivan 2012). Otherwise, it is likely that simplistic attempts to improve isolated physical factors such as sitting behaviour will display the limited effectiveness seen with other physical interventions (Driessen et al. 2010; Van Middelkoop et al. 2011; O'Sullivan et al. 2012e). Therefore, rather than considering the prescription of generic postural, biomechanical or ergonomic advice, it is possible that these interventions be made more effective by matching them to each individual’s clinical presentation, with specific consideration of that person’s predominant pain
mechanism, and NSCLBP subgroup. In such a situation, there may be occasions when physical treatments, psychosocial interventions, or both, are indicated.

Due to the prominence of biomedical approaches to managing NSCLBP (Wand and O'Connell 2008), it is important that the evidence on the importance of adopting a biopsychosocial approach to NSCLBP is effectively disseminated to both clinicians and members of the community. We have taken some steps in this direction. For example, a recent study (O'Sullivan et al. 2012h) (Appendix XII) we completed demonstrated that relatively brief (2-3 day) workshops on NSCLBP can improve the beliefs of physiotherapists about NSCLBP, such that they are less pessimistic, and more in line with the biopsychosocial framework. Further research is planned on investigating whether this improves clinical practice and NSCLBP outcomes. In addition, I chaired a national campaign in Ireland (www.move4health.ie) aimed at addressing unhelpful myths about LBP (Appendix XIII). The campaign received considerable media attention in Ireland, and received a commendation at the Irish HealthCare Media Awards. These campaigns, while simply disseminating what is accepted best practice in the scientific community, are likely to be increasingly important in a world where members of the community can access their own advice independently, and have been shown to be somewhat effective in reducing the costs of NSCLBP internationally (Buchbinder et al. 2001; Buchbinder and Jolley 2005; 2007). For this reason, I have recently, along with my supervisors, been awarded research funding for the development of an online platform aimed at providing evidence-based advice for people with NSCLBP.

5.4 The effectiveness of CFT in the management of NSCLBP
The framework outlined in Figure 27 offers an insight into how a multidimensional intervention like CFT can help target interventions to better manage NSCLBP. This is consistent with the hypothesis (O'Sullivan 2012) that several factors across different domains (genetic, environmental, psychosocial, cognitive, physical and lifestyle) can contribute to NSCLBP. While each of these factors are distinct entities, they are likely to have their
effect by either increasing CNS sensitisation, increasing peripheral nociceptive input, or both. This section deals with two questions; (1) does CFT help, and (2) how does CFT help?

5.4.1 Does CFT help?

Study VII demonstrates that CFT can facilitate statistically significant and clinically meaningful improvements in both pain and disability which are maintained three months after the intervention. When combined with evidence from a RCT among people with mild-moderate NSCLBP that CFT is superior to a combination of manual therapy and exercise (Fersum et al. 2011), it suggests that CFT is a potentially useful intervention, and warrants further investigation in blinded, randomised studies among highly disabled populations.

The effect size of the CFT intervention on disability in both this thesis, and the previous RCT, was large. This is in contrast to the small-moderate effect sizes reported for a range of other interventions used in NSCLBP, which are better than no, or a minimal, intervention, but no better than several other interventions (Linton and Andersson 2000; Linton and Nordin 2006; Keller et al. 2007; Savigny et al. 2009; Henschke et al. 2010; Wetherell et al. 2011). This includes interventions such as injections (Staal et al. 2008; Center et al. 2009), massage (Furlan et al. 2002), acupuncture or dry needling (Furlan et al. 2005), spinal manipulation (Assendelft et al. 2003), workplace interventions (van Oostrom et al. 2009), graded activity (GA) (Karsdorp and Vlaeyen 2009; Macedo et al. 2010), graded exposure (GXP) (Macedo et al. 2010), behavioural therapy (Morley et al. 1999; Henschke et al. 2010), and several forms of physical exercise (Linton and van Tulder 2001; Clare et al. 2004; Rackwitz et al. 2006; Macedo et al. 2009). The evidence for far more costly interventions such as inpatient multidisciplinary treatment (Guzmán et al. 2001; Tavafian et al. 2011; Van Middelkoop et al. 2011) and various surgical procedures (Freeman and Davenport 2006; Mirza and Deyo 2007; Chou et al. 2009a) is also only moderate.

