

**Neuroplasticity and chronic low back pain:
An investigation into altered tactile
discrimination, body schema
and motor function**

Sara Glithro

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Abstract

Chronic low back pain (CLBP) ranks 3rd in the Global Burden of Non-Communicable Diseases, behind heart disease and stroke and the problem is increasing with an aging and growing population. It is a painful, long-term condition contributing to increased morbidity, low quality-of-life and a significant socio-economic burden. Aetiologies are often unknown and unrelated to specific spinal pathology. Treatments typically focus on pain management and improving motor function. However, the outcomes are inadequate, remaining moderate at best with one approach no better than another. Sadly, many sufferers stop seeking help and their quality of life deteriorates.

In other chronic pain conditions such as Phantom Limb Pain (PLP) and Complex Regional Pain Syndrome (CRPS), cortical neurophysiology and sensory outputs such as body schema and perception are altered alongside motor function impairments. Novel interventions to reverse these impairments coincide with reductions in pain intensity and perception. CLBP shares some characteristics with PLP and CRPS so it is plausible that novel interventions may improve CLBP outcomes. However, for intervention studies to be considered reliable they must be underpinned by robust research to identify the baseline characteristics within the population. This study explored sensory and motor characteristics in adults with CLBP.

A systematic review of peer reviewed publications identified seven studies which utilised different techniques and populations to explore tactile discrimination, body schema and motor function. Critically, none explored all three and the review revealed the characteristics of these constructs to be unclear in the CLBP samples. A narrative synthesis concluded two-point discrimination threshold (TPDT) to be impaired at the anatomical region of pain. Limited evidence suggested that sub-groups within the CLBP group may exist and may be related to impaired body schema. Body schema impairment may also be anatomically linked. TPDT appears negatively correlated with body schema and lumbopelvic motor function but the relationship between body schema and motor control was unexplored.

This study sought to address this gap by comparing key measures of TPDT, body schema (motor imagery performance and back perception) and motor function from 31 adults with CLBP which affected their activities of daily living (ADL's), with an equivalent sized control group, within a UK context. Following two reliability studies to select

appropriate methods of data collection, a cross-sectional research design identified differences between the two groups. Correlations between the key measures and pain, disability and kinesiophobia were explored.

Significant differences between the groups were observed for measures of low back TPDT, back-perception and motor function, but not for measures of tactile threshold or motor imagery performance using left/right discrimination tasks. The left/right discrimination results and the predominantly absent correlations between the key variables differed from the findings in previous studies.

New discoveries from this study included; 1) the most accurate and preferred tool to measure low back and fingertip TPDT was identified; 2) that Luomajoki's Battery of Tests were reliable for use by registered chiropractors and osteopaths without the need for further training; 3) TPDT was impaired at and near to the 'typical' region of CLBP; 4) higher 'typical' pain scores moderately correlated with greater low back TPDT impairment; 5) a significant moderate positive correlation occurred between low back motor control and back perception scores; 6) this was the first study to explore tactile threshold, TPDT, body schema and motor function together in the same groups, and 7) it was the first to explore this combination of variables within the UK population.

This study provides reliable baseline measures of factors known to be impaired in other chronic pain conditions. Small studies have found therapeutically targeting these factors reduces pain and disability in some chronic pain conditions. It is anticipated that this new knowledge may guide future sensorimotor therapeutic interventions to support pain management in those with CLBP.

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Abbreviations

\leq	Less than or equal to
\geq	Greater than or equal to
ADL	Activities of Daily Living
A-P	Anterior to Posterior
BMI	Body Mass Index measured in kg/m ²
BS	Body Schema
CI	Confidence Interval
CLBP	Chronic Low Back Pain
CNS	Central Nervous System
CRPS	Complex Regional Pain Syndrome (Type 1)
CST	30-second Chair Stand Test
FDQ-9	Functional Difficulties Questionnaire
FreBAQ	Freemantle Back Awareness Questionnaire
H ₀	Null Hypothesis
H ₁	Alternative Hypothesis
ICC	Intra-class correlation coefficient
IQR	Inter-quartile range
IRR	Inter-rater reliability
kg	Kilogram
KS	Kolmogorov-Smirnov test
L3	Third lumbar vertebra
L4	Fourth lumbar vertebra
L5	Fifth lumbar vertebra
LBP	Low back pain occurring between the 12th ribs and gluteal folds
LBoT	Luomajoki's Battery of Tests
L/R	Left/Right
n	Number of participants
NRS	Numerical ratings scale
<i>p</i>	Probability
P-A	Posterior to Anterior
PLP	Phantom Limb Pain
PNS	Peripheral Nervous System
<i>r</i>	<i>rho</i> (denotes the reporting of correlation coefficients)
RMDQ	Roland Morris Disability Questionnaire
s	Seconds
S1	First sacral vertebral segment
S2	Second sacral vertebral segment
SA1	Slowly Adapting Type 1 neurons, also called A β neurons

SD	Standard Deviation from the mean
SPSS	IMB® SPSS® version 23.0 (IBM Corp 2015)
SW	Shapiro-Wilk test
TPDT	Two-Point Discrimination Threshold
TSK-11	Tampa Scale of Kinesiophobia consisting of 11 questions
TT	Tactile Threshold

Chapter 1. INTRODUCTION

1.1. Overview

This chapter begins by presenting the global problem of chronic low back pain (CLBP), the changing landscape within CLBP epidemiology and the need for better treatment outcomes. Novel treatment approaches in other chronic pain conditions are introduced and the features that these novel treatments target are briefly explored. The authors research journey and clinical experience with those with CLBP is also explained. Finally, a chapter overview is presented.

This aim of this thesis was to explore sensory and motor function in adults with CLBP with the intention of advancing knowledge relating sensory and motor characteristics in those with CLBP and providing robust evidence on which to base future CLBP research aimed at improving pain and disability outcomes. This is an important area of research because CLBP causes pain and disability for over 20% of the global population of working age adults (Meucci et al. 2015). Current outcomes are inadequate, and many people manage CLBP as a long-term condition which negatively impacts the quality of their life and that of their families and colleagues (Bahouq et al. 2013; Thais et al. 2013).

1.2. Background to the study

1.2.1. Chronic low back pain

Pain is a protective mechanism that warns against potential or actual injury. It actively encourages movement away from danger to a place of safety. A widely accepted definition describes pain as;

“An unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage” (International Association for the Study of Pain 2017)

Pain is a subjective experience that exists only in the person that feels it (Treede 2018). In some people, pain is persistently experienced, despite the risk of injury having passed

and the injury healed. These conditions are termed chronic pain conditions, of which CLBP is one.

Since the 1940s, the World Health Organization's (WHO) definition of health has remained 'Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity' (World Health Organization 1946). Anecdotally, CLBP is often being considered a minor complaint by employers, friends and family and even some healthcare professionals but chronic back pain affects all aspects of health. Sufferers report difficulties performing normal activities of daily living, poor physical and psychological wellbeing, limited social relations and a negative environment (Thais et al. 2013). Depression, increased inactivity and low mood are common in those with CLBP, with prevalence rates of major depression three times greater in those with chronic back pain, than in pain-free individuals (Currie and Wang 2004). Work absenteeism is also an issue and the longer a period of work absenteeism lasts, the less likely a return to work is (Woolf and Pfleger 2003).

There are numerous definitions of low back pain within the literature (Von Korff 1994; de Vet et al. 2002) but for the purposes of this study, CLBP is defined as constant or recurrent pain or discomfort occurring between the twelfth ribs and the gluteal folds, lasting longer than 3 months or 12 weeks' duration (Airaksinen et al. 2006; Chou et al. 2007; Treede et al. 2015). It is rarely life-threatening and is often regarded as trivial when compared with infectious and non-communicable diseases (Delmas and Anderson 2000; Dionne 2006). However, it is estimated that 11-12% of the population are disabled by CLBP (Airaksinen et al. 2006; Balagué et al. 2012). Disability-Adjusted Life Years (DALYs), where one DALY can be considered as 'one lost year of healthy life', enable disease burden data to be compared globally (World Health Organisation 2016). CLBP currently ranks 4th globally of all the non-communicable diseases, with only ischaemic heart disease, stroke and lower respiratory infections ranking higher. More alarmingly, CLBP has risen in the rankings each time the report has been published since the 1990's (Murray et al. 2015).

CLBP is the second leading cause of work absenteeism (Woolf and Pfleger 2003) and the cause of significant socioeconomic cost. Hong et al's (2013) investigation into the costs incurred by the United Kingdom's (UK) National Health Service (NHS) regarding CLBP were calculated to be £1.5 billion annually but estimates including lost revenue from work absenteeism, over-the-counter medications and private health care options would increase this figure considerably.

Approximately 80% of adults will experience at least one episode of low back pain during their lifetime (Frymoyer 1988; Walker 2000) but few studies predict the number of adults who go on to experience repeated episodes. Stanton et al. (2008) provided the first reliable estimate, where approximately 25% of participants recovering from their first low back pain episode reported a further episode within 12 months.

Around 58% of those with back pain seek care (Ferreira et al. 2010) but only 25% consult general practitioners about their pain (Dunn and Croft 2005). Anecdotally, it was thought that episodes of acute low back pain of less than 12 weeks duration resolved within a few weeks but it appears that people simply stop reporting them. About 60-80% of those with low back pain who reported to their general practitioner continued to experience pain 12 months later, despite ceasing further consultations (Croft et al. 1998; Hayden et al. 2010). Of those reporting CLBP, around 85% were diagnosed with 'non-specific CLBP', meaning there was no known pathology or specific underlying disease (Deyo and Weinstein 2001; Hollingworth et al. 2002). The absence of a known pathology often means the absence of a specific diagnosis, a failure to legitimise pain and a failure to direct specific treatment which can lead to difficulties in managing the condition for patients and clinicians (Hill et al. 2008).

More recently, long-held beliefs about the epidemiology and prognostic factors for CLBP have been challenged. Childhood prevalence rates were reported to be 37% from a study of more than 400,000 children in 28 countries (Swain et al. 2014). This finding is important because childhood low back pain was previously thought to be rare and low back pain in children predicts CLBP in adulthood. Those experiencing low back pain as a child are more than twice as likely to develop persistent back pain in adulthood (Hestbaek et al. 2006). CLBP affects more women than men (Hoy et al. 2012) and Meucci et al's (2015) recent systematic review of 28 studies and over 500,000 participants, found prevalence increased linearly with age. Point prevalence rates were 4.2% in those aged 24 to 39 years, 19.6% in the 20 to 59 aged group and in those 60 years or older, an even greater increase was noted at 25.4%. Another large systematic review conducted on the African continent reported even higher rates, with point prevalence across adults of all ages at 32% and again, this increased with age (Louw et al. 2007). In Europe, 25% of the population is over 60 years of age and global populations are ageing, with 2.1 billion people expected to reach 60 years or older by 2050 (United Nations 2017). The significance of these findings is multifaceted. CLBP was once considered a self-limiting condition that affected adults in developed countries and typically resolved within a few weeks. None of these assumptions now appear to hold true. CLBP is a global problem, affecting more people, from a wider age demographic, for longer.

In an aging population, the demands on healthcare are increasing (Freburger et al. 2009; Juniper et al. 2009). Inadequate CLBP treatment outcomes add to this burden, resulting in long-term pain and disability which inhibit active, social and healthy lifestyles; factors known to cause non-communicable diseases such as cardiovascular disease, cancer and diabetes (Buchbinder et al. 2018). Thus, CLBP persists at a huge personal and economic cost to individuals, families and economies and more needs to be done to improve outcomes and prevent a decline towards greater pain and disability.

1.2.2. Chronic pain treatments

Musculoskeletal conditions, including CLBP, are typically assessed in terms of pain and functional motor (or movement) impairments or disability (Woolf and Pfleger 2003; Kamper et al. 2011). Consequently, typical treatments are focused on reducing pain and disability and improving motor function. Therapeutic interventions often include education, reassurance, analgesics and non-pharmacological therapies such as exercise, manual therapies and acupuncture but one approach appears no better than another and these approaches have yielded only a small to moderate success at best (Bogduk 2004; Ferreira et al. 2007; Hayden et al. 2010; Van Middelkoop et al. 2011; Garcia et al. 2013; Maher et al. 2017).

Multidisciplinary treatment approaches, addressing CLBP from a biopsychosocial aspect, offer only a moderate improvement in pain and function; yet they are greater than the improvements seen from general practitioner approaches or those that address only physical factors such as exercise or manual therapy (Kamper et al. 2014). Even within one approach, such as exercise therapy, one type of exercise does not appear to be more effective than another. In addition, the effects remain small and it remains unclear which groups of patients benefit from any specific type of exercise (van Middelkoop et al. 2010). Perhaps one reason for poor outcomes is that while those with CLBP are encouraged to engage with physical interventions and perform more exercise, treatment techniques tend to focus on the motor aspects of posture, movement and gait. The sensory and perceptual aspects which are inherently intertwined with motor function, are paid little attention.

Perception is the integration of sensory impressions into psychologically meaningful information (Shumway-Cook and Woollacott 2007). Perceptual rehabilitation techniques for CLBP are uncommon but some sensory perception focused studies have been reported. In Italy, the Surface for Perceptive Rehabilitation (Su-Per) technique, which used the entire back as an area of sensory input during treatment, achieved significant

reductions in short and long-term pain, and disability improvements on a par with traditional back clinic outcomes (Morone et al. 2012; Paolucci et al. 2012; Vetrano et al. 2013). However, such approaches are rarely reported in clinical practice.

The ability to maintain an accurate body position is influenced by the degree of congruity between planned motor functions and the actual motor functions performed. Sensory feedback allows one to determine whether or not congruity is present so is critical to maintaining accurate body positions when moving through the world (Frith et al. 2000). In chronic pain conditions such as Complex Regional Pain Syndrome (CRPS) and Phantom Limb Pain (PLP), incongruence between sensory feedback, planned and actual motor functions such as the problems encountered with moving a phantom limb, may result in erroneous pain sensations (Harris 1999; McCabe et al. 2000). However, novel techniques to restore the sensorimotor conflict appears to reduce the sensation of pain (Ramachandran and Rogers-Ramachandran 1996; McCabe et al. 2003; McCabe 2011).

If restoring sensorimotor conflict reduces pain, it might be plausible that creating sensorimotor conflict could have the opposite effect and produce sensory disturbances or painful sensations in healthy people. Indeed, such findings have been reported by McCabe et al. (2005), Daenen et al. (2012) and Brun et al. (2017) but the evidence provided by Wand et al. (2014c) is contradictory because no sensory disturbances were identified. These discrepancies may be due to the methodological differences across the studies (different samples, methods, outcome measures etc) but when considered together, some healthy people experience sensory disturbances during experimentally created sensorimotor conflict.

This relationship between sensorimotor function and sensory disturbances, including pain, suggests that in some people, altering sensory mechanisms using cortically focused techniques might improve sensory and motor impairments and pain may be modulated (Moseley et al. 2008c; Moseley and Wiech 2009). Studies intended to alter sensory mechanisms using cortically focused techniques have typically involved participants with PLP and CRPS but evidence in other pain conditions, including CLBP, is growing and may provide a new target for CLBP treatment. Pilot studies targeting central processes rather than peripheral mechanisms have improved measures of pain intensity, the impact of pain on activities of daily living and self-reported disability (Wand et al. 2011b; Wand et al. 2012).

Current understanding of such characteristics in different CLBP groups and in relation to motor functional deficits is incomplete. Two common symptoms reported in CLBP are pain and impaired motor function (Hodges and Moseley 2003). However, an initial search

revealed an absence of studies that had simultaneously investigated sensory changes alongside motor function in a single study of participants with CLBP and a control group from the same population.

1.1. The author's research journey

This research project has been influenced by a keen interest in neuroscience and my clinical experience working as a chiropractor, within private practice on the central south coast of the UK. In this clinic, I observed that most of the patients presented with non-traumatic low back or neck pain. In addition, those patients with low back pain presented with recurring mild-to-moderately painful episodes of non-neuropathic pain, where mild pain equates to a pain score of between one and four (out of ten), moderate between five and six, and severe pain being scored seven to ten (Jensen et al. 2001). They rarely reported severely disabling issues or extreme pain and they persisted with work, family and social lives despite their activities of daily living (ADL's) often being affected. Some reported having previously sought help from their National Health Service (NHS) General Practitioner (GP) but ceased further GP consultations following a failure to improve. Many had never consulted their GP for back pain. Discussions with colleagues in similar private practices revealed comparable situations. These observations indicated that many people who were self-managing CLBP remained 'under the radar' of the NHS healthcare system and this led me to consider that CLBP prevalence rates are probably under-reported. It was interesting to note that people with CLBP were determined to stay active and stay in work, meaning they were not burdensome to the UK NHS or economy. Preventing their CLBP episodes from increasing in frequency or intensity was of profound importance to them and their families.

Another observation was that although they met the criteria for CLBP and reported their activities of daily living to be affected, most reported pain and disability to be less severe than levels reported by participants in recent CLBP studies (Bauer et al. 2016; Marty et al. 2016; Pakzad et al. 2016; Pranata et al. 2017). I reflected that if we could increase our understanding of the CLBP features within this mild-to-moderately affected group, we might be able to explore novel treatment methods to support the management of CLBP.

My observations have led me to believe that patient education is an important aspect of any treatment session. For example, after increasing the clinical time I spent educating those with CLBP about back physiology and pain, I noted that Patient Reported Outcome Measures (PROMs) improved. This led me to consider whether outcomes could be

improved further through additional cognitive interventions. I wasn't suggesting abandoning manual therapy or any other CLBP treatments but I was fascinated to know what other adjunctive treatments could be introduced alongside those already valued by patients. It was important to me that techniques were accessible, low budget and low tech. My interest is in providing patients with mechanisms of self-help that give them the opportunity to take ownership of their conditions. I explored the literature on other chronic pain conditions and discovered that interventions which improved sensory and perceptual awareness also improved pain and disability outcomes in Phantom Limb Pain (PLP) and Complex Regional Pain Syndrome (CRPS) (Flor et al. 2001b; McCabe et al. 2003). CLBP shares some characteristics with PLP and CRPS and I began to question whether impaired sensory and perceptual awareness features existed within the CLBP population and whether they could be a target to improve CLBP pain and disability outcomes. To be more specific, I wanted to understand sensory and perceptual function in the CLBP population who reflected the characteristics and demographics of those who regularly attended my clinic. Typically, they presented with intermittent episodes of mild-to-moderate pain and disability and appeared to be a sub-set of the more severely affected CLBP population widely reported within the CLBP literature.

The primary motivation for this study was to explore sensory and motor functions alongside clinical outcome measures in a UK sample of the CLBP population and a control group. The aim was twofold; to deepen the understanding of existing knowledge and identify new relationships between sensory and motor CLBP traits in a UK sample of those with mild to moderate CLBP. By contributing new evidence regarding sensory impairment in CLBP, it may help to determine whether sensory function might be a future target for therapeutic interventions and help this group to manage their condition and maintain active, social, healthy lifestyles for longer.

1.2. Thesis chapters outline

This thesis is divided into seven chapters, see Figure 1-1. Chapter Two contains a review of the literature which entails the theoretical framework, an introduction to the study concepts and a systematic review of the literature pertaining to this study. The results of the systematic review informed the study direction, research questions and study design by highlighting the gaps in knowledge regarding sensory and motor impairment in adults with CLBP. Chapter Three describes the methodology, the study design and the methods for data collection and analysis. The findings from Chapter Two and Three highlighted the need for undertaking two reliability studies which are reported in Chapter Four. The first reliability study compared three different tools for assessing two-point discrimination threshold (TPDT) on the fingertip and back. The second was an inter-rater reliability study to measure agreement between raters when assessing low back movement in people with and without CLBP. Results from both reliability studies guided the main study design. The results from the main study are reported in Chapter Five and discussed in relation to the existing literature and clinical implications in Chapter Six. Chapter Six concludes with the study strengths and limitations. Chapter Seven presents the conclusions, highlights the key contributions to knowledge and proposes important areas for future research. Finally, supporting material is provided as appendices, which are presented sequentially after the references at the end of this thesis.

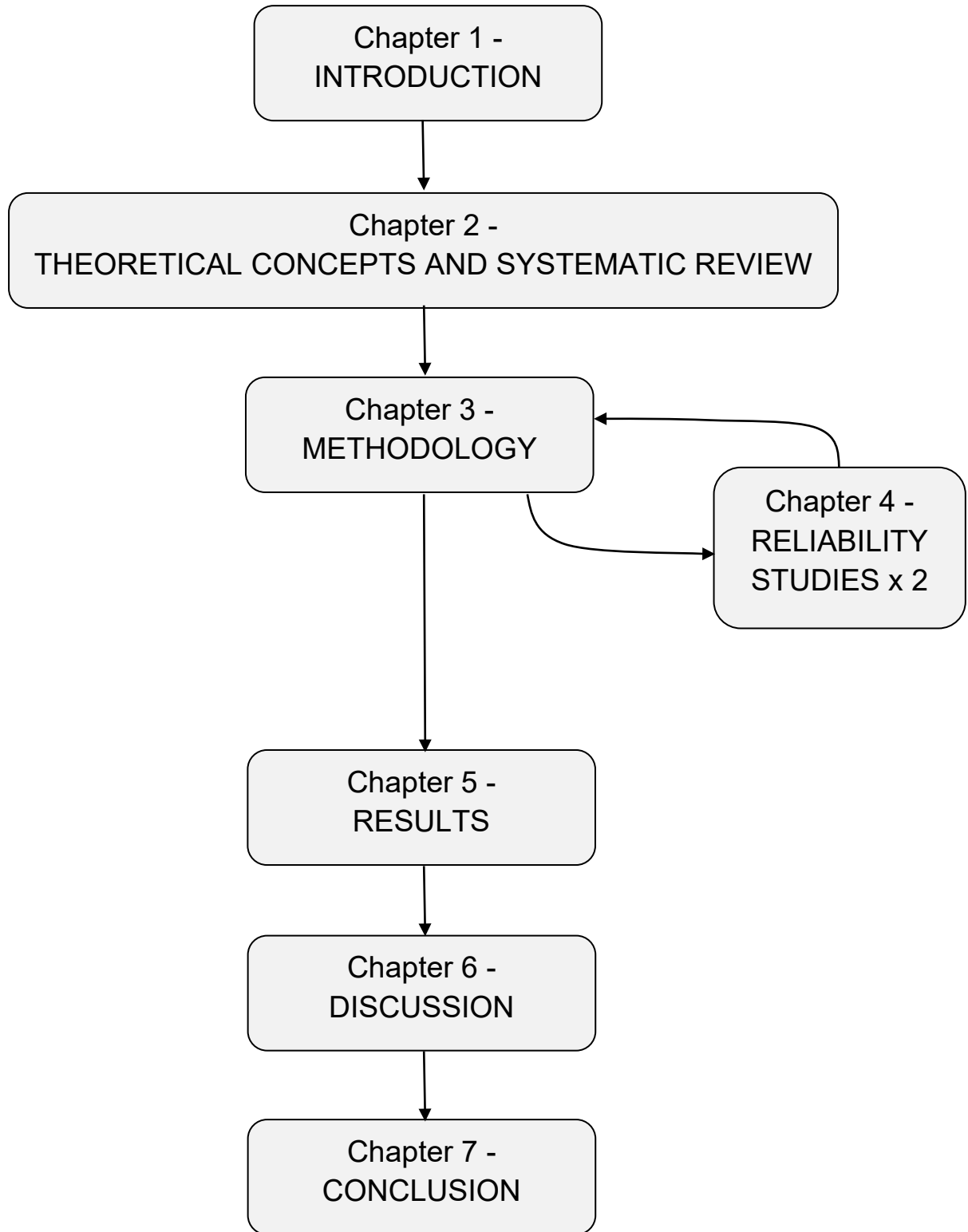


Figure 1-1: Overview of the thesis chapters and content

Chapter 2. THEORIES AND SYSTEMATIC REVIEW

2.1. Introduction

This chapter is presented in three parts. First, a general overview of the neurophysiological concepts and theories relating to this thesis. Second, a systematic review is presented that provides a comprehensive review of what is known about altered sensory function and its relationship to motor functional impairments in adults with CLBP. Together, these two sections provide the rationale for investigating this specific area and helped develop the conceptual framework for this study. The third section presents the study aims, objectives and research questions which were derived from the systematic review findings. The chapter concludes with the clinical and theoretical implications for this study.

2.1.1. Neurophysiological Concepts

Several phenomena occur in response to sustained or changing neural input. Of these, Hebb's Law, neuroplasticity and cortical reorganisation are of particular importance to the theories on which this study is based.

Hebbian Learning or Hebb's Law, proposed in 1949 and republished in 2005 (Hebb 2005), can be paraphrased as neurones that 'fire together, wire together' and those that 'fire apart, wire apart'.

The term neuroplasticity refers to the ability of the CNS to reorganise by forming new neural connections. The connectivity strength between pre- and post-synaptic neurons with changes in the amplitude of responses that occur following action potentials (Cho et al. 2015). Effectively this means that, 1) during a particular task or function, the connectivity between neurons that are activated become stronger, and 2) this connectivity can be diminished or lost if the task or function ceases to be performed. This phenomenon allows dynamic and reversible neuroplastic change to occur throughout the central nervous system and permits adaptation of the CNS in response to changing environments (Demarin and Morović 2014).

Neuroplasticity is widely accepted as being essential in the function of learning, but a growing body of work also links CNS structural and functional neuroplasticity to chronic pain (Pons et al. 1991; Ramachandran et al. 1992; Flor et al. 1997; Maihöfner et al. 2003;

Pleger et al. 2006; Tsao et al. 2010; Tsao et al. 2011). Cortical reorganisation is one consequence of neuroplasticity.

The involvement of cortical reorganisation in chronic pain conditions is integral to the theories underlying this study. As such, a brief overview of the relevant cortical reorganisation processes has been provided.

2.1.1.1. Cortical reorganisation in the primary somatosensory cortex

The primary somatosensory cortices (S1) hold specific, clearly delineated and spatially arranged sensory maps that correlate to highly topographical parts of the body (Woolsey et al. 1942; Nelson et al. 1980; Merzenich et al. 1983; Pons et al. 1991; Kaas 1997). Zones of neural activity within cortical maps are associated with specific regions of the body. These associated structures are referred to as being somatotopically linked.

Using tactile acuity, such as single point skin contact and two-point discrimination threshold (TPDT), as examples, the clinical relevance of cortical reorganisation can be summarised as follows. During single point tactile acuity, a single point on the skin surface is lightly touched, an associated cluster of neurons within the S1 fires multiple action potentials and electrical information is transmitted along their membranes. This action is the normal neural response profile for that somatotopically arranged neuronal cluster. A normal psychophysiological response would be that touch is sensed at the point contact was made. In TPDT, two points are lightly touched on the skin and providing the points are sufficiently distanced from each other, two distinct neuronal clusters are activated. Following activation of this normal response profile, touch would be sensed at the two points where contact was made (Sur et al. 1980; Merzenich et al. 1983; Jenkins et al. 1990; Haggard et al. 2003).

In chronic pain, the relationships between somatotopically linked structures are altered and can result in different neural response profiles and sensations being experienced (Ramachandran et al. 1992). This is referred to as cortical reorganisation. One mechanism known to drive cortical reorganisation is a reduction in intracortical inhibition, which is also known as neural inhibition or disinhibition (Merzenich et al. 1983).

In some chronic pain conditions, the response profiles of the S1 neurons involved in discriminatory touch are altered (Pleger et al. 2005; Pleger et al. 2006). Tactile receptive fields are somatotopically linked to clusters of neurons within the S1 (Sur et al. 1980; Merzenich et al. 1983; Jenkins et al. 1990; Haggard et al. 2003). In healthy humans,

normal response profiles (the activation of a receptive field and its associated cluster of cortical neurons) are maintained through intracortical inhibition, where activated neurons inhibit their neighbouring neurons from firing (Merzenich et al. 1983). Following injury or during chronic pain, these normal response profiles alter because they lose their ability to inhibit neighbouring neurons from firing. As a result, previously demarcated neuronal clusters within the S1 merge with neighbouring territories and cortical reorganisation occurs (Ramachandran et al. 1992; Yang et al. 1994b). See Appendix 9.2.1 for a review of tactile threshold and TPDT.

2.1.1.2. Cortical reorganisation within the motor cortex

A loss of discrete motor cortical organisation within the M1 has been associated with impaired motor control in those with CLBP (Tsao et al. 2008; Tsao et al. 2011). In healthy controls, two separate cortical motor regions are associated with the short/deep multifidus and the long superficial longissimus muscles but in those with CLBP, only one region is apparent. This suggests that in those with CLBP, a blurring of the cortical representations of these muscles occurs within the M1 (Tsao et al. 2008; Tsao et al. 2011). Such blurring may be related to cortical disinhibition. For example, people with CLBP move differently to those without pain (Hodges et al. 2013). In fact, people with CLBP move differently to each other, which may account for the contradictory outcomes where some studies report increased and some report decreased muscle use despite participants performing identical tasks (van Dieën et al. 2003; Hodges et al. 2013). It may be that disinhibition of the motor cortex is involved in these different movement patterns because inhibitory cortical networks modulate the contractile properties of muscles required for the execution of motor function tasks (Liepert et al. 1998). The normal activation patterns of the M1, the resultant muscle contractions and overall spinal stability are altered in those with CLBP, even when participants are performing motor function tasks involving the upper limb (Massé-Alarie et al. 2012). Consequently, cortical disinhibition within the M1 could influence widespread altered muscle activity and the resulting motor task performance in those with chronic pain.

Intracortical inhibition and facilitation reflect the neural activity of the inhibitory and facilitatory pathways of the motor cortex (Ziemann et al. 1996). Cortical disinhibition of neural pathways within the motor cortex is reported in several chronic pain conditions and the magnitude of disinhibition appears to be positively related to pain severity but not to the laterality or location of the pain (Schwenkreis et al. 2003; Schwenkreis et al. 2010; Massé-Alarie et al. 2012). For example, in those with nociceptive pain, which is thought to

result from activity in the neural pathways secondary to actual tissue damage or potentially tissue-damaging stimuli (Nicholson 2006), such as unilateral CRPS type 1 of the hand (developed as a consequence of trauma without obvious nerve lesion), measures using transcranial magnetic stimulation suggest that disinhibition occurs within both hemispheres of the motor cortex (Schwenkreis et al. 2003). Conversely, people with chronic unilateral, neuropathic hand pain display cortical disinhibition within the motor cortex contralateral to the side of the painful hand. Neuropathic pain occurs following by damage to the nervous system which resulted in nerve lesions or dysfunction (Nicholson 2006). Furthermore, this disinhibition appears to be reversible and pain scores can be improved (Lefaucheur et al. 2006). Taken together, these findings suggest a close association between chronic nociceptive and neuropathic pain conditions and the occurrence of cortical disinhibition within the motor cortex. Although the underlying pathophysiological mechanisms involved may vary with differing chronic pain conditions, the implications of cortical reorganisation occurring bilaterally in some conditions and unilaterally in others is not well understood. This is important because chronic pain conditions affecting one side of the body appear to be associated with either unilateral or bilateral disinhibition of the motor cortex and CLBP can be a unilateral or bilateral condition. In fact, anecdotally, the location of pain in those with CLBP can be unilateral, bilateral or variable so it may be that cortical also change varies but how this might impact hemispheric change is unknown.

Cortical reorganisation is also reported in several other musculoskeletal chronic pain conditions including fibromyalgia, ankylosing spondylitis, osteoarthritis, Crohn's disease and inflammatory bowel disease (Kuchinad et al. 2007; Blankstein et al. 2010; Agostini et al. 2013; Agostini et al. 2017). As these conditions share features (pain and or disability resulting from the musculoskeletal tissues) it is suggested that some changes may share a common underlying mechanism for the change (Agostini et al. 2013). In unilateral osteoarthritis of the knee, the cortical representation of the knee and ankle is distorted and this is accompanied by impaired motor function of the affected knee (Shanahan et al. 2015). If disinhibition of the motor cortex occurs in other musculoskeletal conditions and it impacts their execution of motor function tasks, it is possible that such disinhibition may be at least partly responsible for the motor functional impairments seen in those with CLBP.

However, much remains unknown regarding changes in the supraspinal regions in relation to motor function changes in those with chronic pain conditions. A recent systematic review concluded that the evidence which supported the occurrence of cortical change in the M1 of people with various chronic pain conditions, including CLBP, was

inconclusive (Chang et al. 2017). If, as some of the evidence reviewed earlier suggests, disinhibition occurs in the M1 of some people with CLBP, inhibitory cortical networks influence motor function and those with CLBP move differently to those without pain, one might expect to find a significant relationship between changes in M1 structure and altered low back movement. However, this does not appear to be the case and the relationship between the M1 structure and low back motor function remains unclear (Elgueta-Cancino et al. 2018). It is worth noting that this was an isolated small study so may not have been adequately powered to identify significant findings.

If cortical reorganisation of the sensory cortices is associated with altered sensory function, it is plausible that cortical reorganisation of the motor cortex may also be associated with altered motor functions. In those with chronic pain, altered movement patterns might be adopted to avoid further pain. van Dieën et al. (2017) suggests that during episodes of CLBP, altered motor function becomes practised behaviour which may become the normal method of movement.

The M1 is involved with learning and consolidating new motor functions (Kami et al. 1995; Muellbacher et al. 2002) so it might be expected that changes within the M1 would normally occur with the learning of new patterns of motor function, even if the driver behind the learning was pain avoidance. Yet, further evidence supports that maladaptive cortical changes may be contributing to altered motor function in CLBP and in chronic pain of the upper limb. Furthermore, these changes may be associated with the severity and location of pain (Schabrun et al. 2015a; Schabrun et al. 2015c).

2.1.1.3. Cortical reorganisation in chronic pain conditions

Evidence to support what is known about cortical reorganisation, sensory and motor impairments has been undertaken in several chronic pain conditions but the underlying mechanisms behind the changes in each condition remain only partially understood. While there are differences between chronic pain conditions, it could be accepted that there also similarities. As such, several chronic pain conditions are discussed and used to highlight important factors of relevance to this CLBP study.

Cortical reorganisation occurs in different structures of those with different chronic pain conditions. For example, structural and functional changes have been noted in many supraspinal structures in chronic pain conditions such as the S1, M1, the anterior cingulate cortex and insula. These have been noted in those with Phantom Limb Pain (PLP), Complex Regional Pain Syndrome (CRPS), fibromyalgia, ankylosing spondylitis,

osteoarthritis, Crohn's disease, inflammatory bowel disease and in CLBP (Flor et al. 1997; Willoch et al. 2000; Flor et al. 2001a; Juottonen et al. 2002; Apkarian et al. 2004; Kuchinad et al. 2007; Schwenkreis et al. 2009; Blankstein et al. 2010; Moseley and Flor 2012b; Agostini et al. 2013; Kong et al. 2013; Foell et al. 2014; Schabrun et al. 2015a; Schabrun et al. 2015b; Shanahan et al. 2015; Agostini et al. 2017).

Some chronic pain conditions are associated with spatial biases or distorted mental representations of the painful region of the body and these distorted mental representations vary between different chronic pain conditions.

The owners of phantom limbs report their phantoms to feel part of their body but are often unable to visualise moving it from a fixed and often abnormal position; this is thought to contribute to the pain they experience (Melzack 1990; McCabe et al. 2004). In Complex Regional Pain Syndrome, limbs are often perceived to be larger than they really are and their owners report difficulty in knowing the position of their affected limb (Lewis et al. 2007; Lewis et al. 2010; Peltz et al. 2011). Such body schema impairments increase positively with pain intensity and impaired TPDT (Lewis and Schweinhardt 2012). Conversely, some people with osteoarthritis of the hand perceive their affected hand to be smaller than it really is. Interestingly, this perceptual distortion can be manipulated experimentally and (Gilpin et al. 2014). However, differences in the underlying mechanisms behind perceptual distortion of the limb appear to differ between those with and without osteoarthritic hand pain. These findings are relevant to this study because they demonstrate that pain from osteoarthritis is likely to be associated with a disruption of the cortical body matrix (see section 2.1.2.3) and CLBP shares some characteristics with osteoarthritis. Additionally, spatial biases in musculoskeletal chronic pain conditions can be improved through the manipulation of sensory perception which appears to improve congruency between mental representation and the affected body part. This adds evidence to the drive for greater understanding of perceptual disruptions in those with CLBP because new findings may have implications for the development of new treatment interventions based on the cortical representation of the back rather than the physical back.

People with CLBP are known to also display perceptual impairments which may be involved in altered motor function. They display spatial bias and are less accurate in determining joint position (Gill and Callaghan 1998; Brumagne 2000; Clark et al. 2014). While the precise mechanisms behind this phenomena are unclear, differences in the afferent inputs from the paraspinal muscle spindles and the central processing of sensory inputs are known to be involved (Gill and Callaghan 1998; Brumagne 2000; Tong et al.

2017). Additionally, the restriction of proprioceptive cues from factors such as skin stretch at the ankle joint results in impaired joint position sense (Mildren et al. 2017).

Consequently, it is plausible that if those with CLBP move differently to those without pain, the degree of skin stretch, proprioceptive input and joint position sense of the affected joints might be altered in those with CLBP. These factors could alter afferent input from the affected area and the central processing of such information.

Consequently, movement occurring as a response to the processing of such afferent information may also be altered. Therefore, investigating and understanding the relationship between sensory and motor function in the CLBP population remains vital if combined sensory and motor approaches to improving CLBP outcomes are to be considered in the future.

The magnitude of cortical reorganisation of the S1 in those with CRPS has been positively associated with TPDT. As cortical reorganisation increases, tactile acuity becomes less accurate (Juottonen et al. 2002; Maihöfner et al. 2003; Pleger et al. 2004). The change in TPDT appears to occur within the region of pain and it is associated with mean sustained pain, but not current pain scores (Pleger et al. 2006).

Remarkably, treatments or interventions targeting central nervous system processes have restored S1 response profiles and reduced pain intensity in PLP (Moseley 2006) and in CRPS (McCabe et al. 2003; McCabe et al. 2004; Moseley 2004b; Moseley 2005b; Pleger et al. 2005; Pleger et al. 2006).

Cortical reorganisation has also been noted in people with CLBP and a growing body of work provides evidence for structural and functional cortical changes in people with CLBP. Apkarian et al. (2004) identified structural changes including reductions in the volume of neocortical grey matter and the thickness of the dorsolateral prefrontal cortex (DLPFC); both of which were associated with pain duration. Further studies reported volume loss within the DLPFC, identified brainstem and S1 volume reductions and also identified basal ganglia and hypothalamus volume increases; all of which were associated with pain intensity in those with CLBP (Schmidt-Wilcke et al. 2006). Earlier studies linked S1 changes to CLBP duration, with greater change noted in those with CLBP of longer duration (Flor et al. 1997).

Pain intensity during motor function tasks in those with CLBP also appear to impact cortical change. Kong et al. (2013) linked S1 changes somatotopically to the low back and detected altered S1 functional connectivity which fluctuated according to the intensity of pain experienced during the performance of low back motor function tasks (see Appendix **9.2.4** for a definition of motor function).

These findings are important because they link changes in various cortical structures, low back motor function, pain and altered sensory function in those with CLBP. Furthermore, it may be that pursuing a better understanding of cortical, sensory and motor characteristics could reveal new therapeutic approaches which might improve pain outcomes in those with CLBP.

2.1.1.4. Clinical surrogates as measures of cortical reorganisation

Difficulties in accessing the equipment and skills required to directly evaluate cortical organisation might be one reason why direct measurements of cortical reorganisation are not widely reported.

Some researchers choose clinical surrogates as indirect measures of cortical organisation because changes to one construct, appear to correlate with changes in the other (Moseley and Flor 2012b). Measures of clinical surrogates and direct measures of cortical function suggest that cortical reorganisation is initiated and reversed quickly under experimental conditions (Wang et al. 1995; Stavrinou et al. 2007). The absence of longitudinal studies means the rate of change for clinical surrogates and cortical function and the relationship between such changes is unknown. However, changes to sensory and motor function characteristics, including tactile function, are reported in observational studies of people with various chronic pain conditions, including CLBP (Lotze and Moseley 2007; Luomajoki and Moseley 2011; Stanton et al. 2013; Catley et al. 2014b; Gilpin et al. 2014).

One clinical surrogate measure of cortical reorganisation is tactile stimulation (Wang et al. 1995). Two methods of measuring tactile stimulation are tactile threshold and TPDT. Tactile threshold is the minimum force required for touch to be perceived (Kandel et al. 2013). TPDT describes a function of touch, also known as tactile spatial acuity or spatial resolution. It is defined as the shortest distance between two points at which a subject can clearly detect two points of contact (Weber et al. 1996; Jerosch-Herold 2005).

2.1.1.5. Tactile threshold and TPDT neurophysiological processes

Tactile threshold and TPDT are thought to involve very similar structural, physiological, neurological and molecular processes (Abraira and Ginty 2013). However, it should be noted that precisely how the information from the skin contact are transposed into the neural coding that underlies tactile perception continue to remain unknown.

TPDT is considered to rely upon the stimulation of multiple Merkel cell neurite complexes positioned within two distinct receptive fields (Weber et al. 1996; Kandel et al. 2013). Whereas, single point tactile threshold is thought to rely upon the activation of complexes within only one receptive field. Merkel cell complexes are not significantly affected by skin shear or the activation of neighbouring tactile receptive fields during skin contact (Gasser and Erlanger 1927; Haeberle et al. 2004; Abraira and Ginty 2013). Therefore, one could be relatively confident that a static light, direct skin contact, such as that of tactile threshold and TPDT, predominantly activated Merkel cell neurite complexes and their associated neural pathways rather than other low threshold mechanoreceptors which may have been positioned nearby (Abraira and Ginty 2013).

The size and shape of the tactile receptive fields are thought to be related to TPDT acuity. However, a weakness in this theory is the lack of supporting evidence. Few studies report the receptive field sizes associated with Merkel cell neurite complexes and none could be located that were recently published or explored the skin of the back. Two studies from the 1970's assessed nerve impulses from isolated Merkel cell complexes while locating the receptive field boundary using light touch contact. Receptive fields from the glabrous skin of the hands and fingertips were circular or, more commonly, oval with the long axis of the oval lying lateral to medial along the limb in the anatomical position. Several highly sensitive zones were identified within each receptive field and the long axis of single receptive fields ranged from 1-2mm in diameter on the middle finger pad, to 8-10mm on the proximal finger (Johansson 1978; Johansson and Vallbo 1979). A further study of the hands and forearms found receptive fields to be larger, the further they were away from the limb tip (Schady and Torebjörk 1983).

Additionally, an investigation of the lips, fingertip and hands reported the capacity for spatial resolution, a necessary function for TPDT, to be related to a proximal-distal relationship gradient in the density of Merkel cell neurite complexes and the size of their representation areas within the S1 (Johansson and Vallbo 1979). Although the evidence relating to receptive fields does not relate directly to the back, the distribution of Merkel cells does fit the expected distribution, with the greatest density occurring on the middle finger palp (over 100 cells per mm² of skin) and reducing on the back to one of the lowest found anywhere on the body (12 cells per mm² of skin) (Lacour et al. 1991; Tachibana 1995). Taken together, it could be concluded that sufficient supporting evidence might exist to support that TPDT acuity reflects Merkel cell distribution, which in turn reflects the size of the tactile receptive fields. TPDT relies upon more than one tactile receptive field and therefore, acuity of TPDT would alter with a change in the receptive field size.

Receptive field sizes are somatotopically related (meaning a point on the body relates to a specific point within the CNS) to specific clusters of neurons within the S1. Therefore, if the somatotopic structure is altered, with the size of the neuron clusters altered through cortical reorganisation, the size of the corresponding receptive field alters accordingly. Consequently, TPDT acuity would also alter. Tactile acuity is reviewed further in Appendices **9.2.1**.

2.1.1.6. Body schema - neurophysiological processes

This study incorporates established clinical surrogate measures to assess some of the characteristics known to alter in chronic pain conditions. These characteristics include altered tactile acuity, body schema and disability or impairments to motor function (Lotze and Moseley 2007; Luomajoki and Moseley 2011; Stanton et al. 2013; Catley et al. 2014b; Gilpin et al. 2014).

Body schema relates to how one's body feels to its owner (Lotze and Moseley 2007; Moseley et al. 2012). It involves how and where we perceive our bodies to be in space in relation to our ability to position ourselves and move within our environment. It also encompasses the complex integration of data from motor, sensory and vestibular cortical maps and can be considered a 'looking out, from within' perspective (Goldstein 2009). Body schema differs to body image in that body image relates to how we believe others perceive us, so it implies a 'from the outside, looking in' perspective (Goldstein 2009).

Given the strong overlap between the psychology and neuroscience disciplines, terms common to both disciplines have become interchangeable within peer reviewed literature. Some authors, even within the same field, have adopted the term 'body image' (Moseley 2008a; Nishigami et al. 2015) while others use 'body schema' (Bray and Moseley 2011; Wälti et al. 2015) despite assessing the same outcome measures and using the same techniques. This study is founded upon neuroscience concepts, so within the context on this thesis, the term 'body schema' will be adopted, even when the articles under discussion use the term 'body image'.

Disturbances in body schema are common in people with Complex Regional Pain Syndrome (Maihöfner et al. 2003; Moseley 2005a; Lewis et al. 2007; Lotze and Moseley 2007), Phantom Limb Pain (Flor et al. 1997; Moseley et al. 2008a), hand osteoarthritis (Gilpin et al. 2014) and in Chronic Low Back Pain (Moseley 2008a; Bray and Moseley 2011; Wand et al. 2014b; Nishigami et al. 2015).

Sensorimotor integration is essential in normal human function. The combination of sensory input and motor output allows constant evaluation of the state of the internal body and external world (Goldstein 2009; Kandel et al. 2013). Through the function of the superior parietal lobe, cortical or body maps are thought to be created and stored for different physiological systems such as vision, perceptual, tactile, motor function (Wolpert et al. 1998).

Body schemas are constantly changing and rely upon the integration of somatosensory and motor processing, in addition to many cortical body maps such as tactile, visual, vestibular, perceptual and motor maps (Holmes and Spence 2006). However, the motor maps are thought to be different from those used in actual motor function because when disturbed experimentally, incongruence is reported between motor intent and motor output (McCabe et al. 2005; Lotze and Moseley 2007). An accurate body schema, sometimes called a working body schema, is necessary in normal sensorimotor control and it is important in this study because altered body schemas are characteristic of many chronic pain conditions where they appear to alter with changes in cortical function and pain (Melzack 1990; Moseley et al. 2008a).

Spatial biases and motor disturbances are reported in chronic pain conditions associated with incongruities in the working body schema. For example, the pain experienced by those with phantom limbs which cannot be visualised as moving, is thought to result from the incongruence between the perceived and physical structure and function (Melzack 1990; McCabe et al. 2004). In CRPS, disrupted perceptions led to patients report limbs to be larger than they really are and are inaccurate in positioning their affected limb (Lewis et al. 2007; Lewis et al. 2010; Peltz et al. 2011). Such impairments appear to increase with pain intensity and in CRPS increasing impairment is also related to poorer TPDT acuity (Lewis and Schweinhardt 2012).

Motor imagery performance tasks, such as distinguishing between left and right, require the integration of an intact working body schema with the imagined (not actual) movement of specific body parts (Moseley 2004b). Motor imagery performance is widely reported as a measure of body schema in those with chronic pain (Moseley 2004c; Nico et al. 2004; Moseley 2008a; Bray and Moseley 2011; Stanton et al. 2013; Bowering et al. 2014; Trapp et al. 2014a; Linder et al. 2016).

The process of differentiating between left and right limbs is thought to require us to create a mental image of ourselves in a position related to the left and right sides of the task at hand. For example, when shown a photograph of a left hand and asked to identify

which side of the body it originated from; we must imagine our own hand in that position by mentally rotating and manoeuvring it into position. First, we choose either a left or right hand to form the mental image. If we initially selected the left hand, the match is confirmed. However, if the right hand was imagined in the first mental image, despite mentally rotating the limb, the image would remain incongruent with the picture and be recognised as incorrect. The process would begin again, this time selecting the left hand and discovering it correctly matched the image. An intact working body schema is necessary to process and integrate such complex information (Parsons and Fox 1998; Parsons 2001). Body schema is reviewed further in Appendices 9.2.3. It was assumed that this approach was adopted by people determining left and right sides of all regions of the body but recent studies dispute that idea when differentiation between left and right images of the trunk/torso or head/neck (Wallwork et al. 2015; Alazmi et al. 2018). This is discussed in greater detail in Chapter Six.

Importantly, therapeutic interventions designed to restore disturbed body schemas by explicitly focusing on cortical function have been successful in managing CRPS and PLP (Moseley 2004b; Moseley 2005b, 2006). Of great importance to this study, some preliminary investigations into CLBP report features similar in type and characteristic to the impairments previously reported in PLP and CRPS. Such findings justify further CLBP investigations with the objective that a deeper understanding of such characteristics may, in the future, reveal alternative pathways for CLBP rehabilitation.

2.1.1.7. Nociception

Nociception is the afferent neural activity involved in the transmission of sensory information about noxious stimuli (Treede 2006). The precise mechanisms by which pain becomes a conscious experience is complex and not completely understood. What is known, is that to experience pain, cortical activity is necessary (Treede et al. 1999). Furthermore, nociception is not necessary for pain to be experienced, despite it being a common cause of pain (Holmes 2006; Bowlby 2010; Novembre et al. 2014; Singer and Klimecki 2014).

There are differences in the neural mechanisms between pain and other sensory perception functions. In perceptual functions involving the sensory organs, distinct regions of neurons within the cortex are associated with specific tasks, such as deciphering visual, somatosensory and auditory input. Although, these clusters of neurons are associated with different, non-pain related sensory tasks they are similarly structured in their physiology and response properties (Mountcastle 1957; Kandel et al. 2013).

Neuroimaging studies have revealed that the neural basis of pain differs spatially, in its specificity and physiological structure to those of other sensory perceptual mechanisms (Iannetti and Mouraux 2010). For example, the number of neurons likely to be specifically involved in nociception is few and their spatial distribution throughout the cortices is widespread (Brooks and Tracey 2005; Iannetti and Mouraux 2010). Therefore, the physiological structures, the spatial distribution and the specificity of the cortical neurons involved in nociceptive activity differs significantly from the precise, prolific clusters of neurons associated with other sensory perceptual functions. The differences between pain and other sensory functions have given rise to many theories which attempt to explain the pain process.

2.1.2. Pain theories underpinning this study

Several theories are important to this study as they underpin the theoretical framework on which the investigation was based.

2.1.2.1. Theory of the Neuromatrix

Melzack's (1990) theory of the neuromatrix suggests that perceptual outputs, of which pain is one, can be considered the product of the active cortex that forms subjective experiences in response to sensory signalling from sensory experience and learning. Although the central nervous system (CNS) is genetically determined, it is modified by each person's experiences. Therefore, pain cannot be considered the consequence of a passive brain merely registering tissue injury or trauma. This theory proposes that while sensory input from injured tissues may initiate pain or other bodily awareness, it may not be the only, or perhaps even the dominant, causal mechanism.

Some evidence supports that following high intensity nociceptive stimuli, collections of nociceptive-specific neurons in the primary and secondary somatosensory cortices (S1 and S2 respectively), anterior cingulate cortex and the insula are activated and a painful sensation is experienced (Hsieh et al. 1999; Ingvar 1999; Ploghaus et al. 1999; Brooks and Tracey 2005; Boly et al. 2008). These functions do not appear to occur following low intensity nociceptive stimuli. As specific regions of the brain are found to be consistently activated, it has been suggested that a pain specific subsection of Melzack's (1990) neuromatrix had been identified although the first author to report this term is unclear.

Instead of 'neuromatrix', the term "pain matrix" began to appear in publications where it was argued that the pain matrix specifically responded, at least in part, to nociceptive stimuli (Ingvar 1999; Ploghaus et al. 1999; Brooks and Tracey 2005; Boly et al. 2008; Henry et al. 2011). Although the term 'pain matrix' appears to have been widely accepted within the literature, there are anomalies within the model as it cannot explain some of the findings reported by pain researchers.

As a model to explain the pain process, the pain matrix (as a pain specific sub-section of the neuromatrix model) might be expected to match other task specific perceptual functions that are encompassed by the wider neuromatrix model. However, in relation to pain, there is a lack of the structural and functional specificity that is observed in other sensory perceptual functions (Iannetti and Mouraux 2010; Mouraux et al. 2011). For example, the regions of the brain involved in the auditory coding of single verbal words are specific to the task and separate from those areas used to interpret the same words when written or read (Petersen et al. 1988). However, the pain matrix structures involved in nociception do not appear to be specific as they also respond to other non-nociceptive stimuli, such as viewing others in pain or threatening visual stimuli (Kenshalo and Douglass 1995; Godinho et al. 2006; Valeriani et al. 2008).

Given that the pain response of withdrawing and moving away is important to survival (Gifford 2013), it is reasonable to suggest that the structures involved in the supraspinal response to pain, should only respond to pain. Meaning, when a pain response is necessary (i.e. to protect from harm), withdrawing and moving away should be the only possible response because another response could delay such protective mechanisms from occurring and the risk of injury would be increased.

It might also be expected that the magnitude of both the elicited brain response and the sensation of pain should equate to the size of the stimulus. Yet, this is not always the case (Iannetti et al. 2008; Petre et al. 2017; Ružić et al. 2017). As such, other pain theories are also relevant in the understanding of the pain process.

2.1.2.2. Salience Matrix Theory

The saliency of a sensory stimuli is its ability to stand out relative to the background (Itti and Koch 2001). For example, in a lecture theatre full of students wearing black shirts, one student wearing a red shirt would stand out, or appear to be visually salient.

The saliency matrix theory suggests that following its detection within a multi-model neural network, the nociceptive process responds to the most salient sensory input. By its nature, pain is salient. As a protective mechanism it is important that the individual pays attention to pain signal and takes appropriate action to avoid further pain so saliency is proposed to be one of the most important functions of nociception. Additionally, the factors that cannot be explained by the pain matrix, for example why different people respond differently to pain and why the magnitude of the stimulus does not always correspond with the size of the pain response, are also the factors that influence saliency (Iannetti and Mouraux 2010; Mouraux et al. 2011).

The saliency matrix model might offer a better explanation of the incongruent findings from pain research because saliency is also related to experience (Näätänen et al. 2007; Pakarinen et al. 2007). For example, a persistently ringing car or intruder alarm is likely to be less salient than one that rarely sounds. When considered in the context of CLBP, it may be that the longer someone has experienced chronic pain, the better they might cope with it. This might help explain why older people with CLBP of higher pain and disability outcome scores report less negative impact to their quality of life than is reported by their younger counterparts (Houde et al. 2016; Wettstein et al. 2018). Perhaps older people develop better long term coping strategies which reduces the saliency of their pain. This does imply that some outcome measures reported in pain research studies may actually be a result of, or at least partly due to something other than pain.

The theory of the neuromatrix (or pain matrix) and the saliency matrix are important within this study because they suggest that pain is not simply a result of input from nociceptive or neuropathic mechanisms but one that is determined by multisensory factors, including the interpretation of these factors within the supraspinal structures. As such these paradigms fit with the often paradoxical characteristics seen in those with CLBP.

2.1.2.3. Mature Organism model

A further model of interest to this study is that of the Mature Organism Model (Gifford 2013). This model considers pain from the perspective of the organism (single and multicellular) and its response to stress with the intention of maintaining homeostasis (Weiner 1991). It is suggested that pain is a powerful factor intended to motivate the organism to alter its behaviour and enhance recovery and its chance of survival (Gifford 2013).

Specifically, the mature organism model suggests that organisms, including human beings, begin life with only the bare minimum of information, experience and knowledge but these factors increase as the organism matures. As a result, with maturity comes greater prowess in responding appropriately to the external environment and the individual's likelihood of survival increases. The underlying approach by which this knowledge is gained is that the organism samples the environment (or information from their own tissues), the information is scrutinised, a response is determined and undertaken. As a result, the external environment will alter and is resampled, thus beginning the process again.

Pain is considered to have three dimensions (Melzack and Casey 1968; Melzack and Dennis 1986). The first is the sensory dimension which relates to pain location, intensity, quality and how it behaves over time. Altered thoughts in relation to pain are termed the cognitive dimension, whereas altered feelings resulting from the emotional reaction which accompanies pain, form the affective dimension. Together, these dimensions provide value to our pain experiences, so if a situation is considered to be of high value, greater attention is given to it (Gifford 2013).

This is important to this study because emotional and cognitive responses are intertwined with the beliefs people have, and the actions they may take in response to their CLBP. It is significant in this study design because earlier memories could exist if participants had previously experienced severe CLBP during the performance of ADLs. These may have been recalled when asked about ADLS, even if their painful experience occurred years earlier. As a result, some participants may respond differently to others depending on their recalled memories. For example, some may base their responses on their recalled memory rather than on their current activity ability. This could have implications on the groupings so may be a limitation within this study but also to any study which relies upon participant recall.

As knowledge and experience is gained with maturity, the mature organism model suggests that the individual's response to situations alters and the actions taken are intended to improve the chance of survival. However, it does not necessarily mean that people adapt positively to their pain. They may change their behaviour and avoid activities but their altered behaviour could be maladaptive (meaning it is not of benefit to the survival of the organism). It is proposed that such adaptations occur as a result of the individual intending to minimise real or potential risk of further injury/pain. This is often seen in those with CLBP (van Dieën et al. 2003; van Dieën et al. 2017) and it may be a factor in why those with CLBP move differently to those without pain. That people respond

to pain according to their own thoughts and feelings about their pain (in addition to the actual sensory experience) might explain why those with CLBP also move differently to each other (van Dieën et al. 2003; Hodges et al. 2013).

Additionally, knowledge can be gained from first-hand experience or by watching others. The thoughts and feelings experienced at the time of learning something new is thought to become part of the stored information relating to that task. When the information is later recalled, the thoughts and feelings embedded with the initial learning may influence whether the individual perceives the task to be positive or negative (Gifford 2013). This might explain why some people report themselves experiencing increased pain sensations when watching someone else in pain (Osborn and Derbyshire 2010).

This phenomenon is of clinical importance and is one reason for this study being performed. If a person can change their thoughts and feelings about a situation or learn new knowledge to change their understanding of their CLBP, they may be able to change their pain and disability, or the way they allow it to affect their quality of life (Houde et al. 2016). A recent small pilot study found that if someone with low back pain and altered body perception watched an illusion of their own 'stronger' back (enhanced with greater muscle tone), they may feel stronger (Nishigami et al. 2019). The concept of disturbing body perception using illusion is related to a further theory of importance to this study, the cortical body matrix theory and this is discussed below.

2.1.2.4. Cortical Body Matrix

The cortical body matrix was proposed by Moseley et al. (2012) in response to evidence that a multitude of unexpected sensations and physiological responses were experienced by those with chronic pain. For example, regions of the body are perceived to be larger (CRPS and PLP), smaller (osteoarthritis) or are unable to be visualised, located or moved (CLBP, PLP) (McCabe et al. 2004; Lewis et al. 2007; Lewis et al. 2010; Peltz et al. 2011; Lewis and Schweinhardt 2012; Gilpin et al. 2014; Wand et al. 2014b; Wand et al. 2016).

The theory argues that these findings may occur as a result of disturbances to the neural representation of the body, its sensory data, how it moves within the external environment and its maintenance of homeostasis (Moseley et al. 2012). This neural representation and all it encompasses is referred to as the cortical body matrix. This model integrates sensory, perceptual, proprioceptive and motor function and attempts to explain how apparently disparate characteristics are noted in different chronic pain conditions.

Perceptual illusions are reported to alter perception. For example, the sense of ownership of a non-self body part can be instilled in healthy people using the rubber hand illusion (Botvinick and Cohen 1998). However, the illusion appears to go further than simply altering perception. Measurable physiological responses have been reported in the real hand when ownership has been transferred to the rubber hand. For example, a reduction in body temperature and an increase in histamine reactivity, which is an important pathway in the innate immune response, occurs in the real hand of those who adopt 'ownership' of the rubber hand (Barnsley et al. 2011). These results may be more complex than just invoking participants to take ownership of a rubber hand because differences in limb temperature occurred with differing tactile pressure and whether the stroking of the limbs was carried out using a robot arm or by a human researcher (Rohde et al. 2013). Why limb temperature would decrease in the presence of another person is unclear but given the importance of individual experience in guiding efferent responses, as highlighted in the salience and mature organism models, it might not be unexpected.

Furthermore, the wide array of disturbances seen in chronic pain conditions are thought to contribute to chronic pain because experimentally created incongruence in healthy people results in them reporting sensory disturbances or pain sensations (McCabe et al. 2005; Daenen et al. 2012; Gilpin et al. 2014; Brun et al. 2017).

This is clinically important because if disturbances in the cortical body matrix do influence chronic pain, they might be receptive to interferences which could improve the symptoms in those with chronic pain conditions. In fact, some disturbances have already been experimentally modulated in those with different chronic pain conditions (Moseley et al. 2008a; Wand et al. 2011b; Gilpin et al. 2014). It may be that more factors encompassed within this theory can be modulated using illusions, training or other interventions to restore cortical body matrix disruptions and improve situations for those with chronic pain.

Better understanding of the sensory and motor changes related to chronic pain could improve individuals' responses to their pain (or pain-inducing situations). This might occur if the cognitive (thoughts) and affective (feelings) dimensions of their pain could be altered (Melzack and Casey 1968; Melzack and Dennis 1986). The impact of altering perception through training, illusion or other means could improve chronic pain situations, even if previous attempts to treat the sensory dimension of pain has failed. Providing people with approaches to treatment that do not focus directly on the location, type and intensity of pain, might encourage researchers to explore these concepts further and those with chronic pain to seek new methods by which they can understand and manage their pain.

This study builds upon those ideas by clarifying some of the sensory and motor changes that occur in those with CLBP.

2.1.2.5. Biopsychosocial model of healthcare

Engel's (1989) biopsychosocial model of healthcare was also significant in defining this study's framework. The biopsychosocial model enabled the multifaceted nature of CLBP to be embraced by considering the physical nature of back pain (bio-), the psychological impact introduced by the patients beliefs and fears (-psycho-), and the influence of external factors such as work and family (-social) on an individual and their CLBP (Waddell 2004). This was important because each aspect of this model is related to the pain and disability reported by people with chronic pain conditions, including CLBP (Moseley et al. 2008b; Main et al. 2010; Thais et al. 2013).

Section Summary

To summarise the first part of this chapter, structural and functional changes exist in the cortices of people with CLBP and these changes appear to be linked to altered sensory and motor functions of the body. These altered sensory and motor functions of the body may be considered clinical surrogates to indirectly provide insight to cortical organisation. This is significant because cortically targeted therapeutic interventions have improved sensory and motor function (pain and disability) in CLBP (Wand et al. 2011b), PLP and CRPS (Flor et al. 2001a; Moseley et al. 2008c).

However, while these findings are interesting and worthy of further investigation, it should be noted that the CLBP evidence came from one small pilot study with three participants and no control group Wand et al. (2011b). Therefore, this evidence must be considered weak but the quality and reliability of the CLBP evidence could be improved if the study was repeated using a larger CLBP sample and an appropriate control group.

Further CLBP evidence suggests that following successful surgical intervention, CLBP outcome measures significantly improved and the cortical changes observed prior to surgery were reversed (Seminowicz et al. 2011). Taken together, these findings indicate that CLBP and cortical reorganisation are linked and targeting treatment to alter one feature may coincide with a change in the other. This phenomenon justifies the importance of using clinical surrogate measures of cortical reorganisation to simultaneously explore sensory and motor function in those with CLBP. The study aims to identify impairments and improve our understanding of potential new targets for rehabilitation to reduce pain and disability outcome measures.

This research study aimed to add to the evidence regarding what was known about cortical, sensory and motor function changes in those with CLBP and measures of clinical surrogates were proposed to provide an indication of cortical function.

Consequently, a systematic review was undertaken to identify, summarise and understand the evidence relating to measures of TPDT and body schema (motor imagery performance and back perception) and whether these measures were related to altered lumbar motor function in those with CLBP and a control group. The findings from the systematic review guided the direction of the research questions, the study design and the methodology which led to the empirical research study reported in the subsequent chapters of this thesis.

2.2. Systematic Review

2.2.1. Aim

The aim was to conduct a systematic review to understand and summarise the evidence identified in response to the thesis question '***Is low back two-point discrimination threshold and body schema altered in adults with chronic low back pain when compared with a control group and do these alterations relate to impaired lumbar motor function?***' The review outcome was needed to ensure the research questions were specific, relevant and justified an in-depth investigation.

2.2.2. Methods

The review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher et al. 2009). Broad inclusion criteria were chosen to ensure all relevant articles were identified. A literature search of online databases was conducted, relevant articles were gathered, screened for eligibility and assessed for methodological quality across studies. The inclusion criteria are presented in Table 2-1. A systematic review and qualitative data assessment led to a narrative synthesis (HLWIKI Canada contributors 2015).

Table 2-1: Literature search inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
<ul style="list-style-type: none"> Adults aged 18 years or older (no upper age limit) who experience intermittent or constant non-specific chronic low back pain of persistent or recurrent duration longer than three months. 	<ul style="list-style-type: none"> Pregnant women. Women within 6 months' post-partum. Central neurological conditions and nerve root pathologies. Acute or sub-chronic low back pain (duration <3 months).
<ul style="list-style-type: none"> Studies assessing two-point discrimination on the low back and/or body schema in a CLBP group and a comparative/control group. 	<ul style="list-style-type: none"> Clinical studies assessing two-point discrimination only in a location other than the back
	<ul style="list-style-type: none"> Qualitative studies Studies not published in the English language.

2.2.2.1. *The literature searches*

A search strategy was derived from the review question's key concepts using Medical Subject Headings (MeSH) from the National Library of Medicine (2015). The concepts were 'two-point discrimination', 'body schema' and 'chronic low back pain' but derivatives of these terms were developed from revised searches and identifying additional key words from the returned articles. The search strategy was refined over the course of the systematic review and the final version is presented in Appendix 9.2.6.

An online literature search was initially undertaken between February and August 2017 to locate peer-reviewed, randomised controlled trials, cohort and cross-sectional studies that were published in the English language before mid-August 2017. The search strategies were saved and re-run periodically throughout the duration of the research project to ensure new publications were included and the results remained current. The dates were extended each time the search strategies were run to include newly published articles. The results from the most recent literature search date included articles published before the end of May 2018 and it is these results that are included in this thesis systematic review.

The bibliographic databases searched were; British Library EThOS, CINAHL Complete, Cochrane Database of Systematic Reviews, Cochrane Library, Global Health, Web of Science, Medline Complete, OVID, PsycINFO, PubMed, ScienceDirect and Scopus. Wider searches were conducted using the Google Scholar search engine and grey literature was accessed via Open Grey (Open Grey 2012). The reference lists of key articles were hand searched and screened for eligibility.

2.2.2.2. *Inclusion and exclusion criteria*

Resources to interpret journal articles written in languages other than English were not available as part of this study, so excluding them from the literature search was necessary. However, it was found that narrowing the search criteria to only return articles written in English excluded many relevant articles because although they were published in the English language, they had not been categorised as such during the publishing process. By not narrowing the language search criteria to English, all relevant articles were returned but those not written in English were excluded at the manual screening phase. This ensured relevant articles were not inadvertently missed in the literature search. An initial search revealed that the studies assessing TPDT or body schema in

addition to metrics of motor function would be returned using the TPDT or body schema search strategies. However, if the search terms for motor function were included over twenty million articles were returned so the search was narrowed by considering TPDT and body schema to be priority search terms. It was expected that the studies that explored TPDT or body schema alongside motor function would be returned by the TPDT and body schema search strategies.

2.2.2.3. Data extraction

Data extraction took place using a customised extraction form (Appendix 9.2.7) that was based upon the study demographics table presented within a systematic review of tactile acuity and chronic pain (Catley et al. 2014b). The form was adapted to include information regarding study aims, study design, sample population and characteristics, ethics, methodology, data analysis and outcomes.

2.2.2.4. Quality of the evidence

Assessing the quality or internal validity of included studies allowed the methodological strengths and weaknesses to be taken into account when determining how valuable the findings were (Petticrew and Roberts 2008). The findings could be weighted towards or against specific types of bias. For example, in observational studies the internal validity of confounding factors causing the observed result may be considered a greater risk than the bias introduced by the internal validity of selection bias. This is because observational studies cannot control for the included participants because volunteers that meet the criteria are automatically included. This means that although there may be less risk of selection bias occurring in observational studies than in other study designs, the risk of confounding factors affecting the observed outcome remains higher.

Quality assessment also allowed results from those with different methodological designs to be compared. Due to the varied methodological design of the included studies, an adapted version of the Downs and Black Quality Index score (Downs and Black 1998) for measuring methodological quality in both randomised and non-randomised studies was employed and can be seen in Appendix 9.2.8.

The Downs and Black Quality Index score consisted of 27 questions which were grouped under the headings; reporting, external validity, internal validity – bias, internal validity –

confounding (selection bias) and power. Each study was assessed for quality according to a set of questions. However, not all questions were applicable to each methodological design. Questions 8, 14, 19, 23 and 26 specifically related to intervention studies so were excluded when assessing observational studies.

Except for questions 5 and 27, each was awarded a maximum of one point if the answer was deemed to be 'yes' or zero if the answer was 'unable to be determined' or 'no'. Question five asked 'Are the distributions of principal confounders in each group of subjects to be compared clearly described?' and could be awarded up to two points for 'yes', one point for 'partially' and zero points for 'no'.

The question regarding power calculations (question 27) could be awarded a maximum of 5 points but the method reported by Downs and Black (1998) proved difficult to interpret and score. Following discussion with other researchers who had experienced using these forms, it was decided to simplify the scoring for this section. Studies were awarded 1 point for including a power calculation and zero if it was excluded altogether (Reichert et al. 2009; Galland et al. 2012). With these amendments, the maximum score available became 28 for a randomised controlled trial and 23 for a non-randomised observational study. Following quality assessments of all included studies, the final percentage scores were adjusted accordingly.

Downs and Black (1998) did not provide guidance for categorising articles to be of high, medium or low quality and other authors appear to adopt different methods. Galland et al. (2012) indicated that a study could be deemed to be of high methodological quality if the score was equal to or greater than (\geq) 67%. A score between 42% and 66% indicated medium quality and equal to or less than (\leq) 41% could be considered of low quality. Given the scoring variation between similar types of studies, a decision was made to rate those with a checklist score of \geq 70% as high quality, between 60% and 69% indicated medium quality and \leq 59% indicated a low-quality methodology. All studies meeting the inclusion criteria and being rated either high or medium quality were included in the review.

The revised checklist was piloted using the first two articles to ensure the outcomes were as expected. Two independent reviewers assessed the articles for quality. Where a difference of opinion was observed, a discussion took place and an agreement was reached.

2.2.3. Results

2.2.3.1. Included studies

A total of 1950 articles were retrieved from the search strategies. After removing 1255 duplicates, the titles/abstracts of the remaining 695 articles were reviewed. Of these, 676 were excluded, with the remaining 19 being put forward for consideration. Most of the 676 rejected articles did not meet the inclusion criteria because they did not assess at least one of either TPDT on the low back or a measure of body schema. A further six articles were identified through hand searching, and three from verbal communication with other authors. In total, 28 articles progressed to the full review stage. Following full article reviews, 20 papers were excluded and eight were included. A detailed report of the number of articles flow through the process is presented in Appendix 9.2.9. Reasons for 20 fully reviewed but excluded articles can be seen in Appendix 9.2.10. A summary flow of articles through the process is presented in Figure 2-1.

2.2.3.2. Study characteristics

All eight included studies were observational, with seven being of cross-sectional case study or cohort design. The eighth reported a reliability of a new psychometric questionnaire designed to measure self-perception of the back which as a measure of how one's body feels to its owner, can be considered a measure of body schema.

2.2.3.3. Quality assessment

The results of the quality assessment are presented in Table 2-2. Six articles achieved overall quality scores ranging from 70 – 83%. One article, Nishigami et al. (2015) was of medium quality but met the quality threshold of 65% and was included in the review. The final and most recent study, Stanton et al. (2017) was of high or moderate quality in some categories of the Downs and Black Quality Index score, such as reporting, some aspects of bias and power. However, low scores for the categories of selection bias and external validity resulted in an overall quality score of 57%. Unfortunately, as it did not achieve the agreed minimum quality threshold, it was excluded from further analysis. However, it has been included within the systematic review discussion.

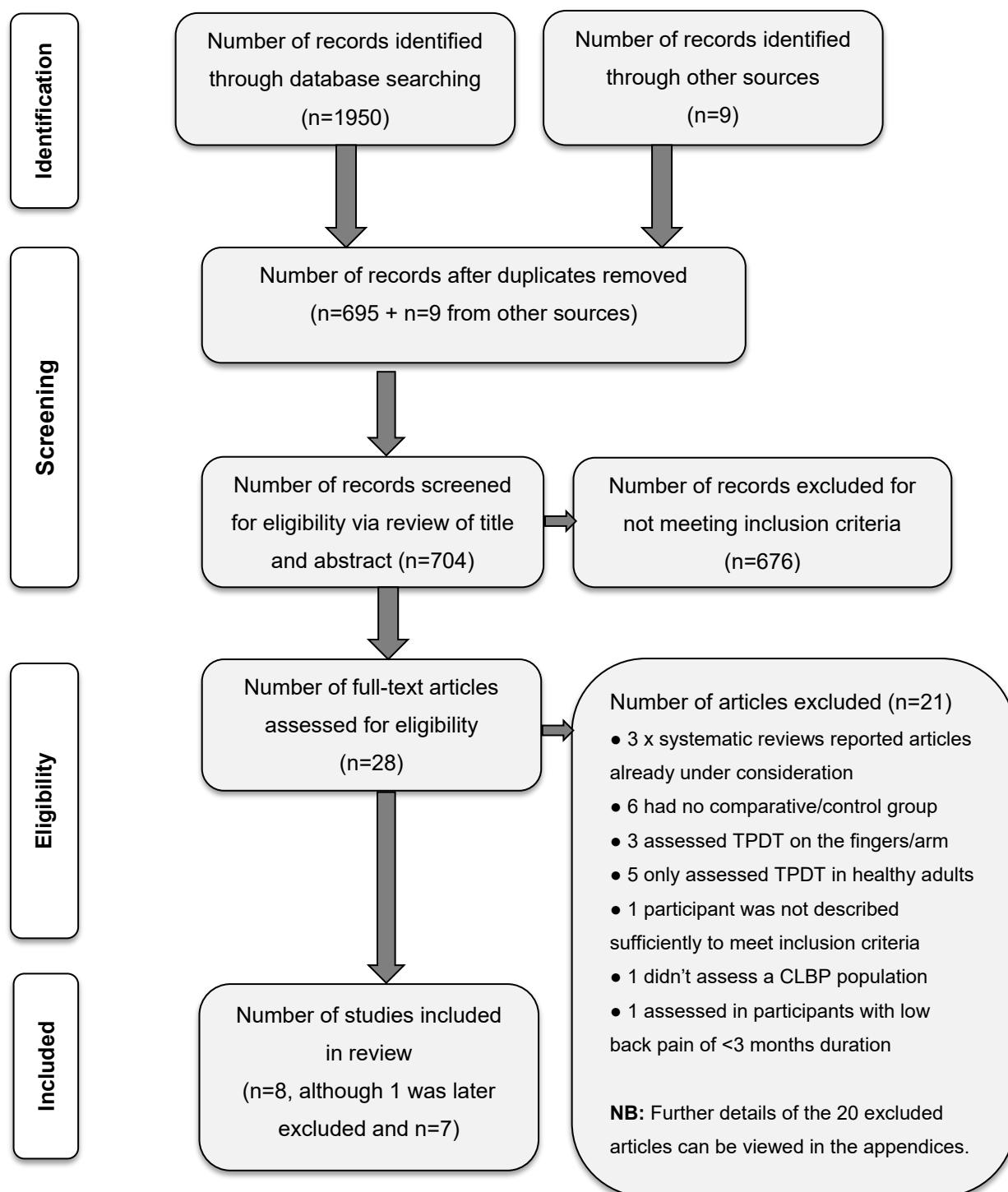


Figure 2-1: Flow chart of literature search results and exclusions

(adapted from Moher et al., 2009) CLBP: chronic low back pain, TPDT: two-point discrimination threshold

Table 2-2: Results of quality assessment using modified Downs and Black (1998) Checklist

	Moseley (2008)	Wand et al. (2010)	Luomajoki & Moseley (2011)	Bray & Moseley (2011)	Stanton et al. (2013)	Wand et al (2014)	Nishigami et al. (2015)	Stanton et al. (2017)
Study design type	A	B	B	B	B	A	A	A
Reporting	9/10	10/10	10/10	10/10	10/10	10/10	9/10	9/10
External validity	2/3	2/3	2/3	2/3	2/3	1/3	1/3	0/3
Internal validity – bias	5/5	4/5	5/5	4/5	5/5	4/5	4/5	3/5
Internal validity – confounding factors	1/4	1/4	2/4	0/4	2/4	0/4	0/4	0/4
Power	0/1	0/1	0/1	0/1	0/1	1/1	0/1	1/1
Total score	17/23	17/23	19/23	16/23	19/23	16/23	14/23	13/23
Total percent	74%	74%	83%	70%	83%	70%	65%	57%
Quality score	High	High	High	High	High	High	Medium	Low
Included in review	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No

Key: Study design type: A = Cohort study; B = Cross-sectional case-control study. Quality scores: $\geq 70\%$ = high, $\geq 60\%$ and $\leq 69\%$ = medium, $\leq 59\%$ = low

2.2.3.4. *Sample populations*

Table 2-4 summarises the concepts explored and the participant characteristics for each study. Of the seven studies included in the systematic review, sample sizes ranged from 6 to 51 with a total of 387 participants. Participants were ≥ 18 years of age with a mean age of 44.2 years. All studies involved male and female participants. Four of the studies took place in Australia (Moseley 2008a; Wand et al. 2010b; Stanton et al. 2013; Wand et al. 2014b), one in Switzerland (Luomajoki and Moseley 2011) and the final two were not stated. However, one entire research team was located in Japan (Nishigami et al. 2015) and it was verbally confirmed that this study took place in Japan. Ethical approval for the final study by Bray and Moseley (2011) was granted by a London Hospital so it may have taken place in the United Kingdom, although this is unconfirmed. Studies recruited participants from orthopaedic clinics, private physiotherapy clinics, hospitals and universities. Some studies used data collected from participants taking part in other studies. Wand et al. (2014b) used data collected from the pain groups in the studies from Wand et al. (2012) and from Wand et al. (2013). Stanton et al. (2013) used data from the pain and control groups from the study by Bray and Moseley (2011). Comparing data collected from multiple locations, by different researchers and over different time periods is likely to introduce sampling errors because the samples being compared are not from the same populations.

2.2.3.5. Assessment techniques

All seven studies assessed their CLBP and control groups for differences in at least one of the three key concepts. One study only assessed two-point discrimination threshold (Wand et al. 2010b), two only assessed body schema (Bray and Moseley 2011; Wand et al. 2014b) and three assessed two-point discrimination threshold and body schema (Moseley 2008a; Stanton et al. 2013; Nishigami et al. 2015). Only one study assessed lumbopelvic motor function in conjunction with one of the other concepts, TPDT (Luomajoki and Moseley 2011). Importantly, none explored all three of the key concepts. These findings are summarised in Table 2-3.

Table 2-3: Table to show which of the systematic review articles assessed which key concept in their CLBP and control group participants

	TPDT	Body Schema	Motor Function
Moseley (2008)	✓	✓	✗
Nishigami et al (2015)	✓	✓	✗
Wand et al (2010)	✓	✗	✗
Bray & Moseley (2011)	✗	✓	✗
Stanton et al (2013)	✓	✓	✗
Luomajoki & Moseley (2011)	✓	✗	✓
Wand et al (2014)	✗	✓	✗

TPDT: Two-point discrimination threshold, ✓ indicates the concept was investigated and reported by the authors, ✗ indicates the concept was not investigated.

2.2.3.6. *Study outcomes*

The results of the final seven articles which met the inclusion criteria, met quality threshold and were included in the systematic review, are presented in Table 2-4 and Table 2-5. Participant characteristics varied between studies (Table 2-4). All studies included male and female participants but the proportions of each varied across studies with female participants establishing between 41% to 73% of the study samples. Mean ages were similar for six of the seven studies, ranging from 41 (SD 13) to 45 (SD 14) years in the pain group, and 34 (SD 12) to 43 (SD 7) years in the control groups. Older participants took part in the seventh study, that of Nishigami et al. (2015), where the pain group's mean age was 61 (SD 13) years and the control group mean was 63 (SD 12) years.

Back pain intensity of the pain groups were measured using tools with different scales of measurement (0-10 and 100mm) but they are comparable (Hjermstad et al. 2011). When converted to the same scales of 0-10, where 0 (no pain) was anchored on the left, the mean current pain intensity ranged from 3.2 (SD 2.2) to 4.8 (SD 1.8). Five studies reported current pain intensities and one reported pain over the past 48 hours. The average pain scores for all CLBP participants was approximately 4.1 (SD 2.0) on a scale of 0-10. The duration of CLBP experienced by participants ranged from less than 2.5 years to almost 10 years. From the six articles reporting pain scores and duration, the average duration of CLBP was 77 months or just over six years and the average standard deviation (calculated by the square root of the sum of the variances) was 94 months or almost eight years. These figures show a widespread distribution in the pain duration data.

Table 2-4: Study characteristics of the seven included studies

	Authors	Variables assessed			Study Type	CLBP participants					Control participants		
		TPDT	Body Schema	Lumbar motor function		N (Female)	Age in years Mean (SD)	Pain tool	Pain intensity* Mean (SD)	Pain duration, months Mean (SD)	Control type	Sample size (Female)	Age years (Mean [SD])
1	Moseley (2008b)	✓	✓	x	CO	6 (3)	44 (11)	VAS 100mm	47.2 (12.5)	52.2 (36.1)	Upper limb pain only	10 (5)	42 (11)
2	Wand et al. (2010b)	✓	x	x	CS	19 (11)	41 (13)	NRS 0-10	3.2 (3.0)	111.6 (117.6)	No back pain in last 5 years	19 (14)	34 (12)
3	Bray and Moseley (2011)	x	✓	x	CS	21 (15)	44 (13)	VAS 100mm	37.0 (21.0)	28.2 (68.4)	No back pain in last 1 year	14 (9)	43 (7)
4	Luomajoki and Moseley (2011)	✓	x	✓	CO	45 (25)	43 (15)	NR	NR	>3 months	No back pain in last 2 years	45 (25)	41 (10)
5	Stanton et al. (2013)*	✓	✓	x	CS	17 (14)	45 (14)	VAS 0-10	3.4 (2.2) ^ω	110.0 (134.0)	Healthy pain free controls	18 (11)	41 (11)
6	Wand et al. (2014b)	x	✓	x	QST	51 (21)	42 (14)	VAS 100mm	48.2 (17.8)	98.4 (124.8)	Healthy pain free controls	51 (20)	39 (13)
7	Nishigami et al. (2015)	✓	✓	x	CO	42 (26)	61 (13)	VAS 100mm	44.2 (23.2)	61.2 (13.4)	No back pain	17 (8)	63 (12)

Abbreviations: SD: Standard deviation from the mean, TPDT: Two-Point Discrimination Threshold, CLBP: chronic low back pain, N: number of participants, CO: Cohort study, CS: Cross Sectional case control, QST: Questionnaire reliability testing study, VAS 100mm: 100mm visual analogue scale anchored with 0 on the left; NRS 0-10: Numerical rating scale 0-10 with 0 on the left, VAS 0-10: 0-10 Visual analogue scale with 0 on the left, ^ω Pain over last 48 hours, * Used data from the pain group in Bray & Moseley (2011) study. NR: data not reported, * Current pain intensity unless specified.

Table 2-5: Systematic Review Results

		Moseley (2008)	Wand et al (2010)	Bray & Moseley (2011)	Luomajoki & Moseley (2011)	Stanton et al (2013)	Nishigami et al (2015)	Wand et al (2014)
	Pain Group (n)	6	19	21	45	17**	42	51
	Control Group (n)	10	19	14	45	20	17	51
TPDT (see below for key)								
	Measure	A	B	-	C	C	D	-
	Pain Group	76.8 (11.6) mm ^{§¥}	62.0 (21.6) mm [¥]	-	60 (13) mm [¥]	59.8 (11.7) mm [¥]	Mean side-to-side differences, mm (% differences >13mm): 'Normal' 5 ± 6mm (6%) 'Expand' 13 ± 7mm (50%) 'Shrunk' 9 ± 7mm (25%)	-
	Control Group	50.1 (6.3) mm ^{§¥}	44.0 (13.7) mm [¥]	-	44 (10) mm [¥]	45.3 (5.1) mm [¥]	Mean side-to-side differences, mm (% differences >13mm): 'Normal' 5 ± 6mm (6%)	-
	P value (if ≤ 0.05)	-	≤0.5 ^a	-	p = 0.03 ^b	-	p = 0.0006 ^c	-

	Table 2-5 continued	Moseley (2008)	Wand et al (2010)	Bray & Moseley (2011)	Luomajoki & Moseley (2011)	Stanton et al (2013)	Nishigami et al (2015)	Wand et al (2014)
BODY SCHEMA (see below for key)								
	Measure	Standing participant drew outline of their back as it felt to them	-	Left/Right Discrimination tasks of back/torso images (NOI Recognise®)	-	Left/Right Discrimination tasks of back/torso images (NOI Recognise®)	Seated participant drew outline of their back as it felt to them	Fremantle Back Awareness questionnaire (FRE-BAQ)
	Pain Group	5 of 6 drew shrunken outlines which coincided with painful region	-	<u>Response time</u> = 2.4 (2.2-2.6) secs <u>Accuracy</u> Bilateral pain group = 53.4% Unilateral pain group = 67.2%	-	<u>% Accuracy</u> - Achieving correct left/right judgements = 61.4 (17.6)‡	Outlines drawn; 'Normal' n=18 'Expanded' n=12 'Shrunken' n=12	11 (0-26) ^ω
	Control Group	Normal outline drawn	-	<u>Response time</u> = 2.4 (2.2-2.5) secs <u>Accuracy</u> = 87%	-	<u>% Accuracy</u> - Achieving correct left/right judgements = 80.5 (8.7)‡	Normal outline drawn by all 17 participants	0 (0-6) ^ω
	P value (if ≤ 0.05)	-	-	Bilateral pain group was less accurate than unilateral pain group, which was less accurate than the control group p = 0.001 ^d	-	-	-	p <0.001 ^e
MOTOR FUNCTION (see below for key)								
	Measure	-	-	-	E	-	-	-
	Pain Group	-	-	-	3 (1.1)‡	-	-	-
	Control Group	-	-	-	1 (1.3)‡	-	-	-
	P value (if ≤ 0.05)	-	-	-	p <0.001 ^f	-	-	-

KEY to Table 2-5:

A: Used Moberg's (1990) technique and calculated the mean of 48 left side and 48 right side of the spine measures (3 per side at 16 levels between T4 to the gluteal folds).

B: Adapted Moberg's (1990) and Seltzer and Seltzer (1986) techniques. Calipers were held parallel to spine and transverse process of the third lumbar vertebra (L3) maintained in centre of calipers. Testing then continued around these initial values using ascending and descending sequences until a consistent response was obtained.

C: Used Moberg's (1990) technique to assess TPDT and calculated the mean of 2 x vertical (calipers parallel to spine) and 2 x horizontal (calipers perpendicular to the spine) measurements of TPDT in each participant. Measurements were taken between the first lumbar vertebrae (L1) and the iliac crest (level with L4) on the left and right sides of the spine.

D: Used Moberg's (1990), calipers positioned perpendicular to spine, TPDT measured twice either side of the spine at the level of most pain (pain group) and at L3 in control group. To obtain one side-to-side value of TPDT per participant, the mean was calculated for the left side of the spine, and again for the right side. The lower value was subtracted from the higher side result in the healthy control group but a different approach occurred in the pain group. The value from the side reported to be least painful was subtracted from the side reported to be most painful to provide a side-to-side TPDT value for each pain group participant. Results: The pain group were sub-grouped according to their self-drawn low back outlines. Subgroups were 'Normal' (normal outline drawn), 'Expanded' (larger than normal outline drawn) and 'Shrunken' (smaller than normal outline drawn). TPDT was reported as the percentage of participants in each sub-group with >13mm side-to-side difference which was reported to equate to a 95% confidence that a difference between sides truly existed (Wand et al. 2014a).

E: Luomajoki's battery of tests involved six validated tests to identify impaired lumbopelvic movement in those with low back pain. Participants performance in each test was assessed according to example images (Appendix 9.4.4) and scored zero points if achieved correctly or 1 point if not achieved, with a maximum score of six points indicating greater impaired movement than lower scores (Luomajoki and Moseley 2011).

§Raw data taken from Catley et al. (2014b), **data for CLBP group taken from subgroup of Bray and Moseley (2011), *Mean (Standard Deviation from the mean), ω Median (range).

^a Two sample t-test, ^b Multivariate Analysis of variance, ^c Chi Squared test, ^d Two-way random effects intraclass correlation coefficients, ^e Mann-Whitney U test, ^f T-Test for independent samples.

- indicated the data was not reported

Table 2-5 shows the results of the systematic review and highlights the areas researched by each study and the areas where investigations were absent.

Five studies assessed TPDT on the low back but none used the same method of assessment. Differences were also identified in calculating and presenting the results. Statistical analysis identified significant differences, where $p \leq 0.05$, between the mean TPDT scores of the pain and control groups of Wand et al. (2010b), Luomajoki and Moseley (2011) and Nishigami et al. (2015).

Five studies measured body schema using three different methods. The methods are discussed in sections 2.2.4.1 and 2.2.4.2. Each study reported differences between the CLBP and control group results, with measurements of body schema in the CLBP groups appearing impaired when compared with the control groups. The studies with techniques that allowed for statistical analysis reported the results to be significant where $p \leq 0.05$ (Bray and Moseley 2011; Wand et al. 2014b).

Moseley (2008a), Stanton et al. (2013) and Nishigami et al. (2015) assessed low back TPDT alongside aspects of body schema. While the techniques and results varied, a negative relationship existed between TPDT and body schema in those with CLBP where TPDT increased and tactile acuity was impaired, accuracy in measures of body schema also become impaired. Stanton et al. (2013) noted this directional relationship to exist in both their groups but they noted the relationship between TPDT and body schema to be almost four-times stronger in their pain group than in their control group.

Nishigami et al. (2015) sub-grouped their CLBP participants in relation to how they perceived the shape of their own back. They identified three clear sub-groups who reported either a normal, an enlarged or a shrunken back outline. Fifty percent of the 'enlarged' sub-group and 25% of the 'shrunken' group also exhibited significantly different side-to-side low back TPDT scores.

Only one study assessed motor function in conjunction with TPDT. Luomajoki and Moseley (2011) identified a relationship between impaired TPDT and impaired lumbopelvic motor function exercises, where TPDT acuity worsened and motor function performance decreased.

No studies explored motor function and body schema, or all three key concepts. The differences in methods of data collection meant further data analysis could not be carried out. As such, a narrative discussion of the systematic review results is presented.

2.2.4. Discussion

This systematic review is unique in that it identifies and appraises medium and high quality evidence relating to assessments of two-point discrimination threshold, body schema and lumbar motor function in adults with CLBP and a control group.

2.2.4.1. Methodological analysis

Quality Assessment

The completion of quality assessment checklists highlighted some common themes between studies. All seven studies were observational by design and exceeded the quality threshold necessary for inclusion within the review. Despite its age, the Downs and Black (1998) assessment tool for observational studies remains the standard used by many published studies when assessing quality of observational studies in systematic reviews (Adamczyk et al. 2017b; Gandara-Sambade et al. 2017; Machado and Pinheiro 2017; Tong et al. 2017; van der Scheer et al. 2017) and it was therefore considered to be appropriate when assessing quality in this study. The Downs and Black (1998) instrument allows for the assessment of quality for reporting, external validity, internal validity (split into bias and confounding factors) and power. Scoring was similar and consistent across all seven articles with each article sharing similar areas of strength and weakness.

Very high levels of reporting quality were identified among all seven articles which provided greater confidence in the understanding of how studies were completed, particularly with the aim of reducing selection bias. Most studies recruited convenience samples from local hospital or physiotherapy clinics and their researchers academic or working environments. This may have limited the heterogeneous characteristics of participants to include only health-seeking and working individuals. The increased participant ages within the Nishigami et al. (2015) study implied a higher proportion of retired participants, perhaps with greater health-seeking characteristics due to increased age-related conditions. This may have increased the differences in group characteristics, returned different results for different studies and reduced the ability to directly compare the results.