Looking specifically at the clinical relevance of the CFT intervention in Study VII, 71% of participants reported a reduction in disability which was
greater than the MIC (Ostelo et al. 2008). This proportion is almost identical to that reported in the previous RCT (Fersum et al. 2011). This proportion of “responders” is slightly better than that reported for other interventions which demonstrate some effectiveness in the management of NSCLBP, such as GXP and GA (Leeuw et al. 2008). This is especially interesting considering that the average number of interventions provided in Study VII was between one-half (GXP) and one-third (GA) of that used for these other interventions among people with NSCLBP of similar disability (Leeuw et al. 2008).

Therefore, it appears that CFT is a potentially helpful intervention for NSCLBP. Further research is however needed to clarify if it is more helpful than other useful interventions (e.g. CBT), how important the contribution of the various components of CFT are to recovery, and the long-term effectiveness of the intervention.

5.4.2 How does CFT help?

CFT aims to teach patients to perform painful or physically-impaired activities by reducing the threat of movement, enhancing mindfulness of the body’s behaviours and responses to pain and providing the patient with other movement options through a process of cognitive and functional rehabilitation, aimed at reducing pain and enhancing functional capacity. The precise emphasis placed on peripheral nociceptive and central sensitising factors is specific to each participant, based on their underlying pain mechanism and the contributing factors associated with their disorder. For that reason, it is unsurprising that analysis of the secondary outcomes measures from Study VII demonstrated that, in that subgroup of people with disabling NSCLBP, the benefit was primarily achieved through modification of psychosocial rather than physical factors. While this could be interpreted as suggesting that the physical dimension of the CFT intervention is unimportant, the high baseline level of psychosocial factors suggest that these participants were highly centrally sensitised. In contrast, the less disabled participants in Study VI, with a greater peripheral nociceptive contribution to their pain, appeared to benefit – at least in the short-term - from a greater emphasis on physical factors in
their rehabilitation. Similar results have also been seen in sporting populations where CFT has been studied (Thorpe et al. 2010; Perich et al. 2011).

Since CFT combines cognitive and functional rehabilitation, it could be incorrectly perceived as a generic combination of education (CBT and neurophysiology) and physical exercise. However, it is clear that simply combining physical and psychosocial interventions is of little or no additional benefit (Linton et al. 2005; Smeets et al. 2006a; Smeets et al. 2008; Ryan et al. 2010). Therefore, the benefit from an integrated behavioural-based CFT approach may not be from simply combining different interventions, but from linking these peripheral and central contributions to develop a greater insight into pain among patients on an individual level. This aims to facilitate mindful body control with enhanced pain control. This interlinking of contributing factors reflects their physiological interaction (Marras et al. 2000; Mannion et al. 2001b; Geisser et al. 2004; Moseley 2004a; Woby et al. 2007; Sullivan et al. 2009; Lewis et al. 2012), rather than viewing them as being mutually exclusive (O’Sullivan 2012). This also overcomes a key risk with traditional multidisciplinary rehabilitation programmes for NSCLBP, where conflicting advice between healthcare professionals (HCPs) could lead to greater patient confusion and concern.

Improvements in patient outcomes after NSCLBP interventions, which appear quite different (such as CBT and various forms of physical exercise) are mediated by similar psychosocial factors, including reductions in catastrophising, distress, fear and enhanced self-efficacy (Mannion et al. 2001a; Spinhoven et al. 2004; Smeets et al. 2006b; Leeuw et al. 2007a; Woby et al. 2007). In fact, it appears that even if the benefit of such interventions was mostly related to improvements in psychosocial factors, that physical rehabilitation programmes can modify psychosocial factors such as catastrophising as successfully as interventions like CBT (Mannion et al. 2001b; Smeets et al. 2006b). Research also indicates that reducing the unpredictability of pain reduces pain-related fear and anxiety (Meulders and Vlaeyen 2012). This may explain the benefit of helping patients move with less pain and greater confidence, and helping them understand how the way they move relates to their NSCLBP. This enhanced awareness of their movement behaviours may help reduce the common patient report of their
pain changing “for no reason”, and the fear and anxiety which this causes. This would also help explain why the benefits of physical exercise do not appear to be related to the specific type of physical exercise performed (Mannion et al. 2012; Steiger et al. 2012). Therefore, it should not be assumed that an absence of changes in physical measures after rehabilitation suggests the physical rehabilitation did not contribute to recovery. In addition, it must be acknowledged that several other potentially relevant physical measures (e.g. trunk muscle activation) were not assessed.