Internal validity provides a measure of how strong the inferences from the studies can be considered. The two categories of internal validity scores; bias and confounding factors, revealed differences with confounding factors receiving the lowest scores. Lower scores indicate a greater risk that the differences observed between the two groups might be caused by systematic error, rather than true between group differences (Carlson and

Morrison 2009). The seven studies were undertaken in different countries so the introduction of bias through unreported cultural and economic factors may have been possible. Efforts were taken to reduce systematic bias but few confounding factors were reported across all articles. The resulting internal validity scores were moderate and consistent across all studies, meaning the study outcomes could be considered equally reliable.

Some areas consistently scored poorly across most studies. Only one study reported their study to be appropriately powered (Wand et al. 2014b) but actual power calculations were not reported in any of the studies and therefore the results need to be interpreted with caution (Button et al. 2013).

External validity scores were moderate but the observational nature of all seven studies limited the generalisability of the results to a wider population. However, these studies were designed to explore health characteristics in people and observational studies are often the most appropriate for this task. While randomised controlled trials are considered more robust and provide a higher quality of generalisable knowledge, they are only appropriate if the theory being explored is based upon firm findings. Such findings often originate from exploratory observational studies and the findings from these seven studies are important as they have begun building a foundation of knowledge about sensory and motor impairment in those with CLBP.

Tools and Techniques - Two-Point Discrimination Threshold

All articles assessing TPDT reported using Moberg's (1990) technique but methodological error is likely to have been introduced unless the method was adapted when assessing TPDT on the back. Such measures may have been taken but they are not reported in the journal articles. The predominant issues were that Moberg's (1990) technique was designed and reported for use on the hands, using calipers to measure small TPDT (<10mm) on an easy to stabilise region of the body. Transferring this technique directly to the back without considering technique adaptations could introduce measurement error. These issues are discussed in detail in the methodology chapter (Chapter Three) and reliability study chapter (Chapter Four).

TPDT was assessed in different places on the low back, either over or laterally to; the vertebral spinal processes of the third lumbar vertebra (Wand et al. 2010b); the most painful lumbar vertebral level (Nishigami et al. 2015); 16 levels from the fourth thoracic

vertebra to the gluteal folds (Moseley 2008a); or bilaterally between the first lumbar vertebra and the iliac crests (Luomajoki and Moseley 2011).

As TPDT relies upon the integrity of the relationship between specific cortical regions and the areas of skin associated with these cortical regions, changes to the functional representation of the specific skin areas within the S1 are likely to alter the perception of discriminatory touch on the skin. As such, assessing TPDT in different locations on the back and comparing them might not be considered best practise yet each study independently formed similar conclusions. When the results of these studies were considered together, themes emerged to suggest that TPDT is impaired in those with CLBP when compared with a pain-free or healthy control group.

It was not always clear whether the tools used were constructed of plastic or metal. Metal calipers would have greater thermal conductivity than plastic calipers, which is why metals feel colder than plastics even when they are at room temperature. As such, metal tools would have felt colder to participants, thus activating different neurophysiological pathways and may have measured participants sensitivity to temperature, in addition to tactile sensitivity. Measures could have been taken to minimise methodological bias from such measurement errors by using plastic calipers. If measures were taken, they were not reported and so comparing results between studies may not be a fair comparison because we cannot be certain that the same processes were assessed in each study.

Tools and Techniques – Body Schema

Body schema was measured differently in each of the five studies that reported it. Two pairs of studies, Moseley (2008a) and Nishigami et al. (2015); Stanton et al. (2013) and Bray and Moseley (2011), reported using the same techniques. However, on investigation, each pair adapted the technique within their own study or reported results from a different perspective; meaning they were not directly comparable.

Two studies adopted a technique of asking participants to draw an outline of their back (Moseley 2008a; Nishigami et al. 2015). This technique was originally developed by Gandevia and Phegan (1999) as a method for assessing whether the perceived size of a body part (lips or hands) changes when its sensory input changed. In Moseley's study (2008a) participants were provided with specific instructions and required to draw their back outlines while standing. Although participants in the study of Nishigami et al (2015) were provided with exactly the same written task instructions, they were seated while drawing. This may have been done to ensure safety or comfort for Nishigami et al's

(2015) older group of participants but being seated would have altered joint position sense, skin stretch receptor positions, weight bearing and postural receptors in comparison to Moseley's (2008a) standing participants (Haggard et al. 2003; Mildren et al. 2017). The relationship between cortical function and physical movement is complex, but different movements of the body correspond with the activation of different regions of the motor cortex (Graziano et al. 2002; Graziano and Aflalo 2007; Parkinson et al. 2010; Graziano 2016). Standing and sitting postures engage different patterns of motor function so different parts of the cortex were probably activated in the standing group of Moseley (2008a) and the seated participants of (Nishigami et al. 2015). This difference may have influenced their findings and limit the validity of any direct comparisons made between these two studies.

Two studies (Bray and Moseley 2011; Stanton et al. 2013) used a commercially available tool called Recognise® Backs (Neuro Orthopaedic Institute 2016) to measure left/right discrimination tasks. Participants were asked to identify images as being either the left or right side low back or torso from a bank of randomly presented images and the average time to answer and the number of correct answers were recorded. Stanton et al. (2013) used the data from the control group and a sub-set of pain group participants (n=17) from the 21 CLBP participants in Bray and Moseley's (2011) study. Both teams interrogated the results from different viewpoints which resulted in different perspectives of body schema being published from the same dataset.

In exploratory studies which aim to identify whether specific characteristics exist in a sample population, exploring multiple concepts within the same dataset is common, but issues can arise from this practice and there are arguments that these risks need to be accounted for in the analysis and reporting (these arguments are discussed in detail in Chapter Three, section 3.9.5.5). Performing multiple analysis on datasets increases the risk of identifying statistically significant findings when none exist (called type I errors or false positives). Even if statistical significance was set to $p \leq 0.05$, approximately one in twenty tests were likely to return significant results when no such significance truly existed. The application of Bonferroni calculations helps reduce the risk of type I errors, but they do not appear to have been reported in these studies, so the results should be interpreted with caution.

Only one study used the Freemantle Back Awareness Questionnaire (FreBAQ); a validated, self-report questionnaire to assess participants level of agreement or disagreement towards statements regarding back perception (Wand et al. 2014b). As such, these results could not be compared with any other perception scores within this

systematic review but the results did contribute to the theme that body schema might be impaired in those with CLBP.

Body schema relates to how a person perceives their body and as such it is a complex and subjective entity. Perception relies upon multiple, ever-changing cortical maps, including those of motor, visual and tactile origin. As such it could be argued that many research methods assess aspects of body schema but knowing exactly what each method is measuring is impossible to know. The techniques used by Bray and Moseley (2011), Stanton et al. (2013) and Wand et al. (2014b) asked participants about their feelings, perception, memory and learnt knowledge of their own and other peoples' bodies (in the left/right discrimination task). While it is unlikely that each method measured the same components of body schema, they all likely measured some element of the construct and the results discussed in the sensory and motor outcomes section (section 2.2.4.2 of this chapter) contribute to understanding whether body schema is altered in those with CLBP.

Tools and Techniques – Motor Function

Luomajoki and Moseley (2011) identified ten established lumbopelvic orthopaedic tests and through validation studies identified six that would provide a quantitative measure of lumbopelvic motor function for adults with CLBP. Higher scores indicate greater motor function impairment. This method was used by the only study found to investigate low back motor function alongside measurements of TPDT (Luomajoki and Moseley 2011). As such, comparing motor function techniques was not possible.

2.2.4.2. Sensory and motor outcomes

Sensory and Motor Outcomes - Two-Point Discrimination Threshold

Five of the seven studies assessed TPDT but further data analysis or direct comparisons between the results were not possible because each study used different measurement techniques, assessment locations, methods of calculation and/or reporting values. However, of the three concepts investigated by this systematic review, the results regarding TPDT provide the strongest evidence. TPDT was consistently impaired on the low backs of those with CLBP. This meant that the two points were wider apart before participants could correctly identify two points of contact rather than one. Moseley (2008a) and Wand et al. (2010b) reported different TPDT alongside almost identical low back tactile threshold measurements from their pain and control groups.

Tactile threshold and TPDT are thought to share many of the same neurophysiological structures and pathways (Abraira and Ginty 2013), so if damage were to occur to these structures, it could be expected that both tactile threshold and TPDT would be altered. However, that was not the case. In the absence of altered tactile threshold, the CLBP groups TPDT impairments reported by Moseley (2008a) and Wand et al. (2010b) were unlikely to have occurred due to damaged structures or pathways or from an information transmission issue because the rate of transmission from the cutaneous stimuli to the cortex is not diminished in people with CLBP (Flor et al. 1997). As such, the differences were probably the result of other processes. One process that may have returned differing measures of tactile threshold and TPDT was that of cortical reorganisation of the primary somatosensory cortex (S1) in chronic pain conditions. For a brief review of tactile threshold and TPDT in relation to cortical reorganisation, see section 2.1.1.5.

Cortical reorganisation occurs in those with chronic pain conditions and tactile acuity is considered a clinical signature of cortical reorganisation (Pleger et al. 2001; Haggard et al. 2003; Pleger et al. 2003; Pleger et al. 2005; Pleger et al. 2006; Moseley and Flor 2012b). TPDT is the recognised, reliable method of assessing cortical reorganisation in musculoskeletal medicine (Moseley and Flor 2012b; Catley et al. 2013b). In CLBP, cortical reorganisation is known to alter by a medial shift and the enlargement of the somatotopic representation of the back in the S1 (Flor et al. 1997). It is possible that the TPDT impairments reported in the CLBP groups of Moseley (2008a) and Wand et al. (2010b) were associated with S1 cortical reorganisation but without functional imaging to verify the proposal, the suggestion remains hypothetical.

Sensory and Motor Outcomes - Body Schema

The results from the two studies that assessed back perception through participants' drawings reported their results from slightly different perspectives so direct comparison of the results was not possible. Moseley's (2008a) work revealed five out of the six standing participants perceived the outline of their backs to feel shrunken. The distorted part of their drawings corresponded with the level, side and region of their typical back pain, and with the area of greatest TPDT impairment and may be an indication of altered body schema.

Nishigami et al's (2015) participants sat while drawing and the results were reported as the percentage of participants in each group (or sub-group) where a significant side-to-side difference in TPDT was recorded (Wand et al. 2014a). In both studies, neither age, gender, pain intensity or duration, disability nor pain catastrophising correlated with

altered body schema. However, from the study of Nishigami et al. (2015), three sub-groups emerged from the CLBP group who drew either an enlarged, shrunken or normal outline. Those that reported an enlarged or shrunken back outline also displayed greater differences in low back TPDT. Nishigami et al's (2015) study revealed further evidence in support that altered sensory impairments corresponded with the area of low back pain and with impaired TPDT.

Furthermore, although Stanton et al. (2017) was excluded from the systematic review due to a low scores for quality regarding selection bias and external validity, it is of interest that they used the same method and reported similar findings to those of Moseley (2008a) and Nishigami et al (2015). Stanton et al. (2017) reported statistically significant differences between the back drawings produced by their pain and control groups with the CLBP group producing more incorrect or incomplete drawings than the control group. On average, the participants of Stanton et al. (2017) were much younger (most were less than 30 years of age), their pain was typically less intense but had occurred for a longer duration. This is of interest because while participants appeared demographically different between the three studies, their perceptual awareness regarding the shape of their painful backs was altered. This suggests that some of the processes involved in accurate performance of a task determining the proprioceptive properties of the back are impaired in those with CLBP.

The findings from Moseley (2008a) and Nishigami et al (2015) revealed a pattern of sensory disturbances that occur within the region of back pain in groups of participants with CLBP. These findings were similar in characteristic to specific sub-groups which have been identified in CRPS, where the link to cortical reorganisation is widely acknowledged (Lewis et al. 2007; Peltz et al. 2011). Therefore, it may be that cortical changes relating to proprioception of the back could be occurring. The small participant groups and sub-groups of Moseley (2008a) and Nishigami et al (2015) mean that the findings should be treated with caution, but when considered with the findings of Stanton et al. (2017), proprioception of the painful back appears altered in those with CLBP and it might be suggested that themes of wider proprioceptive anomalies (altered TPDT and body schema) appear to be emerging in these CLBP studies. These themes warrant further investigation because in healthy-pain free adults, little side-to-side difference in TPDT occurs so in the presence of a difference between each side in those with CLBP may indicate the occurrence of altered body schema (Wand et al. 2014a).

In the two studies that used left/right discrimination tasks as a measure of working body schema (Bray and Moseley 2011; Stanton et al. 2013), both found their pain groups

performed differently to their control groups. Stanton et al's (2013) back pain and control groups comprised a sub-group of Bray and Moseley's (2011) data, although researchers analysed their data from different points of interest. Bray and Moseley (2011) created sub-groups within their pain group according to whether participants reported their pain to be bilateral or unilateral; effectively creating one control group and two pain sub-groups.

Bray and Moseley's (2011) pain group were found to display significant impairments in accuracy (the percentage of images correctly identified), but not in the length of time it took to select the correct answer. In fact, those who reported bilateral CLBP experienced greater body schema impairments than those with one sided, or unilateral, CLBP. Those with unilateral CLBP demonstrated greater impairments than the pain-free control group. In Bray and Moseley's (2011) study, the extent of body schema impairment was altered in relation to the painful region and with the magnitude of CLBP but impairments were absent in the pain-free control group. These findings, which resembled findings from CRPS and PLP studies, may indicate that body schema changes because of altered sensory input from the painful region.

Stanton et al's (2013) results for left/right discrimination accuracy were similar, as might be expected from using sub-groups of Bray and Moseley's (2011) pain and control group participants. Stanton et al (2013) did not sub-group their data prior to analysis and comparisons of the pain groups left/right discrimination results to those from the control group found significant differences in accuracy, with the pain group performing more poorly. Time differences between the two groups were not reported, but Stanton's team (2013) identified a negative relationship between accuracy of left/right tasks and TPDT in their CLBP group and their control group. As accuracy in choosing the correct images declined, TPDT became greater, thus more impaired. Although the relationship occurred in both groups, the effect was almost four times greater in the pain group. Generalising results from one small study is unwise but this study concluded that a relationship existed between TPDT and body schema (measured as left/right discrimination tasks) and this relationship appeared to be exaggerated in those with CLBP.

One study assessed body schema through a simple validated questionnaire (Wand et al. 2014b). It is likely that the Freemantle Back Awareness Questionnaire (FreBAQ) measured different aspects of body schema to those assessed by Moseley (2008a) and Nishigami et al. (2015) because it asked participants how strongly they felt towards a set of statements regarding their low back. The processes that participants undertook included being asked how much they agreed or disagreed with statements such as 'my back feels like it is enlarged (swollen)' or 'I need to focus all my attention on my back to

make it move the way I want it to'. The processes participants undertook to arrive at their answers was unclear but clear differences in the responses from those with and without CLBP were identified. The CLBP group agreed with more statements regarding their back feeling distorted, disrupted or altered.

Despite differences in the methods and results reported to measure body schema, when taken together, conclusions can be drawn that body schema may be altered in those with CLBP when compared with a control group.

Only one study in this systematic review reported body schema changes in relation to altered back TPDT (Stanton et al. 2013). Body schema function is dependent upon ongoing input from many cortical body maps, including those holding motor, tactile and visual information and it is reported to be altered in many chronic pain conditions (Lotze and Moseley 2007). The S1 structure and function, which is integral to sensory perception, is also altered in those with chronic pain (Flor et al. 1997; Flor 2003). TPDT is considered a clinical signature of the S1 and it too is impaired in chronic pain conditions (Pleger et al. 2001; Haggard et al. 2003; Pleger et al. 2003; Pleger et al. 2005; Pleger et al. 2006; Moseley and Flor 2012b). Taken together, it is likely that changes to the S1 and TPDT changes reported in those with chronic pain could alter the perceptual information involved in at least some of the cortical tactile maps integrated into body schema. As such, while the altered body schema seen in these studies could be related to some of the many complex processes taking place within those with chronic pain, the relationship between altered TPDT and body schema suggests that TPDT may be of particular importance.

In healthy young adults, a relationship has been identified between individuals ability to accurately perform implicit motor imagery tasks (identifying images of hands as either the left or right) which required mental representation of the image and their ability to make directional 'in-flight' corrections to their own limb during a task which required reaching and touching targets (Hyde et al. 2013). Those with faster and more accurate motor imagery ability were able to make faster corrections to their own moving limb. This may indicate a link between the body schema processes that are thought to be involved in accurately performing implicit motor imagery tasks and actual explicit motor function. The relationship between body schema and motor function of the low back in those with CLBP is currently unknown but as TPDT, body schema and motor function are altered in this group and body schema appears linked to motor function in healthy adults, it warrants investigation.

Sensory and Motor Outcomes - Motor Function

This systematic review highlighted that motor function is rarely explored in relation to sensory function in the same group of volunteers. Only one article was identified that investigated motor function alongside the sensory concept of TPDT and none were identified that explored lumbopelvic motor function, TPDT and body schema. Additionally, no studies that examined lumbopelvic motor function alongside body schema were found.

Luomajoki and Moseley (2011) identified a negative correlation between TPDT and impaired motor function of the lumbar spine during a battery of validated tests. As tactile discrimination became less sensitive (less accurate), motor function was more impaired.

People in pain move differently to those that are pain free (Hodges et al. 2013). They appear to move in a more considered way, perhaps avoiding movements they perceive will cause or increase their pain. Proprioceptive input from skin mechanoreceptors, muscle spindles and joint position sensors help maintain a stable body position but proprioceptive functionality is altered in those with low back pain (Brumagne 2000; Yazdani and Farahpour 2009; Janssens et al. 2014; Kiers et al. 2014). Impaired motor function is common in those with back pain (Karayannis et al. 2012; Hodges et al. 2013; Gildea et al. 2014) and reduced movement would reduce the proprioceptive input from mechanoreceptors in the joints, muscles and skin (Mildren et al. 2017). Given the close relationship, one might expect aspects of sensory and motor function to be altered in those with CLBP but whether the impaired TPDT reported by Luomajoki and Moseley (2011) was a result of motor function impairments or just a coexisting event is impossible to say, particularly from one study. These findings may be coincidental and the observational nature of this study certainly does not imply cause and effect but the link between such sensory changes and motor function are worthy of further investigation because their relationships are so entwined.

2.2.5. Conclusion

This systematic review contributes to the academic conversation regarding altered sensory and motor function in adults with chronic low back pain. It aimed to answer the question *'Is low back two-point discrimination threshold and body schema altered in adults with chronic low back pain when compared with a control group and do these alterations relate to impaired lumbar motor function?'*

The review identified six high quality and one medium quality study that explored TPDT, body schema and/or motor function in adults with CLBP and a control group. Themes emerged that provided evidence in varying degrees to support that low back two-point discrimination threshold and body schema was altered in those with CLBP. Only one study explored and identified a significant relationship between TPDT and lumbar motor function. It implied that as motor function worsened, TPDT became more greatly impaired. The systematic review revealed no articles that explored the association between body schema and lumbar motor function. Consequently, the existence of such a relationship remains unknown.

The key findings of this systematic review were that in those with CLBP;

1. TPDT was altered on the back (five studies but each used different methods).
2. TPDT was altered on the low back within the participant's region of low back pain (two studies).
3. TPDT negatively correlated with impaired lumbopelvic motor function (one study).
4. A negative relationship was identified between TPDT and body schema (one study).
5. Aspects of body schema were altered (five studies but none used the same methods or reporting techniques so may have measured or reported different aspects of body schema)
 - a. Three distinct sub-groups may exist where an enlarged, shrunken or normal back is perceived. The enlarged group may be related to impaired TPDT (one study).
 - b. Body schema impairment is greater in those with bilateral CLBP when compared with those with unilateral pain, and greater in those with unilateral pain when compared with the control group (one study).
6. The relationship between body schema and lumbopelvic motor function is unknown.
7. The relationship between TPDT, body schema and motor function (measured in the same sample) is unknown.

2.2.6. Limitations of the systematic review

One limitation was wide variability in the search terms relating to CLBP, TPDT and body schema used within the published literature. Despite a thorough search to determine the various terms, it is likely that further unknown derivatives of each term may be in use their omission from the search strategy excluded the identification of possibly relevant articles. Additionally, if this study's search strategy terms were considered to be secondary outcomes in other studies, the other studies authors may not have included our search terms as their searchable keywords. Again, these articles not have been identified by this study's search strategy and omitted from the systematic review.

This systematic review was planned and the search strategies first run in 2014. Since then, many more articles related to CLBP in this discipline have been published. This was expected because the discipline is relatively new in respect of CLBP so repeated searches were undertaken with the most recent being in May 2018. The number of returned articles had risen dramatically during this period. Between 2015 to May 2018, a further 12 articles were published and identified for review but all were excluded because they did not meet the systematic review inclusion criteria or the minimum quality score (see Appendix 9.2.10 for details). Consequently, the number meeting the inclusion criteria remained at seven. Thus, the number of articles included in the review remained small, revealing that few studies explored each concept of tactile acuity, body schema and motor function and critically, none explored all three.

Only one study reported how they sufficiently powered their study (Wand et al. 2014b) although it is possible that power was considered by the other six studies yet it was not reported. However, small numbers of participants were included in some of the studies and in two studies, participants were divided into sub-groups (Bray and Moseley 2011; Nishigami et al. 2015); further increasing the impact of the studies being insufficiently powered. It should also be noted that the control groups were not always recruited from the same populations, locations or at the same time as the pain groups (Stanton et al. 2013; Wand et al. 2014b). This may have introduced bias, perhaps due to sampling, population or even cultural differences between the comparative groups.

Different methods of data collection, analysis and reporting were used across all studies, even in those that reported using the same techniques and this made direct comparisons of the results difficult. These issues are discussed in the methodology and reliability study chapters within this thesis.

The methodological quality of each study varied. However, there were similarities in the scoring. All studies received low scores regarding aspects of internal validity (confounding

factors), which indicated that the risk of selection bias was increased. However, most studies recruited through convenience samples which meant that providing volunteers met the inclusion criteria, researchers could not control which volunteers became participants and joined the study so the risk of selection bias was reduced.

Most CLBP participants were recruited as convenience samples from orthopaedic or physiotherapy clinical lists where they were seeking treatment for their back pain. It was unclear at what stage of treatment they were at when recruited and whether the researcher felt this may have influenced their study outcomes. Recruiting from clinical lists would have narrowed the characteristics of participants by excluding CLBP adults who did not seek treatment and it is possible that non-health seekers may have responded differently to those who sought healthcare.

Despite the limitations of this review, the findings led the researcher to the conclusion that further research in this area was required to corroborate these preliminary findings but that this work must be adequately powered and compare measures of sensory and motor function obtained from CLBP and control groups recruited from the same population.

2.3. Justification of the Research Questions

In some chronic pain conditions the reversal of S1 cortical reorganisation is associated with improvements in TPDT, pain intensity and disability (Pleger et al. 2005; Pleger et al. 2006). The reversal of TPDT and body schema impairments are associated with improved pain and disability (McCabe et al. 2003; Moseley et al. 2008c; Wand et al. 2011b). Additionally, specific skilled motor training in those with CLBP was found to be related to the restoration of motor cortical reorganisation (Tsao et al. 2010). Therefore, if impaired TPDT and body schema were better understood in relation to impaired lumbopelvic motor function, it may be possible to incorporate sensory therapeutic interventions or adapt existing interventions and improve CLBP outcomes. The first step was to gain better understanding of the impairments and relationships between TPDT, body schema and motor function in those with CLBP when compared with a control group from a similar population.

2.4. Research Aims, Objectives and Questions

2.4.1. Aims

The research aims evolved from the findings of the systematic review. As such, the primary research aim was to explore and understand measures of tactile threshold, two-point discrimination threshold (TPDT), body schema and low back motor function when assessed in adults with CLBP of sufficient magnitude to affect their activities of daily living (ADLs) and in a control group recruited from the same UK population. The intention was to clarify whether specific sensory impairments existed alongside altered motor function in those with CLBP and to increase the evidence relevant to the argument of targeting such impairments with sensorimotor therapeutic interventions. Prior to new sensorimotor interventions being considered, establishing strong evidence is critical to secure the necessary research investment.

A pragmatic approach ensured the tools were low-tech, simple to use, clinically relevant, accessible and inexpensive because conducting research which does not meet these criteria is a problem faced by clinicians in many disciplines. This is important because inaccessible research is likely to deter others from investigating the topic further (Sobell 2016).

2.4.2. Objectives

The main objectives of the research were to identify differences in tactile threshold, two-point discrimination threshold, body schema and low back motor function in adults with and without chronic low back pain of sufficient magnitude to affect their activities of daily living. To do this the following steps were necessary;

1. Collect quantitative sensory/motor data from a group of adults with chronic low back pain (of sufficient magnitude to affect their activities of daily living) and a control group.
2. Identify if differences exist in TPDT, body schema and low back motor function between the CLBP and control groups and identify if relationships exist between TPDT, body schema and low back motor function.
3. Collect clinical data from a group of adults with chronic low back pain (of sufficient magnitude to affect their activities of daily living) and a control group. Identify if relationships exist between them and TPDT, body schema and low back motor function.

2.4.3. Research questions and hypotheses

The following research questions evolved from the research aims and objectives;

1. Is there a difference in tactile threshold, two-point discrimination threshold, body schema and low back motor function between adults with chronic low back pain and a control group?
2. Is there a correlation between low back two-point discrimination threshold, body schema and low back motor function in adults with chronic low back pain?
3. Is there a correlation between low back two-point discrimination threshold and clinical or psychosocial outcome measures in adults with chronic low back pain?
4. Is there a correlation between body schema and clinical or psychosocial outcome measures in adults with chronic low back pain?

The research questions were to be investigated by addressing the hypotheses presented in Table 2-6.

These questions and hypotheses were central in seeking to understand the interaction of tactile acuity, body schema and low back motor function in adults with chronic low back pain and impaired activities of daily living.

Table 2-6: Main Study Hypotheses

Question 1		Is there a difference in tactile threshold, two-point discrimination threshold, body schema and low back motor function between adults with chronic low back pain and a control group?
Null Hypotheses	1	There is no statistically significant difference in low back tactile threshold (g) between adults with chronic low back pain and a control group
	2	There is no statistically significant difference in low back two-point discrimination threshold (mm) between adults with chronic low back pain and a control group
	3	There is no statistically significant difference in body schema between adults with chronic low back pain and a control group
	4	There is no statistically significant difference in low back motor function between adults with chronic low back pain and a control group
Question 2		Is there a correlation between low back two-point discrimination threshold, body schema and low back motor function in adults with chronic low back pain?
Null Hypotheses	1	There is no correlation between low back two-point discrimination threshold and body schema in adults with chronic low back pain
	2	There is no correlation between low back two-point discrimination threshold and low back motor function in adults with chronic low back pain
	3	There is no correlation between body schema and low back motor function in adults with chronic low back pain
Question 3		Is there a correlation between low back two-point discrimination threshold and clinical or psychosocial outcome measures in adults with chronic low back pain?
Null Hypotheses	1	There is no correlation between low back two-point discrimination threshold and clinical or psychosocial outcomes in adults with chronic low back pain
Question 4		Is there a correlation between body schema and clinical or psychosocial outcome measures in adults with chronic low back pain?
Null Hypotheses	1	There is no correlation between body schema and clinical or psychosocial outcomes in adults with chronic low back pain

2.5. Clinical and Non-Clinical Implications for the Study

These study findings will extend the work in CLBP by Moseley (2008a), Nishigami et al. (2015) and Luomajoki and Moseley (2011) by applying the theory of the cortical body matrix and cortical re-organisation when assessing tactile acuity, body schema and motor function in a group of UK adults with mild to moderate CLBP and a control group. The findings will have significant implications for CLBP research which has not typically considered the condition from this perspective or in this CLBP sub-group. It will add to a growing body of CLBP evidence that increases the understanding of sensory impairment in adults with CLBP and how it might be associated with altered motor function. It is anticipated that a greater understanding of the pathological features relating to CLBP and how recently identified features might relate to more established CLBP characteristics will enhance the understanding of this multifaceted condition, ultimately aiding in its future clinical management.

Chapter 3. **METHODOLOGY AND RESEARCH DESIGN**

“Quantitative research should begin with an idea.” (Greenhalgh 2014)

3.1. Introduction

This chapter presents the methodology, strategy of inquiry and the research design used to explore tactile acuity, body schema and low back motor function in a group of adults with chronic low back pain (CLBP) and a control group recruited from a similar UK population. Due to the exploratory nature of this study, multiple methods of data collection were necessary. The methods included questionnaires, practical measures of tactile acuity, body schema and low back motor function. The justification and detail of these methods are discussed. This chapter presents the methods for collecting demographic, psychosocial and behavioural data and it also outlines ethical considerations and participant recruitment. Finally, the statistical approaches taken to analyse the results are presented.

3.2. Study Hypothesis

The systematic review reported in Chapter Two of this thesis revealed limited evidence relating to altered motor function in adults with CLBP but there was evidence relating to altered sensory function. The evidence suggested that TPDT and body schema was altered in those with CLBP, although the evidence for body schema was more limited.

Therefore, this study aimed to explore aspects of altered sensory and low back motor function in adults with CLBP and to compare the results to those from a control group without CLBP.

Identifying the relationships between TPDT, body schema and CLBP was a priority for this study but given the inextricable relationship between sensory and motor function, determining links to low back motor function was also deemed important. This was because it is suggested that impaired motor function corresponds with impaired sensory function. Therefore, future interventions involving one may also improve the other (Luomajoki and Moseley 2011).

The overarching study hypothesis was that performance in sensory and low back motor function tasks will be worse in adults with CLBP than in those without CLBP.

The research questions, derived from the systematic review in Chapter Two, were:

5. Is there a difference in tactile threshold, two-point discrimination threshold, body schema and low back motor function between adults with CLBP and a control group?
6. Is there a correlation between low back two-point discrimination, body schema and low back motor function in adults with CLBP?
7. Is there a correlation between low back two-point discrimination threshold and clinical or psychosocial outcome measures in adults with chronic low back pain?
8. Is there a correlation between body schema and clinical or psychosocial outcome measures in adults with chronic low back pain?

3.3. Strategy of Inquiry and Research Design

An observational, analytical, case-controlled, cross-sectional survey design was chosen as the type of study, or strategy of enquiry, most appropriate to this study (Grimes and Schulz 2002; Carlson and Morrison 2009; Creswell 2013). This was because the aim was to compare the prevalence of motor and sensory impairments between a group with CLBP and a control group.

Cross-sectional studies investigate outcomes and exposures at the same time. For example, in this study TPDT (the outcome) was measured on the lower back in those with and without CLBP (the exposure). As such, cross-sectional studies are appropriate in determining point-prevalence, or the proportion of a sample with a characteristic assessed at that point in time (Maihöfner et al. 2003; Shields and Twycross 2003). This study assessed the point-prevalence of specific characteristics in a chronic pain and a control group.

For this research study, participants were allocated into either the pain or control group according to their responses to questions regarding their low back pain and its impact upon their activities of daily living (ADL's). This criterion was important to include because those with CLBP that repeatedly seek medical treatment despite unsuccessful outcomes, are driven by difficulties in performing their activities of daily living (McPhillips-Tangum et

al. 1998). Improving outcomes for this group could reduce demands on healthcare systems, including the NHS.

There are several considerations that can demonstrate improved legitimacy or soundness of the methodological process, or enhance the rigor, of case-controlled studies (Creswell 2013). Blinding the assessor to the participants information and groupings, randomising the order different instruments and tests being performed can reduce the threat of introducing bias to the data.

It was considered that an independent assessor could be recruited to collect the data as the researcher had undertaken all pre-inclusion assessments for all participants but this was not possible due to the time, and financial limitations of this doctoral study. As a consequence, a method of pseudo-blinding was adopted where the researcher did not allocate participants to either group until the data was collected, anonymised and entered into SPSS. This reduced the risk of the researcher treating those with pain differently to those without, or unwittingly introducing biases based upon their questionnaires.

Randomising the performance of the tests was not undertaken in this study because the need was not identified until after the data collection had been performed. This failing and that of not being able to fully-blind the assessor to the participants is discussed in the study strengths and limitations which are presented towards the end of Chapter Six.

It was recognised that in not adopting a random sampling method, the ability to generalise the results to the wider population would be limited (Jupp 2006). Furthermore, both cross-sectional data and the lack of random sampling meant that even if correlations between the exposure (CLBP) and the key outcome measures (TPDT, body schema and low back motor function) were identified, it could not be claimed that one variable caused another (Carlson and Morrison 2009).

Demographic and socioeconomic data such as age, gender and employment status were also collected to ensure specific characteristics were represented equally within the groups but also to help in the explanation of the findings and emerging theory.

Table 3-1: An overview of the phases of the study

Phase	Research Activity	Summary
Phase 1	Systematic review	A systematic review of the literature was conducted to direct the research questions, research design and methods.
	Ethical approval	Ethical approval was obtained for all stages of the study
Phase 2	Reliability Study One	A Two-Point Discrimination Threshold (TPDT) tool reliability study was conducted to identify the most appropriate tool to measure TPDT on the fingertip and low back. The study is reported in Chapter Four.
Phase 3	Reliability Study Two	An inter-rater reliability study assessed rater agreement when visually assessing low back motor function tasks. This reliability study is reported in Chapter Four.
Phase 4	Main Study	62 participants (31 in each of the pain and control groups) completed questionnaires which provided demographic and clinical outcome data. They also took part in a clinical investigation into altered tactile discrimination of the finger-tip and low back, body schema and low back motor function

3.4. Questionnaire Outcome Measures

Participant demographic data were collected to set context and ensure the inclusion and exclusion criteria were met. Participants age, gender and the highest level of education data were used to ensure characteristics were similarly represented within the pain and control groups. Employment status and work-related absences added context, thus helping to describe the samples. The demographic questions formed part of the participant pack which can be seen in Appendix 9.3.1.

The data collection was framed within a biopsychosocial model and clinical, psychosocial and socioeconomic measurables were based upon the minimum standards of data collection recommended within CLBP research (Deyo et al. 1998; Bombardier 2000; Deyo et al. 2014).

Lengthy or complex questionnaires increase participant burden and drop-out rates, so one factor in the questionnaire selection was that they could be completed within 30 minutes (Matzat et al. 2009; Hoerger 2010). Questionnaire selection was also based on their appropriateness to answer the research questions, their ease of use and whether validation results had been published in at least one peer reviewed journal. Finally, questionnaires were required to capture the minimum data set recommended for CLBP research. This would enable better cross-study comparisons in the future (Deyo et al. 2014). Questionnaire quality was considered by reviewing published peer reviewed validity and reliability studies.

3.4.1. Psychosocial and behavioural data

The term 'psychosocial' refers to factors '*Of or relating to the interrelation of social factors and individual thought and behaviour*' (Oxford English Dictionary 2000) and is commonly used as an umbrella term to classify diverse health research inquiries (Martikainen et al. 2002).

Psychosocial factors are particularly relevant to pain research. For example, cognitive and emotional factors are strong pain modulators and depressed mood is associated with greater pain (Berna et al. 2010). Such factors, often clinically called 'yellow flags', are widely accepted to increase the risk of developing or prolonging chronic pain, long term disability and work absence resulting from low back pain (Kendall 1997).

For CLBP, stronger relationships exist between psychosocial/cognitive measures and pain and chronicity outcomes than between the same outcomes and anatomical or physiological issues (Airaksinen et al. 2006; Van Tulder et al. 2006). As psychosocial health is related to CLBP outcomes, it is plausible that psychosocial metrics might enhance the understanding of other aspects of CLBP, such as measures of sensory function. Therefore, questionnaires recording psychosocial measures were included in this study.

Within the context of this study, the term psychosocial relates to a range of the variables assessed using questionnaires. They included data collection relating to catastrophising and fear related behaviours (fear of injury), anxiety, depression and pain-related beliefs and attributions.

3.4.1.1. Pain intensity and duration

Participants were provided with 11 point Numerical Rating Scales (NRS-11) and asked to mark their 'typical' and 'current' low back pain score (Jensen and Karoly 1992; Farrar et al. 2001). The scale reports a unidimensional measure of pain intensity and takes less than a minute to complete. Scoring was straight-forward because the number the respondent selects on the scale relates to their pain intensity. Higher scores indicate pain of greater intensity. The left side of the scales were anchored at zero which represented 'No pain', and the right side was anchored at ten which represented the 'Worst pain imaginable' (Deyo et al. 2014).

The NRS-11 was chosen over a visual analogue scale (VAS) because despite their similarities, the NRS was easier to administer in writing and verbally, such as during a telephone call or during a face-to-face discussion (McCormack et al. 1988; Breivik et al. 2000; Breivik et al. 2008).

In the absence of a gold standard for measuring pain, criterion validity cannot be evaluated. However, construct validity was considered good with the NRS-11 shown to be highly correlated with the VAS in people with chronic pain (Pearson's Product Moment Correlation Coefficient, $r = 0.86$ to 0.95) (Ferraz et al. 1990). A two-point change represents clinically meaningful change in those with low back pain (Childs et al. 2005; Ostelo et al. 2008) and while the unidimensional nature of the NRS fails to capture information regarding the complex and personal nature of pain (Hawker et al. 2011), this shortcoming was not deemed important because of the exploratory nature of this study with the recompense being its simplicity in use and scoring.

The duration of low back pain was established to ensure participants were categorised correctly into the CLBP or control groups according to defined group characteristics. The pain group characteristics included pain location, duration and recurrence. Establishing the duration of low back pain also enabled the identification of participants reporting an episode of recurrent CLBP and those reporting an isolated (or first) incident of low back pain. This was necessary to ensure those who had recently experienced a painful low back episode for the first time was not mistakenly categorised into the pain group.

Obtaining such information is not straightforward because the meaning of pain, and therefore the responses given to pain questioning differs between people (Aldrich and Eccleston 2000; Bullington et al. 2003). Memory recall is widely reported to be impaired in those with chronic pain which means the recollection of dates regarding pain onset and duration can be inaccurate (Linton and Melin 1982; Mazza et al. 2017). As such, asking participants a single question to establish pain duration was not a robust method.

Pain group characteristics, including pain duration, were defined within the literature but definitions were often lengthy and complex. For example, de Vet et al. (2002) defined a low back pain episode as a “period of pain in the lower back lasting for more than 24 hours, preceded and followed by a period of at least one month without low back pain”. The researcher was concerned that presenting such definitions for the consideration of participants was too onerous a task and they may not complete the questionnaires fully or might discontinue with the study entirely. Consequently, a series of questions were posed to the participants in the pre-assessment questionnaire pack. These were based upon the suggestions for recording low back pain data in pain research from (Deyo et al. 2014). The questions asked included; whether participants ever had low back pain? whether their low back pain persisted or recurred for longer than 3 months?, how long had their low back pain been an ongoing problem (ranges were offered to participants with the maximum range being 5 years or more), how often had low back pain been an ongoing problem in the past 6 months? (Every day? At least half the days? Less than half the days?) and when was the first time they had experienced low back pain? The combination of these questions was intended to provide key information which the researcher could investigate further with the participant during the assessment appointment.

3.4.1.2. Pain location

Identifying the location of participant's back pain was important to establish whether pain location was related to tactile acuity. Participants were provided with a diagram and asked to highlight their typical region of pain. Pain drawn within the shaded region was considered to be LBP (Deyo et al. 1998). The aim was to identify their back pain as: bilateral back pain (pain occurred both sides of the spine) or unilateral (one side of the spine). A transparent grid was created which divided the image into nine coded regions – to the left, right and midline of T12-L3, L4-S1 and inferior to S2. Additionally, those that reported pain in multiple regions were categorised as 'more than one region'. The grid was placed over each participant's drawing and the coded region was recorded. This data enabled frequency analysis regarding the location of the participant's low back pain. Additionally, these grids were used to identify whether tactile acuity was altered within the region of pain.

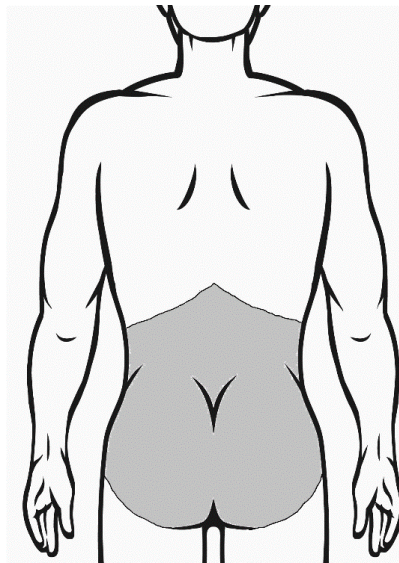


Figure 3-1 - Diagram on which participants highlighted their region of low back pain

3.4.1.3. Disability

The Roland Morris Disability Questionnaire (RMDQ) (see Appendix 9.3.1.2) is a short, simple, self-administered questionnaire used to assess functional disability in those with low back pain (Roland and Morris 1983). Scored from zero to 24, higher scores indicate greater disability. Widely used in back pain research, it has acceptable validity; the RMDQ correlates moderately well with the Oswestry Disability Index, $ICC = 0.66$, $p < 0.0001$, in those with CLBP without radiculopathy (Leclaire et al. 1997). It also has acceptable

reliability with good repeatability, particularly with shorter periods between the test and re-test [ICC between 0.88 and 0.91 (Roland and Morris 1983; Stratford et al. 1996; Johansson and Lindberg 1998)]. Further reliability was demonstrated by good internal consistency scores where Cronbach's α was ≥ 0.84 (Roland and Morris 1983; Roland and Fairbank 2000). As with other self-report measures of disability, the RMDQ only modestly correlates with assessments of actual physical function such as a change in spine flexion (Spearman's $\rho = 0.29$, $p = <0.001$) (Deyo and Centor 1986).

The RMDQ was chosen over other disability assessment tools such as the similar Oswestry Disability Index, because the RMDQ was better suited to assessing disability in those with mild to moderate disability (Bombardier 2000; Roland and Fairbank 2000). This was important because it was anticipated that participants would likely report mild to moderate CLBP symptoms (pain and disability) due to the populations from which they were sampled. As such, the RMDQ (Roland and Morris 1983) provided a self-reported, quantitative measure of back pain related disability for all the main study participants who reported low back pain. Participants with no history of CLBP were not required to complete the questionnaire.

3.4.1.4. *Kinesiophobia*

Individuals with CLBP and disability display increased fear-avoidance beliefs and behaviours relating to physical activity and fear in relation to pain (Briggs et al. 2010; Briggs et al. 2011). As this study assessed motor function, tools were chosen that identified fear of movement. Identifying such differences between the groups could provide insight as to whether fear of movement related behaviours was related to measures of tactile acuity, body schema and/or motor function.

Many validated tools assess fear avoidance beliefs and behaviours, but they do not relate to fear of physical movement. Within the group of questionnaires measuring fear-avoidance; the Pain Anxiety Symptoms Scale (McCracken et al. 1992) and the Fear of Pain Questionnaire (Roelofs et al. 2005) were designed to measure 'pain related fear'; the Fear Avoidance Beliefs Questionnaire (Waddell et al. 1993) and the Fear Avoidance of Pain Scale (Crowley and Kendall 1999) measure 'fear avoidance beliefs'. Only the Tampa Scale for Kinesiophobia (TSK) and its derivatives measured fear of movement. Within this study, kinesiophobia was considered as an excessive, irrational and debilitating fear of physical movement resulting from a fear of painful injury or re-injury (Kori et al. 1990; Miller et al. 1990).

The TSK is an established, validated and widely used measure of fear of movement and re-injury in people with back pain. The shorter Tampa Scale for Kinesiophobia-11 (TSK-11) (see Appendix 9.3.1.1), has only 11 questions but demonstrates good levels of internal consistency when compared with the full-length TSK; where the TSK: $\alpha = 0.76$ and the TSK-11: $\alpha = 0.79$.

Good test-retest reliability was demonstrated (TSK: ICC = 0.82, SEM = 3.16; TSK-11: ICC = 0.81, SEM = 2.54). The TSK-11 also reports good concurrent and predictive validity (Woby et al. 2005; Roelofs et al. 2007; Tkachuk and Harris 2012).

The shorter TSK-11 also reduces participant burden so it was chosen to measure participants' fear of movement or re-injury in the CLBP group. It was not completed by those with no CLBP history.

3.4.1.5. Prognostic outcome metrics

The Keele Subgroups for Targeted Treatment (STarT) Back Screening Tool (Hill et al. 2008) (see Appendix 9.3.1.3) has been extensively used to stratify the management of low back pain care by predicting patient prognosis. The STarT Back metric stratifies those with low back pain into low-, medium- and high-risk (of a poor prognosis) groups from a biological, psychological and social perspective (Figure 3-2). Risk was defined by the likelihood of developing persistent disabling symptoms (Hill et al. 2008; Hill et al. 2010; Hill et al. 2011). Of its 9 questions, items 5 to 9, explored bothersomeness, catastrophising, fear, anxiety and depression. These five questions formed a single-dimension, psychosocial sub-scale with no redundant items (Cronbach's alpha = 0.74). Test-retest reliability weighted kappa scores for the complete tool and the psychosocial subscale scores were 0.73 (95% CI 0.57–0.84) and 0.69 (95% CI 0.51–0.81), respectively which signified substantial reliability (Cohen 1992).

STarT Back was chosen because it provided a simple score indicating the impact of CLBP within the context of catastrophising, fear, anxiety and depression. This was important because identifying correlations between TPDT or body schema and STarT Back scores may indicate that TPDT or body schema impairments are linked to the low-, medium- or high-risk categories of CLBP chronicity identified by STarT Back. This could identify CLBP sub-groups which may benefit from different approaches to treatment. Additionally, the STarT Back Screening Tool was shorter and easier to score than the similar Örebro Musculoskeletal Pain Screening Questionnaire (Hill et al. 2010). Although the low-, medium- and high-risk stratification groups were intended to direct the stratified management of low back pain (Hill et al. 2008), the groupings provided a biopsychosocial metric of how severely the pain group were affected by their CLBP. Additionally, correlation analyses were used to explore the relationships between the scores for STarT Back, TPDT and body schema.

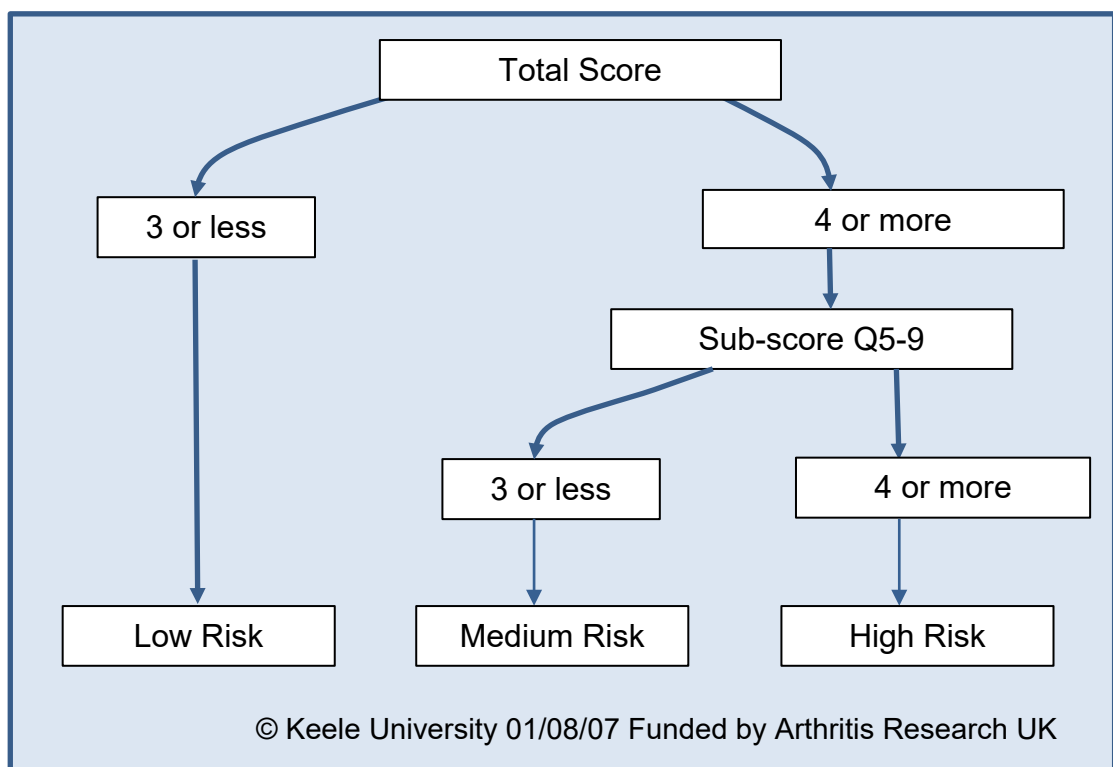


Figure 3-2 - The STarT Back Tool Scoring System (from www.keele.ac.uk/sbst)

3.4.2. Participant Comments diary

A data collection diary was used to log similar comments made by different participants during the data collection process. These comments are reported in Appendix 9.5.2. Although not used in the analysis, these comments were considered in the discussion. The aim of collecting these comments was to provide a resource to help guide the interpretation of the results.

3.5. Observational Outcome Measures

This section discusses the methodological approaches to the key study outcome measures of two-point discrimination threshold (TPDT), body schema and low back motor function. Tactile threshold was also included because of the close relationship to TPDT and its relevance within the context of this study.

Firstly, tactile threshold and TPDT are discussed. These two measures of tactile acuity share similar neurophysiological pathways and although TPDT is a more complex process, by measuring both functions, better interpretation of the results was possible (Abraira and Ginty 2013). For example, if one metric was altered while the other remained within the normative range, certain conclusions might be drawn. If both were altered, impairments within the neurophysiological pathways might exist for that participant. As such, both were important metrics. However, different regions of the body are receptive to different tactile forces, so identifying a method which was appropriate for measuring tactile threshold and TPDT on both the finger-tip and low back was a requirement when considering possible methods.

3.5.1. Locations of tactile threshold and TPDT assessment

Tactile threshold and TPDT functions involve very similar processes. Static, light, direct touch of the skin stimulates low threshold mechanoreceptors called Merkel cells and their slowly adapting type 1 (SA1), or A β neurons (Gasser and Erlanger 1927; Abraira and Ginty 2013). Merkel cell distribution varies with body region, with the highest density occurring on the fingertips (60-100 cells per mm² of skin) and the lowest density in the axillae (7 cells per mm²). On the low back, distribution is only 12 \pm 5 cells per mm² of skin so the capacity for tactile sensitivity is less on the back than for the fingertip. Of all the fingers, the highest density occurs on the middle fingertip (104 \pm 14 cells per mm² of skin)

(Lacour et al. 1991). For these reasons, the middle fingertip was chosen as the site of tactile assessment.

On the low back, assessment was conducted at two locations on either side of the spine. In the researcher's clinical experience as a registered healthcare professional, L3 was rarely reported to be a focal point of low back pain and it was not an area reported to be painful by participants in other studies (Moseley 2008a; Wand et al. 2010b; Nishigami et al. 2015). To gauge a baseline measure of low back tactile acuity at a region unlikely to be reported as painful by the study participants, tactile threshold and TPDT was assessed over the transverse processes of the L3 vertebra. The second location of low back tactile acuity assessments were the transverse processes of the vertebra nearest to the location of each participants CLBP. If participants did not report low back pain, tactile acuity metrics were only recorded at L3. The process to locate the transverse processes of L3 and L5 are presented in Appendix 9.3.3.

3.5.2. Tactile Threshold

Deformation of the human skin with a small (2-3mm²), non-noxious implement, usually produces the sensation humans refer to as touch (Burgess and Perl 1973). Tactile threshold is the term used to describe the minimum force necessary for touch to be perceived (Yarnitsky and Pud 1997).

This study aimed to identify TPDT impairments in those with CLBP, but measures of tactile threshold were necessary to interpret the results because both functions share similar neurophysiological pathways (Abraira and Ginty 2013). As such, this study assessed tactile threshold on the low backs and fingertips of participants in the pain and control groups. This metric provided one of two baseline measures of tactile acuity, the other being TPDT. It was expected that an impairment in tactile threshold would be reciprocated by an impairment in TPDT at the same location. Conversely, due to the neurophysiological processes involved, TPDT impairments would not necessarily be accompanied by impaired tactile threshold. This is discussed in more detail in section 3.5.3.

There are several methods for detecting tactile threshold, one of which is the method of constant stimuli. It requires the researcher to present several values of a stimulus in a random or semi-random order and calculate the average from a sequence of several

stimuli (Yarnitsky and Pud 1997). It was decided to use this method because of its simplicity and the ease in calculating a metric.

The tool chosen to apply the stimulus were von Frey filaments because they were the only instruments known to objectively exert a precise force on contact (Bell-Krotoski et al. 1993; Bell-Krotoski et al. 1995; Jerosch-Herold 2005; de Sousa et al. 2014).

Von Frey filaments are constructed of a standardised elastic, filament which when compressed along its long axis, buckles at a specific force. The buckling is dependent on its length, diameter and the stiffness of the filament and once buckled, the force imparted by the filament remains constant, irrespective of the degree of buckling (Bird and Ross 2014).

3.5.2.1. Tactile threshold using von Frey filaments - normative values

Von Frey filaments are widely used in assessing tactile threshold on different regions of the body in healthy subjects and those with chronic pain (Martínez-Jauand et al. 2013; Puta et al. 2013).

When assessed on the hands and fingertips, normal tactile threshold on healthy adults was found to be 0.07g of target force. This is also known as the '2.83 filament' if measured using standardised von Frey filament sizes (Bell-Krotoski et al. 1993; Bell-Krotoski et al. 1995).

Tactile threshold on the low back was expected to be less sensitive than the finger-tip but little evidence could be found except for two studies reported in Chapter Two's systematic review (Moseley 2008a; Wand et al. 2010b). Wand et al. (2010b) measured tactile threshold between the 1st and 5th lumbar vertebrae of 19 CLBP and 19 control group participants and reported both group means to be 1.7mg (IQR 0.7). Moseley (2008a) measured tactile threshold 16 times between the 4th thoracic vertebra and the gluteal folds in each of six CLBP and six control group participants. Identical group means were of 1.2g (SD 0.4) were also reported.

As such, von Frey filaments were selected to measure tactile thresholds on the low backs and finger-tips of the pain and control groups.

3.5.2.2. *Tactile Threshold Method*

The von Frey monofilaments brand used were Aesthesio™ Precision Tactile Sensory Evaluators, DanMic Global, LLC (Figure 3-3 and Figure 3-4). The kit consisted of 20 nylon hairs with increasing diameters ranging in tactile pressure-equivalent from 0.008 to 300 grams of target force. They were certified to meet target force with a standard deviation $\pm 5\%$ at ambient room temperature. In other studies, the size of the filament (from 1.65 to 6.65) or the target force in millinewtons (from 0.08 to 2940mN) was sometimes reported, rather than grams. The conversion chart for these metrics is provided on the tactile threshold assessment page of the data collection sheets (see Appendix **9.3.2**).

Tactile threshold was assessed on the fingertip pad of the middle (3rd) digit on the dominant hand for all participants. On the low back, for all participants reporting pain, tactile threshold was assessed over the left and right transverse processes of L3 and the vertebra nearest to the centre of their pain. For control participants not reporting pain, tactile threshold was assessed over the left and right transverse processes of L3 only.

Beginning with the lightest filament, they were applied in order of increasing force until one was detected by the participant. The average of three tests (to the nearest filament size) at each location was taken to be tactile threshold. The step-by-step method for measuring tactile threshold on the fingertip and low back within this study are presented in appendices **9.3.4** and **9.3.5** respectively.



Figure 3-3 - Aesthesio™ Precision Tactile Sensory Evaluators - DanMic Global, LLC



Figure 3-4 - Aesthesio™ Precision Tactile Sensory Evaluator filament

3.5.3. Two-Point Discrimination Threshold

The ability of individuals to accurately discriminate between one or two nearby points when touched lightly on the skin varies. Many factors are known to influence this acuity such as the region of the body being assessed, the persons age, gender and body mass index (BMI) (Weinstein 1968; Dellon 1981; Chandhok and Bagust 2002; Schmauss et al. 2014; Schmauss et al. 2015; Falling and Mani 2016a, 2016b). However, some pathological conditions also appear to influence this acuity.

Two-Point Discrimination Threshold (TPDT) is the term used to describe the shortest distance between two points at which a subject can clearly detect two points of contact (Weber et al. 1996; Jerosch-Herold 2005). It is also known as tactile spatial acuity or spatial resolution and it is a widely recognised measure of discriminatory tactile acuity (Moberg 1990; Foster and Bagust 2004; Eryilmaz et al. 2013; Kim et al. 2015; Debenham et al. 2016; Luedtke et al. 2018).

This study aimed to assess discriminatory tactile acuity alongside measures of body schema and motor function in a CLBP and control group to identify impairments between them and highlight targets for future therapeutic intervention.

The ability to discriminate between two points of contact occur when two distinct tactile receptive fields on the skin surface are stimulated. It requires cortical integration and a response to be formed. Therefore, it should be considered more than a simple measure of peripheral nerve function (Lundborg and Rosen 2004). It remains one of the most commonly used techniques in assessing hand responsiveness following reconstructive neurosurgery (Kim et al. 2015; Lai et al. 2015) and its potential uses in neuropathic medicine continue to be researched (Eryilmaz et al. 2013). Some argue it requires nothing more than a paperclip to assess TPDT on the fingertips (Finnell et al. 2004). However, assessing other areas require different tools with a capacity for assessing a larger area. Its simplicity has been the source of both its appeal and its criticism, where issues of inter-rater reliability and over-interpreting results are reported (Lundborg and Rosen 2004).

However, as a comparative measure of tactile acuity between groups of adults, it has value. A systematic review from Catley et al. (2014b) reported low back TPDT to be significantly increased (where a larger measure of TPDT indicated impairment), by 26% (95% CI: 12% to 39%) in those with CLBP when compared with control groups.

Intra-rater reliability of TPDT on the hands range from good to excellent (Catley et al. (2013b) ICC 0.82, CI 0.65 - 0.91; Novak et al. (1993) ICC 0.989, CI were not reported).

Concurrent validity compared TPDT with tactile object recognition tests (another test of discriminative tactile function) and they were strongly correlated ($r = 0.77$) (Novak et al. 1992) so TPDT and tactile object recognition tests may be measuring similar metrics.

Intra-rater reliability of TPDT on the low backs of healthy adults is considered moderate to good (Catley et al. 2013b; Adamczyk et al. 2015). Catley et al. (2013b) reported intra-rater reliability to be good at L3 (ICC 0.81, CI 0.63 - 0.91) whereas, Adamczyk et al. (2015) found it to be moderate at the same location (ICC 0.72, CI 0.50 – 0.94). Conversely, inter-rater reliability of TPDT on the back of healthy adults is reportedly poor to moderate (Adamczyk et al. (2015) ICC 0.56, CI 0.26 - 0.85; Catley et al. (2013b) ICC 0.66, CI 0.38 - 0.82). However, in the Adamczyk et al. (2015) study, only one researcher collected the data, so the findings must be considered of low quality although they may help explain why different studies report such varying normative TPDT values.

Similar methods of measuring low back TPDT in different studies produced similar results in healthy adults (Moseley 2008a; Stanton et al. 2013; Nishigami et al. 2015). However, assessing different regions of the low back using different methods can produce varying results (Wand et al. 2010b). Wand et al. (2010b) identified near identical TPDT on each side of the spine in healthy pain-free adults. However, the results for the same participants differed according to whether the calipers were held parallel or perpendicular to the spine. Smaller, side-to-side differences were found to be statistically significant ($p = 0.05$) when the calipers were placed on the skin perpendicularly to the spine (the horizontal technique). Greater side-to-side differences were required to reach statistical significance when the calipers were positioned parallel to the spine.

The ease and immediate results of TPDT have led to its extensive use on many regions of the body, including the back and hands, as metrics of tactile discrimination (Stanton et al. 2013; Lai et al. 2015; Beaudette et al. 2016; Botnmark et al. 2016; Falling and Mani 2016a, 2016b; Adamczyk et al. 2017b; Boesch et al. 2017). The simplicity of the technique was appealing because it was of low burden to participants, avoided the potential for technical issues that might be experienced from more technical methods and it provided the researcher and participant with immediate results.

TPDT does have limitations in that it does not only measure spatial acuity in determining two points. By definition, two point tactile contact stimulates at least two regions of tactile receptors within the skin. Spatial summation occurs when together, the simultaneous synaptic potentials of two or more presynaptic neurones exceed the threshold of the postsynaptic neurone and action potentials are generated (Kandel et al. 2013). Considerable spatial summation is thought to occur in tactile TPDT but the degree of

spatial summation does not appear to vary significantly with an increasing distance between the two points of contact. Conversely, in regions where the distance between the points are relatively large (60-120mm), participants performance increases as the distance between the two points increases and this finding has been reported on more than one area of the body (Morch et al. 2010). These findings indicate that although spatial summation may occur during tactile TPDT assessment, spatial acuity is also contributing to data being collected. Although the neurophysiological properties of spatial summation must be considered a limitation of the tactile TPDT method, the phenomenon is one which likely occurs in both the pain and control groups. Therefore, both datasets may be similarly skewed and between group comparisons remain possible. It cannot be said that the data collected using this method is likely to reflect spatial discrimination entirely but the data probably reflects a combination of tactile acuity sensitivity; including spatial discrimination, spatial summation and low-threshold mechanoreceptive input from the caliper tips touching the skin.

Other methods of assessing tactile discrimination were considered but rejected. For example, tests requiring participants pointing to the location of touch would have introduced unwanted motor function during the pointing part of the task (Bickley and Szilagyi 2012; Adamczyk et al. 2015). Using graphesthesia, the ability to correctly identify simple symbols when drawn on the skin, was ruled out because it assessed moving rather than static touch. Different tactile receptors, neurons and their neurophysiological pathways would have been involved and the results would not have been comparable to the findings from earlier findings (Wand et al. 2010b; Abraira and Ginty 2013).

It was concluded that to measure discriminative tactile acuity on the low back and fingertip using a simple method that was known to utilise similar neurophysiological pathways as the process of tactile threshold, TPDT was the most appropriate method.

3.5.3.1. Discriminative touch using TPDT - Normative values

Normative values of TPDT are typically between 1-4mm on healthy human fingertips (Weinstein 1968; Dellon 1981; Chandhok and Bagust 2002). On the lumbar spine, values varied between 40 - 67mm for healthy humans (Nolan 1985; Wand et al. 2010b; Luomajoki and Moseley 2011; Stanton et al. 2013; Wand et al. 2014a; Falling and Mani 2016a).

There are some differences in TPDT relating to age. After the 3rd decade, TPDT appears to decline on the fingertips (Schmauss et al. 2014; Schmauss et al. 2015). Results are

less widely reported on the back but Falling and Mani (2016a) identified differences in measurements made either side of the spine in healthy adults in their 5th decade. Whether this decline continues into later decades is unknown. To account for this within this study, data were collected to ensure participants ages were not significantly different between the pain and control groups.

3.5.3.2. Tools for assessing TPDT on the fingertip and low back

Many studies assessed TPDT using Vernier calipers but few reported the specific details necessary to allow the tools to be identified (Moseley 2008a; Wand et al. 2010b; Luomajoki and Moseley 2011; Stanton et al. 2013; Trapp et al. 2014a; Nishigami et al. 2015; Wälti et al. 2015; Adamczyk et al. 2017b). A reliability study to recommend calipers of a specific type or construction (plastic or metal, sharp or rounded tips) could not be located within the published literature.

It was feasible that if the tips making contact with the skin were of different materials, sizes, and shapes, variation in the results could be generated. Levin et al. (1989) compared metal probes of different sizes and shapes when measuring finger-tip TPDT. Small, pointed ended probes ($\leq 1\text{mm}$ diameter) proved most reliable but no reference was made regarding the impact of temperature on tactile acuity. If participants perceived the light touch contact with metal calipers tips as cold rather than as pressure, the neural pathways involved in detecting temperature and pressure would probably be concurrently activated, rather than just the activation of those involved in the detection of pressure. A comparable study that investigated similar properties of plastic tipped probes could not be found.

A TPDT tool reliability study was undertaken to identify whether Vernier calipers of different materials and tip shapes returned similar results when TPDT was assessed by the same researcher on the fingertips and low backs of a group of adults. This reliability study is reported in Chapter Four. The results of this reliability study determined which type of calipers were selected to collect TPDT data on the fingertip and low backs of all participants in the main study.

3.5.3.3. *TPDT Method*

Moberg's (1990) method of measuring TPDT was the only technique reported by other researchers. It had been used extensively to assess TPDT on various regions of the body, including the back (Moseley 2008a; Wand et al. 2010b; Luomajoki and Moseley 2011; Stanton et al. 2013; Trapp et al. 2014a; Nishigami et al. 2015; Wälti et al. 2015; Adamczyk et al. 2017b). However, the technique was designed for assessing the volar surface of the hands, not other regions of the body (Moberg 1990; Moberg 1991).

It was feared that directly transferring the TPDT technique to the back without deeper analysis of the method might overlook the fine nuances that Moberg (1990) considered essential to the reliability of his technique. As such, an analysis of the potential issues in transferring the TPDT technique from the hand to the back was undertaken. The full analysis is reported in Appendix 9.3.6 but the most critical issues identified were the need of a tool capable of measuring large areas and minimising the fluctuations in contact pressure that a larger tool might bring. Through testing the procedure, it was decided that by bracing her arms against her body, the researcher could minimise these issues.

Luomajoki and Moseley (2011) highlighted that although both vertical and horizontal TPDT readings were greater, and therefore less accurate, in those with low back pain when compared with healthy controls, greater differences were noted when TPDT was assessed with the two points parallel to the spine rather than held perpendicularly. However, Wand et al. (2014a) determined that smaller statistically and clinically significant differences could be detected when TPDT measurements were made perpendicular to the spine.

While it was noted that the results from Wand et al. (2014a) were only relevant to participants reporting unilateral pain and where within-participant analysis took place, neither of which were part of this study's design, this was the only evidence indicating one technique to be better than another. There were no similar studies with participants reporting bilateral pain so the horizontal technique, with calipers held perpendicular to the spine, was used within this study.

TPDT was assessed at the same locations as for tactile threshold. TPDT was first assessed on the third fingertip palp, then the low back. The side and vertebral level of low back assessment were randomised with a coin toss (heads = left, heads = L3) and two ascending and two descending runs were recorded per location.

Caliper points were moved further apart during ascending and closer together in descending runs. Each run used a three-alternative, forced-choice (“one”, “two” or “don’t know”) adaptive staircase (illustrated in Figure 3-5) where the change from an ascending to a descending run (or vice versa) was directed by the participant’s correct response. The adaptive staircase reduces reporting bias when quantifying sensory metrics (Yarnitsky and Pud 1997; Klein 2001).

TPDT testing began with an ascending run using the adaptive staircase method. Participants were asked to only answer “one”, “two” or “I don’t know”. In the ascending trials, the distance between caliper points was decreased following a correct answer. Similarly, following a correct identification in descending trials, the distance between caliper points was increased. On the back, 10mm steps were used in the initial staircase, 5mm in the next and 1mm in the remaining staircases. On the fingertip, 1 mm steps were used in the initial staircase and 0.5 mm steps in remaining staircases. Single points of contact ‘catch trials’ were introduced between every three to five two-point contacts to ensure participants were not guessing.

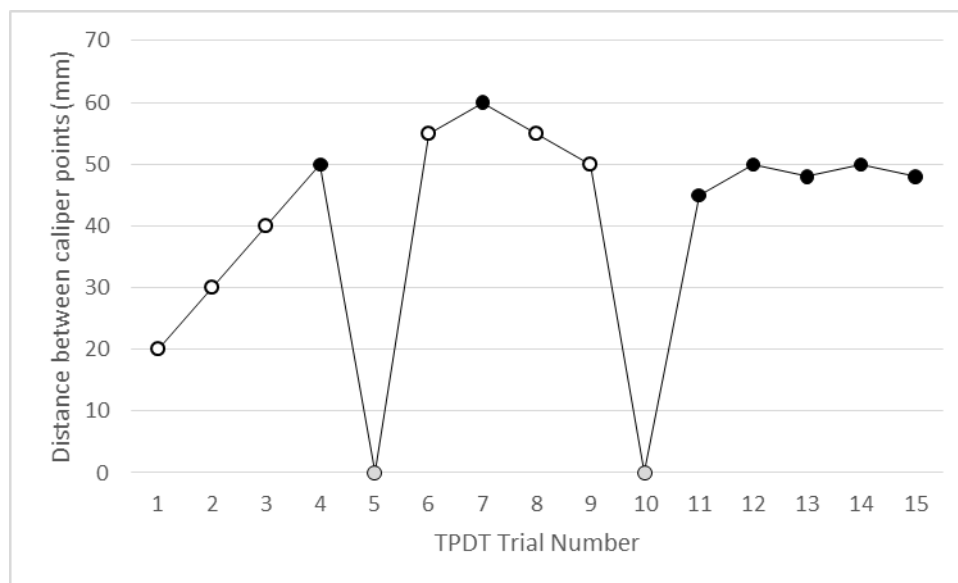


Figure 3-5: Chart to show expected results when using an adaptive staircase technique when assessing TPDT on the low back.

Possible three-alternative forced-choice answers were either “one”, “two” or “I don’t know”. Black circles = correct answers which triggered a change in staircase direction, White circles = incorrect answers, Grey circles = catch trials using single points of contact

This process was repeated for each of the two ascending runs, which started with the caliper points close together and the two descending runs. Descending runs began with the distance between the points greater than could feasibly be assessed as “one” for that region of the body.

Mean TPDT scores were calculated, per run, per location, using the measurements from the last five staircases where “two” was identified correctly.

The step-by-step method for measuring TPDT on the fingertip and low back within this study are presented in appendices 9.3.7 and 0. Scoring and interpretation of TPDT scores are presented in section 3.9.3 of this chapter.

3.5.3.4. *Other tactile acuity considerations*

Avoiding hairs on non-glabrous skin

In humans, non-glabrous (hairy) skin is covered with fine hairs and these activate different cutaneous mechanoreceptors to those from skin deformation alone (Burgess and Perl 1973). Caution was necessary when taking measurements on the back. There was a need to avoid touching hairs because their movement would trigger tactile sensation through different mechano-sensory and neurological pathways. This would result in a different sensory metric being recorded so where participants were found to have dense hair at the test locations, tactile threshold readings were not recorded for those participants.

Low Back Width

The size of the low back may be important in sensory function performance. It is plausible that those with a larger low back surface area due to a large BMI, as determined by Quetelet's Index in kg/m^2 (Garrow and Webster 1985), may perform sensory function tasks differently to those with a normal BMI metric.

In those with a larger BMI, it was unknown whether the tactile structures within the skin become more widely dispersed over a larger area or increased in numbers to maintain their previous distribution ratio. However, many sensory impairments are related to BMI. Pain, cold/heat and pressure detection are impaired in those with a higher BMI (Tashani et al. 2017). Falling and Mani (2016a) report low back TPDT to be related to BMI in healthy individuals although studies linking tactile threshold to BMI, or those including participants with CLBP could not be located.

Consequently, along with height and weight to calculate BMI using Quetelet's Index in kg/m² (Garrow and Webster 1985), low back width was measured for all participants. Back width was assessed using digital calipers at the level of the transverse processes of L3, while participants lay prone. Back width measurements were recorded from the centre of the spine to the lateral sides of the trunk. The back-width measurements were used to set context between the pain and control groups and to explore the relationship between measures of tactile acuity and back width.

3.5.4. Body Schema

In some chronic pain conditions, body perception, or the feelings people have about their own body, are disrupted (Moseley and Flor 2012b). Body Schema is the term used to describe the real-time, ever-changing representation of the body in space (Wolpert et al. 1998; Schwoebel et al. 2001). It has been assessed extensively in those with chronic pain by assessing body schema maps which rely upon visual, proprioceptive, perceptual, somatosensory and motor maps. It has also been assessed using metrics of the somatosensory systems such as those involved in the perception of touch, pressure, pain, position, movement and vibration from the muscles, joints and fascia (Moseley 2005a; Mulder 2007; Moseley 2008a; Bray and Moseley 2011; Stanton et al. 2013; van der Maas et al. 2014; Wand et al. 2014b; Nishigami et al. 2015; Berger et al. 2016; van der Maas et al. 2016; Sobie 2017). For a review of body schema, see Appendix 9.2.3.

The rationale for measuring body schema was to ascertain whether body schema was altered in a sample of adults from the UK with CLBP and whether these alterations were related to tactile acuity, motor function or clinical measures. These questions have only partly been addressed in populations from other geographical and cultural locations but none have been reported in a UK population (Moseley 2008a; Bray and Moseley 2011; Stanton et al. 2013; Wand et al. 2014b; Nishigami et al. 2015).

There many different methods to assess body schema but to permit comparison of this study's results to those that reported body schema and were included in the systematic review in Chapter Two (Moseley 2008a; Bray and Moseley 2011; Stanton et al. 2013; Wand et al. 2014b; Nishigami et al. 2015). It was decided to use one of their three methods, if the method appeared robust, to address this study's research questions.

3.5.4.1. *Drawing back outlines on a template*

Moseley (2008a) and Nishigami et al. (2015) assessed body schema of the low back by asking participants to draw the outline of their own back on a template (for a discussion relating to this technique see Chapter Two, section 2.2.4 entitled *Tools and Techniques - Body Schema*). As far as could be established, these were the only two published articles which referred to using this technique when assessing low back body schema. The simplicity of this technique was appealing but concerns relating to validity, reliability and how the task might be interpreted led to a small pilot amongst six of the researcher's peers and colleagues. Four of the six pilot participants reported CLBP. Individually, they were provided with an A5 sized dotted outline of a posterior torso which included the upper arms, gluteal folds and upper thighs. They were provided with verbal and written instructions which were identical to those used by Moseley (2008a) and Nishigami et al. (2015). The instructions stated; "Concentrate on your back. Add to this drawing by following the outline of your own back as you track it in your mind. Concentrate on where you feel your back to be. Draw in the vertebra that you can feel. Do this without touching your back. Do not draw any part you cannot sense. Do not draw what you think your back looks like, draw what it feels like".

The results of the pilot were not as expected. Four volunteers (three with CLBP; one without) could not understand or relate to the instructions and reported they were not able to feel the outline of their back. Two became frustrated, saying they knew what their back should look like but were not consciously aware of what it felt like. The final two volunteers declared they had drawn what they expected a back to look like, not what their *own* back felt like. When questioned regarding how they perceived their own back, both referred to the drawing and said it felt like a normal back. None of the results agreed with those reported by Moseley (2008a) or Nishigami et al. (2015). The unreliability of this technique brought great uncertainty as to what it was measuring and whether the same variable was measured in each participant. As such, the method was rejected.

3.5.4.2. *Motor imagery performance using left/right discrimination*

Two studies included in the systematic review assessed body schema using the implicit motor imagery performance tasks of left/right discrimination (Bray and Moseley 2011; Stanton et al. 2013). These tasks provide a measure of body schema and involve the mental execution of a motor function task without overt movement of the muscles or the other peripheral tissues involved in actual motor function (Mulder 2007). These tasks are

a component of Graded Motor Imagery (GMI) which is becoming increasingly successful in the grouping and treatment of participants with chronic pain conditions, including CLBP (Bowering et al. 2013; Bowering et al. 2014).

Left/right discrimination tasks, where participants view photographs and judge whether they correspond to the left or right side of the body, are a common and pragmatic measure of implicit motor imagery performance (Moseley 2004c; Nico et al. 2004; Moseley 2008a; Bowering et al. 2014; Trapp et al. 2014a; Linder et al. 2016). Implicit motor imagery involves the participant unconsciously mentally rotating their own body (or region of the body) to match the image which they are tasked with determining laterality (Parsons et al. 1995; Parsons 2001; Osuagwu and Vuckovic 2014).

The ability to correctly distinguish between left and right is a complex process and demands input from many higher neurological regions of the brain. Functionally, it involves the successful integration of sensory, motor and visual cortical map information, along with memory recall and language function. When correctly judging a subject performing a left or right sided task of the back or trunk, tasks are more complex because the subject in the image may be facing towards or away from the person judging. If the subject is facing the judge, the subjects left side mirrors the judge's right side and vice versa. The judges visual-spatial function of mentally rotating images is necessary to recreate the correct mental image (Wolpert et al. 1998; Goldstein 2008; Kandel et al. 2013). An intact working body schema is necessary to process and integrate the complex information necessary to perform these implicit motor imagery tasks (Parsons and Fox 1998; Parsons 2001). For a review of left/right discrimination in the context of measuring body schema, see section 2.1.1.6.

Explicit motor imagery requires conscious mental rotation of the body into a specific position. The relationship between explicit and implicit motor imagery is important because the planning of motor tasks, including those involved in explicit motor imagery, can increase the level of pain even in the absence of actual movement (Decety 1996; Moseley et al. 2008b). Although this study does not knowingly involve explicit motor imagery tasks, many regions of the brain known to participate in the explicit planning and execution of movement (explicit motor imagery) are also activated by tasks requiring implicit motor imagery (Parsons et al. 1995; Osuagwu and Vuckovic 2014). In fact, the prefrontal cortical activity involved in planning movement can even begin with the appearance of the visual cues that precede the planned, actual movement (Nachev et al. 2008; Purves 2013).

If explicit motor imagery used to plan movement can increase pain and similar regions of the brain are involved in explicit and implicit motor imagery, it is plausible that implicit motor imagery could also influence pain levels. Increasing participants pain was to be avoided for two reasons; first, there was an ethical responsibility to avoid causing unnecessary pain; and second, assessing participants performances during experimentally inflated levels of pain might alter the task outcome, increase bias and make interpretation of the results more difficult.

When individuals are instructed to perform an explicit task, they are likely to invest greater thought and concentration than they would if the task been more familiar to them. Greater practice increases the implicitness of task performance (Masters 1992; Mullen et al. 2007). By asking participants to perform a practice left/right discrimination assessment of 80 images prior to the data collection taking place, it was intended that the task became more familiar and implicit. Additionally, any learning effect resulting from practising the task was minimised prior to the data being collected.

The rationale behind using left/right discrimination as a metric for body schema was that accuracy appears diminished when those with some chronic pain conditions perform left/right discrimination tasks which are related to their own painful limb. Importantly, the impairments can be improved through training and these changes are accompanied by a reduction in limb pain and disability (Schwoebel et al. 2001; Moseley 2004c; Moseley et al. 2005; Hudson et al. 2006).

3.5.4.3. Left/Right discrimination method using the Recognise® app for backs

A commercially available web-based tool (Recognise®) from the Neuro Orthopaedic Institutes (NOI) has been used for collecting left/right discrimination research data for back pain (Bray and Moseley 2011; Stanton et al. 2013; Bowering et al. 2014; Linder et al. 2016), osteoarthritic knee pain (Stanton et al. 2013) and from groups of healthy children (Dey et al. 2012).

Recognise® is a computerised left/right discrimination task programme which displays a set number of randomly selected computerised images from a bank of 98. These 98 images consisted of 49 images of torsos bending, rotating or leaning towards the subject's right side and their 49 mirrored images to create left-sided images. The programme ensured participants were presented with 50% left and 50% right-sided images during a task.

Below each image were two large touch screen buttons labelled as 'left' and 'right'. Participants were asked whether the subject in the image was twisting, turning or leaning to their (the subjects) left or right side. The speed of achieving the correct and incorrect responses (in seconds) and accuracy (as the percentage of correct answers) were recorded by the app. The researcher was able to set the level of difficulty and the time between each image. The 2016 version for backs was used (available on IOS for iPhone and iPad from the iTunes app store for £5.99).

Bray and Moseley (2011) report inter-rater and test-retest reliability for the tool among volunteers with and without CLBP. Intra-class correlation coefficients ranged from ICC =0.738 [CI 95% 0.447 to 0.90], to ICC =0.920 [CI 95% 0.831 to 0.970]. They also assessed hand left/right discrimination tasks, using the Recognise[®] hand app and found comparable results to earlier hand reliability studies from Moseley (2004c) and Moseley (2004b). Based on the work of Cicchetti (1994), these results indicate the reliability of Recognise[®] for backs to be considered 'good' or 'excellent'.

It was decided to use the Recognise[®] app in assessing left/right discrimination tasks of the back as a metric of body schema in this study because it had good intra- and inter-rater reliability, and the results are simple to record and interpret. Finally, from the pilot of the main study methods, participants were engaged and appeared to enjoy using the app. This was important because it ensured participants remained interested and involved throughout the data collection process.

3.5.4.4. Recognise[®] app method in assessing back left/right discrimination tasks

Different images for the back were available which represented three levels of difficulty. The lowest level of difficulty (Vanilla) was chosen for this study. Vanilla images had a plain, non-distracting background but appeared as a normal or a ± 90 -degree rotated image (see Figure 3-6 and Figure 3-7).

Instructions were given using specific guidance from the Recognise[®] software app. These were phrased as "Is this person turning to the left, or right?", rather than "is this the left-side or right-side?". Participants were encouraged to make accurate responses as quickly as possible. Detailed step-by-step methods for using the Recognise[®] app in this study, including participant set-up and assessment processes, are reported in Appendix 9.3.9.

Recognise[®] app guidelines report that a score of 85% and a response time of 1.5 seconds can be considered 'normal' when assessing the back (unpublished data).

Participants practiced using the Recognise® software during two practice runs of 40 images each. The results of these runs were not recorded. Two data collecting runs of 40 images each, with a short break between each run, were then performed by each participant. During these data collecting runs, the percentage of correctly identified images (termed accuracy) and the average speed taken to choose the correct answer (termed speed) were recorded by the app and on paper by the researcher. The mean accuracy and mean speed, per participant and per group were calculated.

A limitation was that the app did not report which images, from the image bank, were shown to participants so reporting the percentage of matching, rated images across the groups was not possible. Data analysis was used to identify significant differences between the groups and correlation analysis assessed the relationships between speed, accuracy and other key variables.

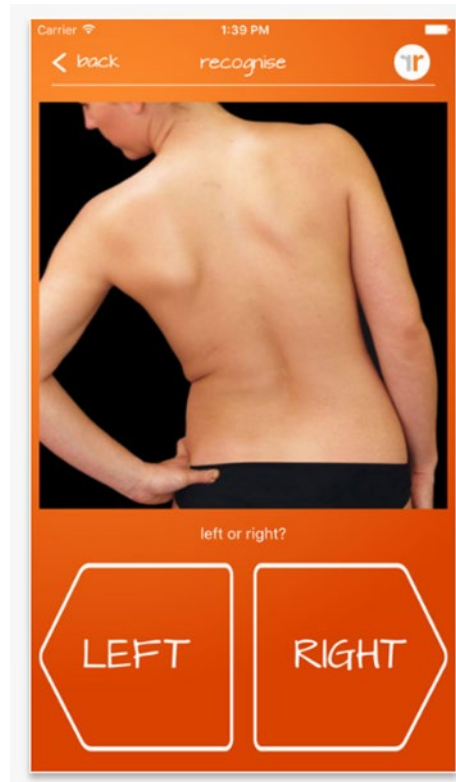


Figure 3-6 – Example of an image from NOI Recognise® for backs app



Figure 3-7 - Example of a 90-degree rotated image

(Both images are from the NOI Recognise® for backs app for iPhone and iPad www.noigroup.com)

3.5.4.5. *The Freemantle Back Awareness Questionnaire (FreBAQ)*

In some chronic pain conditions body perception or the feelings people have about their own body are disrupted. This study aimed to measure perceptual awareness of the back as a measure of body schema. While back perception is a subjective measure, the left/right discrimination tasks are objective metrics. While both methods can provide metrics of body schema, each task probably measures different aspects of the body schema construct.

During the research study design phase, the first questionnaire known to the researcher that assessed back-specific self-perception in people with CLBP was published - The Fremantle Back Awareness Questionnaire (FreBAQ) (Wand et al. 2014b). The questionnaire was designed to assess body perceptual impairment in people with back pain but appears to differentiate between those with and without back pain when used in mixed groups (Wand et al. 2014b).

Communication with the first author, revealed that three non-UK studies were underway that were investigating different CLBP groups, including pregnant women, but none were known to be planned that would assess a UK population.

FreBAQ was based upon the five-item questionnaire from Galer and Jensen (1999) which was designed to measure neglect like symptoms in the limbs of patients with CRPS. It presents participants with nine statements relating to the perception of back pain. The questionnaire has five Likert scale type response categories ranging from my back “never feels like that” which was scored as zero, to my back “always or most of the time feels like that” which received the maximum score of four. A total score was obtained for each participant by adding the scores from each of the response statements. Higher scores indicated more severe body perceptual impairments.

FreBAQ has acceptable internal-consistency (Cronbach's $\alpha = 0.777$) along with acceptable test-retest reliability and inter-rater reliability (ICC = 0.652, 95% CI: 0.307-0.848). Additionally, statistically significant univariate correlations to low back pain duration (Spearman's $\rho = 0.357$, $p = 0.010$), intensity (Pearson's $R = 0.400$, $p = 0.004$), and disability (RMDQ) (Pearson's $R = 0.366$, $p = 0.008$) were reported (Wand et al. 2014b). The findings were corroborated further in 2016 by Wand et al. (2016).

The FreBAQ questionnaire was used to explore back perception, a measure of body schema, in the pain and control groups of this study. The FreBAQ questionnaire is presented in Appendix **9.3.1.4**.

3.5.5. Motor Function

People with low back pain move differently to those without but gold standards for measuring low back movement control do not currently exist. Physical assessments of the lower body strength and range of motion are widely reported to be impaired in those with chronic low back pain. Consequently, functional assessment of the low back has become firmly entrenched within current practice and research disciplines (Baena-Beato et al. 2014; Cooper et al. 2016; Simson et al. 2017). Additionally, observing active functional movements are an important part of the low back pain assessment for manual therapists (Delitto et al. 2012). Such observations provide qualitative information to clinicians regarding lumbopelvic control and are an important part of the manual therapist's assessment and treatment design process.

Identifying differences between those with and without CLBP, such as trunk muscle recruitment variability or firing patterns, improves our understanding of specific aspects of CLBP (Abboud et al. 2014; Ghamkhar and Kahlaee 2015). However, assessing participants when performing tasks which resemble the activities that are typically impaired in CLBP, and collecting questionnaire based data, provides a more complete measure of a person's function (Simmonds et al. 1998; Dworkin et al. 2005).

Techniques to objectively explore specific differences between the pain and control groups were initially considered, such as electromyography (EMG) or video analysis of movement patterns.

Electromyography (EMG) was initially considered as an objective measure of motor function but it was feared the technique was too onerous when included alongside the other metrics. The complex application of the EMG equipment would have increased the length of the appointment, adding to the participant burden which may have deterred participants from volunteering. Additionally, stick-on electrodes placed over adipose tissue of more than 4cm deep were unlikely to record useful data (Konrad 2005). Adipose tissue is usually more prolific in women and older adults and but excluding this group would have excluded a large proportion of this study's target population (Roldán-Jiménez et al. 2015). As such, EMG was rejected as a method of data collection.

Video analysis using accelerometers to quantify patterns of movement and range of motion was also considered. However, the equipment required an intricate set-up processes which was burdensome for participants. The resulting abundance of complex data were superfluous in answering the research questions. A theme of this study was, where possible, to utilise straightforward, low-tech, clinically and participant appropriate

measures. EMG, video analysis and accelerometers did not meet these criteria. For this and the reasons above, these methods of measuring motor function were disregarded.

Functional assessments that reflect the activities compromised by CLBP (for example, standing, sitting, walking, climbing stairs) are important assessments of CLBP and provide simple and objective measures for monitoring patient outcomes (Simmonds et al. 1998; Sahrman 2002; Dworkin et al. 2005). However, in practice, clinical assessments of specific walking, stair climbing or sit-to-stand tests in those with CLBP are unusual.

Self-report questionnaires, such as the Roland Morris Disability Questionnaire (Roland and Morris 1983), capture functional data but mismatches between functional ability and performance reported by clinicians and patients are common (Jette et al. 1994; Gardner et al. 2015). In fact, the five-minute walk test, the 50-foot walking test, the chair stand test (also called the sit to stand test) and loaded forward reach tests only moderately correlate ($r = 0.37 - 0.60$) with RMDQ disability questionnaires (Simmonds et al. 1998).

Using simple functional tasks to obtain metrics of movement ability, in addition to self-reported functional measures, was of value to this study because together they provided a more rounded impression of participant function and revealed functional limitations experienced by the different groups. Although this study did not include any interventions, identifying and reporting functional assessment metrics alongside the other clinical metrics for the pain and control groups will add to the body of CLBP knowledge and provide other researchers with comparative data.

In choosing an approach to measure functional performance, it was decided that a straight-forward, quantifiable assessment of lumbopelvic motor function was required that could be performed by participants of different ages and abilities.

Motor function is defined as the normal or proper physiologic movement arising from the muscles, nerves or centres that produce motion (Dorland 2011). For the purpose of this study, motor control is defined as the combination of neurophysiological and biomechanical mechanisms that contribute to control of the spine during voluntary movement (Hodges et al. 2013).

Many motor function tests designed to assess the movement of the lumbar spine and pelvis can be considered subjective because the observer judges the subject's performance as successful or not. Providing those judging the subject's performance receive appropriate training, some have acceptable or good intra-and inter-rater reliability

(O'Sullivan 2000; Sahrman 2002; Dankaerts et al. 2006; Murphy et al. 2006; Luomajoki et al. 2007; Luomajoki et al. 2008).

Motor control dysfunction is the diagnosis given based upon observing reduced control of active motor function (O'Sullivan 2000; O'Sullivan 2005). Other synonyms for motor control dysfunction include relative flexibility, movement impairment syndromes and movement control dysfunction (Sahrman 2002; Luomajoki et al. 2007; Luomajoki et al. 2008). Normal biomechanical movement occurs through the pathway of least resistance. Therefore, if a joint is stiff, adjacent freely-moving joints will become more involved during the movements normally undertaken by the stiff joint (Sahrman 2002; O'Sullivan 2005). Such compensatory movement patterns have been termed 'provocative'. Additionally, CLBP patients who inadvertently move in a provocative way, may be causing themselves further back pain (O'Sullivan 2005; Hodges et al. 2013).

Motor Control tests measure a subject's ability to differentiate between movement of two different body segments. For example, stabilising the lumbosacral spine during movement of the hip and knee while performing smooth movement (Bauer et al. 2016). One battery of tests validated to assess lumbopelvic motor control is the Luomajoki's battery of tests (Luomajoki et al. 2007; Luomajoki et al. 2008).

3.5.5.1. Luomajoki's Battery of Tests

Luomajoki's battery of tests are a set of six tests which assess lumbopelvic motor control dysfunction (Luomajoki et al. 2007; Luomajoki et al. 2008). The battery identified that those with back pain perform more poorly than healthy controls (Luomajoki et al. 2007; Luomajoki et al. 2008; Luomajoki and Moseley 2011).

Luomajoki's battery of tests included six of the ten motor control dysfunction tests reported by O'Sullivan (2000) and Sahrman (2002) to test flexion and extension control of the lumbar spine in those with CLBP and healthy controls. Raters observed videoed performances of the six tests by adults with and without CLBP and rated them as either achieving the specific movement required (scoring them zero) or not achieving the required movement (scoring them one). Scores were added together to give a total score per participant and higher scores indicated greater lumbopelvic motor control dysfunction.

Reliability studies reported all six tests to have acceptable internal consistency and substantial inter-rater and intra-rater reliability (kappa, $k > 0.6$, $p \leq 0.001$) where the percentage agreement across all 6 tests ranged from 65% – 97.5%. The 95% Confidence

intervals for the six tests ranged from 95% CI 0.27 to 0.99 (Luomajoki et al. 2007; Luomajoki et al. 2008)

The Luomajoki Battery of Tests was included in the methods pilot (see Appendix **9.3.15** for the pilot results) and were found to be straightforward to perform and of low physical burden for participants.

Luomajoki et al's (2007, 2008) physiotherapist raters either had at least 25 years' experience in motor control assessment or they received three-days motor control dysfunction training prior to rating the subjects videoed performances. Despite the researcher's musculoskeletal assessment experience as a practising chiropractor, she was concerned whether she could expect similar levels of reliability without completing the specific motor control dysfunction training that was provided by Luomajoki (2007; 2008).