In conclusion, all beneficial interventions for NSCLBP are likely to have their effect through reducing CNS sensitivity (Zusman 2011). However, there may be different routes through which this can be achieved, either by targeting peripheral nociceptive drivers of pain, central sensitising factors contributing to pain, or both. CFT has the potential to address both contributing domains, in an integrated way and to direct the CFT intervention according to the needs of each individual patient. However, it is not anticipated that CFT will ever involve addressing the peripheral nociceptive drivers alone, as the contribution of central sensitising factors is always likely to be relevant to some degree in all chronic pain disorders.

5.5 Do the findings suggest there are subgroups within the NSCLBP population?
Several aspects regarding subgrouping are worthy of consideration at this stage. Firstly, it has been established in several studies that there are distinct subgroups of patients who share certain characteristics which increase their risk of chronicity or ongoing severe disability (Hill et al. 2008; Hockings et al. 2008; Melloh et al. 2009; Dunn et al. 2011; Westman et al. 2011; Beneciuk et al. 2012). While the specific questionnaires and characteristics studied varied between studies, the high risk groups were generally those with evidence of greater psychosocial involvement, with some demonstrating an influence of occupational factors, and factors such as pain intensity, a history of previous pain and gender (Sieben et al. 2005; Melloh et al. 2009; Dunn et al. 2011). In addition, the ability to predict risk or outcome appears to be better when multiple questionnaires or domains are considered rather than looking at
these separately (Hockings et al. 2008; Westman et al. 2011; Beneciuk et al. 2012; Wideman and Sullivan 2012). While this doctoral thesis did not investigate the risk of developing NSCLBP, the proposed multidimensional framework, which considers both central sensitising and peripheral nociceptive factors, is consistent with the concept of assessing NSCLBP patients across multiple domains.

The hypothesis that the contribution of these different domains could vary between NSCLBP subgroups (O’Sullivan 2012) is partially supported by these results. While participants in Studies VI and VII both reported aggravation with sitting, participants in Study VI would appear to represent a lower risk of chronicity and disability, with a far smaller contribution from psychosocial factors. As such, their predominant pain mechanism was likely to be a peripheral nociceptive one (Smart et al. 2010). In contrast, participants in Study VII probably had a greater contribution from both peripheral nociceptive and central sensitisation components (Smart et al. 2010), as reflected by the wider distribution of pain, greater disability and greater influence of psychosocial factors.

Another aspect of subgrouping worth considering is the possibility that such subgroups will respond best, or perhaps only, to an intervention which is individualised to match their own clinical presentation. Once again, different ways of matching interventions to specific subgroups have been tested. There is some evidence to support tailoring rehabilitation to patient profiles across multiple domains (George et al. 2003; Asenlof et al. 2009; Sheeran 2010; Fersum et al. 2011; Hill et al. 2011). However, another study (Westman et al. 2010) demonstrated that individualised treatment, which considered a range of physical and psychosocial factors, was no more effective in reducing pain and disability than usual care. Based on the likely pain mechanisms involved for the participants in each study, it appears logical that maladaptive sitting behaviour, which can act as a source of peripheral nociceptive input, was seen as important both in the development of LBP during testing, and also its reduction with biofeedback, in Study VI. In contrast, the role of sitting behaviour was less important in Study VII, considering the more powerful influence of the psychosocial contributing factors on central nervous system sensitisation. It was for this reason that the effectiveness of the simple
postural biofeedback intervention was not investigated among the more disabled participants in Study VII, as it was deemed unlikely to be of significant benefit. A multidimensional CFT intervention addressing the breadth of contributing factors in their NSCLBP disorder was instead more likely to be effective in Study VII. As such, this provides some evidence to substantiate the hypothesis that the CFT – or any NSCLBP intervention – will have better outcomes when “weighted” according to the individual patient’s presentation.