Consequently, an inter-rater reliability study was undertaken to assess reliability of Luomajoki's Battery of Tests when undertaken by multiple raters with similar professional training and experience but who had not received specific motor control dysfunction training. Following the reliability study, which is reported in Chapter Four, Luomajoki's Battery of Tests (Luomajoki et al. 2007; Luomajoki et al. 2008) were used to assess lumbopelvic motor control in the main study's pain and control groups.

3.5.5.2. Main Study Method - Luomajoki's Battery of Tests

For each of the six tests, the movements required by the participants were demonstrated by the researcher and participants were shown images which demonstrated the target and unwanted alignment of the pelvis and lumbar spine for each test. Following standardised verbal instructions, they sequentially performed each test. Firstly, the standing tests, secondly, the sitting tests and finally, the prone-lying tests. The researcher assessed whether the correct alignment was obtained. If performed correctly, the researcher scored the test as 'achieved' and the participant continued to the next test. If incorrectly performed, guidance was offered, and the participant performed the test again. If the second attempt was performed incorrectly, the test was scored as 'not achieved'. The images of 'achieved' and 'not-achieved' movements from Luomajoki et al (2008) are presented with the authors kind permission in Appendix **9.4.4**.

Participants were awarded zero if the position was 'achieved' and 1 point if it was 'not achieved'. Total scores for the test were added to provide an overall participant score,

which ranged between 0 and 6. A score of zero indicated perfect motor control test performance for each of the six tests and higher scores signified greater impairment.

Most participants consented to being videoed while performing the tasks on the understanding that their video may be randomly selected for inclusion within the motor control reliability study which is reported in Chapter Four. However, five of the pain group and seven control group participants did not consent to be videoed so the researcher scored all participants as they performed the tasks. She then scored all those from the videos at least one month after the data collection was completed. The results were compared and no significant differences between the approaches were identified. This was important because the scoring of actual performances reflected those scored from the videos. Consequently, rating performance from videos was the method used in the motor control reliability study and in the main study.

3.5.5.3. 30-second chair stand test

The 30-second chair stand test (30-CST), or sit to stand test, is part of the Fullerton Functional Fitness Test Battery (Jones et al. 1999; Rikli and Jones 1999) and was originally developed as a measurement of strength and endurance of the lower body in older adults.

The 30-CST has been used extensively to assess progress following knee, hip and back interventions in different populations of different ages (Boonstra et al. 2008; Bennell et al. 2011; French et al. 2011; Wright et al. 2011). It has also been widely used to assess functional performance in adults with CLBP because getting up from a chair to a standing position is a common task and is typically performed more slowly by those with CLBP. Therefore, it is a useful clinical outcome measure (Simmonds et al. 1998; Dworkin et al. 2005; Smeets et al. 2007; Andersson et al. 2010).

This study excluded volunteers older than 65 years of age but 30-CST scores reportedly decrease significantly with age in those over 60 years of age (Jones et al. 1999). In those aged 60-64 who were healthy and moderately active, scores of 15 for women and 17 for men could be considered normal (Rikli and Jones 1999) but formal normative values do not appear to have been published for younger age groups. However, it has excellent repeatability, inter-rater reliability ($ICC_{1,1} > 0.95$) and test-retest reliability ($ICC_{1,1} > 0.83$) in those over 60 years of age (Simmonds et al. 1998; Jones et al. 1999).

The 30-CST method was included in this study because it assessed whole body movement, rather than the lumbopelvic region which was measured by Luomajoki's

Battery of Tests (Luomajoki et al. 2007; Luomajoki et al. 2008). The 30-CST provided a metric to compare the performance of the two groups in their ability to achieve a common functional task; that of rising from and sitting down on a chair.

3.5.5.4. Method – 30 second chair stand test

Jones et al. (1999) reported the 30-CST method to be administered using a chair without arms, with rubber feet and a seat height of 17 inches (43.2 cm) which was placed against a wall to prevent it from moving.

The method used in this study was adapted from that of Jones et al. (1999) and used a manual therapy bench rather than a chair. The bench was heavy, had rubber feet and was placed against the wall. However, its height was altered to allow each participant to sit with their hips and knees bent to 90 degrees and rest their feet flat on the floor. This approach was taken because taller and shorter participants may have been disadvantaged by a fixed chair height due to differing positions of their lower body and the biomechanical influence this might have.

The step-by-step method for the 30-CST is reported in Appendix **9.3.11**. The number of complete stands a person could complete within 30 seconds was recorded.

3.6. Ethics, Participants and Confidentiality

3.6.1. Ethical approval and informed consent

Measures were taken to ensure volunteers received participant information sheets and consent forms at least 24 hours prior to their data collection appointment. This allowed them time to read and decide whether to take part in the study.

All participants provided written informed consent prior to taking part in the study. Ethical approval for the project was granted from Bournemouth University Research Ethics Committee (Reference ID: 9677) and the AECC Research Ethics Sub-Committee (Approval Number: E71/11/15). Copies of the approval letters are provided in Appendix **9.3.12**.

3.6.2. Participant recruitment, telephone screening and data collection venue

A convenience sample, where the most conveniently available people were included within the study (Polit and Beck 2012), were recruited through a printed poster and online social media campaign. The researcher's phone number and email address were provided on the posters for interested volunteers to get in touch.

Copies of the recruitment poster were also posted on social media (Facebook.com) through the researcher's network and local business networking groups. To avoid attracting volunteers with severe symptoms who might be receiving ongoing NHS care or awaiting back surgery, the advertising campaign avoided targeting NHS settings. This was to avoid the inclusion of confounding factors from any care that these volunteers may have been undergoing because such factors may have altered the study's findings. This study evolved from the researcher's interest in supporting CLBP patients using manual therapy, education and advice on self-management for their mild to moderate CLBP (see Chapter One, section 1.1). Anecdotally, the population presenting to the researcher for manual therapy reported back pain with fluctuating intensity and disability which intermittently impacted upon their activities of daily living. They were employed and engaged with exercise of various types. As a group, they were not well documented within the published literature. Consequently, the impact CLBP had for that group was not well reported and this study intended to add to what was known about the group.

Subsequently, posters advertising the study (see Appendix **9.3.13**) were placed in local private healthcare clinics (manual therapy clinics and dentists), sports clubs, martial arts studios, dance studios and throughout Bournemouth University buildings in the UK.

It was not known which location would attract the majority of participants but it was recognised that if a significant proportion of the total number of participants were recruited from one location, bias may be introduced to the data from characteristics that were represented more in those recruited from one location than another. For example, a limitation of recruiting from fitness clubs and dance groups was that one might expect a higher level of general fitness and motor skills which may not reflect the level seen in the wider CLBP population. This issue is reported as a limitation in Chapter Six, section 6.7, but some results may have been subject to a ceiling or floor effect. These effects can occur when a tool of measurement is developed for use in general populations but extreme characteristics are overly represented within the sample population. A tool designed to assess the general population may not be sufficiently sensitive to correctly measure people with different abilities and the results may be skewed (Andresen 2000). A visual assessment for skewness of the data was to be performed to ensure that not more than 15% of the groups data were significantly skewed and the most appropriate statistical test was applied (McHorney and Tarlov 1995).

3.6.3. Telephone screening and appointment booking

During a telephone call, information about the study was provided and volunteers were given the opportunity to ask questions. Telephone screening determined eligibility and ensured the inclusion and exclusion criteria were met prior to making a data collection appointment. Paper copies of the participant information sheet, participant agreement form, questionnaires and a stamped addressed envelope (to return the completed documents to the researcher) were posted to each participant.

During the screening telephone call, most volunteers reported a history of CLBP. To expand the pool of possible participants who might fit the control group criteria, volunteers were asked if they would like to invite a friend or partner who did not have a history of CLBP to accompany them and perhaps join the study. If in agreement and where preferred, appointments were booked sequentially. Appointments lasted for up to one hour and all data collection took place within a clinic in Bournemouth on the south coast of the UK.

3.6.4. Participant Appointments

On arrival at the data collection appointment, participants were reminded of the study details and what was involved as a participant. Their paper questionnaires, completed prior to the appointment, were checked for completeness. Missing data were discussed, agreed and added to their forms.

3.6.5. Medical screening

A medical history and clinical examination excluded those with signs or symptoms of 'red flags'. Red flags are a series of clinical features which may indicate serious underlying pathological conditions (Kendall 1997).

As such, prior to inclusion in the study, volunteers were screened for the following: a first incidence of low back pain when aged <20 or >55 years old, non-mechanical pain, radicular pain originating from spinal nerve root, thoracic pain, history of cancer, steroid use, structural changes to the spine, general feeling of un-wellness, night pains, unexplained weight-loss, bladder dysfunction or diffuse neurological deficits (Kendall 1997; Airaksinen et al. 2006; Chou et al. 2007). Where issues of concern were identified, volunteers were referred to their own general medical practitioner for assessment and excluded from the study.

3.6.6. Inclusion and Exclusion Criteria

CLBP affects adults of all ages from diverse cultural and socioeconomic groups (Hestbaek et al. 2006; Swain et al. 2014; Meucci et al. 2015). In an attempt for the study sample to reflect a wide population, within the limitations of geographic location and study recruitment strategies, the study inclusion criteria were purposefully kept broad and the exclusion criteria narrow while ensuring participants could safely undertake the tasks involved.

Established classification guidelines exist for diagnostically triaging those with low back pain into three groups (see Appendix 9.3.14 for a summary) (Karayannis et al. 2012). These guidelines were used to ensure that only volunteers meeting the criteria for chronic low back pain (also referred to as simple, ordinary or mechanical back pain in the literature) were included as participants within this study.

3.6.6.1. *Inclusion criteria*

Volunteers were included providing they were aged between 18 and 65 years of age, could read, understand and respond appropriately to the written and verbal instructions which were provided in the English language and could provide written consent.

3.6.6.2. *Exclusion criteria*

Volunteers were excluded if they reported, or the telephone or medical screen revealed: and of the red flags reported in 3.6.5, specific spinal pathology, nerve root pain/radicular pain (e.g. malignancy, fracture, infection, inflammatory joint or bone disease), lumbar spine surgery within the previous 2 years, osteoporosis, any major medical disease or condition that would affect tactile acuity or lumbopelvic motor function, visual or motor impairment, pregnancy or were 6 months' post-partum. They were also excluded if they reported any altered tactile sensation on their 3rd fingertip of their dominant hand because tactile acuity was measured at this location.

3.6.7. Defining the chronic low back pain and control groups

3.6.7.1. *The pain group:*

Participants were included in the pain group if they;

- met the inclusion criteria and;
- reported pain or discomfort persisting or recurring for longer than 3 months (Hildebrandt et al. 2004) which occurs on the dorsal region between the inferior twelfth ribs and the gluteal folds (Anderson 1977), with or without leg pain (Dionne et al. 2008; Treede et al. 2015) and;
- reported their pain to be of sufficient magnitude to limit or interfere with their activities of daily living (Dionne et al. 2008) OR they scored ≥ 5 points on the Roland Morris Disability Questionnaire (Roland and Morris 1983; Stratford et al. 1996).

3.6.7.2. *The control group:*

Participants were included in the control group if they;

- met the inclusion criteria and either;
- had never experienced low back pain or;
- reported a history of low back pain but it had *not* limited or interfered with their activities of daily living within the past two years and were;
- low back pain free on the day of testing

3.6.8. Anonymity and Confidentiality

Only one document was produced that contained non-anonymised data. This log held participants' names, contact details and corresponding study identification number and was stored as a password protected Microsoft Excel document. To ensure anonymity, on all other documentation, participants were identified using only their participant identification number (ID No).

3.6.9. Matching pain and control group participants

CLBP prevalence is greater in females and it increases with age (Meucci et al. 2015). To control for group selection bias introduced by unequal proportions of participant ages and genders, the matching of participants for age (± 3 years) and gender was planned using SPSS version 23.0 syntax (Taing and Carollo 2014; IBM Corp 2015).

3.6.10. Insurance, data storage and destruction

This study was insured under the Bournemouth University Public and Product liability insurance policy throughout its duration. Insurance certificates were renewed annually but copies of those at the time of data collecting are included in Appendix **9.3.15**.

All study data, personal details and test results will remain confidential, anonymous and kept in a lockable filing cabinet and/or a password protected computer/USB file. In accordance with Bournemouth University guidelines, data collected during the study will be destroyed after five years from the submission of the thesis for examination by viva.

3.6.11. Health and Safety Assessments

It was important to consider and reduce, where feasible, the health and safety risks that anyone involved with this project may have been exposed to. Bournemouth University risk assessments were completed prior to the commencement of this study. Approval was granted, and ongoing risk was monitored by the School Research Committee.

3.7. Piloting the Main Method

The entire main method was tested with two volunteers to ensure the participants understood the instructions and the number of elements was not overly burdensome. The full results of the pilot study (n=2) are reported in Appendix **9.3.16**.

The entire data collection process took longer than expected, but to reduce the appointment duration participants were to receive and complete their study documentation at least 24 hours prior to their appointment

One very important issue emerged; participants answers relating to low back pain required discussion to confirm their responses. This was because one of the pilot participants, who was known to have CLBP, reported she had no back pain because she had “learnt to live with her pain” so no longer regarded it as pain.

To ensure that the participants reporting ‘no pain’ really had no pain (within the realms of the study definition) and that different participants were referring to the same experienced sensations, a discussion was included within the medical screen to confirm the information provided on the questionnaire. Additionally, the questionnaire wording was amended to ask if participants experienced ‘pain or discomfort’ rather than ‘pain’.

3.8. Data Collection Process

A chronological summary of the complete data collection process for the main study is presented in Figure 3-8. Additionally, Figure 3-9 presents a flowchart to illustrate the planned data analysis to explore between group differences.

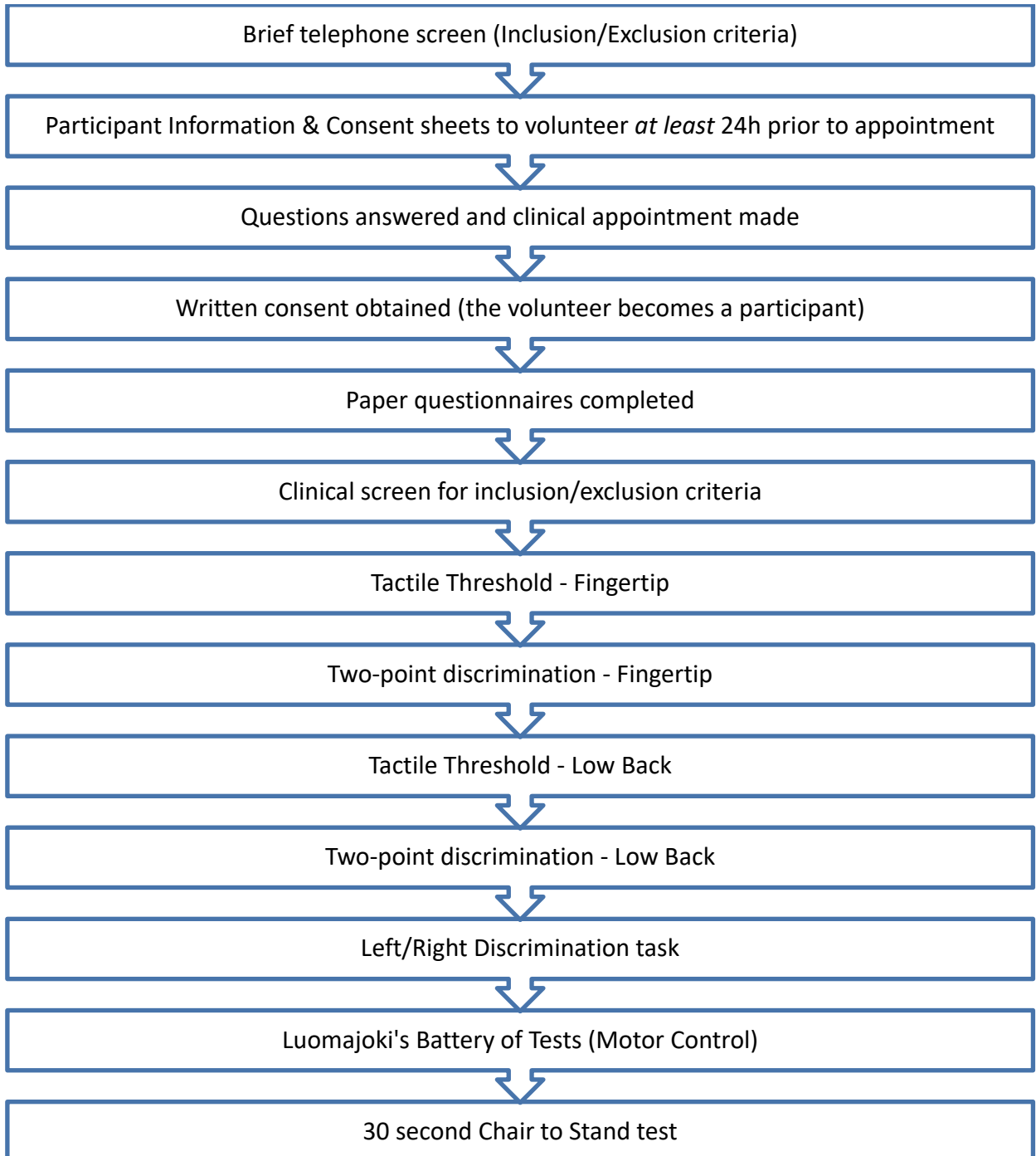


Figure 3-8 – Chronological process of data collection in the main study

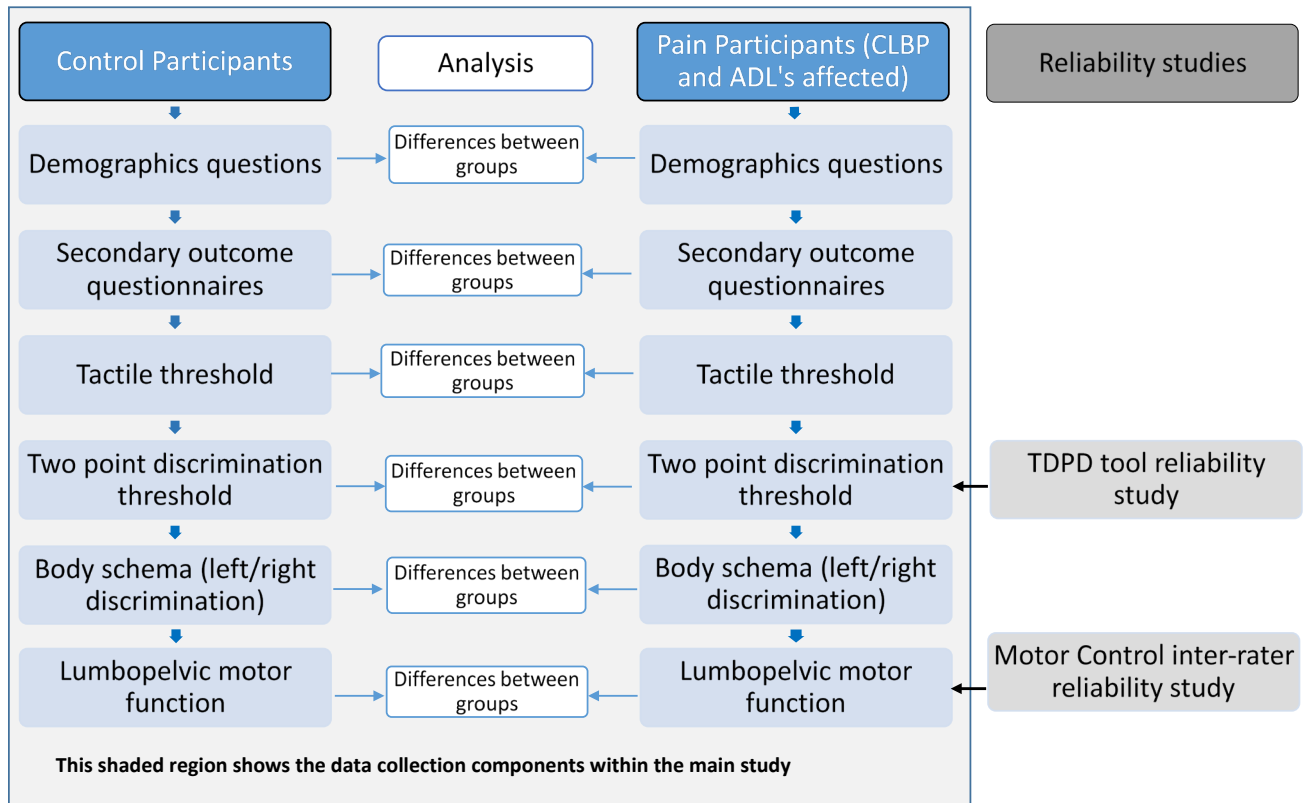


Figure 3-9 – Illustration to show participant flow through study and analysis plan to identify between group differences

NB: Secondary outcome questionnaires include measures of disability, pain and kinesiophobia

3.9. Methods of Data Processing and Analysis

3.9.1. Statistical Power and Sample Size Justification

Statistical power (β) indicates the probability that a study will fail to identify significance (α) when it was present. This is termed a Type II error. When one fails to reject a null hypothesis that is false, it is termed a Type I error.

It remains unknown whether we incorrectly fail to reject H_0 , or incorrectly reject it, but by setting limits to what is considered an acceptable risk and carefully considering the study design, the probability of committing each type of error can be controlled (Field 2013). Assessing the entire CLBP population is clearly not-feasible but increasing the sample size provides a better estimation of what is happening in the wider CLBP population. Larger sample sizes should return results that are closer to the 'true' mean (the mean of the entire population) and that have smaller amounts of variation. However, large sample sizes provide greater statistical power but ethical, time and financial limitations may prevent recruitment of large samples without adequate justification.

A further consideration is that statistical power (β) and significance (α) are inextricably linked. One cannot be improved without causing detriment to the other (Harris et al. 2008; Field 2013; Petrie and Sabin 2013).

Health and social care research commonly adopts the recommendation made by Fisher in 1925, where the probability of committing a Type I error was considered acceptable when α was set to 0.05, or one in 20 (Field 2013). Power was set to $\beta = 90\%$ because on an exploratory study of this nature, these levels for α and β were considered acceptable.

3.9.1.1. Sample Size calculation

An a priori power analysis was conducted using some of the low back TPDT data collected during the tool reliability study reported in Chapter Four and an online tool, www.ClinCalc.com (Kane 2016) to identify the number of participants required in the pain and control groups. The data used was that collected with the modified calipers as these were used in the main study. A sample size calculation for two groups and a continuous means endpoint, where $\alpha=0.05$ and $\beta=0.90$, revealed that to achieve 90% power of identifying a difference in TPDT, 31 participants needed to be recruited to each group, see Figure 3-10.

Table 3-2 – TPDT reliability study data used to calculate sample size for the main study

	History of CLBP (duration ≥ 3 months), n=10	No back pain, n=6	β = 90% power (Number per group)
TPDT at L3 vertebra Mean (SD)	69.75 (8.07)	78.95 (11.17)	31

Statistical Parameters

Anticipated Means

Group 1 ±

Group 2

Mean

Enrollment ratio

Type I/II Error Rate

Alpha

Power

RESULTS

Continuous Endpoint, Two Independent Sample Study

Sample Size		Study Parameters	
Group 1	31	Mean, group 1	78.95
Group 2	31	Mean, group 2	69.75
Total	62	Alpha	0.05
		Beta	0.1
		Power	0.9

$$k = \frac{n_2}{n_1} = 1$$

$$n_1 = \frac{(\sigma_1^2 + \sigma_2^2/K)(z_{1-\alpha/2} + z_{1-\beta})^2}{\Delta^2}$$

$$n_1 = \frac{(11.17^2 + 11.17^2/1)(1.96 + 1.28)^2}{9.2^2}$$

$$n_1 = 31$$

$$n_2 = K * n_1 = 31$$

$\Delta = |\mu_2 - \mu_1|$ = absolute difference between two means
 σ_1, σ_2 = variance of mean #1 and #2
 n_1 = sample size for group #1
 n_2 = sample size for group #2
 α = probability of type I error (usually 0.05)
 β = probability of type II error (usually 0.2)
 z = critical Z value for a given α or β
 k = ratio of sample size for group #2 to group #1

Figure 3-10 - Sample size calculation and formula (from www.clinicalcalc.com)

3.9.2. Processing Tactile threshold scores

Individual mean tactile threshold scores (in mm) were calculated for each location from the three repeated measures at each location per participant. The five locations were; 1) middle fingertip, 2) left L3 transverse process, 3) right L3 transverse process, 4) left transverse process central to painful region and 5) the right transverse process central to the painful region. Any participants not reporting low back pain would only have scores for the first three locations.

As there were no differences between tactile threshold scores at any of the back locations, all measurements were combined to calculate an overall mean tactile threshold score for each participant's back.

3.9.3. Processing TPDT scores

Calculating a mean TPDT score for the low back in individuals was complex. Based on a single study of pain-free healthy controls, a side-to-side TPDT difference of $\geq 13\text{mm}$, when assessed horizontally (with calipers placed perpendicularly to the spine), equated to a 95% confidence that a clinically important difference in TPDT truly existed in that individual (Wand et al. 2014a). However, this approach was not suitable for participants reporting bilateral pain. Bilateral in the context of this study refers to both the left and the right sides of the spine.

This study hypothesises that TPDT may be altered in those with CLBP and posits that alterations in TPDT are due to neuroplastic reorganisation of the cortices rather than from impairments to the tactile sensory structures. Cortical reorganisation of the S1 and S2 in relation to TPDT on the fingertip of those with CRPS occurs contralaterally to the side of typical pain (Pleger et al. 2006). There are no equivalent back studies but it could be argued that chronic pain related TPDT impairments elsewhere on the body may also be accompanied by similar patterns of cortical reorganisation.

CLBP frequently changes in location, side, pain intensity and quality. Therefore, if TPDT was impaired within the region of CLBP, any related cortical reorganisation that might be occurring within the contralateral hemisphere might also be influenced by these changing characteristics.

Although the direct assessment of cortical reorganisation was beyond this study's remit, it was important that these theoretical permutations were considered to allow for robust interpretations of the results. In practical terms, averaging TPDT scores from either side of a participant's spine to calculate a mean score for that individual was inappropriate.

This was because the significance of impaired TPDT measures on one side of the spine might be lost when averaging them with TPDT scores from the opposite, and perhaps more accurate side.

In those with unilateral pain this was not an issue because TPDT for the pain-free side can be considered a person's 'normal' value (Wand et al. 2014a). However, in those reporting bilateral pain, an individual's TPDT might be impaired to different degrees on either side of the spine. Therefore, in people reporting bilateral pain, the magnitude of altered TPDT might differ between the left and right sides of the spine.

There is no published literature pertaining to the problem, so a pragmatic approach was taken. The method for calculating an individual score of TPDT with regards to the participant's history of either; no pain, unilateral CLBP or bilateral CLBP is reported below.

3.9.4. Method of processing low back TPDT scores for individuals

The following procedure was undertaken for each participant to allow a fair comparison between participants reporting bilateral pain, unilateral pain or no pain.

Participants reporting bilateral low back pain (pain and control group) - For each vertebral level, a coin was tossed to select either the left or right side of the spine. TPDT data from the randomly chosen side was included in the data analysis.

The results from the two ascending and two descending runs of TPDT measurement were combined and the mean TPDT calculated. This was considered the TPDT score for that participant within the data analysis.

Participants reporting unilateral low back pain (pain and control group) - For participants reporting unilateral low back pain, individual low back TPDT mean scores were calculated from the data collected only from the pain side and these scores were used within the analysis.

Participants reporting no low back pain (control group) – Wand et al. (2014a) reported a negligible difference in TPDT when measured either side of the spine in healthy pain-free subjects. However, an identical method to that used for bilateral low back pain was adopted where data from one side of the spine was randomly selected for inclusion in the analysis. This approach improved the method robustness. For each vertebral level, a coin was tossed to select either the left or right side of the spine and TPDT mean scores were calculated using the TPDT measurements from that side.

3.9.5. Statistical analysis

Statistical analysis was conducted using IBM® SPSS Statistics Version 23.0 (IBM Corp 2015). Raw data from paper questionnaires and data recording sheets were keyed into an SPSS data file with the help of another person to avoid keying errors. One person read the scores and the other keyed in the data. Ten randomly selected data sets were then cross-checked. No errors were identified in keying the results.

3.9.5.1. *Normality testing*

Methods employed to compare the distribution of the study data to a standardised normal distribution included; visual assessment of frequency distributions, skewness and kurtosis, the Kolmogorov-Smirnov test (KS) and the Shapiro-Wilk test (SW) within SPSS.

For the KS and SW tests, data were considered normally distributed when significance >0.05 and parametric statistical tests were adopted. Significance ≤ 0.05 indicated that the data distribution differed significantly from normal and in this situation, non-parametric statistical tests were applied.

Finally, Q-Q Plots or normality plots were generated within SPSS and visually assessed. These plot the observed values against the expected values from a standard normalised distribution. A line-of-fit is plotted to represent the relationship between the observed values and the expected values based on the assumption that they belonged to the same distribution. Points that differed from the expected normal distribution were identified by their distance from the plotted line. Where data points lay away from the line, the data were considered not-normally distributed and non-parametric statistical tests were applied.

3.9.5.2. *Statistical testing of differences*

Descriptive statistics were performed to identify statistically significant differences between groups. Most of the data were not-normally distributed. The mean and standard deviation (SD) are more likely to be affected by the extreme values when the data is not-normally distributed. As such, rather than reporting the mean and SD, the median and interquartile ranges (IQR) were reported to describe the measure of central tendency and spread (Field 2013; Petrie and Sabin 2013).

Following assessment of the data for normality, appropriate tests to identify differences between the groups were applied. The means for each of the continuous variables, for example age and back width from the CLBP and control groups, were analysed for differences using the unpaired Student's *t* test. The medians from non-normal distributions, such as the pain scores (NRS-11) and the key outcome measures of TPDT, body schema and motor function were analysed for differences using the Mann-Whitney *U* test. Differences between groups for nominal data such as gender, work status and level of education were analysed using a chi-squared test.

A Wilcoxon signed ranks test for two related samples identified statistically significant differences in measures of TPDT from two regions on the low backs of the same participants in the pain and control groups.

3.9.5.3. Statistical testing of correlations

Correlation coefficients assess the strength and direction of a linear relationship between two variables. This measure is useful in that it quantifies how much a change in one variable correlates with a change in another.

Correlations between the key study outcome measures (TPDT, body schema and motor function), between TPDT and clinical outcome measures and between body schema scores and clinical outcome measures were made with the Spearman's rank correlation coefficient for non-normally distributed data. Spearman's rank correlation coefficient is denoted by r .

3.9.5.4. Interpreting Correlation Coefficients

Statistical correlation tests assess the strength and direction of relationships between variables. Cohen's (1988) guidelines are commonly used for interpreting the magnitude of correlation coefficients. Cut-off values for interpreting the magnitude of correlation coefficients are arbitrary. It is suggested that cut-off values should be justified in accordance to the clinical relevance of the study (Hemphill 2003). Robust clinical study design helps control for issues such as confounding factors, but their influence cannot be ruled out completely.

Although the cut-off values of Cohen (1988) are high in comparison to other recommendations such as those from Hemphill (2003), Cohen's (1988) guidelines were adopted to interpret the strength of correlation coefficients (r) where $r \geq 0.10$ indicates a small correlation, $r \geq 0.3$ a medium and if $r \geq 0.5$ a large correlation can be assumed (Cohen 1988).

3.9.5.5. Justification for not transforming data to normal distribution

By not following the 'normal' Gaussian distribution (meaning data being symmetrical with most data points clustered around the middle of the distribution, fewer scores at the tails, a smooth transition between them and the mean, median and mode lying perfectly in the

middle of the normal distribution), the data were appropriate for analysis using non-parametric statistics. Non-parametric tests are reportedly less robust than the parametric statistical tests designed to analyse normally distributed data. Consequently, many researchers transform non-normally distributed data using log transformations and analyse them using parametric tests (Fagerland and Sandvik 2009; Field 2013; Feng et al. 2014).

However, there are arguments for not transforming non-normally distributed data (Grissom 2000; Wilson 2007; Field 2013; Feng et al. 2014). The main reason of importance to this study is that the hypothesis being tested, and therefore the construct being measured, changes following data transformation. For example, if transforming data using a log transformation, instead of comparing arithmetic means, the comparison becomes one of comparing geometric means (Bland and Altman 1996b, 1996a; Field 2013). Therefore, even if no difference is found between the geometric means of the transformed data, it does not mean that there is no difference between the arithmetic means of the original data of the two samples (Feng et al. 2014).

Additionally, transforming data prior to analysis would mean that the results from this study were not comparative to those already published and examined within this study's systematic review (Moseley 2008a; Wand et al. 2010b; Bray and Moseley 2011; Luomajoki and Moseley 2011; Stanton et al. 2013; Wand et al. 2014b; Nishigami et al. 2015).

Finally, the outliers in the raw data, which may prove to be of great interest when exploring the data further as to why they might be different from the rest of the group, could be lost due to the data transformation process.

For these reasons this study's non-normally distributed data were not transformed and non-parametric statistical tests were used to test the hypotheses.

3.9.6. Justification of performing multiple tests

Performing multiple tests on clinical data increases the risk of identifying statistically significant findings when none exist. If statistical significance was set to $p = 0.05$, approximately one in twenty tests will likely be significant when no such significance exists. These are called type I errors, or false positives.

In this study, the aim was to explore sensory and motor function impairments in adults with and without CLBP. Previous studies have only explored one, or occasionally two, of

this study's three key areas of interest, so making comparisons between samples from different populations has not been possible. The multifaceted nature of CLBP adds to the importance of exploring multiple related factors in the same sample to provide a more rounded understanding of the relationship between these characteristics.

Perneger (1998) suggests the best way of dealing with multiple comparisons in such situations is to detail why and how tests of significance were performed and this has been undertaken within this thesis. Additionally, statistical corrections can be used to reduce the risk of type I errors, the most widely used is the Bonferroni calculation. Although, only about 1.2% of researchers report using corrective adjustments (Stacey et al. 2012). The Bonferroni calculation reduces the significance cut-off from 0.05 to 0.05 divided by the number of tests being conducted. For example, if 15 tests are performed, $0.05/15$ calculates a new value for significance where $p \leq 0.0033$. The Bonferroni calculation ensures that the probability of making type I errors across all tests remains at 0.05. However, it is overly conservative because it assumes 'that all null hypotheses are true simultaneously', which is unlikely (Perneger 1998; McLaughlin and Sainani 2014).

The exploratory nature of this study required a wide range of data collection from two groups to identify differences and correlations between the range of data collected. As such, a Bonferroni adjustment was calculated based upon data being collected from 17 sites per participant (assuming the left and right sides of the body were considered separate variables). This Bonferroni adjustment reduced the p value from $p = 0.05$ to $p \leq 0.0029$, or 2.9 in 1000.

None of the studies identified in the systematic review reported correcting their data for multiple analyses (Moseley 2008a; Wand et al. 2010b; Bray and Moseley 2011; Luomajoki and Moseley 2011; Stanton et al. 2013; Wand et al. 2014b; Nishigami et al. 2015). Their results might be comparable to those from this study, but if this study's data were corrected, dissimilar variables would be compared. Additionally, this study was exploratory in nature, meaning it aimed to identify specific areas for further investigation from a broadly investigated topic.

For these reasons, and the criticisms of the Bonferroni correction and similar corrective tests discussed earlier, the data was not corrected for multiple analyses and significance was maintained at $p \leq 0.05$ for this study. However, the Bonferroni correction was calculated and a summary of the results where significance was $p \leq 0.0029$ are presented in the appendices and are referred to in the results reported in Chapter Five.

3.10. Chapter Summary

This study aimed to explore sensory and motor function within CLBP and a control group. It designed to achieve this by analysing measures of TPDT, body schema, motor function and biopsychosocial metrics from a sample of 31 UK adults with CLBP that impaired their activities of daily living and an equivalent sized control group.

This chapter presented a description of the study hypothesis, strategy of enquiry, research design and data collection methods. The rationale for using an observational, analytical study design is justified and considerations for the ethical aspects of the study are presented. The chapter concludes with an explanation of the approaches taken to analyse the data with the aim of addressing the study's research questions.

Chapter 4. RELIABILITY STUDIES

4.1. Introduction

The two reliability studies reported in this chapter were undertaken to improve the robustness of the methodological study design by a) identifying the most appropriate calipers to measure TPDT on the fingertip and the low back and b) measuring the inter-rater reliability of Luomajoki's Battery of Tests when scored by raters who had not received specific training because the tests had previously been validated for use by raters who had received training (Luomajoki et al. 2007; Luomajoki et al. 2008). The two reliability studies were necessary because such data could not be located within the published literature. These reliability studies form Phase Two and Phase Three of the study (see **Table 3-1**) and contribute important information to the methods used in the main data collection stage of Phase Four.

Reliability is the degree to which an instrument or tool consistently returns the same measure when repeatedly used by the same rater (consistency) or by multiple raters measuring the same object (agreement) (Kim 2013). Error is expected during the measurement of all variables and quantifying such error is necessary to aid choosing the most appropriate instrument for a measurement task. Comparing differences, relationships and agreements between instruments informs decisions concerning whether instruments are appropriate for the purpose they were intended for, therefore ensuring reliability within the chosen method.

4.2. TPDT Tool Reliability Study

Two-point discrimination threshold (TPDT) is the term used to describe the shortest distance between two points at which a subject can clearly detect two points of contact without having sight of the instrument (Weber et al. 1996; Jerosch-Herold 2005).

Measuring TPDT using calipers is increasingly reported as a quantitative measure of tactile acuity (Cashin and McAuley 2017). This method has been tested for reliability in studies using a number of tools: opened out paperclips (Finnell et al. 2004), commercially produced tools such as the Disk-Criminator™ (Dellon et al. 1987; Crosby and Dellon 1989) and machined metal probes (Levin et al. 1989).

Fingertip TPDT typically ranges between 1 and 4mm in healthy adults (Weinstein 1968; Dellon 1981; Chandhok and Bagust 2002) and between 40mm and 67mm on the backs of healthy humans (Nolan 1985; Wand et al. 2010b; Luomajoki and Moseley 2011; Stanton et al. 2013; Wand et al. 2014a; Falling and Mani 2016a).

Various types of calipers, including Vernier calipers, have been used to assess small scale (fingertip) and larger scale (back) TPDT (Dellon et al. 1987; Moberg 1990; Catley et al. 2013b; Wand et al. 2014a). To date, no reviews have been published that investigate participant preference or the results obtained from different types of calipers. Therefore, it is unknown whether different calipers measure TPDT with acceptable levels of agreement. Presently, TPDT results between studies are discussed as if calipers are interchangeable and the results produced are synonymous (Catley et al. 2014b; Adamczyk et al. 2017b). Understanding agreement in TPDT measurements between calipers is important if between-study comparisons are to be made but also in deciding which instrument is most appropriate.

It is also possible that metal prongs, perceived by volunteers in practise sessions to be colder and sharper than plastic prongs, add to the sensory input by triggering thermal receptors in addition to tactile receptors. Increasing acuity through knowingly activating additional neurophysiological pathways would not be an equivalent method of measuring TPDT to the studies identified in the systematic review. This led to a search for calipers that would reliably report measures of fingertip and low back TPDT and be comfortable for participants during use.

4.2.1. Aim

This study aimed to quantify the measurement agreement between metal, plastic and modified Vernier calipers when measuring TPDT on the low back and fingertip in a group of adult volunteers. Fingertip TPDT studies are widely reported in the literature (Tong et al. 2013; Schmauss et al. 2014; Lai et al. 2015), so the main aim of this study was to investigate TPDT on the low back. In addition, the participants were asked which tool they preferred. The results were used to determine which tool would be used to measure TPDT in the main part of this study.

4.2.1.1. Informed Consent

Participant information packs were issued to all participants at least 24 hours prior to beginning data collection (Appendix 9.4.1 and 9.4.3). The study was discussed, questions were answered and the consent forms signed at the data collection meeting (Appendix 9.4.2). Participants were reminded they could withdraw at any time, but none did so. All participants provided written informed consent prior to taking part in the study.

4.2.1.2. Ethical approval

Ethical approval for the project was granted by Bournemouth University Research Ethics Committee (Reference ID: 9677) and the AECC Research Ethics Sub-Committee (Approval Number: E71/11/15). Copies of the approval letters are provided in Appendix **9.3.12**.

4.2.1.3. Inclusion criteria

Adults aged between 18 and 65 years of age, with or without CLBP, were included providing they could read, understand and respond appropriately to the written and verbal instructions in the English language and they could provide written consent.

4.2.1.4. Exclusion criteria

Volunteers were excluded if they were unable to lie prone comfortably for at least 10 minutes, were pregnant or 6 months' post-partum, reported any neurological condition or scar tissue over the region of assessment on the low back or fingertip.

4.2.2. Null Hypothesis

Given that differences between the metal and plastic calipers might be expected due to the cold metal activating thermal neural pathways perhaps not activated by the warmer plastic, H_0 was defined as: There is agreement between TPDT measurements resulting from three types of Vernier calipers.

4.2.3. Method

A pragmatic approach to recruitment provided a convenience sample of 16 volunteers within a one week period in February 2016. Volunteers were recruited through Bournemouth University, a private healthcare clinic, business contacts and social media. Volunteers were between 18 and 65 years of age and were recruited whether or not they reported a history of CLBP.

Demographic data (gender, age, height and weight) were collected to provide descriptive statistics for the sample group.

Vernier calipers, also known as a Vernier Scale, were originally designed to measure internal and external distances with great accuracy. They are most commonly used in engineering situations. However, several studies have used metal or plastic versions to assess low back TPDT (Moseley 2008a; Catley et al. 2013b; Catley et al. 2014c; Trapp et al. 2014a; Wand et al. 2014a; Nishigami et al. 2015; Wälti et al. 2015).

The calipers used in this study included a plastic set, a metal set which were purchased and not altered in any way and a modified set which were based upon the work of Levin et al. (1989) but plastic pointed tips were used instead of metal (see Figure 4-1).

The modified calipers were constructed from a cheap set of Vernier calipers (£6, www.ebay.co.uk), plastic cocktail sticks, Blu-tac™ and duct tape (see Figure 4-2). The modifications prevented the probes from touching, meaning the tips of the cocktail sticks were separated by 2mm when closed. This meant the tips measured 2mm wider than the digital display reported. To compensate the calipers digital screen was set to zero when the tips were 'closed' and 2mm was added to each reading from the digital screen prior to data analysis. Metal cocktail sticks were sourced but were considered too sharp and the researchers concern of piercing skin meant they were not included in the study.

Three different Vernier calipers were used;

- a) **'Metal'** - Metal tipped 150mm digital Vernier calipers (Digitronic Caliper 110-DBL series supplied by Moore and Wright with a certificate of accuracy to $\pm 0.02\text{mm}$ and repeatability of 0.01mm and resolution of 0.1mm — certificate number 273430). Cost £22 (local hardware suppliers).
- b) **'Plastic'** - Plastic 150mm digital Vernier calipers (Unbranded and non-certified but suggested accuracy of $\pm 0.2\text{mm}$ and resolution of 0.1mm). Cost £6 (www.ebay.co.uk).

- c) **'Modified'** - Modified plastic 150mm digital Vernier calipers (as reported in b. above) using smooth, pointed, but not sharp plastic cocktail sticks, Blu-tac™ and duct tape. Cost £7 for calipers and materials (www.ebay.co.uk).

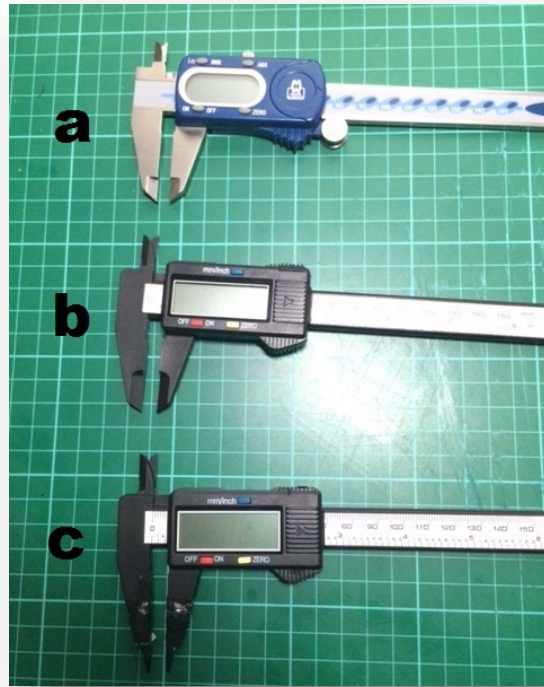


Figure 4-1 - Reliability study Vernier calipers

(a: Metal, b: Plastic, c: Modified)



Figure 4-2 - Modified calipers

(NB: The tips remain 2mm apart when 'closed')

4.2.4. Validation of calipers

Construct validity assesses how well an instrument measures what it claims to measure (Creswell 2013). The metal calipers were received with a certificate of accuracy so this set was used to validate the others which had no certificate. A precision machined stainless steel part with a known diameter of 19mm was measured three times with each of the calipers, see Figure 4-3. All calipers recorded the diameter as 19mm for each assessment, indicating perfect agreement between the three sets of calipers.



Figure 4-3 - Validity assessment using a precision machined part of 19mm diameter

4.2.5. Location of TPDT assessment

TPDT was assessed twice at three anatomical sites in each volunteer. The first and second sites were bilaterally at the left and right lateral tips of the transverse processes of the 3rd lumbar vertebra (L3). These vertebral sites were located as described in section 9.3.3. Thirdly, TPDT was measured on the pad of the middle finger of each participant's dominant hand (their self-reported writing hand) to provide a baseline measure TPDT in the sample group.

Most studies reporting low back TPDT assess it bilaterally at L3 (Wand et al. 2010b; Luomajoki and Moseley 2011; Trapp et al. 2014a; Adamczyk et al. 2015; Nishigami et al.

2015; Wälti et al. 2015). However, the researcher was unable to identify any justification for assessment at this vertebral level over any other. To enable comparisons with published results and because in the researcher's experience, CLBP is rarely reported at the L3 vertebral level so pain related TPDT impairments at that region were less likely, the low back assessment for this reliability study took place either side of the spine at L3.

4.2.6. TPDT Measurement Method

Measurements took place in the same location, a room maintained at 21°C and were made by a left-hand dominant (for writing) assessor who uses their right hand for some tasks, such as using a computer mouse and scissors.

All assessments were made in the following order; metal, plastic and finally modified calipers. Assessments of the finger palp took place first, then the left L3 and the right L3 transverse process. One ascending and one descending run was recorded per location and participants were asked which calipers they preferred. Calipers points were moved further apart during ascending runs and closer together in descending runs. These types of assessment are known as a staircase due to their shape when plotted on a chart. An adaptive staircase, where the change from an ascending to a descending run (or vice versa) was directed by the participant's response was adopted for this study. The adaptive staircase had a three alternate forced-choice method ("one", "two" or "don't know") and was used because it introduced less reporting bias than other methods available to quantify sensation measurements, such as TPDT (Yarnitsky and Pud 1997; Klein 2001).

TPDT testing began with an ascending run (staircase) and participants were asked to respond with only "one", "two" or "don't know". When they correctly identified two points, the direction of increase between the calipers was reversed and a descending run or staircase began and the calipers moved closer together. On the back, beginning with calipers 30mm apart, 10mm increasing steps were used in the initial staircase, 5mm in the next and 1mm in the remaining staircases. On the fingertip, beginning with calipers 5mm apart, 1mm steps were used in the initial staircase and 0.5 mm steps in the remaining staircases. Single points of contact, 'catch trials', were introduced between every three to five two points of contact to check participants were not guessing. Mean TPDT was calculated using the measurements from the last five staircases.

The modified calipers were inspected after TPDT was recorded at each part of the body and the checks revealed no damage or movement of the tips throughout the study. The two points were simultaneously contacted with the skin until the 'very first blanching' of the skin could be seen (Moberg 1990) or slight indentations if the skin was very pale.

4.2.6.1. Method specific to the Fingertip

During assessment of the hand, the participant and assessor were seated with a small table between them to reduce unwanted movement. The participant rested their dominant upturned (supinated) hand on a firm, foam cushion placed on the table. Their forearm also rested on the table. The assessor stabilised the participant's middle finger by holding it laterally to the palp of the distal phalanges. Participants were asked to close their eyes.

The assessor's elbows and wrists were resting on the table throughout and the calipers were grasped near the probe-tips with the right hand. The left index finger guided the right hands' approach to the skin to avoid further unwanted movement.

The assessor applied the prongs simultaneously with sufficient pressure for participants to 'just sense light contact'. This technique was demonstrated on the index fingertip so the participant knew what to expect and the assessor could adapt the pressure as necessary.

4.2.6.2. Method specific to the Low back

During assessment of the back, volunteers lay prone on a padded bench, with their head supported by a head rest. To improve comfort of the low back and to encourage participants to relax, a slight knee flexion was created by raising their ankles on small bolster cushion.

The researcher adjusted bench height as necessary, sat on a wheeled stool and ensured her arms remained relaxed but braced against her body. The calipers were held in the right hand, as close to the tips as possible and the left hand supported the right wrist. Contacting the points onto the low back was carefully observed and if simultaneous contact was not achieved, the process was repeated to avoid recording measurements obtained using poor techniques.

Assessments at L3 occurred on a medial to lateral axis (tool held perpendicular to the spine). The transverse processes were located using landmark position assessments with the patient prone and a technique reported by Biel (2014). The landmarks of the superior iliac crests were palpated, then the palpatory fingers were moved medially to locate the spinous process of the L4 vertebra, which lies directly between the iliac crests. Moving superiorly while palpating the spinous processes allowed for the location of the L3

vertebra. Using one finger, light contact was maintained over the L3 spinous process while locating its superiorly and laterally positioned transverse processes. The transverse processes of L3 are located laterally to the inferior part of the L2 spinous process. To ensure the correct structure was located, a slight posterior to anterior (P-A) pressure was applied to the transverse process. If correctly positioned, the slight P-A pressure resulted in lateral movement of the L3 spinous process under the finger maintaining contact. The L3 transverse processes were marked with a temporary marker pen and used as the medial anchors for the medial caliper probe. TPDT was assessed using an adaptive staircase method as reported above.

4.2.7. Analysis

Results for the modified calipers were corrected prior to fingertip and left/right low back TPDT means being calculated. Repeated measures Analysis of Variance (ANOVA) tests identified the presence of significant differences between the measures of TPDT and post-hoc Pairwise Comparisons identified where the differences lay.

Pearson Product Moment Correlation Coefficients (r) were calculated and described the linear relationships between the measurements from the caliper pairs (plastic and metal, metal and modified, or modified and plastic) and significance was set at $p \leq 0.05$. Performing multiple analyses on the same data sets increases the chance of type I errors occurring (finding significant results when none really exist). Bonferroni Corrections were performed to counteract this effect by lowering the threshold for statistical significance (McLaughlin and Sainani 2014).

The Pearson Product Moment Correlation Coefficient (r) is a measure of the unknown and unpredictable error (random error) between two measurements. As such, r describes the strength of the relationship but not the agreement between two sets of variables (Ludbrook 1997; Giavarina 2015). Likewise, r^2 provides the proportion of variance that the two measurements share (Giavarina 2015).

The Bland Altman Limit of Agreement Test (Bland and Altman 1986) quantify the agreement between two variables by constructing limits of agreement, recommended to be ± 1.96 x standard deviations of the mean difference between the variables, within which 95% of the plotted data points should fall (Bland and Altman 1986). The limits of agreement are particularly useful in that they allow assessment for both systematic bias and random error (Bland and Altman 1986). Visual assessment of the plots allows for an assessment to be made of the systematic bias and agreement between the two variables and can be used to compare the reliability of two instruments in measuring the same

entity (Atkinson and Nevill 1998; Giavarina 2015). If the distribution of the within-pair mean differences, rather than the distribution of the raw data, is normally distributed; the pairs of measurements come from different individuals and finally, equal variability across the range of measurements exists. Therefore, the Bland-Altman Limit of Agreement Test is an appropriate measure of agreement. Following visual assessment of frequency histograms and the Kolmogorov-Smirnov Test for normality (Field 2013), plots were created per caliper pair with the *difference* between the two TPDT score obtained using different calipers (within-pair mean difference) on the y-axis, against the same individual's *mean* TPDT score from the same two calipers on the x-axis (Bland and Altman 1986).

Bland Altman plots and their limits of agreement cannot provide a definitive answer to whether two methods are comparable, but the plots can indicate whether the bias seen between pairs is significant. Therefore, they can provide evidence on which a decision can be made providing the purpose and goals of the study are taken into consideration.

The size of the maximum acceptable difference or the limit of acceptable agreement varies with different clinical situations so it was important that the researcher had knowledge of the specific field being investigated. Based upon the literature review, the researcher's knowledge of the tool and the methods used in measuring two-point discrimination, the maximum acceptable differences in measurements obtained using different calipers were set *a priori* to 10mm between low back TPDT measurements and 1mm between fingertip TPDT measurements. These maximum acceptable differences reflected the size of the largest steps in the adaptive staircase method used to measure TPDT. This meant that a change in staircase direction following a correct response would be less likely due to systematic error introduced by the instrument type. Any value greater than these acceptable differences reflected a substantial difference between calipers and indicated that calipers were not interchangeable within the context of this study. It may also indicate the measurement of different entities.

Bland-Altman plots were created using SPSS version 23.0 (IBM Corp 2015). Upper and lower limits of agreement were calculated for each pair using the mean differences ± 1.96 x the standard deviation of the differences. Limits of agreement confidence intervals of 95% were calculated and added to the plots prior to visual assessment. Mean differences and limits of agreement were tabulated alongside 95% confidence intervals for each caliper pair.

Bland Altman plots were created for all caliper pairs measuring TPDT at the low back and fingertip. The aim of this reliability study was predominantly to assess agreement in TPDT measurements on the low back between each of the three caliper pairs. This was

because low back TPDT assessment was of primary importance to this study and while a few reliability studies existed relating to inter- and intra-rater reliability, none related to the type of tools used in measuring TPDT. As such, the method for choosing an appropriate tool required clarity. Only one such study was known to the author and that compared the shape of metal probe tips in measuring fingertip TPDT (Levin et al. 1989). This study guided the design of the modified caliper tips tested in this reliability study. Examining agreement between different calipers was undertaken to help choose the correct tool for assessing low back TPDT on the low back in the main study.

4.2.8. Results

Participant demographics are presented in Table 4-1 to set context and the mean TPDT for the fingertip and low back scores, by caliper type, are presented in Table 4-2.

Assumptions were met and data was normally distributed.

Table 4-1 – TPDT caliper reliability study - Participant Characteristics

Variable	
N, female	16 (8)
Age (years), mean (SD)	46.5 (10.0)
Right hand dominant (self-reported)	15
Height (cm), mean (SD)	175.0 (11.0)
Weight (kg), mean (SD)	80.0 (15.5)
BMI, (kg/m ²), mean (SD)	26.0 (3.4)
History of CLBP (duration ≥ 3 months), n	10
NRS pain score today, mean (SD)	2.0 (1.3)

N: number, SD: standard deviation from the mean, cm: centimetres, kg: kilograms, BMI: body mass index, kg/m²: kilograms per square meter, CLBP: Chronic low back pain, NRS: Numerical rating scale 0-10.

Table 4-2 - TPDT caliper reliability study - Mean TPDT by location and caliper type

TPDT location	TPDT mm, mean (SD)			p value
	Plastic	Metal	Modified	
Middle finger palp	2.6 (0.5)	2.7 (0.4)	2.8 (0.6)	0.528 [§]
Back TPDT	78.6 (11.2)	78.7 (10.4)	76.1 (10.0)	0.025 ^{*§}

n = 16 for each group, TPDT: two-point discrimination threshold, mm: millimetres, SD: standard deviation from the mean, § One-Way Repeated Measures Analysis of Variance, * p ≤ 0.05.

4.2.8.1. Fingertip TPDT results

Fingertip TPDT measurements ranged from 1.8 to 3.9mm when measured using three different sets of calipers in 16 participants.

Visual assessment of the Bland Altman plots for the fingertip revealed no obvious pattern to the plotted data points and estimated the bias between caliper pairs. The plots are presented in Figure 4-4 and show the mean differences between each caliper pair ranged from -0.07 to 0.14mm but a one-way repeated measure ANOVA found the effect of the calipers on the fingertip TPDT measurements was not significant, ($F(2, 30) = 0.652, p = 0.528$).

Pearson Product Moment Correlation Coefficients computed the strength of the relationships between fingertip TPDT measurements from the different calipers. There were significant positive correlations between metal and plastic calipers, $r(16) = 0.617, p = 0.011$ and between the plastic and modified calipers $r(16) = 0.643, p = 0.007$, but not between the metal and modified caliper sets, $r(16) = 0.338, p = 0.201$.

R^2 reported the proportion of variance shared by the calipers to be 38% between the metal and plastic calipers, 41% between the plastic and modified calipers and 11% between the metal and modified calipers.

The mean differences and limits of agreement for the fingertip are presented in Table 4-3 and were used to create the Bland Altman plots presented in Figure 4:4. Following visual assessment of the fingertip Bland Altman plots, the upper and lower limits of agreement and the most conservative estimates from the 95% confidence intervals revealed fingertip TPDT measurements between calipers could differ by up to -1.76mm below zero and 1.62mm above zero, where zero indicated absolute agreement between the caliper pairs.

Table 4-3 - Mean Differences and Limits of Agreement for all caliper pairs measuring TPDT on the Fingertip

Caliper Pairs	Mean difference in TPDT between calipers (95% CI)	Lower LOA (95% CI)	Upper LOA (95% CI)
Metal Vs. Modified	-0.07 (-0.36, 0.22)	-1.25 (-1.76, -0.74)	1.11 (0.60, 1.62)
Metal Vs. Plastic	0.07 (0.27, -0.13)	-0.72 (-1.06, -0.38)	0.86 (0.52, 1.20)
Plastic Vs. Modified	0.14 (-0.10, 0.38)	-0.81 (-1.23, -0.34)	1.09 (0.67, 1.51)

Vs: versus, TPDT: Two-point Discrimination Threshold in millimetres, CI: Confidence Interval, LOA: Limits of Agreement.

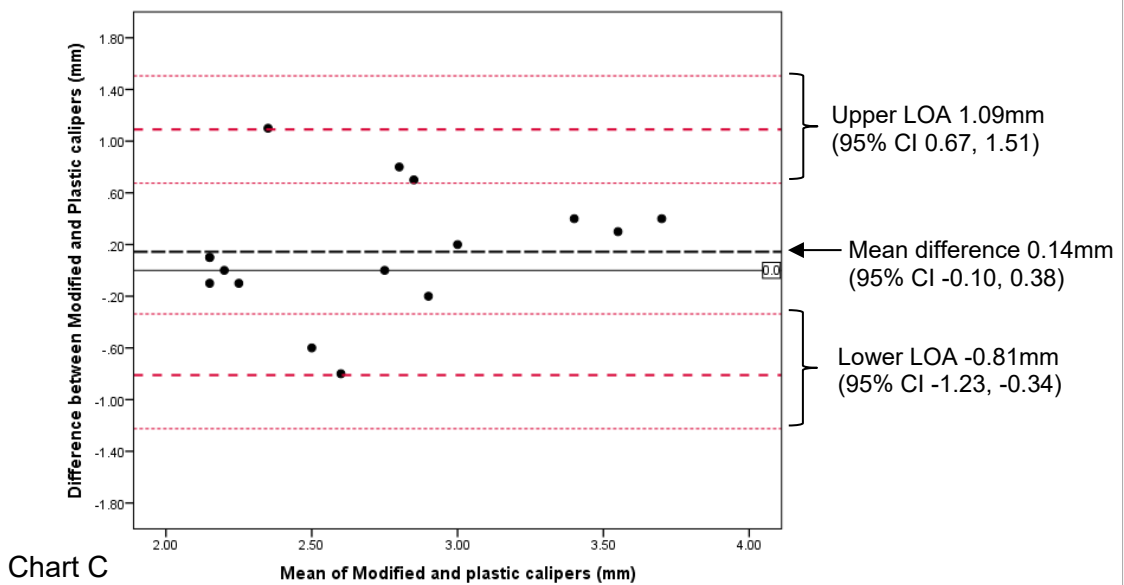
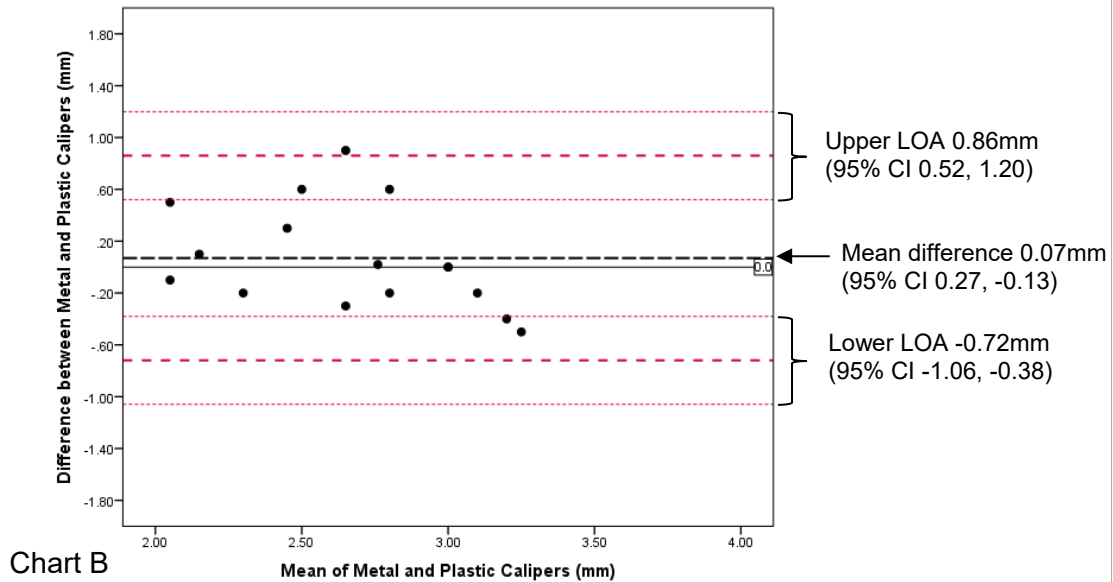
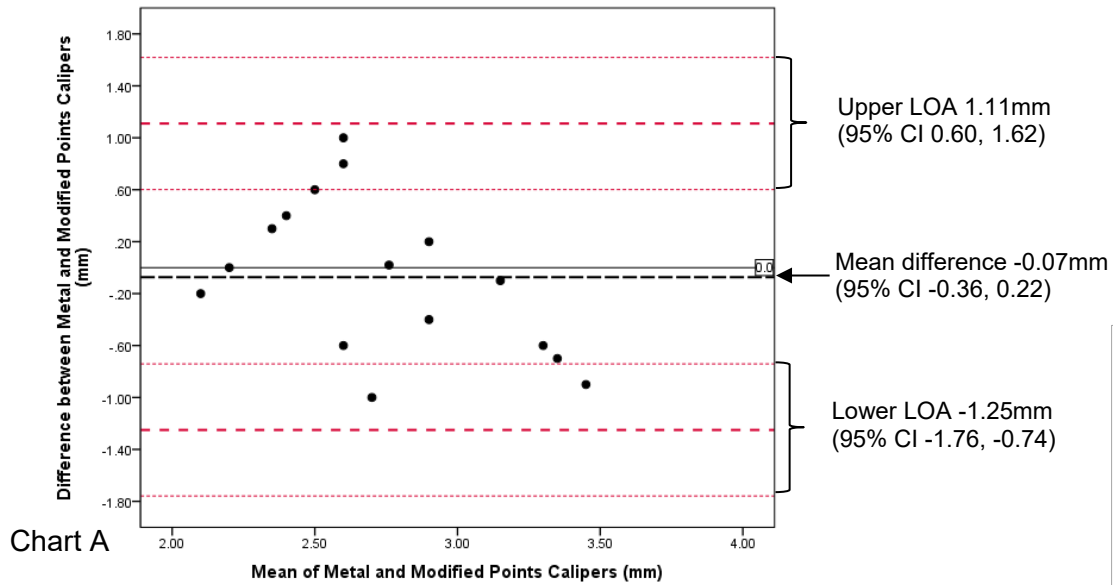


Figure 4-4 - Bland-Altman plots to show agreement between Fingertip TPDT measured with three calipers

n=16

Upper chart (A) – Bland-Altman plot to show agreement between fingertip TPDT measured with metal and modified point calipers.

Middle chart (B) – Bland-Altman plot to show agreement between fingertip TPDT measured with metal vs. plastic calipers.

Lower Chart (C) - Bland-Altman plot to show agreement between fingertip TPDT measured with modified point vs. plastic calipers

Black dashed lines indicate the mean difference between TPDT measurements obtained using each pair of calipers.

Red dashed lines show the upper and lower 95% Limits of Agreement (LOA).

Red dotted lines above and below the upper and lower limits of agreement show 95% confidence intervals for each limit.

Solid lines denote zero (line of equality)

4.2.8.2. Low Back TPDT Results - Differences, Correlation and Agreement

Low back TPDT measurements ranged between 54 to 98mm when measured using three different sets of calipers in all 16 participants. Mean TPDT by location and caliper type are presented in Table 4-2. There were no significant differences between left or right back measurements, so an overall back mean was calculated using the left and right back means and this was utilised in the further analysis.

A statistically significant difference in low back TPDT when measured using different caliper sets was identified using a one-way repeated measures ANOVA ($F(2,30) = 4.202$, $p = 0.025$). A Pairwise Comparison Test, adjusted to account for multiple comparisons using the Bonferroni Correction, identified where these differences lay. The test revealed that after the correction needed due to the modified calipers construction (see section 4.2.3 for details), the modified calipers measured low back TPDT to be 2.5mm less than plastic calipers and this was statistically significant ($2.5 \text{ SE} \pm 0.892$, $p = 0.04$).

The mean differences and limits of agreement presented in Table 4-4 were used to construct the Bland Altman plots in Figure 4-5.

Table 4-4 - Mean Differences and Limits of Agreement for all caliper pairs measuring TPDT on the Low Back

Caliper Pairs	Mean difference in TPDT between calipers (95% CI)	Lower LOA (95% CI)	Upper LOA (95% CI)
Metal Vs. Modified	2.61 (0.26, 4.96)	-6.78 (-10.9, -2.66)	12.0 (7.9, 16.1)
Metal Vs. Plastic	0.12 (-1.72, 1.96)	-0.72 (-1.06, -0.38)	7.49 (4.30, 10.68)
Plastic Vs. Modified	-2.5 (-4.06, -0.95)	-9.5 (-12.54, -6.48)	4.5 (1.46, 7.84)

Vs: versus, TPDT: Two-point Discrimination Threshold in millimetres, CI: Confidence Interval, LOA: Limits of Agreement.

The modified calipers also returned low back TPDT measurements to be 2.6mm less than the metal calipers. Visual assessment of the Bland Altman plot (Figure 4:5, plot A) revealed the line of equality to fall just outside the confidence intervals of the mean, which provides an estimate that the bias between the two measures may be significant (Giavarina 2015). However, further Pairwise Comparisons and Bonferroni Corrections reported this difference not to be significant ($2.61 \text{ SE} \pm 1.196$, $p = 0.136$). No notable differences were observed or calculated between the metal and plastic calipers ($-0.109 \text{ SE} \pm 0.94$, $p = 1.0$).

Pearson Product Moment Correlation Coefficients revealed significant positive correlations between each pair of calipers where r was greater than 0.89 and $p \leq 0.001$ for each pair. However, the strongest correlation occurred between modified and plastic calipers, $r(16) = 0.949$, $p \leq 0.001$.

R^2 calculated the proportion of variance shared by the calipers to be 89% between metal and plastic calipers, 90% between the plastic and modified calipers and 79% between the metal and modified calipers.

Visual assessment of the Bland Altman plots revealed wide variability in the limits of agreement between the pairs, with the greatest distance between the limits occurring between the metal and modified calipers (Chart A in Figure 4-5). All data points fell between the 95% limit of agreements and there were no obvious patterns to the data distribution.

The upper and lower limits of agreement and the most conservative confidence intervals for low back TPDT measurements between the metal and modified calipers (Chart A in Figure 4-5) could differ by up to -10.90mm below zero and 16.10mm above zero, where zero indicated absolute agreement. Metal and plastic caliper measurements (Chart B in Figure 4-5) differed by up to -10.40 to 10.68mm. Plastic and modified caliper measurements (Chart C in Figure 4-5) differed by up to -12.54 to 7.84mm. For perspective, the plastic versus modified caliper measurements of the low back differed by up to 26%.

Figure 4-5 - Bland-Altman plots to show agreement between low back TPDT measured with three caliper pairs

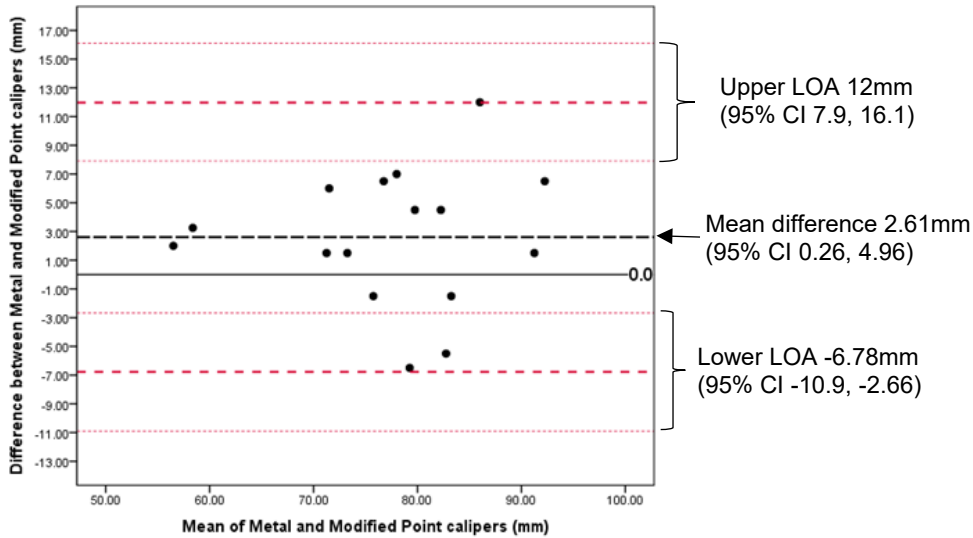


Chart A

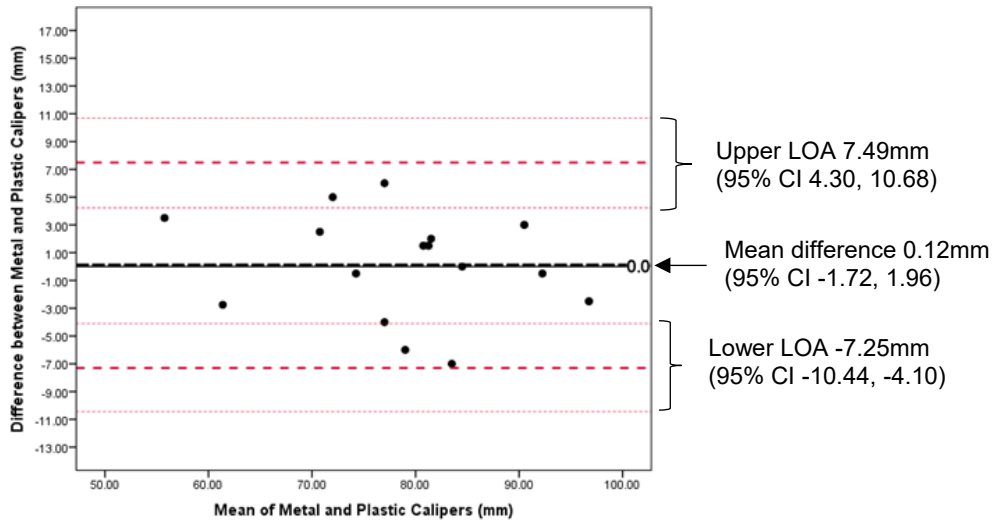


Chart B

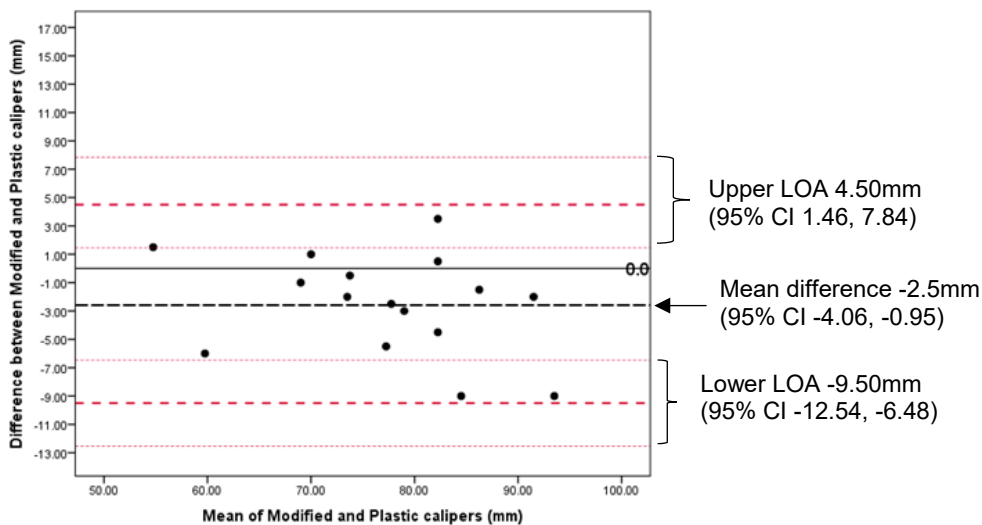


Chart C

n=16

Upper chart – Bland-Altman plot to show agreement between low back TPDT measured with metal vs. modified point calipers.

Middle chart – Bland-Altman plot to show agreement between low back TPDT measured with metal vs. plastic calipers.

Lower Chart - Bland-Altman plot to show agreement between low back TPDT measured with modified point vs. plastic calipers

Black dashed lines indicate the mean difference between TPDT measurements obtained using each pair of calipers.

Red dashed lines show the upper and lower 95% Limits of Agreement (LOA).

Red dotted lines above and below the upper and lower limits of agreement show 95% confidence intervals for each limit.

Solid black lines denote zero (line of equality)

4.2.8.3. Tool preference

Participants preferred tool preferences are reported in Table 4-5. Most participants preferred the modified calipers. Only one person preferred the metal and none preferred the calipers constructed of plastic.

Table 4-5 - Participant preference of calipers - results

Caliper description	Participant preference, <i>n</i>
Plastic	0
Metal	1
Modified	13
Either Metal or plastic	1
Either Metal or Modified	1

n = 16

4.2.9. Discussion

This reliability study investigated TPDT measurements collected from the same participants, by the same researcher, using three sets of calipers. The aim was to quantify agreement between the calipers and inform the methodological process of selecting the most appropriate calipers to collect TPDT data in the main part of this research project. This was important because it was unknown whether different calipers returned different measurements of low back TPDT. The findings from this study provided robustness to the process of choosing the most appropriate type of calipers for the task.

Strong positive correlations were seen between measurements of TPDT from each caliper pair but the strongest correlation occurred between the modified and plastic calipers. The strength of these correlations indicated that the relationships between caliper pairs were maintained when measuring TPDT of different magnitudes. High levels of correlation were expected because any two methods designed to measure the same variable should be highly related. However, correlation analyses identify the strength of the relationships between two variables and not the differences between them (Bland and Altman 1986). Therefore, the significant correlations seen between each caliper pair did not mean the measurements returned by one caliper set agreed with those returned by another.

The Bland Altman plots compared the mean differences between caliper pairs and enabled visual assessment of the limits of agreement. Bland Altman limits of agreement are typically set at 95%, indicating that an estimated 95% of the mean differences in measurements between the two methods, in this case TPDT measured using two different types of calipers, would be expected to fall between them. These limits provided an estimate of the measurement bias that could be expected between any further assessments made using these methods in a wider population.

In this reliability study, all the low back data points fell between these 95% limits. As Bland Altman's limits of agreement are only estimating the values which might apply to the wider population, 95% confidence intervals for the upper and lower limits of agreement were calculated to determine how precise the limits of agreement were. These 95% confidence intervals were much wider for the metal versus modified calipers (Figure 4-5, chart A) than for the modified versus plastic calipers (Figure 4-5, chart C), which probably reflects the greater variation in the mean differences seen between the metal and modified calipers.

Wide confidence intervals can indicate problems with sample sizes (Bland and Altman 1986), but the confidence intervals differed between each pair, despite the same sample being used throughout the study. If sample sizes were too small, wide confidence intervals would have been observed for each plotted pair, but this was not the case. Therefore, something other than sample size must have influenced the results.

The acceptable level of difference, as a measure of acceptable agreement, was set *a priori* to match the adaptive staircase method used for measuring TPDT where the level of acceptable difference equalled one step in the measurement of TPDT (10mm for the low back and 1mm for the fingertip). However, the low back 95% confidence intervals of the limits of agreement disclosed that the most conservative estimates returned large differences between the caliper pairs which exceeded the set level of acceptable difference. Clearly, the scale of fingertip TPDT measurement was smaller than that of the low back, but proportionally large differences were also seen in the fingertip which exceeded the predetermined level of acceptable difference. Thus, the calipers did not agree and could not be considered interchangeable when measuring TPDT at either the low back or fingertip. However, consistency when measuring different magnitudes of TPDT and patient comfort, rather than caliper interchangeability, were important to this study design. Agreement between calipers would have provided wider choice in the selection of the most appropriate type, but the lack of agreement did not impact the proposed main study method.

These findings could guide future researchers in the selection of an instrument to measure TPDT, in the level of detail required when reporting the instrument (including the make, model and whether the caliper tip was metal or plastic) and in highlighting previously unreported issues when comparing cross-study results which will have been influenced by the methods used to measure TPDT.

Despite this lack of agreement, most mean differences between calipers were not significantly different. In the fingertip, none of the differences between any of the calipers were significant. From the low back, only the modified calipers consistently returned smaller TPDT measurements than the plastic and metal calipers. The more widely distributed mean differences noted between the metal versus modified calipers may have been the reason significance was not met between this pair when it was met between the modified versus plastic calipers which had more closely distributed data points. Visible assessment of the data points on the Bland Altman plots for the low back revealed no obvious relationships between the mean differences and the means for each caliper pair. This suggested that none of the mean differences were related to the magnitude of TPDT.

Consequently, the measurement bias seen between the calipers appeared to be random rather than systematic. The precise nature of why there was a small mean difference between the modified and plastic calipers may have simply been due to chance. After all, $p = 0.05$ represents a 1/20 possibility of the result being due to chance, or that we can only be 95% certain that the difference observed was real. In fact, prior to data collection all three calipers were validated to accurately measure a 19mm solid metal part and 100% agreement was reported between them. Therefore, something else was occurring when using the same tool to measure TPDT. It may be that something more than just TPDT was being measured, as some subjects reported that metal calipers felt colder or sharper. However, the precise nature of this and the measurement of these factors in the context of such a clinically small difference was considered beyond the scope of this project.

Most participants preferred the modified calipers. Interestingly, none preferred the plastic and only one participant preferred metal calipers. The reasons behind participant's choices were not investigated as part of this study. However, the points of the modified calipers had slightly rounder tips than those of the metal and plastic calipers and most participants reported them to be more comfortable.

Previous reliability studies published in this area have investigated intra-rater, inter-rater and test-retest reliability in the back (Catley et al. 2013b; Adamczyk et al. 2015) but none compared the instruments used to measure low back TPDT. As such, this may be the first reliability study to compare the results from different calipers when measuring TPDT on different parts of the body.

4.2.10. Limitations of reliability study

There are several important limitations to this reliability study.

All assessments were made with the same tool sequence; metal, plastic and finally modified calipers. On the low back, the left side of L3 was assessed first and the right side second. With later insight, gained through further reading and discussion with other researchers, the side and tool order should have been randomised to counteract bias from the tools, assessor's technique, participant learnt behaviours and altered sensitivity through repeated light contact. By not randomising or counterbalancing the application of the different calipers (applying to one side of the spine and then the other), meant that participants responses may have been altered if they learnt to detect light touch on the back more accurately throughout the data collection process. If this occurred, the effect

could have been amplified because the back is a relatively imprecise region of the body regarding tactile acuity in comparison to the fingertip and small improvements in learning would have a greater impact (Johansson 1978; Johansson and Vallbo 1979; Lacour et al. 1991; Tachibana 1995). Failing to randomise the calipers may have created an order effect and the receptiveness of participants to detect touch could have been altered with greater magnitude for the last few measurements and less for the first few. As the modified calipers were always used after the metal and unmodified plastic calipers, it cannot be ruled out that the smaller measures returned by the modified tool may have been a result of learning effects rather than the caliper modifications. Although, if learning and an order effect was responsible for the difference, one might expect to have seen a gradual increase between the metal and unmodified plastic caliper measurements and then a further increase between the unmodified and modified plastic caliper measurements. This was not the case. These methodological issues were corrected within the main study where the order of TPDT assessment was randomised.

A further limitation was that participants with and without a history of CLBP were included in this reliability study. This meant that if differences in TPDT sensitivity occurred between these two groups, the differences would not have been identified. Therefore, treating the results obtained from participants with and without CLBP as one dataset, could have skewed the overall findings and incorrectly influenced the decision to use the modified calipers in the main study.

Finally, this reliability study was performed early in this research project and prior to the researcher fully appreciating the need for a power calculation to determine an adequate sample size. As such, a power calculation was not performed and participants were recruited on a pragmatic basis. The implication of the reliability study being underpowered is discussed on page 149 but as a limitation, the study may have been underpowered to detect statistically significant differences between the calipers (Hickey et al. 2018). One reason was the inclusion of participants with and without CLBP. Those with CLBP may have experienced hypersensitivity due to their chronic pain which may have altered their sensitivity to TPDT assessment. As a result, the TPDT results obtained from participants with CLBP may not have been comparable with those obtained from those without CLBP.

These limitations may have influenced subsequent decisions regarding part of the main study design and in turn, influenced the main study findings. These issues were noted as limitations and help improve the design of future research studies undertaken by the researcher.

4.2.11. Summary

This reliability study compared the TPDT measurements from metal, plastic and modified calipers on the low back and fingertip. When used by the same rater and on the same participants, only TPDT measurements from the modified versus metal calipers were significantly different, but none of the caliper pairs met the pre-defined limits of acceptable differences, so could not be considered to agree. However, the calipers did provide consistent measures at different TPDT magnitudes despite measurement bias occurring between calipers. Participants preferred the feel of the modified calipers which provided further support in favour of choosing them for use in the main study methods.

These findings led to the rejection of the null hypothesis of ‘there is agreement between TPDT measurements resulting from three types of Vernier calipers’.

For these reasons, the modified calipers were chosen to assess TPDT within the main study. The methods for TPDT assessment are reported in Appendices **9.3.7** and **9.3.8**.

4.3. Motor Control Inter-rater reliability study

4.3.1. Introduction

Previous studies assessing lumbopelvic motor control using Luomajoki's Battery of Tests reported that their raters had received specific motor control dysfunction training before using the tool (Luomajoki et al. 2007; Luomajoki et al. 2008). The researcher had not undertaken any specific assessment training so to assess the wider clinical applicability of the tool, an inter-rater reliability study was carried out. It assessed the reliability of Luomajoki's Battery of Tests when used by registered musculoskeletal healthcare professionals who had not received specific training in the use of these tests.

The reliability study was designed to measure agreement between raters when they independently rated videoed participants performing motor control tests of the lumbar spine using Luomajoki's Battery of Tests (Luomajoki et al. 2007; Luomajoki et al. 2008; Luomajoki and Moseley 2011). Raters were blinded to the researcher's and each other's scores. This investigation differed from previously reported studies in that raters did not receive specific training.

To assess whether any results from raters who had not received specific training were comparable to those reported by Luomajoki et al. (2007) and Luomajoki et al. (2008), the results from a sample of trained raters would need to be compared to those from untrained raters. Unfortunately, this was beyond the scope of the study due to financial and time constraints but it is planned for further investigation in the future. Reducing study costs and time were only beneficial if test scores were found comparable across similarly trained raters. It was proposed that identifying similar scores between raters would confirm test reliability adequately without the need for specific training, thus adding to the robustness of the main study design. However, it was noted that non-trained raters could be incorrect but still in agreement.

In the study of Luomajoki et al (2007), all four raters were physiotherapists. Two of these had over 25 years of working experience, post-graduate manual therapy degrees and were experienced in assessing movement control dysfunction assessment. The other two had five years' experience as physiotherapists but none of the other attributes so they received 3 days' movement control dysfunction assessment training provided by the researcher. The 12 raters in the second study, Luomajoki et al (2008) were physiotherapists with seven years' experience (± 2.3 years). They had all completed 2.5 years of a postgraduate manual therapy programme which included a three-day course assessing movement control dysfunctions. The training appeared intensive and included

instruction on the test procedures, discussions, case studies, examples of typical dysfunctions and the rating of videotaped tests.

Within this motor control inter-rater reliability study, the definition of 'participants' is slightly different from that of the main study. In this reliability study, 'participants' are defined as the videoed volunteers performing the motor function tasks. 'Raters' are the healthcare professionals rating the participants' videoed performance.

4.3.2. Aim

The study aimed to answer the question 'Is there agreement between the scores of registered musculoskeletal healthcare professionals when independently assessing videos of adults with and without chronic low back pain, performing Luomajoki's battery of lumbar motor control tests?'

4.3.3. Null Hypothesis

H₀: There is no agreement between the scores of registered musculoskeletal healthcare professionals when independently assessing videos of adults with and without chronic low back pain performing Luomajoki's battery of lumbar motor control tests.

4.3.4. Methods

Healthcare professionals with experience in assessing and providing treatment to those with CLBP were the targeted raters. In the UK, the minimum education and training requirements to register as a physiotherapist includes a three-year bachelor's degree; whereas chiropractors and osteopaths complete a four or five-year master's degree. All three professions incorporate intensive anatomical, biomechanical and musculoskeletal assessment training. As such, registered chiropractors, physiotherapists and osteopaths were included as raters. Demographical and professional data was collected to set context. It included gender, professional experience, length of time as a registered professional, highest musculoskeletal qualification and an estimate of time spent performing low back assessments.

4.3.4.1. Ethics and Consent

Ethical approval was granted from Bournemouth University Research Ethics Committee, UK (Reference ID:9677) and the Anglo-European College of Chiropractic Research Ethics Sub-Committee, UK (Approval Number: E71/11/15) (Appendix 9.3.12).

Videomed participants received consent forms along with participant information sheets (see Appendices **9.4.1** and 9.4.2) at least 48 hours prior to their arrival for their data collection appointment.

Informed consent from raters was also obtained in writing but their participant information sheets and consent forms were emailed to them. Raters were provided with the researcher's telephone, email and social media contact details and encouraged to discuss any issues prior to taking part in the study. They were asked to print, read, sign and return a scanned copy (or photo) of the consent form prior to them being sent any videomed participant data. One section of the consent form referred specifically to their agreement to delete all video files on completion of the tasks. Failure to complete and sign this section, automatically excluded them from the study.

4.3.4.2. Inclusion criteria

The Inclusion criteria included holding the status of UK registered Chiropractor, Osteopath or Physiotherapist. This was defined as someone who was registered with the UK's General Chiropractic Council (GCC), the General Osteopathic Council (GOC) or as a physiotherapist with the Health and Care Professions Council (HCPC).

4.3.4.3. Data protection

Enhanced security measures were taken to protect participants' videomed data. Video files were password protected and files were transferred to raters using the secure Bournemouth University File Transfer System rather than sending them via email or post. To provide additional security, the password to open the files was sent by text (SMS) to the rater's mobile telephone number which they provided on their written consent forms. Raters consented to deleting all video files upon completion of the tasks, or if they chose not to complete the study. Files within the BU Transfer system were automatically deleted within two weeks of being uploaded.

4.3.4.4. Videomed participants

A pool of thirty-seven participants (18 control and 19 pain group participants) who took part in the main study, consented to being videomed and their data being used within this reliability study. The participants were videomed while performing Luomajoki's Battery of Tests. The method of performing the tests is reported in detail in the methodology chapter (see section **3.5.5.2**). To recap, Luomajoki's Battery of Tests comprise of six tests used to assess lumbopelvic motor control dysfunction of the lumbar spine in adults with CLBP.

Adults with CLBP perform more poorly than healthy controls (Luomajoki et al. 2007; Luomajoki et al. 2008).

Five participants from each of the pain and control groups (ten in total) were randomly chosen from the pool for inclusion within the study. The ten participants were chosen from the pool using an online random selection tool (Urbaniak and Plous 2017). Ten participants were chosen to avoid raters being deterred from volunteering for the study due to an overwhelming participant burden. Each of the ten participants performed Luomajoki's Battery of Tests which comprised of six motor control tests. This generated 60 videos for raters to view and assess. An informal discussion with the researcher's healthcare profession colleagues resulted in agreement that any increase in participant numbers would likely increase rater burden to a level which may have been a deterrent for potential raters to take part in the study.

4.3.4.5. Video method

A tripod and iPhone were used to video participants. The camera tripod position was marked on the clinic floor to ensure each video was recorded from the same angle. To improve rater ease of use and reduce rater recording errors, individual videos of participants performing the six tests were edited using Adobe® After Effects® software (Adobe Creative Cloud 2017) to create one continuous video per participant. Audio was removed and a BU logo and the researcher's name was embedded within each video. Exercise titles, participant numbers and a five second gap were edited in-between each exercise to allow raters time to record their decisions on the score sheet.

4.3.4.6. Rater recruitment

The study aimed to recruit a convenience sample of ten registered healthcare professionals (raters). They were recruited in April 2017 from a request via manual therapy groups on social media platforms (<https://www.facebook.com>) and through the researcher's network of healthcare colleagues, for volunteers registered as chiropractors, physiotherapists or osteopaths. Volunteers contacted the researcher through private messaging on these platforms. Screening ensured volunteers met the inclusion criteria prior to a participant information sheet and consent form being sent to them.

The researcher checked volunteers' registration status using online facilities within their regulator's websites. All met the registration criteria.

4.3.4.7. *Rating of test performances – method*

On receipt of raters' consent forms, rater study packs and password protected video data files were provided to them. Study packs included detailed scoring criteria, a link to download free media player software, a questionnaire and a results sheet for completion. Additionally, an example was provided which demonstrated how to complete the results sheet. The raters study packs are presented in Appendices **9.4.3** to **9.4.6**.

Raters completed a short questionnaire to capture demographic and clinical experience data. Then they were asked to read the instruction sheet which described the six movement control tests of the low back. With Dr Hannu Luomajoki's kind permission, raters were provided with written and photographic instructions from Luomajoki et al. (2008). The instructions were accompanied by Dr Luomajoki's photographs to show correct examples ('achieved') and incorrect ('not-achieved') performances.

None of the raters had taken part in any other part of this research project and they were blind to the videoed participants clinical assessment results and back pain history which was undertaken as part of the main study.

Raters independently watched videos of ten participants performing Luomajoki's Battery of Tests. Each participants' videoed performance of the tests was rated as either 'achieved' or 'not-achieved' based on the guidance from the instructions sheet provided. Raters were not restricted in the number of times they could watch each video recording but they were asked to record how many times each video was viewed prior to making their decisions.

The raters were asked to consider the same question when rating each participant's performances, 'Did the participant achieve the correct motor control movement, as described in the instructions?' A rating of 'achieved' received a score of zero and 'not achieved' scored one point. A single score for each participant was calculated by adding the scores for each of the six tests. Scores ranged from zero to six, with higher scores indicating impaired lumbar motor control.

The researcher also rated the participants' videoed motor control performances and it was of concern that her involvement in the data collection may have introduced bias. Multiple sensitivity analyses were completed that excluded the researcher, who was unblinded to low back pain status, and each of the other raters so as to determine if there was an undue impact on reliability or internal consistency. Subsequently, the results were combined and analysed.