The presence of direction-specific postural preferences among NSCLBP subgroups was supported by the findings of Study VI. In contrast, participant postural behaviours were changed in Study VII after the intervention, despite large improvements in pain and disability. This likely reflects the greater importance of movement behaviour among participants in Study VI, as already mentioned.

It is important to highlight that to fully support the need for targeted interventions aimed at specific subgroups, a comparison to an intervention which are not matched to that specific subgroup is required. Since such comparisons were not performed, it is possible that participants in Studies VI and VII reported reduced LBP for reasons other than the targeted nature of the intervention.

5.6 Using minimally invasive technologies to monitor lumbo-pelvic posture

This doctoral thesis has demonstrated both the potential for using novel, minimally invasive technologies to enhance our understanding of sitting behaviour in “real-world” environments, as well as the considerable logistical and technical restrictions which apply to current technologies. It is clear that the detailed analysis of spinal movement behaviour available with several different sophisticated laboratory-based systems (Pearcy and Hindle 1989; Schuit et al. 1997; Mannion and Troke 1999; Dankaerts et al. 2006b) remains superior to the portable posture monitors that are currently available, including the BodyGuard™ monitor used in this doctoral thesis. However, to enhance the ecological validity of data on movement behaviour in NSCLBP, posture
monitoring systems which can accurately analyse spinal movement behaviour outside the laboratory are required.

This doctoral thesis has demonstrated excellent between-day and inter-rater reliability for the BodyGuard™ device, in addition to good concurrent validity during a range of daily postures and tasks. No other portable posture monitor is currently available which has as many advantages in terms of cost, size, simplicity of use and ability to analyse posture dynamically, and which also has published data supporting its reliability (O'Sullivan et al. 2011a), validity (O'Sullivan et al. 2012f; O'Sullivan et al. 2012k) and application for both assessment and biofeedback in clinical populations (Van Hoof et al. 2011; Van Hoof et al. 2012) in real-world environments. Nevertheless, it is clear that considerable refinement of this posture monitor is required. This is particularly important regarding the potential influence of trunk lean on its output. Furthermore its use without clear clinical direction would likely render the device somewhat meaningless. These limitations, and those of the doctoral thesis overall, will now be summarised once again.
Limitations and Recommendations

Several limitations have been identified in each chapter already. In summary, the primary limitations and recommendations for further investigation are;

- The novel posture monitor has only been validated in the sagittal plane.
- Furthermore, the novel posture monitor cannot provide angular data, and requires a separate method of discriminating between sitting and standing postures, such as the accelerometer used in Study VII.
- In its current design, it is prone to underestimating spinal flexion, especially during varying degrees of trunk lean. Further development to incorporate a method of interpreting trunk lean should be undertaken before studying activities involving forward bending, and non-sagittal plane activities.
- While the perceptions of people with NSCLBP were no different to those without NSCLBP, their ability to detect their own posture was not evaluated, and should be evaluated in a future study.
- It is possible that several other interventions could have helped participants in Study VI, including a psychosocial intervention, or biofeedback which was not matched to their NSCLBP subgroup. There was also no follow-up of participants in Study VI. Plans are already in place to compare the effectiveness of these interventions with subgroup-matched postural biofeedback during prolonged sitting, including a longer follow-up period.
- Neither Study VI nor VII had a control group receiving no intervention or a different intervention. This means that the benefit in each study could have been through non-specific effects such as placebo, or in study VII natural recovery. Similarly, neither of the intervention studies (Studies VI and VII) used a blinded assessor. In Study VII, the role of natural recovery is less likely based on the lack of change during repeated baseline measurements. Only a three-month follow-up was performed in Study VII, although further six and 12 month follow-ups are planned. A multi-centre, blinded RCT examining the effectiveness of CFT in the management of NSCLBP is currently being planned.
- While Study VI supported the role of direction-specific subgroups within NSCLBP, there was no clear evidence that changes in sitting behaviour contributed to recovery in study VII.
The number of participants in Study VII who go on to have medical procedures has not been reported, as the length of public waiting lists in Ireland means many would not yet have been called for medical consultant review at this stage. However, their uptake of, and response to, medical interventions is being monitored, and will be reported in the future.