4.3.5. Data Analysis

4.3.5.1. Inter-rater reliability

Inter-rater reliability can be measured in terms of consistent agreement or absolute agreement and the decision regarding which to report depends upon the intended purpose of the outcome (Cicchetti 1994; Kim 2013). Some raters may consistently award higher or lower scores when judging the same task, making their results consistently and reliably different from other raters scores. However, reliability measures of absolute agreement assess the degree to which raters return the same values and this was of greater importance in this study. Inter-Rater Reliability (IRR) analysis is used to report the degree of reliability among observational ratings, when rated by multiple raters (Davies and Fleiss 1982; Stolarova et al. 2014). There are many statistical tests to assess IRR and they are chosen based upon the type of data being coded, the design methodology and the purpose of the IRR estimate (Hallgren 2012).

Individual test results were scored as either 'achieved' = 0, 'not achieved' = 1. As per Luomajoki et al (2007; 2008; 2011), these dichotomous scores were combined to create a single score per participant, per rater. Combined scores were ranked and treated as ordinal data because scores of one specified worse low back movement than a score of zero. Combined scores ranged from 0-6 where higher scores indicated greater low back movement impairment.

The design was fully-crossed meaning that all participants were rated by all raters and the purpose of the IRR was to estimate the absolute agreement reliability of the scores from multiple raters.

Given all these factors, Intra-Class Correlation Coefficients (ICC) were considered the most appropriate statistical test to assess absolute agreement between multiple raters (Hallgren 2012). Shrout and Fleiss (1979) reported the mathematical models for ICC's where two factors, (model and form) dictated the approach to data analysis. This study met their criteria of model three and form one, reported as $ICC_{(3,1)}$, where each participant was assessed by each rater and all raters were included (model 3), and reliability (absolute agreement) was calculated from individual measurements rather than average measurements (form 1).

ICC's were calculated using IBM® SPSS Statistics version 23.0 (IBM Corp 2015). The Shrout and Fleiss (1979) model $ICC_{(3,1)}$ equated to the Two-Way Mixed Model_{Absolute Agreement} within the SPSS statistics software because the raters were selected through convenience rather than random sampling (Weir 2005; Field 2013).

ICC's as rates of inter-rater reliability are reported alongside 95% confidence intervals (CI). A number of similar guidelines report the level of clinical significance for different levels of reliability coefficients (Landis and Koch 1977; Cicchetti and Sparrow 1990). The thresholds of agreement based on ICC values used within this study are cited from those reviewed by Cicchetti (1994), with the level of clinical significance considered poor when ICC values <0.40, fair between 0.40 and 0.59, good between 0.60 and 0.74, and excellent between 0.75 and 1.0, with 1 indicating perfect agreement.

4.3.5.2. *Internal consistency*

Internal consistency assesses how well each rater is measuring the same entity as each of the other raters (Cicchetti 1994). Cronbach's alpha (Cronbach's α) examines the correlation between every rater's scores with every other raters' scores and averages each correlation to identify how consistent any one rater's scores are with any other raters' scores. Cronbach's α was used to identify internal consistency between the 11 raters and how it would alter if rater's results were removed (one at a time) from the analysis. Guidelines to distinguish threshold levels of internal consistency that are clinically meaningful vary but Cicchetti and Sparrow (1990) report the level of clinical significance to be unacceptable when the size of the measure of internal consistency is below 0.70; fair between 0.70 and 0.79; good between 0.80 and 0.89 and excellent when equal to or greater than 0.90. Nunnally's classic work of 1978 went even further and proposed that internal consistency measures should exceed 0.95 to be considered an acceptable level for important clinical scenarios, although his work is often misinterpreted and values of 0.70 are reported to be acceptable (Lance et al. 2006). In this study Nunnally's values of 0.95, as reported by Lance et al. (2006), was used as the acceptable level of clinical significance.

4.3.6. Results

In total, 15 healthcare professionals volunteered, met the inclusion criteria and were sent participant information sheets and consent forms. Fourteen provided written consent and were sent information packs and videos. Four of these failed to return sufficient data to enable their inclusion within the study. In total, five of the fifteen volunteers were excluded and ten were included. The results from the ten included raters were pooled with the researchers own results which provided 11 complete datasets for the analysis. No data was missing from these 11 datasets.

A summary of the demographics and experience for the 11 participants are presented in Table 4-6 The researcher and nine of the raters who took part were chiropractors and one was an osteopath. All 11 were listed on their respective professional registers within the UK.

Table 4-6: Demographic and professional experience of raters in the motor control inter-rater reliability study

Variable	Result
Raters, <i>n</i> (female)	11 (7)
Chiropractors, <i>n</i>	10
Osteopaths, <i>n</i>	1
Registration in years, median (IQR)	15.0 (5.0 – 30.0)
Master's degree, <i>n</i>	8
Completed postgraduate MSK assessment training, <i>n</i>	3
Time spent performing MSK low back assessments (%), median (IQR)	60 (50 – 70)

N: number, MSK: Musculoskeletal, %: percentage, Median: measure of central tendency
IQR: Inter Quartile Range

4.3.6.1. Rater scores

The total scores awarded by each rater for each participant are presented in Table 4-7. Mean rater scores ranged from 2.80 (SD 1.32) to 4.0 (SD 2.0), where higher scores indicated greater motor control impairment than lower scores.

Table 4-7 - Luomajoki's Battery of Test scores, by rater in the motor control inter-rater reliability study

Raters	Videoted Participants Scores performing Luomajoki's Battery of Tests										Median (IQR)
	A	B	C	D	E	F	G	H	I	J	
1	2	4	2	4	1	1	5	5	4	4	4.0 (1.75-4.25)
2	1	3	1	3	2	3	5	5	3	4	3.0 (1.75-4.25)
3	0	3	2	3	2	4	5	5	3	5	3.0 (2.0-5.0)
4	1	2	3	4	1	2	4	5	3	3	3.0 (1.75-4.0)
5	1	6	2	5	2	2	6	6	5	5	5.0 (2.0-6.0)
6	0	2	2	3	2	4	5	5	2	4	2.5 (2.0-4.25)
7	1	4	4	5	3	3	4	6	4	2	4.0 (2.75-4.25)
8	0	4	3	2	2	4	5	5	4	3	3.5 (2.0-4.25)
9	1	5	3	3	2	2	4	4	3	3	3.0 (2.0-4.0)
10	1	3	2	2	2	2	5	5	3	4	2.5 (2.0-4.25)
11	0	3	2	2	2	3	5	5	2	4	2.5 (2.0-4.25)

Median: measure of central tendency, IQR: Interquartile Range.

4.3.6.1. Inter-rater reliability

Table 4-8 reports intra-class correlation coefficients as a measure of inter-rater reliability.

Single measures $ICC_{(3,1)} = 0.69$ (95% CI 0.485 to 0.886), ($F(9,90) = 27.93$, $p < 0.001$).

These statistics indicate how reliable a single rater would be in assessing motor control of the lumbar spine using Luomajoki's Battery of Tests. These can be interpreted as the scores from a single rater could be 69% reliable when using Luomajoki's Battery of Tests.

Average measures $ICC_{(3,1)} = 0.961$ (95% CI 0.912 to 0.988), ($F(9,90) = 27.93$, $p < 0.001$).

These indicate the inter-rater reliability, made up of the average scores of the different raters, could be 96% reliable when using the instrument.

Table 4-8 - Intra-class correlation coefficient table to show inter-rater reliability between raters in the motor control inter-rater reliability study

	Intra-class Correlation Coefficient	95% Confidence Intervals	p value
Single measures	0.690	0.485 – 0.889	≤ 0.001
Average measures	0.961	0.912 – 0.988	≤ 0.001

4.3.6.2. Internal Consistency

Cronbach's alpha (α) represents a measure of internal consistency across all raters ($n = 11$). In this reliability study, Cronbach's $\alpha = 0.964$.

Table 4-9 reports the changes to internal consistency if specific rater's results were deleted from the model. Analysis of the data in Table 4-9 revealed that Cronbach's α could be increased slightly to 0.966 by removing Rater_7. However, removing any of the other ten raters slightly reduced internal consistency, but none reduced Cronbach's α below the *a priori* threshold of Cronbach's $\alpha > 0.95$.

Table 4-9 - Table to show effect of deleting raters on Cronbach's Alpha

	Cronbach's α if a rater was deleted from the model
Rater_1	0.962
Rater_2	0.958
Rater_3	0.959
Rater_4	0.961
Rater_5	0.961
Rater_6	0.961
Rater_7	0.966
Rater_8	0.961
Rater_9	0.963
Rater_10	0.958
Rater_11	0.958

4.3.7. Discussion

This reliability study aimed to measure the level of agreement between registered musculoskeletal healthcare professionals who had not received specific training to rate the lumbar motor control of videoed participants using the Luomajoki's Battery of Tests (Luomajoki et al. 2007; Luomajoki et al. 2008). This was important because evaluating the battery of tests reliability for use in an untrained sample of raters was an important factor in deciding to use the method within the main study as a measure of low back motor function.

More women than men volunteered for the study and the range in their number of years of professional registration was noted to be very wide. One participant had only been registered for one year and another for 46 years. All participants reported spending at least 50% of their work time performing musculoskeletal assessments of the low back. Data was captured in order to gain an indication of the level of professional experience within the group. However, it was difficult to associate years registered with actual experience in performing low back assessments because some may only work part-time or see very few patients a week. The minimum qualifications now required to register as a healthcare professional have been altered in many professions. Where a diploma was once sufficient, a bachelor's or a master's degree is now necessary for new registrants to be considered for inclusion on many professional registers.

Inter-rater reliability, the degree to which raters agreed with each other, was measured using the intraclass correlation coefficient (ICC). The ICC results from this study indicated an excellent degree of average agreement between the 11 raters based on the values cited by Cicchetti (1994). Results for this group could be interpreted as there being 96% agreement between the means of their scores. However, this value is not beneficial in determining whether similar agreement could be expected in future studies, such as the main study that this reliability study is contributing to, because a group of raters will not be using Luomajoki's Battery of Tests when assessing motor control. In most clinical situations, including the main study, the assessments will be performed by a single rater. Therefore, the single measures score is considered a more appropriate measurement to quantify inter-rater reliability (Cicchetti 1994; Kim 2013). The single measures ICC scores indicated that the results from a single rater could be 69% reliable when using Luomajoki's Battery of Tests without them receiving specific training. Although this is a lower score than that for the average measures, it falls firmly within the range of values considered to have a good level of clinical significance by Cicchetti (1994).

In measuring internal consistency, the high Cronbach's alpha score provided acceptable evidence for each rater to be measuring the same entity as each of the other raters (Lance et al. 2006). Internal consistency remained acceptable (Cronbach's $\alpha \geq 0.95$) when any of the raters scores were removed from the calculation. Therefore, the internal consistency of raters who had not received specific training from the researcher in measuring the same entities when using Luomajoki's Battery of Tests could be considered acceptable in clinical situations.

Compared with earlier reliability studies reporting Luomajoki's Battery of Tests, the agreement between raters within this study were at least comparable or greater than the agreement reported between the raters in Luomajoki et al. (2007) and (2008). Good inter-rater reliability was noted in all studies, where $k > 0.6$ (Luomajoki et al. 2007; Luomajoki et al. 2008).

The main differences between Luomajoki et al. (2007) and (2008) and this reliability study was that this study did not provide specific practical training in using the instrument prior to its use. In Luomajoki et al. (2007) and (2008), all raters were physiotherapists and received up to three days training which included intensive multimodal instruction such as; discussion, patient cases, examples of typical dysfunctions and the rating of videotaped tests. This study demonstrated that in a similar sized group of UK registered chiropractors and an osteopath, comparable or better agreement was achieved using only their clinical experience, guidance notes and the images adapted from Luomajoki et al. (2008).

These finding may have positive implications for Luomajoki's Battery of Tests to be considered for use in future studies although this study had its limitations.

4.3.8. Limitations of the inter-rater reliability study

There are a number of limitations within this reliability study. First, a sample size calculation was not performed so the study may not have been sufficiently powered to identify subtle but potentially important findings. This was due to a lack of knowledge from the researcher when the reliability studies were undertaken. The data obtained during the TPDT reliability study was utilised in performing sample size calculations prior to the main study taking place.

Second, raters were not restricted in the number of times they could view each video recording prior to judging whether the task was achieved or not. Requests for raters to restrict the number of times they viewed each video was not made because adherence to

the request could not be monitored. Raters perform physical assessments as part of their professional responsibilities so may have felt pressurised to perform well. This may have led to multiple viewings of the videos but raters may not have been willing to reveal how many times prior to making a judgement. Therefore, the analysis of agreement between raters might not have been assessing comparable data so the number of times videos were viewed was not limited. Consequently, the results from this reliability study are not comparable to studies 'real-time' performances of the tests, or to real life clinical assessments, where performances of tasks may differ (Hodges et al. 2013).

Finally, there is an issue of the limited generalisability of these findings to the wider population because while there was agreement between the untrained raters, it is unknown whether their judgements were correct. This is because the study design failed to account for a comparison to a known reference standard, such as results from a sample of trained raters. The researcher plans to extend the scope of this reliability study in the future and include this comparison measure which might enable widespread use of the tests.

4.3.9. Summary

In this group of musculoskeletal healthcare professionals, Luomajoki's Battery of Tests had good inter-rater reliability when used to assess lumbopelvic motor control in adults. Importantly for the next stage of this research project, the researcher's own scores agreed with those from a sample of similarly trained professional peers. It remains unknown whether the judgements made by the raters in this reliability study were correct, or how these results might compare to Luomajoki et al. (2007) and Luomajoki et al. (2008). Consequently, it cannot be said that these findings are comparable to those from other studies but the tests were reliable to assess lumbopelvic motor control in the main study CLBP and control groups.

4.4. Reliability Studies Chapter Summary

This chapter investigated and reported the results for two reliability studies which were necessary to guide the methods described in Chapter Three. The first study compared three TPDT tools of different materials for measurement reliability and participant preference. The second study tested the reliability of Luomajoki's Battery of Tests for assessing lumbopelvic motor control when used by registered healthcare professionals who had not received specific training in its use.

To summarise;

TPDT Tool Reliability Study

- Agreement in TPDT measurements between any caliper pair did not meet pre-determined levels of acceptability for the low back or fingertip, although agreement between modified and plastic calipers was borderline acceptable for the low back.
- Only one significant difference between measurements was observed between modified versus plastic calipers when assessing low back TPDT, where the modified calipers were consistently biased towards assessing low back TPDT to be 2.5mm less than plastic calipers.
- A strong correlation was observed between all caliper pairs
- Most participants preferred the modified calipers
- Modified calipers were chosen to assess TPDT on the fingertip and low back of participants within the main study.
- The methods for using these calipers to collect data in the main study are reported in Chapter Three, section 0.

Motor Control Inter-rater Reliability Study

- Inter-rater reliability was considered 'good' for Luomajoki's Battery of Tests to assess lumbopelvic motor control tasks when used by chiropractors and an osteopath who had not received specific training. Internal Consistency was 'excellent' (Cronbach's $\alpha > 0.95$) (Cicchetti 1994).
- Luomajoki's Battery of Tests was chosen as the instrument to assess lumbopelvic motor control of participants within the main study.
- The method for using Luomajoki's Battery of Tests to collect data within the main study is reported in Chapter Three, section 3.5.5.1.

Chapter 5. RESULTS

5.1. Introduction

This chapter presents the main study results following the collection of measurements of tactile threshold, TPDT, body schema and motor function from the study sample of adults with chronic low back pain (CLBP) and the control group. First, participant demographics, back pain history and clinical outcomes are presented to set context and describe the participants. Second, measurements of tactile threshold, two-point discrimination threshold (TPDT), body schema and low back motor function are reported. Third, evidence regarding relationships between the variables is presented. The second and third sections address the research questions and associated hypotheses.

Significance for this study was set at $p \leq 0.05$, despite the increased risk of returning type I errors (false positives) when performing multiple analyses on a single data set (see section 3.9.6, Chapter Three). The more stringent levels of significance provided by the Bonferroni correction, where $p \leq 0.0029$ for this study, were considered overly rigorous for the exploratory nature of this study and the reasons previously discussed in Chapter Three, section 3.9.6, but for completeness, a summary of the Bonferroni corrected results is presented in Appendix 9.5.1.

5.1.1. Results from the recruitment campaign

The flow of volunteers through the main study research process can be seen in Figure 5-1. Of the 71 adult volunteers, all met the inclusion criteria, none met the exclusion criteria. All provided written consent. The data collection period coincided with the summer holidays and nine volunteers could not attend an appointment due to childcare or holiday commitments. The remaining 62 volunteers attended appointments and after undertaking a clinical screen to ensure they could safely take part, became the study participants. There were no exclusions following the clinical screen and none of the participants dropped out.

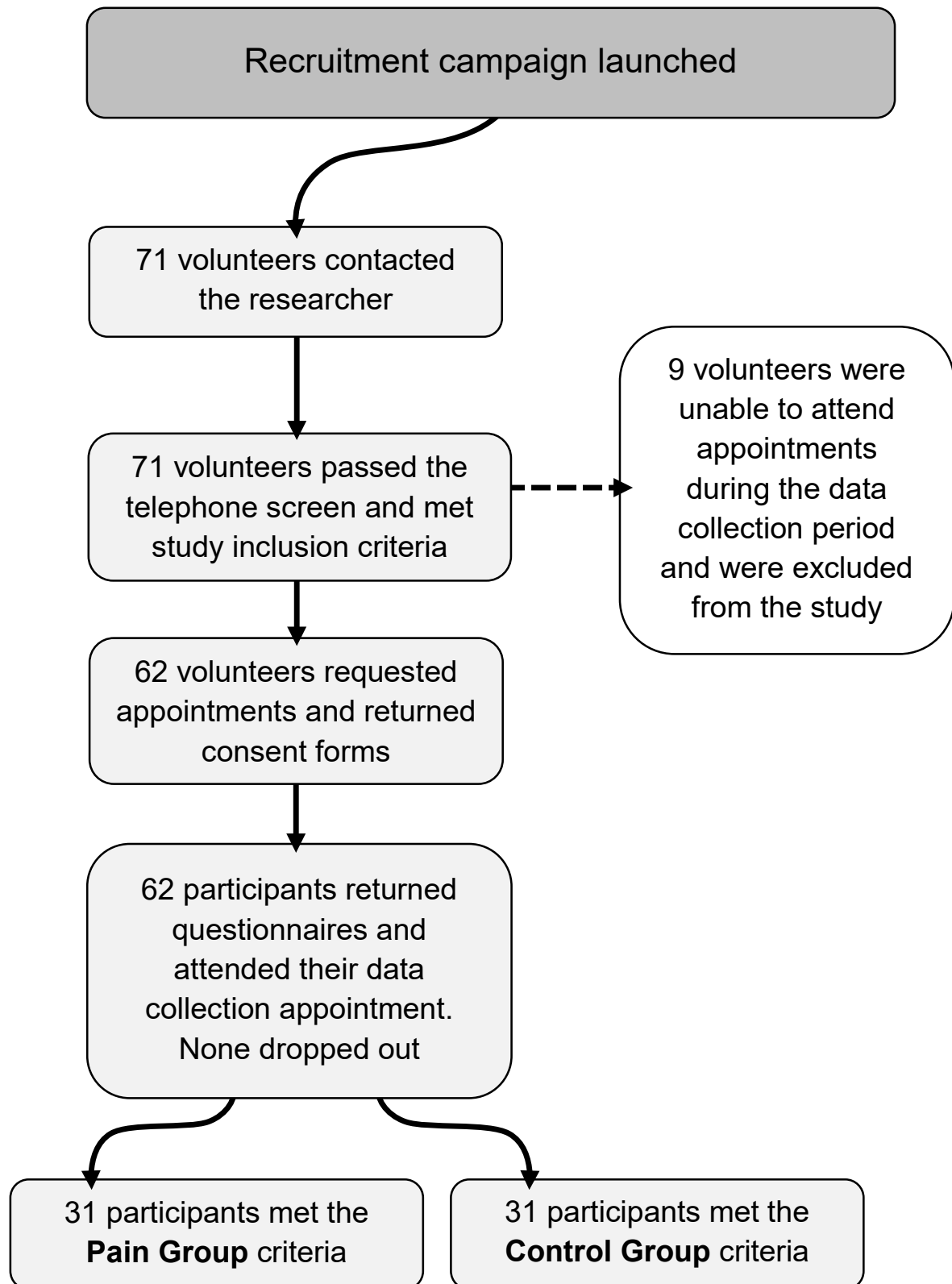


Figure 5-1: Schematic to show the flow of volunteers through the main research study

5.2. Matching for Age and Gender

This section presents the results of matching of participants in the pain group with the control group for age and gender. Matching was performed using syntax for SPSS version 23.0 (IBM Corp 2015). Matching for age and gender resulted in 27 genders matched and 23 age matched pairs (± 3 years). Widening the matching range to ± 5 years increased the matches to 25 age matched pairs but matching for age ± 5 years and gender reduced the total matches to 17 pairs.

Applying an Independent t-test for age and a Chi-Squared test for gender revealed no statistically significant differences between the pain and control groups for either age or gender (see Table 5-2). Consequently, rather than exclude data sets from unmatched participants, associations between age, gender and group were investigated using multiple linear regression which informed the decision whether to include data from all 62 participants.

The independent variables for the model were age and gender and the dependent variable was the membership of the pain or control group. Gender was categorised dichotomously (females = 0; males = 1) and age was recorded in years. The combined sample size of the two groups was 62. The results are presented in Table 5-1.

Table 5-1 - Multiple linear regression analysis to investigate the relationship between group membership and age/gender in adults with and without CLBP

Variable	Unstandardised coefficients				95% Confidence Intervals	
	B	Standard Error	t	P	Lower	Upper
Age	-0.129	0.129	-0.999	0.322	-0.386	0.129
Gender	0.011	0.006	1.889	0.064	-0.001	0.022

None of the independent variables were multi co-linear so there was no biasing of the regression model. An R^2 value of 0.074, indicating 7.4% of the variance in the dependant variable (pain or control group) was explained by age and gender and this was not statistically significant. Neither age (0.011 [95% CI -0.001 to 0.022]) nor gender (-0.129 [95% CI -0.386 to 0.129]) were significant predictors of pain or control group membership. As a result, all further analyses were conducted on the complete datasets.

5.3. Demographics and Clinical Outcome Measures

All volunteers attended clinical assessments, met the inclusion criteria and became study participants (for a review of the study inclusion and exclusion criteria, see Chapter Three, section 3.6.6). One participant revealed a history of cervical myelopathy but had been asymptomatic since surgery 3 years prior and had been discharged from care more than two years prior. As such they were included within the study. Of the 62 participants, 31 met the pain group and 31 met the control group inclusion criteria.

5.3.1. Participant Demographics

The two groups did not differ significantly with respect to age, gender, BMI or back width (Table 5-2). Ages ranged from 19 to 65 years of age and BMI's from 21 to 40kg/m². More women were in the pain group ($n = 21$, 68%) than the control group ($n = 17$, 56%). Both groups were similarly employed and educated to college or university degree level. The pain group reported more work absence due to low back pain than the control group and this difference was statistically significant. Only ten of the 31 people in the pain group had never had time off work due to their low back pain. Most of those in the pain group reported back pain related work absenteeism to be limited to periods of between 3-5 days, although three participants reported absences ranging from one to six months. In the control group, of which all except three participants had experienced at least one episode of low back pain, five reported a single episode of low back pain which had led to work absenteeism lasting between one and ten days, but none occurred within the previous three years.

Table 5-2 - Participant demographic, education and employment status, by group

	Pain Group (n=31)	Control Group (n=31)	P value
Age (years), mean (\pm SD)	47.0 (10.9)	41.8 (10.5)	0.60 [†]
Gender (female), n (%)	21 (67.7)	17 (54.8)	0.30 [§]
BMI, (kg/m ²), median (IQR)	26.0 (23.0, 30.0)	26.0 (23.0, 29.0)	0.75 [†]
Width of the back at L3, mean (\pm SD) cm	32.0 (4.3)	31.0 (4.1)	0.64 [†]
College or university degree, n (%)	17 (54.8)	20 (64.5)	0.34 [§]
Currently in work or retired, n (%)	31 (100)	29 (94.0)	0.37 [§]
Any work absence lasting longer than three days due to LBP, n (%)	16 (51.6)	3 (9.7)	0.03 ^{§*}

n : number of participants, %: percentage, mean: mean value of central tendency, SD: Standard Deviation from the mean, median: median value of central tendency, IQR: Interquartile Range, BMI: body mass index, L3: 3rd lumbar vertebra, LBP: low back pain. [†]Independent t-test for parametric data, [§]Chi-Squared test for nominal data, * significance $p \leq 0.05$.

Of the 31 control group participants, 28 had experienced at least one episode of low back pain during their adult life (Table 5-3). Ten of the people in the control group reported recurring or persistent low back pain which lasted longer than three months, yet their activities of daily living were unaffected which led to inclusion within the control group, rather than the pain group. None of the control group participants reported low back pain on the day of data collection.

Table 5-3 - Participant back pain history, disability and fear of movement scores, by group

Low Back Pain history	Pain Group (n=31)	Control Group (n=31)	P value
History of at least one LBP episode, n (%)	31 (100)	28 (90)	0.08 [§]
CLBP ≥3 months duration affecting ADL's, n (%)	31 (100)	-	-
LBP Duration >5 years, n (%)	24 (77.4)	-	-
Pain occurs bilateral to spine, n (%)	24 (77.4)	-	-
Pain occurs between L4 – S1 vertebrae, n (%)	31 (100)	27 (87)	-
Typical LBP intensity, NRS (0-10), mean, SD	5.8 (2.0)	-	-
Current LBP intensity, NRS (0-10), median (IQR)	1.9 (0.0 – 3.0)	0.0 (0 - 0)	0.002 ^{ω*}
Self-reported outcome measures			
Disability (RMDQ), median (IQR)	2.0 (0, 4.0)	-	-
Kinesiophobia (TSK-11), median (IQR)	22.5 (19.8, 25.0)	-	-

n: number of participants, LBP: low back pain, n: number of participants, %: percentage, CLBP: Chronic Low Back Pain, ADL: Activities of Daily Living, L4: 4th lumbar vertebra, S1: 1st sacral vertebra, NRS-10: pain numerical rating scale 0-10, RMDQ: Roland Morris Disability Questionnaire, TSK-11: Tampa scale of kinesiophobia-11, mean: mean value of central tendency, Median: median value of central tendency, SD: Standard Deviation from the mean, IQR: Interquartile range, [§]Chi-Squared test for nominal data, ^ω Mann-Whitney U test for non-parametric distribution, * significance $p \leq 0.05$, ** significance $p \leq 0.001$.

The pain group pain scores ranged from one to eight on a numerical rating scale of 0-10 (NRS-10). However, 13 pain group participants reported no pain on the day of data collection which resulted in a low median pain score for the group. The pain group's 'typical' pain scores ranged from 2 to 10 on NRS-10.

Measurements of tactile threshold and TPDT were recorded at L3 for all participants and at the typical location of low back pain, if one was reported. However, tactile metrics could not be recorded from two hirsute male control group members, resulting in low back tactile threshold and TPDT data being collected from 25 control group and 31 pain group participants.

In the pain group, all 31 participants reported their low back pain to typically occur between the 4th lumbar and the 1st sacral vertebra (Table 5-3). The fifth lumbar vertebra (L5) was reported as the central point of pain by 81% but L5 also lay centrally to the more widespread regions of pain reported by the remaining 19% of pain participants. As a result, the term 'L5' has been used going forward in this thesis to describe the collective painful low back regions reported by the pain group.

As also seen in Table 5-3, the median disability score reported by the pain group using the Roland Morris Disability Questionnaire (RMDQ) (Roland and Morris 1983) was low at 2.0 with individual disability scores ranged from zero to four. The RMDQ maximum score which reflected maximum disability due to back pain was 24 points. Fifteen of 31 pain group participants declared that none of the RMDQ statements of disability applied to them at the time of completing the questionnaire.

Fear of movement or re-injury scores measured in the pain group using the Tampa Scale of Kinesiophobia-11 (Woby et al. 2005) were moderate where individual scores ranged from 11 to 30 (the TSK-11 maximum score, reflecting maximum fear of movement or re-injury = 44).

5.4. Tactile Threshold, TPDT, Body Schema and Motor Function Outcome Measures

5.4.1. Results - research question one

Research Question One: Is there a difference in tactile threshold, two-point discrimination threshold, body schema and low back motor function between adults with chronic low back pain and a control group?

Question One, Null Hypothesis One: H^0 There is no statistically significant difference in low back tactile threshold (g) between adults with chronic low back pain and a control group.

The median values and interquartile ranges (IQR) for the pain and control groups fingertip and low back tactile threshold measurements are presented in *Table 5-4*. Fingertip metrics were recorded to provide a baseline comparative tactile measure from a non-painful region of the body.

Table 5-4 - Tactile threshold (g) of fingertip and lumbar spine

Region of body assessed	Tactile Threshold, g, median (IQR)		
	Pain Group n = 31	Control Group n = see key below	P value
L3 vertebra	0.4 (0.16, 0.6)	0.4 (0.15, 0.6)	0.825 ^ω
L5 vertebra	0.4 (0.16, 0.4)	0.4 (0.16, 0.6)	0.863 ^ω
Finger-tip	0.07 (0.04, 0.16)	0.07 (0.04, 0.07)	0.370 ^ω

n = 31 participants per group, except for L5 vertebra measurements in the control group where n = 25, n: number of participants, g: grams, median: median value of central tendency, IQR: interquartile range, L3: 3rd Lumbar vertebra, L5: 5th Lumbar vertebra, ^ω Mann-Whitney U test for non-parametric distribution, *significance $p \leq 0.05$.

A Mann-Whitney U test confirmed the low back median tactile thresholds did not differ between participants in the pain or control group at either L3 (U 465.0, $p = 0.825$, z -0.222), L5 (U 392.0, $p = 0.863$, z -0.172). In this sample, there were no statistically significant differences in tactile threshold between the pain or control groups, when measured on the low back. *These results supported a failure to reject the null hypothesis.*

Question one, null hypothesis two: H^0 There is no statistically significant difference in low back two-point discrimination threshold between adults with chronic low back pain and a control group.

To investigate the distribution of the TPDT data, bar charts are presented in Figure 5-2 and Figure 5-3 which show frequencies of TPDT scores at L3 and L5 on the low backs of the pain and control groups. TPDT ranged from 32 to 102mm in the control group and 32 to 122mm in the pain group. A visual assessment of the bar charts revealed a trend for higher TPDT scores to occur in the pain group at L3 and L5 although this was more pronounced at L5. TPDT measures for the low back and fingertip were not-normally distributed. Low back median TPDT and interquartile ranges (IQR) for the pain and control groups are presented in Table 5-5.

Table 5-5 – Two-point discrimination threshold (mm) over the L3 and L5 vertebrae

Region of body assessed	Two-point Discrimination Threshold mm, median (IQR)		
	Pain Group n = 31	Control Group n = see key below	P value
L3	67.7 (58.4, 81.5)	59.8 (52.2, 68.2)	0.031 ω^*
L5	77.8 (68.3, 93.0)	64.9 (59.3, 73.9)	0.007 ω^*

n = 31 per group except for L5 vertebra measurements in the control group where n = 25, n: number of participants, mm: millimetres, IQR: Interquartile range, L3: 3rd Lumbar vertebra, L5: 5th Lumbar vertebra, ω Mann-Whitney U test for non-parametric distribution, * significance $p \leq 0.05$.

Using a Mann-Whitney U test, a comparison was made between the low back TPDT measurements from the pain and control groups. TPDT measurements were greater for the pain group than the control group at the L3 vertebra, U 327.0, p = 0.031, z -2.161, and at the L5 vertebra, U 235.0, p = 0.007, z -2.692. *These results were significant and supported the rejection of the null hypothesis.*

Further investigation of the data revealed that fingertip TPDT was not significantly different between the pain group (2.4mm [IQR 2.07 - 3.0]) and control group (2.4mm [IQR 2.4 – 2.7]), where U 454.0, p = 0.709, z -0.374.

Differences in TPDT between the L3 and L5 vertebrae - A Wilcoxon Signed Ranks test for two related samples revealed significant differences in TPDT between L3 and L5 regions, within both the pain and control groups (pain group: Z = -2.026, p = 0.043, r = 0.36 and control group: Z = -2.248, p = 0.025, r = 0.44).

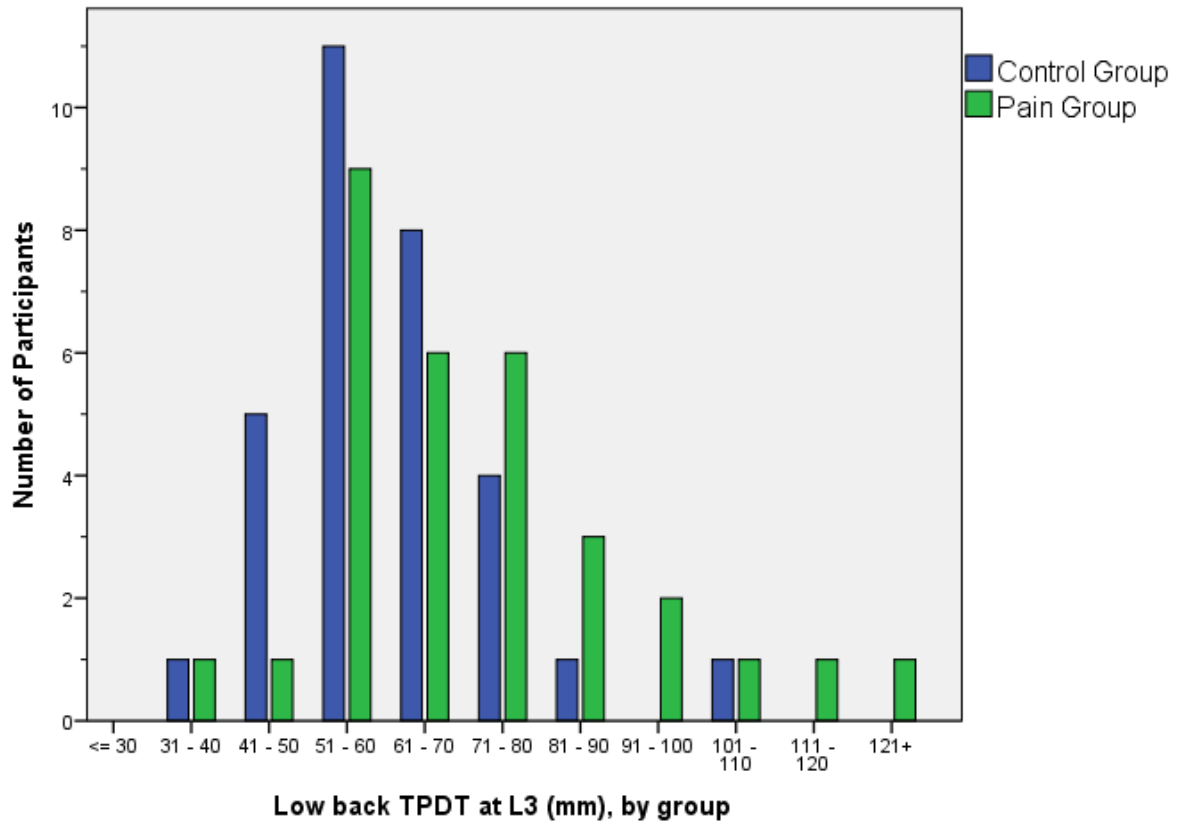


Figure 5-2: Two-point discrimination threshold at the third lumbar vertebra (L3)
n = 31 per group

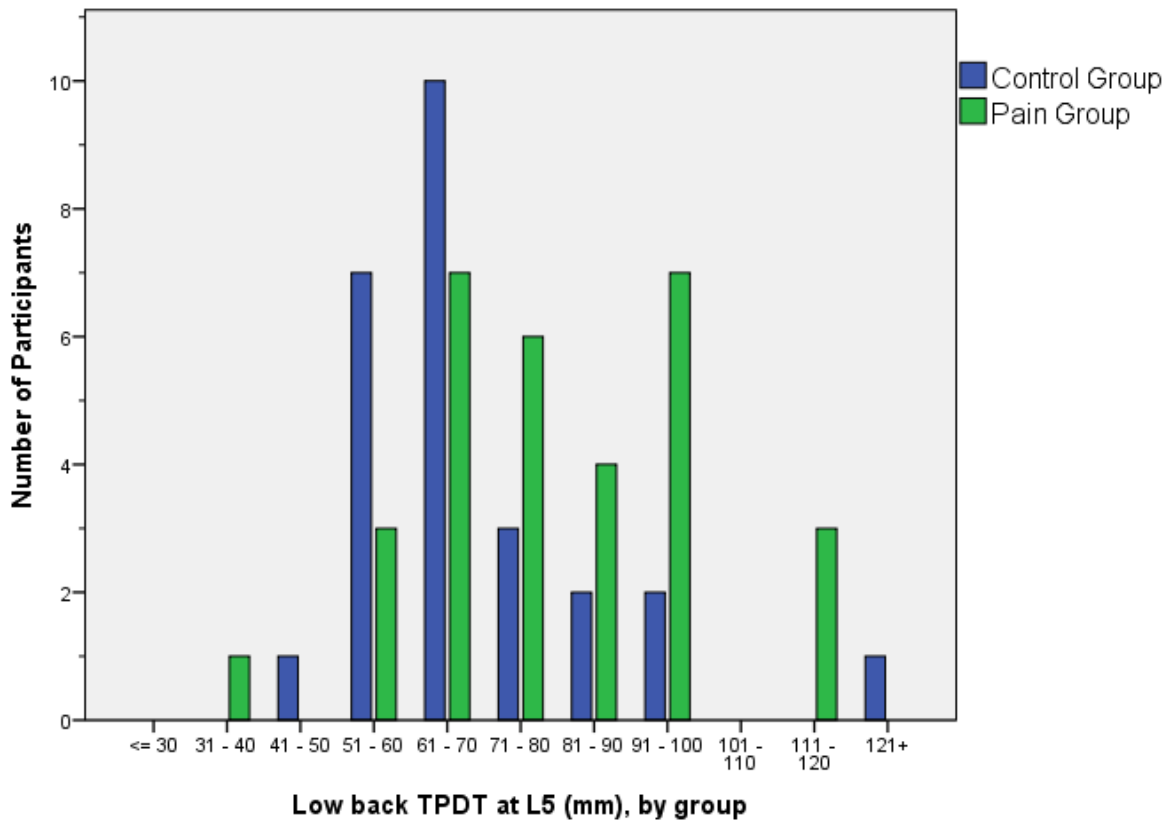


Figure 5-3: Two-point discrimination threshold at the fifth lumbar vertebra (L5)
n = 31 for the Pain group and n = 25 for the Control group

Question one, null hypothesis three: There is no statistically significant difference in body schema between adults with chronic low back pain and a control group.

Accuracy and time were recorded for left/right discrimination tasks of the torso as a measure of body schema using Recognise® (Neuro Orthopaedic Institute, 2016).

Accuracy was scored as the percentage of correctly identified images of left and right torsos/back as a proportion of the 80 images assessed. Lower accuracy scores may indicate an impaired body schema (Bray and Moseley 2011; Stanton et al. 2013).

Participants accuracy scores ranged from 61.3% to 98.8% within the pain group and from 70% to 100% within the control group. Group medians for accuracy were similar (see

Table 5-6) and the differences observed between the pain and control group were not significant.

The median time recorded for participants to select the correct answer ranged from 0.95 to 2.33 seconds for the pain group and 0.88 to 1.75 seconds for the control group.

It was of concern that participants with high speed and low accuracy may be guessing their responses, meaning the task was not being performed properly. Correlation analyses using the Spearman's Rank Correlation Coefficient (r) established the relationship between accuracy and speed. In the pain group, a statistically significant negative, correlation of medium strength was found between accuracy and the time taken to achieve the correct answer [$r(31) = -0.444, p = 0.012$]. Therefore, the pain group chose accurate responses quickly but took longer before choosing an incorrect response. This indicated participants were not guessing. In the control group this relationship did not reach statistical significance [$r(31) = -0.293, p = 0.110$].

Back perception, a further measure of body schema, was measured using the Fremantle Back Awareness Questionnaire (FreBAQ) (Wand et al. 2014b). Significant differences in back perception scores were observed between the pain and control groups (see

Table 5-6 for group body schema measurement results). From a maximum score of 36 points, where higher scores indicated poorer perceptual awareness of the back, individual back perception scores ranged from zero to 22 for participants in the pain group and zero to 13 for those in the control group. Median group scores were 8 (IQR 4 – 11) in the pain group and 2 (IQR 1-4) in the control group.

Table 5-6 - Differences in measures of body schema between the pain and control groups

Measurement of body schema	Variable	Pain Group n = 31	Control Group n = 31	P value
Left/right discrimination task of torso/back (Recognise [®])	Accuracy (%), median (IQR)	92.5 (88.8, 96.3)	93.8 (92.5, 95.0)	0.561 ^ω
	Time to select correct answer (s), median (IQR)	1.3 (1.2, 1.5)	1.2 (1.1, 1.4)	0.183 ^ω
Back perception questionnaire (FreBAQ)	Scores, median (IQR)	8.0 (4.0, 11.0)	2.0 (1.0, 4.0)	≤0.001 ^{ω**}

n: number of participants, %: percentage, IQR: Interquartile Range, s: seconds, FreBAQ: Fremantle Back Awareness Questionnaire, ^ω Mann-Whitney U test for non-parametric data, ^{**}Significance $p \leq 0.001$.

A Mann-Whitney U test revealed the differences observed between the control group and pain group in accuracy and speed in differentiating between left and right backs/torsos did not meet statistical significance (accuracy, $U 439.5$, $p = 0.561$, $z -0.581$ and time, $U 386.0$, $p = 0.183$, $z -1.332$), so the differences were probably due to chance.

However, there were statistically significant differences in the back-perception scores, measured using FreBAQ, between the pain and control groups ($U 190.0$, $p \leq 0.001$, $z -3.577$). Yet, these back perception results conflicted with the left/right discrimination task results. When considered together, the results from the body schema measurements must be considered inconclusive. As a result, the evidence from this study supported ***neither the rejection of, nor the failure to reject the null hypothesis.***

Question one, null hypothesis four: There is no statistically significant difference in low back motor function between adults with chronic low back pain and a control group.

Data from Luomajoki's Battery of Tests (Luomajoki et al. 2007; Luomajoki et al. 2008) and the 30-Second Chair Stand Test (Jones et al. 1999; Rikli and Jones 1999) were not-normally distributed, so the median scores and interquartile ranges are presented in Table 5-7.

Table 5-7 – Table to show motor function results: Luomajoki's and 30-Second Chair Stand test for pain and control groups

Variable	Pain Group n = 31	Control Group n = 31	P value
Luomajoki's Battery of Tests, median (IQR), (maximum score = 6)	3 (1, 4)	1 (0, 2)	≤0.001 ^{ω**}
30-second Chair Stand Test, median (IQR)	15 (13, 19)	18 (13, 23)	0.04 ^{ω*}

n: number of participants, IQR: Interquartile Range, ^ω Mann-Whitney U test for non-parametric data, *Significance $p \leq 0.05$, **Significance $p \leq 0.001$.

While test scores for Luomajoki's Battery of Tests ranged from 0 to 5 (Table 5-8) in both the pain and control groups (out of a maximum of 6), median scores were significantly higher for the pain group than the control group (Mann-Whitney U 224.0, $p = \leq 0.001$, $z = -3.685$).

The 30-Second Chair Stand Test scores ranged between 11 to 41 full stands counted in the control group and 7 to 21 in the pain group. The difference noted between groups was significantly different ($U = 337.0$, $p = 0.04$, $z = -2.028$).

The results indicated that there was a statistically significant difference between the pain and the control group for the Luomajoki's Battery of Tests Scores and the 30-second Chair Stand Test scores. As such, the results from the two tests agreed and supported the **rejection of the null hypothesis**.

5.4.2. Results - research question two

Research Question Two: Is there a correlation between low back two-point discrimination threshold, body schema and low back motor function in adults with chronic low back pain?

Question two, null hypothesis one: There is no correlation between low back two-point discrimination threshold and body schema in adults with chronic low back pain.

A summary of the correlations between TPDT and measures of body schema using the Recognise® (Neuro Orthopaedic Institute, 2016) left/right discrimination tasks and the FreBAQ scores from the pain group are presented in Table 5-8.

Table 5-8 - Table to show correlations between low back TPDT and Body Schema scores of the pain group participants

Pain Group TPDT (mm)		Body Schema – Left/Right Discrimination: Accuracy (%) n=31	Body Schema – Left/Right Discrimination: Time (s) n=31	Body Schema – FreBAQ scores n=31
L3 n=31	<i>r</i>	-0.123	0.073	-0.077
	<i>p</i> value	0.510	0.695	0.680
	Strength of correlation	-	-	-
L5 n=31	<i>r</i>	-0.185	0.292	0.191
	<i>p</i> value	0.319	0.111	0.303
	Strength of correlation	-	-	-

n: number of participants, TPDT: Two-point Discrimination Threshold, mm: millimetres, Accuracy: percentage of correct answers, Time: time in seconds taken to select the correct answer, FreBAQ: Fremantle Back Awareness Questionnaire, L3: 3rd Lumbar vertebra, L5: 5th Lumbar vertebra, *r*: Spearman's Rank Correlation Coefficient, * significance $p \leq 0.05$, Strength of correlation (Based on Cohen, 1988): small $r \geq 0.1$, medium $r \geq 0.3$, large $r \geq 0.5$.

There were no statistically significant correlations between TPDT at L3 or L5 and body schema when measured with left/right discrimination tasks of the low back/torso or with the Fremantle Back Awareness Questionnaire. As such, the results supported **a failure to reject the null hypothesis**.

Question two, null hypothesis two: There is no correlation between low back TPDT and low back motor function in adults with chronic low back pain.

Table 5-9 – Table to show correlations between low back TPDT and motor function scores of the pain group participants

TPDT (mm)		Luomajoki's Battery of Tests scores n=31	30-second Chair Stand test scores n=31
L3 n=31	<i>r</i>	-0.108	0.017
	<i>p</i> value	0.562	0.929
	Strength of correlation	-	-
L5 n=31	<i>r</i>	0.321	-0.018
	<i>p</i> value	0.079	0.922
	Strength of correlation	-	-

r: Spearman's Rank Correlation Coefficient, *n*: number of participants, TPDT: Two-point Discrimination Threshold, mm: millimetres, L3: 3rd Lumbar vertebra, L5: 5th Lumbar vertebra, * significance $p \leq 0.05$, Strength of correlation (Based on Cohen, 1988): small $r \geq 0.1$, medium $r \geq 0.3$, large $r \geq 0.5$.