In Study VII, other physical factors which were not analysed could have changed with the CFT intervention, such as trunk muscle activation (Geisser et al. 2005), and these are worthy of further investigation.

Offering participants in Study VII the same postural biofeedback intervention as was provided in Study VI would have provided a useful comparison with data from the less disabled participants in Study VI. However, this would be hard to justify considering the evidence that addressing significant psychosocial factors, as seen in study VII, plays a large role in the resolution of disabling NSCLBP (Mannion et al. 2001b; Smeets et al. 2006b). Future studies could consider whether adding postural biofeedback would be of benefit to CFT.

The intervention studies (Studies VI and VII) specifically only included NSCLBP participants whose pain was at least partly related to mechanical aggravating and easing factors, and the findings may not reflect other more widespread pain disorders e.g. fibromyalgia.

While the improvements in Study VII were statistically and clinically meaningful, providing an average of eight hours of treatment on an individualised basis could be costly, and a cost-effectiveness analysis was not performed. Currently, it is unclear how much treatment would provide the best long-term benefit, while minimising costs. For example, some studies have shown that more treatment may actually be linked to poorer outcomes (Indahl et al. 1995), while others have shown interventions which actively involve the NSCLBP patient are better than simple, brief interventions (Guzmán et al. 2001; Henschke et al. 2010; Hill et al. 2011). Further research could examine the clinical- and cost-effectiveness of providing CFT as a class-based intervention as opposed to individual sessions, and whether providing a brief intervention is as successful as a prolonged intervention (Rose et al. 1997; Kääpä et al. 2006; Louw et al. 2011).
While the identification of psychosocial factors which can contribute to NSCLBP can be facilitated through the use of validated questionnaires, it remains to be seen if a large proportion of HCPs are capable of seamlessly integrating appropriate strategies to address these in their usual management of NSCLBP (Cherkin et al. 1991; Jellema et al. 2005).

While there is an emerging awareness of the central role of CNS sensitisation in people with NSCLBP and other chronic pain disorders, the underlying mechanisms by which it is linked to a wide range of other symptoms (sleep disturbance, fatigue, irritable bowel syndrome, depression etc) is poorly understood. There may be much to be gained from researching how severe disabling NSCLBP, and other chronic widespread pain conditions, represent one dimension of a maladaptive, organism-wide stress response (Lyon et al. 2011). In this regard, chronic pain symptoms may be simply one component of their overall disorder.
Conclusions

The findings of this doctoral thesis demonstrated that:

- There is only limited evidence that existing interventions aimed at changing seated behaviour reduce NSCLBP.
- Monitoring lumbo-pelvic sitting behaviour can be done with good reliability and validity outside laboratory environments.
- Both physiotherapists and members of the community had a strong preference for lordotic sitting postures, despite no strong evidence that such postures prevent or reduce NSCLBP. No significant differences in the perceptions of good sitting posture were evident between those with and without NSCLBP.
- In a well selected subgroup of people with NSCLBP, sitting behaviour contributed to the development of LBP during a two-hour seated task. Providing postural biofeedback to help change sitting behaviour reduced NSCLBP.
- For more disabling NSCLBP, a multi-dimensional behavioural-based intervention (Cognitive Functional Therapy) improved pain and disability in a case-series, and these improvements were maintained at three month follow-up. However, the improvements primarily related to changes in psychosocial measures rather than physical measures.

Therefore, sitting behaviour should be viewed as one potential contributing factor in NSCLBP. This is consistent with a multi-dimensional view of NSCLBP, where both central sensitising factors (genetic, psychosocial, lifestyle) and peripheral nociceptive (movement behaviour, pathology, inflammation) can be involved. It is proposed that further research should examine the effectiveness of interventions which take into account the relative contribution of central sensitising and peripheral nociceptive factors in NSCLBP.


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Appendices

For the detailed appendices, see the separate volume.