The results of correlation analysis between low back TPDT and the two measurements of motor function in the pain group are presented in Table 5-9. No statistically significant correlations were identified between low back TPDT, either at L3 or L5, and the Luomajoki's Battery of Tests scores or those from the 30-Second Chair Stand Test scores. The findings supported **a failure to reject the null hypothesis**.

Question two, null hypothesis three: There is no correlation between body schema and low back motor function in adults with chronic low back pain.

One statistically significant correlation was identified between body schema function and motor function and is highlighted by the grey shading in

Table 5-10. This moderate, significant correlation occurred between the pain groups FreBAQ scores as a measure of body schema, and the Battery of Tests scores, as a measure of motor function. Higher scores indicated impaired back perception and higher Luomajoki's Battery of Tests scores indicated impaired motor function. Higher FreBAQ scores corresponded with higher battery of test scores so increases in body schema impairment were accompanied by increases in motor function impairment. Conversely, correlation analysis between the other body schema and motor function variables failed to reach statistical significance.

Table 5-10 - Table to show correlations between body schema and motor function results of the pain group participants

Body Schema		Luomajoki's Battery of Tests scores n=31	30-second Chair Stand test scores n=31
Left/Right Discrimination Task - Accuracy, % n=31	<i>r</i>	0.224	0.138
	<i>p</i> value	0.225	0.458
	Strength of correlation	-	-
Left/Right Discrimination Task - Time, s n=31	<i>r</i>	-0.137	-0.255
	<i>p</i> value	0.462	0.166
	Strength of correlation	-	-
FreBAQ scores n=31	<i>r</i>	0.362	-0.076
	<i>p</i> value	0.045	0.686
	Strength of correlation	Medium	-

n: number of participants, *r*: Spearman's Rank Correlation Coefficient, Accuracy: percentage of correct answers, Time: time in seconds taken to select the correct answer, FreBAQ: Fremantle Back Awareness Questionnaire, *significance $p \leq 0.05$ (highlighted by grey shading), Strength of correlation (Based on Cohen, 1988): small $r \geq 0.1$, medium $r \geq 0.3$, large $r \geq 0.5$.

When all measures of body schema and motor function were considered, the results were conflicting, meaning the **null hypothesis could be neither rejected nor failed to be rejected**. No significant correlations were identified between any TPDT, body schema and low back motor function measurements for the control group.

5.4.3. Results - research question three

Research question three: Is there a correlation between low back two-point discrimination threshold and clinical or psychosocial outcome measures in adults with chronic low back pain?

Question three, null hypothesis: There is no correlation between low back two-point discrimination threshold and clinical or psychosocial outcomes in adults with chronic low back pain.

Table 5-11 presents a summary of the results following Spearman's Rank Correlation Coefficient (r) calculations for TPDT and the demographic measures in the pain group. The grey sections highlight significant correlations where $p \leq 0.05$.

Table 5-11 – Table to show correlations between low back TPDT, descriptive and demographic characteristics for the pain group participants

TPDT (mm)		Gender	Age, years	Back width, cm	BMI
L3 n=31	r	-0.008	-0.075	0.268	0.457
	p value	0.967	0.688	0.145	0.010**
	Strength of correlation	-	-	-	Medium
L5 n=31	r	-0.609	0.018	0.148	0.310
	p value	≤ 0.001 **	0.923	0.428	0.090
	Strength of correlation	Large	-	-	-

n: number of participants, r : Spearman's Rank Correlation Coefficient, TPDT: Two-point Discrimination Threshold, mm: millimetres, L3: 3rd Lumbar vertebra, L5: 5th Lumbar vertebra, BMI: Body mass index in kg/m^2 , cm: centimetres, * significance $p \leq 0.05$, ** significance $p \leq 0.01$ (highlighted by grey shading). Strength of correlation (Based on Cohen, 1988): small $r \geq 0.1$, medium $r \geq 0.3$, large $r \geq 0.5$.

A large, negative correlation was identified between low back TPDT at L5 and gender, where smaller TPDT measurements were associated with female participants [$r(31) = -0.609$, $p \leq 0.001$]. Such relationships were not identified between TPDT measured at the L3 vertebra and gender.

Medium, positive correlations were seen between TPDT at L3 and BMI, where larger TPDT measurements correlated with larger body mass indices [$r(31) = 0.457$, $p = 0.010$]. This relationship did not exist with L5 TPDT [$r(31) = 0.310$, $p = 0.090$].

Table 5-12 - Table to show correlations between low back TPDT and clinical outcome measures of the pain group participants

TPDT (mm)		LBP duration	Typical pain score	Pain score on day	RMDQ	TSK-11	StarT Back
L3 n=31	<i>r</i>	0.037	0.026	0.117	0.063	0.042	-0.010
	<i>p</i> value	0.845	0.888	0.531	0.735	0.826	0.957
	Strength of significant correlation	-	-	-	-	-	-
L5 n=31	<i>r</i>	-0.201	0.397	0.179	-0.012	0.007	0.087
	<i>p</i> value	0.279	0.027*	0.336	0.949	0.972	0.641
	Strength of significant correlation	-	Medium	-	-	-	-

r: Spearman's Rank Correlation Coefficient, n: number of participants, TPDT: Two-point Discrimination Threshold, mm: millimetres, L3: 3rd Lumbar vertebra, L5: 5th Lumbar vertebra, LBP: low back pain, RMDQ: Roland Morris Disability Questionnaire, TSK-11: Tampa Scale of Kinesiophobia-11, STarT Back: Subgroups for Targeted Treatment Back Screening Tool, * significance $p \leq 0.05$ (highlighted by grey shading), Strength of correlation (Based on Cohen, 1988): small $r \geq 0.1$, medium $r \geq 0.3$, large $r \geq 0.5$.

A summary of the Spearman's rank correlation coefficient results for TPDT and clinical outcome measures of the main group participants are presented in Table 5-12. Medium, positive, significant correlations were found between the low back TPDT at L5 and the typical pain score [$r(31) = 0.397$, $p = 0.027$]. No significant correlations were observed between L3 TPDT and any of the clinical outcome measures.

In summary, statistically significant correlations were identified between L5 TPDT and gender, and L5 TPDT and typical pain score. The correlations were also statistically significant between L3 TPDT and BMI, but not between the other variables. Such findings must be considered inconclusive with the results supporting ***neither the rejection of, nor the failure to reject the null hypothesis.***

5.4.4. Results - research question four

Research question four: Is there a correlation between body schema and clinical or psychosocial outcome measures in adults with chronic low back pain?

Question four, null hypothesis: There is no correlation between body schema and clinical or psychosocial outcomes in adults with chronic low back pain.

Table 5-13 presents a summary of the results following Spearman's rank correlation coefficient (r) calculations for left/right discrimination tasks (accuracy and time) and the FreBAQ scores as measures of body schema and the demographic measures in the pain group. The grey highlighted section identifies significant correlations where $p \leq 0.05$.

Table 5-13 – Table to show correlations between measures of body schema, descriptive and demographic characteristics of the pain group participants

Measures of Body Schema		Gender	Age, years	Back width, cm	BMI
Left/Right Discrimination Task - Accuracy, % n=31	r	0.008	-0.281	-0.048	-0.081
	p value	0.967	0.126	0.798	0.665
	Strength of correlation	-	-	-	-
Left/Right Discrimination Task - Time, s n=31	r	-0.282	0.168	-0.213	-0.140
	p value	0.125	0.366	0.249	0.454
	Strength of correlation	-	-	-	-
FreBAQ Scores n=31	r	-0.190	0.464	-0.118	-0.105
	p value	0.307	0.009*	0.529	0.575
	Strength of correlation	-	Medium	-	-

r : Spearman's Rank Correlation Coefficient, n: number of participants, %: percentage correct, s: seconds, cm: centimetres, BMI: Body mass index in kg/m^2 , * significance $p \leq 0.05$ (highlighted by grey shading), FreBAQ: Fremantle Back Awareness Questionnaire, Strength of correlation (Based on Cohen, 1988): moderate $r \geq 0.3$, strong $r \geq 0.5$.

A significant positive correlation of medium strength was identified between the body schema scores, measured by FreBAQ, and age, where higher FreBAQ scores, signifying poorer back perception, occurred more frequently amongst the older participants. This relationship was not observed within the control group.

Table 5-14 - Table to show correlations between measures of body schema and the clinical outcome measures of the pain group participants

Body Schema		LBP duration	Typical pain score	Pain score on day	RMDQ	TSK-11	StarT Back
Left/Right Discrimination Task – Accuracy, % n=31	<i>r</i>	0.193	0.278	-0.110	-0.163	-0.185	0.054
	<i>p</i> value	0.299	0.130	0.556	0.381	0.328	0.774
	Strength of significant correlation	-	-	-	-	-	-
Left/Right Discrimination Task – Time, s n=31	<i>r</i>	-0.370	0.129	0.233	-0.042	-0.305	0.026
	<i>p</i> value	0.041	0.488	0.207	0.821	0.101	0.890
	Strength of significant correlation	Medium	-	-	-	-	-
FreBAQ scores n=31	<i>r</i>	0.238	0.145	-0.084	0.179	0.217	0.157
	<i>p</i> value	0.197	0.435	0.655	0.335	0.250	0.400
	Strength of significant correlation	-	-	-	-	-	-

r: Spearman's Rank Correlation Coefficient, *n*: number of participants, LBP: low back pain, RMDQ: Roland Morris Disability Questionnaire, TSK-11: Tampa Scale of Kinesiophobia-11, STarT Back: Subgroups for Targeted Treatment Back Screening Tool, FreBAQ: Freemantle Back Awareness Questionnaire, * significance $p \leq 0.05$ (highlighted by grey shading), Strength of correlation (Based on Cohen, 1988): small $r \geq 0.1$, medium $r \geq 0.3$, large $r \geq 0.5$.

Only one significant correlation was identified between body schema measurements and any of the clinical outcome measures and this is highlighted by Table 5-14. This was a negative correlation of medium strength, identified between low back pain duration and the time taken to select the correct answer when assessing left/right images of torsos [$r(31) = -0.370$, $p = 0.041$]. Those with pain of longer duration took less time in selecting the correct answer. No other significant correlations to the clinical outcome measures were noted.

In summary, the analyses undertaken to explore correlations between body schema and clinical or psychosocial outcome measures in adults with CLBP only returned two significant findings of medium strength. Such inconclusive results meant the ***null hypothesis could be neither rejected nor failed to be rejected.***

5.5. Summary Tables of the Main Study Results

Table 5-15 - Table to summarise the significant statistical differences in key variables between the CLBP and control groups

	CLBP Group										
	Tactile Threshold			TPDT			Body schema			Motor Function	
	FT	L3	L5	FT	L3	L5	L/R %	L/R s	FBQ	LBoT	CST
Control Group	✗	✗	✗	✗	✓	✓	✗	✗	✓	✓	✓

KEY

✓ Statistically significant differences were found between the pain and control groups,

✗ No significant differences were found between the pain and control groups

TPDT: two-point discrimination threshold, FT: fingertip, L3: 3rd Lumbar vertebra, L5 5th Lumbar vertebra, L/R %: percent correct in left/right discrimination tasks of the low back, L/R s: seconds taken to select the correct answer in left/right discrimination tasks, FBQ: Fremantle Back Awareness Questionnaire, LBoT: Luomajoki's Battery of Tests, CST: 30-second Chair Stand Test.

Table 5-16 - Table to summarise the significant correlations between the key variables for the CLBP group

		Tactile Threshold			TPDT			Body schema			Motor Function	
		FT	L3	L5	FT	L3	L5	L/R %	L/R s	FBQ	LBoT	CST
Tactile Threshold	FT		✗	✗	✗	✗	✗	N/A	N/A	N/A	N/A	N/A
	L3			✓+	✗	✗	✗	N/A	N/A	N/A	N/A	N/A
	L5				✗	✗	✗	N/A	N/A	N/A	N/A	N/A
TPDT	FT					✗	✗	N/A	N/A	N/A	N/A	N/A
	L3						✗	✗	✗	✗	✗	✗
	L5							✗	✗	✗	✗	✗
Body schema	L/R %								✓-	✗	✗	✗
	L/R s									✗	✗	✗
	FBQ										✓+	✗
Motor Function	LBoT											✗
	CST											

KEY

N/A – not analysed

✓ Statistically significant correlations occurred between variables, $p \leq 0.05$

+ Indicates a positive correlation, - Indicates a negative correlation

✗ No significant correlations were found between variables in the pain group

TPDT: two-point discrimination threshold, FT: fingertip, L3: 3rd Lumbar vertebra, L5 5th Lumbar vertebra, L/R %: percent correct in left/right discrimination tasks of the low back, L/R s: seconds taken to select the correct answer in left/right discrimination tasks, FBQ: Fremantle Back Awareness Questionnaire, LBoT: Luomajoki's Battery of Tests, CST: 30-second Chair Stand Test

5.6. Summary of the Null Hypotheses Outcomes

Question 1 - Is there a difference in tactile threshold, two-point discrimination threshold, body schema and low back motor function between adults with chronic low back pain and a control group?			H⁰ outcome
Null Hypotheses (H⁰)	1	There is no statistically significant difference in low back tactile threshold (g) between adults with chronic low back pain and a control group	Not rejected
	2	There is no statistically significant difference in low back two-point discrimination threshold (mm) between adults with chronic low back pain and a control group	Rejected
	3	There is no statistically significant difference in body schema between adults with chronic low back pain and a control group	Inconclusive
	4	There is no statistically significant difference in low back motor function between adults with chronic low back pain and a control group	Rejected

Question 2 - Is there a correlation between low back two-point discrimination threshold, body schema and low back motor function in adults with chronic low back pain?			H⁰ outcome
Null Hypotheses H⁰	1	There is no correlation between low back two-point discrimination threshold and body schema in adults with chronic low back pain	Not rejected
	2	There is no correlation between low back two-point discrimination threshold and low back motor function in adults with chronic low back pain	Not rejected
	3	There is no correlation between body schema and low back motor function in adults with chronic low back pain	Inconclusive

Question 3 - Is there a correlation between low back two-point discrimination threshold and clinical or psychosocial outcome measures in adults with chronic low back pain?			H⁰ outcome
H⁰	1	There is no correlation between low back two-point discrimination threshold and clinical or psychosocial outcomes in adults with chronic low back pain	Inconclusive

Question 4 - Is there a correlation between body schema and clinical or psychosocial outcome measures in adults with chronic low back pain?			H⁰ outcome
H⁰	1	There is no correlation between body schema and clinical or psychosocial outcomes in adults with chronic low back pain	Inconclusive

5.7. Chapter Summary

This chapter presents the main study results following the collection of measurements of tactile threshold, TPDT, body schema and motor function from a sample of adults with CLBP of sufficient magnitude to affect their activities of daily living (ADL's) and a control group. The hypotheses derived to address each research question are reported sequentially and a summary table of the overall findings and hypotheses outcomes are presented.

The hypotheses outcomes are discussed in detail with regards to this study and in the context of previously published research in Chapter Six.

Chapter 6. DISCUSSION

6.1. Introduction

This research study aimed to explore and understand measures of tactile threshold, two-point discrimination threshold (TPDT), body schema and low back motor function when assessed in adults with CLBP of sufficient magnitude to affect their activities of daily living (ADLs), and in a control group recruited from the same UK population.

This study contributes new knowledge in several areas of research. From the systematic review, it was identified that each of the included studies had explored only one or two of either tactile threshold, TPDT, body schema or low back motor function. None had explored all three and gaps in knowledge were identified. Body schema had not been investigated alongside motor function and none of the studies had investigated any of these factors with participants from a UK population.

New findings from the tool validation study were that Vernier calipers modified with rounded plastic tips consistently returned smaller measures of low back TPDT than 'off-the-shelf' Vernier calipers constructed of metal or plastic. Modified rounded plastic tipped calipers were also the preferred choice of participants. The implications of these new findings are discussed in Chapter Four, section 4.3.7.

A new finding was also identified in the Luomajoki's Battery of Tests (Luomajoki et al. 2007; Luomajoki et al. 2008) inter-rater reliability study presented in Chapter Four. Previously the tool had been validated for use by physiotherapists who had received specific motor control assessment training. This study reported that when the tool was used by registered chiropractors or osteopaths without receiving specific motor control assessment training, reliability was good to excellent depending upon how it was used. The scale was 69% reliable when used by one rater and 96% reliable when the average scores from a group of raters were considered. Internal consistency when used among this group was excellent (Cronbach's $\alpha = 0.964$). These results indicate that the tool might be reliable when used by chiropractors and osteopaths and results obtained from different healthcare professionals may be comparable, but future studies are required to confirm these findings.

New findings regarding tactile acuity were identified from the main study. TPDT, but not tactile threshold, was impaired within the region of low back pain reported by the participants in the CLBP group. While this has been previously reported by Moseley (2008a) and Wand et al. (2010b), this study identified that the greatest impairment

occurred within the region of reported low back pain and a smaller but statistically significant impairment was also noted at a nearby region of the low back which was reported to be pain-free. The researcher believes this to be the first report of TPDT impairments occurring on pain-free low back regions in those with CLBP.

There was no significant difference in the measures of TPDT and tactile threshold when tested on the fingertips of those with CLBP, compared with the control group.

Furthermore, this study was the first to explore measures of body schema in relation to motor function in a CLBP group. A statistically significant correlation was identified between higher measures of back perception impairment measured using FreBAQ (Wand et al. 2014b) and poorer performance in low back motor control tasks when scored using Luomajoki's Battery of Tests (Luomajoki et al. 2007; Luomajoki et al. 2008) in those with CLBP. This implied that those with greater back perceptual impairments performed more poorly in the low back motor control tasks. No such correlations were seen between FreBAQ scores and the 30 second Chair Stand test scores, or between other measures of body schema and any of the motor function test scores.

The aim of the research was to clarify whether sensory impairments existed alongside altered motor function in those with CLBP. It is anticipated that this new knowledge may guide future sensorimotor therapeutic interventions to support pain management in those with CLBP.

The four research questions investigated were:

1. Is there a difference in tactile threshold, two-point discrimination threshold, body schema and low back motor function between adults with chronic low back pain and a control group?
2. Is there a correlation between low back two-point discrimination threshold, body schema and low back motor function in adults with chronic low back pain?
3. Is there a correlation between low back two-point discrimination threshold and clinical or psychosocial outcome measures in adults with chronic low back pain?
4. Is there a correlation between body schema and clinical or psychosocial outcome measures in adults with chronic low back pain?

The chapter begins by discussing the characteristics of the two groups and continues to consider each research question and their null hypotheses (for a reminder of the hypotheses, see Chapter Five, section 5.6). Discussions are based on the theories of neuroplasticity underpinning this study, the biopsychosocial model and existing literature.

The implications for practice are considered and the chapter concludes with the strengths and limitations of the study.

Unless otherwise stated, the terms 'the study' or 'this study' refer to the empirical data collected as part of this study and reported within this thesis.

6.2. Group Characteristics

Good quality observational studies are reliant upon comparing equivalent results collected from similar participants under similar conditions (Billewicz 1964; Mann 2003; Mann and Wood 2012). As such, it was intended that participants for the CLBP and control groups were to be recruited from a similar population and share similar demographic characteristics to allow the comparison of results between groups. Demographic data was collected to quantify similarities and differences between the characteristics of the two groups.

The demographic data revealed no significant differences between the CLBP and control groups for age, gender, back width, BMI, education or employment status. This study's CLBP group mean age was 47 years (± 10.9) and the presence of slightly more females (68%) to males was similar to Moseley (2008a) (43 ± 15 years; 55% female), Wand et al. (2010b) (41 ± 12.5 years; 58% female) and Nishigami et al. (2015) (61 ± 13 years; 61% female). None of these studies reported significant demographic differences between their pain and control groups and these results mirrored our own. This was to be expected because CLBP affects around 20% of adults aged between 20 to 59 years of age and over 25% in those of older than 60 years of age and CLBP prevalence is reported to be higher in females than males (Hoy et al. 2012; Meucci et al. 2015).

Low back width was not reported by other studies exploring low back TPDT, but it was measured alongside BMI in this study to identify whether larger measures of low back TPDT correlated with a larger BMI or width of the low back. This was important because larger TPDT measures might be explained by the larger tactile surface area of those with larger BMI's or low back widths. Such findings would have provided an alternative explanation as to why differences in TPDT might occur between different participants. However, there was no significant difference in back widths or BMI's between the pain and control groups. Neither were there significant correlations between low back widths and TPDT measures. This finding suggested low back widths or BMI's, and therefore the surface area of the tactile receptive surface, was not related to TPDT accuracy on the low back. This was important because it confirmed that differences in low back TPDT

between this study's pain and control groups were due to something other than the size of the tactile surface area.

Within this study, the proportion of control and pain group participants with college or university degrees was around twice that expected within the wider UK population of a similar age (Chevalier and Lindley 2009). Participants that volunteer for research studies tend to display higher levels of conscientiousness, are from higher socioeconomic backgrounds and have normally achieved higher levels of education than non-volunteers (Kirby and Davis 1972; Lonnqvist et al. 2007). These factors may have influenced the levels of education reported. The recruitment campaign, which targeted social media and posters within private healthcare clinics, university buildings and local businesses, could also have influenced the sample of volunteers.

There was one statistically significant demographic difference between the pain and control groups. Over half of the pain group reported low back pain related work absenteeism, which was five times that reported by the control group. However, the duration of periods of absence in this study were considerably less than those reported by other CLBP studies. Work absence in this study was recorded in range categories such as '1-2 days', '3-5 days' etc so calculating a mean value for the group was not feasible. However, 32% (n=10) of participants from the CLBP group reported no CLBP related work absence and another 40% (n=15) reported a maximum of between one and five days.

It is estimated that 85% of the indirect costs related to low back pain are incurred through work absence or forced early retirement due to CLBP. Absenteeism due to CLBP results in longer periods of work absence and decreases the probability of ever returning to work (Elfering 2006; Wynne-Jones et al. 2014). Participants in this study did not fit this pattern because the entire pain group and 94% of the control group were either in work or retired and the two control group participants who were not in work, were actively seeking work. This finding indicated that the issues experienced by the CLBP group participants did not prevent them from working.

The pain group's 'current' pain scores, where 'current' meant pain on the day of data collection, were mild with the pain group scoring less than two out of ten. However, their 'typical' mean pain levels were 5.8 SD 2.0 (NRS 0-10) and were classified as 'moderate' pain (Jensen et al. 2001). If ranked according to typical pain scores, this study's CLBP group were positioned at the higher end of the ranges reported in the systematic review (see Chapter Two) (Moseley 2008a; Wand et al. 2010b; Bray and Moseley 2011;

Luomajoki and Moseley 2011; Stanton et al. 2013; Wand et al. 2014b; Nishigami et al. 2015).

Differences between the 'current' and 'typical' pain scores could have been due to the episodic nature of CLBP and perhaps on average, fewer pain group participants were experiencing painful episodes at the time of data collection. Therefore, despite this study's pain group reporting moderately painful low back pain episodes, many were pain-free or they experienced low levels of pain between episodes. The reason for this was beyond the scope of this study but these results might explain why the pain group participants reported such low disability scores and all were in work.

One issue that may have significantly impacted this study's findings is that over 90% of the control group participants reported at least one previous episode of low back pain. Additionally, a third of the control group reported recurring or persistent low back pain which lasted longer than three months. While their symptoms met the criteria for the study definition of CLBP (Treede et al. 2015), these participants did not meet other inclusion criteria for the pain group but they did meet those of the control group. Specifically, they had never experienced low back pain, or they had no back pain on the day of testing but reported one or more low back pain episodes which had not limited or interfered with their activities of daily living (ADLs) within the past two years.

In both groups, the participants who reported a history of low back pain, reported intermittent episodes of pain interspersed with pain-free, or low level pain periods. These fluctuations may implicate cortical change because cortical reorganisation does change quickly under experimental conditions (Stavrinou et al. 2007; Lissek et al. 2009). It is unknown how fluctuations in chronic pain are related to cortical reorganisation or sensory changes such as TPDT but if rapid cortical change can occur under experimental conditions, it is possible that similar changes could also occur with fluctuating real-world symptoms. Including these participants within the control group may have influenced this study's findings because the cortical changes thought to occur alongside this study's sensory and motor outcome measures are believed to occur with recurrent or persistent pain in a variety of conditions, including CLBP (Flor et al. 1997; Pleger et al. 2005; Moseley 2006; Pleger et al. 2006; Tsao et al. 2008; Tsao et al. 2010; Tsao et al. 2011).

Therefore, day to day fluctuations in the pain or motor function symptoms of those reporting low back pain (in the pain or control groups) could have evened-out differences in the outcome measures observed between the groups. As such, any differences could have been smaller and not reached statistical significance. Consequently, the representation of persistent or recurrent low back pain characteristics within the control

group increased the possibility that the study was underpowered and important differences in measures between the pain and control group may not have been identified as statistically significant.

A further factor used to differentiate participants into either the pain or control group may have also impacted upon the findings. In addition to their back pain history, participants were differentiated into groups depending on whether their ADLs were negatively affected due to back pain.

CLBP pain is positively related to disability (including ADL function) but the strength of this relationship and whether quality of life is impaired differs with age, where young adults report being more greatly affected than older adults (Houde et al. 2016; Wettstein et al. 2018). Therefore, older participants in this study may have considered their quality of life to be less impacted by their CLBP and may have considered their ADL's to have been unaffected by their symptoms. This was beyond the scope of this study but it might have been expected that the mean age of the control group would be greater than that of the pain group had this occurred and this was not the case. Asking specifically whether their ADL's were affected helped to categorise participants into groups which increased the likelihood that the pain group participants symptoms were of sufficient magnitude to negatively impact their motor functional performance.

This study assessed clinical surrogates of cortical reorganisation to further understand changes to these sensory and motor functions in those with CLBP. Cortical reorganisation is related to impaired sensory and motor function in different chronic pain conditions (Pleger et al. 2005; Pleger et al. 2006; Tsao et al. 2008; Lissek et al. 2009; Tsao et al. 2010; Tsao et al. 2011). Furthermore, there is evidence that temporary sensory and motor function changes occur alongside altered cortical organisation in those with impaired limb movement (Lissek et al. 2009). Although Lissek et al. (2009) assessed limb movement, which has clear differences regarding laterality and dominance compared with movement of the trunk, the study does demonstrate the existence of such a relationship. It is possible that further relationships may occur elsewhere in the body where motor functional impairments exist.

Those with CLBP move differently to those without pain and to each other (van Dieën et al. 2003; Hodges et al. 2013). Subsequently, those reporting difficulty in performing ADLs (as a result of back pain) probably move differently to and engage different motor strategies to those who are unaffected (van Dieën et al. 2017). Therefore, factors thought to be affected by cortical reorganisation may be more likely in those presenting with CLBP and current motor function difficulties. By ensuring that the pain group presented with

CLBP and motor functional difficulties, identifying differences between the pain and control group was more likely. Using CLBP and ADLs as group differentiators, rather than using CLBP alone, was of greater importance because this study's pain group reported low current pain and disability scores so the differences between the pain and control groups regarding pain scores were clinically minimal, yet statistically significant.

The researcher could not locate other studies assessing TPDT, motor imagery and motor function where the approach of differentiating pain and control group participants was explicitly reported. However, verbal communication with some of the authors of the papers included within the systematic review, revealed the methodological approaches used to differentiating the control from the pain group participants to be very similar. However, such conversations must be considered to be anecdotal and unspecified differences between the studies groupings are likely, which may be why this study's findings are different to those previously reported.

The disability data from the pain group provided a comparison to other studies. In this study, the RMDQ score was very low, with a median group score of only two (a maximum score of 24 reflected greater disability) (Roland and Morris 1983). The lowest scoring participants scored zero and the highest scored only four. This would indicate that this study's participants with pain were less disabled than those described by Luomajoki and Moseley (2011), Nishigami et al. (2015) and Wand et al. (2010b); Wand et al. (2014b). The reason for the difference in the population disabilities of the studies may be because of where participants were recruited. For example, one study recruited from a combination of private clinics in Japan (Nishigami et al. 2015). Another study recruited from community physiotherapy practices and a hospital pain management department in Western Australia (Wand et al. 2014b) and the third study recruited from a private physiotherapy clinic in Switzerland (Luomajoki and Moseley 2011). The study recording the highest pain group disability was Wand et al. (2014b) (RMDQ mean 10.1, SD 5.9) but no suggestion was made as to what might be the reason for the high score.

The participants in this study, were recruited from clinics and universities on the south-central coast of the UK and social media platforms but not from hospital environments which might be the reason for the lower disability score.

Overall, the participants in this study shared many similar characteristics to those included within the systematic review. It is accepted that generalising observational study results to the wider population is unwise, but confirming that the participants in this study shared characteristics to participants in similar studies drawn from populations across different geographical locations and cultures, adds weight to the findings (Black 1996).

6.3. Differences in Tactile Acuity, Body Schema and Motor Function

6.3.1. Tactile Threshold and TPDT

Fingertip tactile acuity was important in this study in that it provided baseline measurements of tactile threshold and TPDT on a remote region of the body in both groups. There was no statistically significant difference for fingertip tactile threshold and TPDT between the pain and control groups.

The data collected in this study closely reflected typical adult measurements reported in other studies and key texts (Weinstein 1968; Bell-Krotoski et al. 1993; Bell-Krotoski et al. 1995; Kandel et al. 2013). Identifying fingertip tactile threshold and TPDT to be similar for both groups in this study and like other studies, confirms that tactile threshold and TPDT on the fingertip was within the normal ranges for participants in this study's pain and control groups. This indicated that the neurophysiological processes which enabled participants to correctly detect light touch tactile stimuli and differentiate between one or two stimuli at a pain-free region of the body were consistent in both groups.

As measurements of tactile threshold and TPDT are related through their neurophysiology, the first two null hypotheses from question one have been discussed together. As a reminder, these hypotheses were: *'There is no statistically significant difference in low back tactile threshold (g) between adults with chronic low back pain and a control group'*, and *'There is no statistically significant difference in low back two-point discrimination threshold (mm) between adults with chronic low back pain and a control group'*.

This study found no statistically significant difference in low back tactile threshold at the spinal regions of L3 and L5 between the pain and control groups. These findings were similar to those reported by Moseley (2008a) and Wand et al. (2010b) despite the dissimilar sample sizes (six pain and ten control group participants for Moseley (2008a) and nineteen participants for each of Wand et al's (2010b) pain and control groups). The ratios of female to male participants were similar across all three studies. This study adds to the existing evidence from Moseley (2008a) and Wand et al. (2010b) that low back tactile threshold does not appear to be altered in the region of low back pain in adults with CLBP. It also provides evidence that tactile threshold did not differ on the pain-free fingertips between the same groups. This is the first study to report these findings in a sample from a UK population.

The TPDT results differed to those of tactile threshold. In this study, while no differences were noted on the fingertips, low back TPDT was larger, therefore less accurate, at L5 and L3 in the pain group when compared with TPDT from the same locations in the control group. Not only did these low back TPDT findings concur with those of Moseley (2008a) and Wand et al. (2010b), but also with Stanton et al. (2013) whose study consisted of 17 pain and 20 control group participants, and Luomajoki and Moseley (2011) who reported 45 participants in each of their groups. This was important because finding that TPDT accuracy in the low back area for those with pain was less accurate than the control groups in five separate studies (including this one), adds to the evidence that this feature occurs in different populations with CLBP.

Tactile threshold and TPDT were assessed at L3 to provide control measurements of low back tactile acuity. This was because none of the participants (pain or control) reported their typical back pain to occur at L3. TPDT measured at L3 helped to determine whether TPDT had altered only within the region of low back pain.

Assessing TPDT at L3 revealed a pattern of impairment. Measures of TPDT at L3 were impaired in the pain group when compared with the control group at the same location, but also when compared with TPDT measures made at L5. This within-group difference in TPDT occurred in the pain and control groups and within each group, the differences were statistically significant. There also appeared to be a scale of impairment. Low back TPDT was most accurate at L3 in the control group, slightly less accurate at L5 in the control group (some of whom had reported a history of low back pain episodes), even less accurate at L3 in the CLBP group and least accurate at L5 in the pain group.

This finding revealed new information about the distribution of TPDT impairments in those with CLBP and returning to the data collection notes may have provided an explanation. Although L5 was central to participants' typical low back pain, some participants reported their pain to change in location, side and quality. Some reported that on occasions, their pain was widespread and could include the L3 region. It cannot be known from this study but if chronic pain was related to the changes in TPDT, then this changeable pattern of chronic pain might help explain the pattern of TPDT impairments seen between and within these groups. It is worth remembering that other factors may be involved in this phenomenon. For example, changes in low back TPDT might be related to movement of the low back where impaired movement would likely occur at multiple spinal segments and the pelvis (Hodges et al. 2013). Had TPDT been assessed at different regions of the back and specific assessments of individual joint biomechanics been made, perhaps such a relationship might have been clearer.

When comparing the TPDT results with previous studies, this study's control group low back TPDT measurements were larger (less accurate) than those reported by Moseley (2008a) and Wand et al. (2010b). In this study, the control group median low back TPDT was 59.8mm (IQR 52.2-68.2) and these results were at the upper end of the normal range reported for healthy adults of 40-67mm (Nolan 1985; Luomajoki and Moseley 2011; Stanton et al. 2013; Wand et al. 2014a; Falling and Mani 2016a). This may be explained by the fact that many of this study's control group participants reported at least one previous low back pain episode. TPDT was positively correlated to the CLBP groups 'typical' pain score so it may be that larger TPDT measurements existed in the control group because of their prior experiences of low back pain. Although causality between the region of CLBP and altered TPDT cannot be implied from the findings of this study as this was an observational study, these findings might suggest that if pain is involved in altering TPDT, pain need not be severe or long-lasting for changes in TPDT to occur.

Therefore, if the control groups in other studies experienced fewer low back pain episodes than those reported by this study's control group, this might explain why the median TPDT for the control group was greater than those reported by Moseley (2008a) and Wand et al. (2010b). The control group inclusion criteria were based upon those in common use for back pain studies from Anderson (1977); Roland and Morris (1983); Stratford et al. (1996); Hildebrandt et al. (2004); Dionne et al. (2008); Karayannis et al. (2012); Treede et al. (2015) and also those used by the studies included within the systematic review reported in Chapter Two. However, given the findings of this study, it may be that when separating participants into CLBP and control groups to explore for differences in characteristics of a neuroplastic rather than biomechanical origin, using these criteria may not be appropriate.

Alternatively, the differences in control group TPDT may have been due to previously reported issues in inter-rater reliability (Catley et al. 2013b; Adamczyk et al. 2015). Although, if this was the source of the discrepancy, one might expect to have seen similar differences between the pain group scores and this was not the case.

Although it is difficult to compare the results directly due to the heterogeneous nature of the study methodologies, the results suggest that measurements of TPDT are larger and therefore discriminative tactile acuity is less accurate on the low backs of those with CLBP. That the method detected differences between groups, even in small sample sizes, suggests that the measure is sensitive and capable of identifying statistically significant differences in discriminative tactile acuity, even when the differences are small.

However, from the tool reliability study reported in Chapter Four, it must be noted that statistically significant differences in TPDT values were returned using Vernier calipers with different tips. These findings raise concern as to the value of comparing TPDT measurements between studies, even when they appear to be assessed using similar Vernier calipers. The modified calipers used in this study clearly limit the generalisability of this study's results to others and whether this study could be repeated by other researchers but the reliability study was valuable in that it highlighted this issue in this widely adopted method.

These findings are of interest because in studies of participants with other chronic pain conditions, including one with CLBP participants, specific behaviour related sensory rehabilitation, such as TPDT training on the painful region, found localised TPDT impairments to be reversed and to be associated with improved pain and disability (McCabe et al. 2003; Pleger et al. 2005; Moseley et al. 2008c; Wand et al. 2011b). These improvements were found to be maintained some months later in the study of CLBP participants (Wand et al. 2011b) but all of these studies were small and the findings must be considered with regards to the limitations that such studies entail. In fact, Wand et al. (2011b) only had three participants and studies small studies are more likely to be underpowered (meaning the chance of discovering genuinely true effects is less) and more greatly affected by bias than larger studies. One reason for this is the 'Vibration of effects' (Ioannidis 2008). These are where the estimates of the size of the effect differ depending upon the analytical approach used by each study (Button et al. 2013). The 'Vibration of effects' can dramatically influence a study's findings because it introduces unwanted bias and bias in small studies has a proportionally greater effect on the findings than it does when found in large studies (Button et al. 2013). For example, a large estimate measured in two participants, where $n=3$, would have a dramatic effect on the statistical analysis, but had $n=50$, or even $n=500$, the impact would likely to have been inconsequential. Subsequently, the findings reported from small studies are more likely to deviate from those seen in the wider population.

The results from this study add to the evidence that TPDT is impaired within the region of low back pain in different CLBP populations. Current management of CLBP is inadequate and these results support the need for larger scale intervention studies to investigate the potential for this currently underused target for therapeutic rehabilitation.

These findings are significant because structural and functional cortical reorganisation occurs in people with CLBP (Flor et al. 1997; Lloyd et al. 2008; Tsao et al. 2008; Tsao et al. 2011). TPDT is considered a clinical signature of cortical reorganisation (Pleger et al.

2001; Haggard et al. 2003; Pleger et al. 2003; Pleger et al. 2005; Pleger et al. 2006; Lissek et al. 2009; Moseley and Flor 2012b) and although this study did not assess cortical organisation directly, previous evidence implies that in the presence of impaired TPDT, cortical reorganisation exists in some people with CLBP (Flor et al. 1997). TPDT may provide a simple outcome measure to monitor cortical organisation following therapeutic rehabilitation techniques (Lissek et al. 2009).

There are three main reasons why TPDT function may have been impaired on the low backs of the pain group. First, the impairment of the peripheral skin structures; second, the transmission of information from the peripheral nervous system (PNS) to the central nervous system (CNS) or third, the integration and interpretation of information within the CNS and its resultant efferent response.

It is not possible that problems in the transmission of information between the PNS and CNS were the reason for the TPDT impairments seen on the low backs of the pain group. This is because tactile threshold and TPDT function share similar structures and pathways. Had these structures and functions been involved, tactile threshold impairments would have been seen alongside those of TPDT.

Although they share neurophysiological structures and pathways, TPDT is a more complex process than tactile threshold. Tactile threshold is reliant upon stimulating mechanoreceptors within one tactile receptive field on the skin surface. Receptive fields vary in size. The smallest occur on the fingertip and increasing in size with distance towards the anatomical midline (Johansson 1978; Johansson and Vallbo 1979; Schady and Torebjörk 1983). TPDT differs in that it requires the stimulation of mechanoreceptors located in more than one receptive field (Lundborg and Rosen 2004).

Tactile receptive fields are somatotopically linked to clusters of neurons within the primary somatosensory cortex (S1) (Sur et al. 1980; Merzenich et al. 1983; Jenkins et al. 1990; Haggard et al. 2003). In healthy humans, normal response profiles (the activation of a receptive field and its associated cluster of cortical neurons) are maintained through intracortical inhibition, where activated neurons inhibit their neighbouring neurons from firing (Merzenich et al. 1983). Following injury or during chronic pain, these normal response profiles alter because they lose their ability to inhibit neighbouring neurons from firing. As a result, previously demarcated neuronal clusters within the S1 merge with neighbouring territories and this is referred to as cortical reorganisation (Ramachandran et al. 1992; Yang et al. 1994b). Consequently, the somatotopically linked receptive fields on the skin surface also enlarge. These concepts are illustrated in *Figure 6-1* and may help to explain why TPDT was impaired in this study's pain group within or nearby the

region of low back pain, but it was not altered on the pain-free fingertips of the same participants. Additionally, it might explain why there were no differences in tactile threshold measurements between the pain and control groups when measured at the finger-tips and the low back. Therefore, TPDT impairments in the presence of normal tactile threshold were likely to have been related to the CNS processing of tactile information and the production of an appropriate efferent response.

This is important because it evidences measurable sensory changes on the low backs of those with CLBP which could have resulted from CNS rather than PNS processes. In PLP and CRPS, similar sensory impairments have been identified and successfully targeted with therapeutic interventions to restore cortical impairments and reduce pain (McCabe et al. 2003; McCabe et al. 2004; Moseley 2004b; Moseley 2005b; Pleger et al. 2005; Moseley 2006; Pleger et al. 2006).

To summarise, tactile threshold and TPDT were assessed on the fingertips and low backs of CLBP and control group participants. Of these measures, only TPDT on the low back were significantly different between the groups. These findings suggest that the mechanisms involved were of CNS rather than PNS origin and that the normal tactile threshold and impaired TPDT characteristics within (or near to) the region of pain as seen in other chronic pain conditions, also existed in this study's sample of UK adults with CLBP.

It might be argued that the changes seen at the low back were a result of supraspinal factors rather than the spinal factors involved in central sensitisation, the phenomenon which is characterised by widespread pain hypersensitivity (Woolf 2014). However, if the changes in low back TPDT resulted from central sensitivity, participants would have reported pain in response to the tactile contact on the low back and probably a similar response at the remote site on the fingertip. Neither of these factors occurred so changes to discriminative tactile acuity in the absence of a heightened pain response was unlikely to have resulted from pain central sensitisation and more likely to be related to changes in supraspinal processes.

Although this is not the first study to have assessed TPDT in those with CLBP and a control group, it is the first to investigate these findings in a sample from the UK population. Additionally, despite very little pain and disability, and a history of LBP in the control group, the study identified significant impairments in low back TPDT in the pain group.

These findings support future CLBP research in testing the therapeutic interventions to improve TPDT within and near to the region of chronic pain. There is a growing body of evidence that shows that improving sensory function in PLP and in CRPS, such as retraining impaired TPDT on the painful area have improved pain outcomes (McCabe et al. 2003; McCabe et al. 2004; Moseley 2004b; Moseley 2005b, 2006). It might be suggested that improving impaired TPDT through tactile training in those with CLBP might also improve pain and disability outcomes for those with CLBP (Wand et al. 2011b).

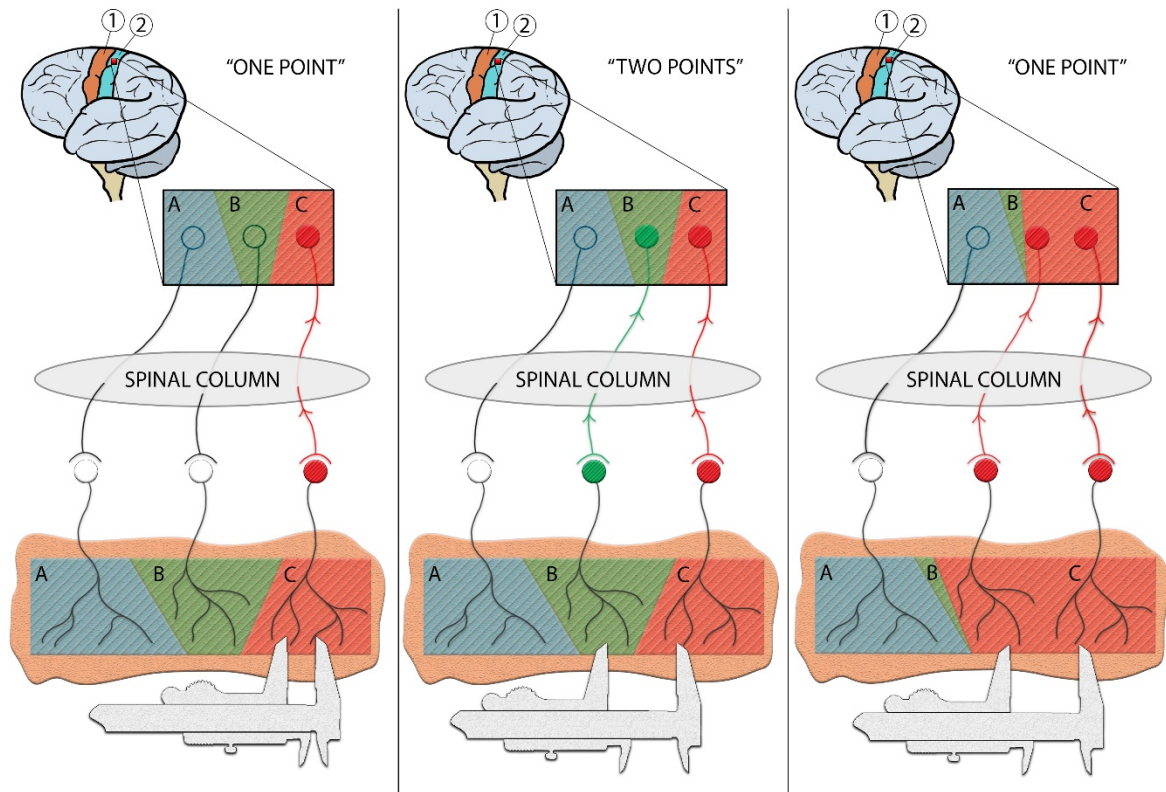


Figure 6-1: Conceptual illustration to show why low back Two-Point Discrimination Threshold (TPDT) may be impaired on the low backs of the pain group but not the control group.

Concept based on Yang et al. (1994b), Yang et al. (1994a) and Buonomano and Merzenich (1998)

Key and Explanation

1: Primary motor cortex (M1), 2: Primary somatosensory cortex (S1), Blue 'A', Green 'B' and Red 'C' regions represent separate neuronal response profiles which incorporate a specific cortical neuronal cluster and their associated tactile receptive fields on the superficial, skin surface.

The **left image** shows normal TPDT function when the two points of contact are too close together for the subject to correctly identify two points and only one receptive field (red 'A') is contacted - the subject perceives "one point".

The **middle image** shows normal TPDT function when the two points of contact are far enough apart to contact two receptive fields (green 'B' and red 'C') for the subject to correctly identify "two points".

The **right image** illustrates the concept of altered neuronal response profiles, where cortical reorganisation in the S1 is mirrored by a reciprocal response in the associated tactile receptive field – the red region 'C' has engulfed the areas previously related to the response profile of the green 'B' region in the cortex and the superficial, skin surface. In this situation, the subject perceives only "one point" of contact.

6.3.2. Body Schema

The third null hypothesis relating to question one stated '*There is no statistically significant difference in body schema between adults with chronic low back pain and a control group*'.

Body schema was assessed using two methods; Recognise® software (Neuro Orthopaedic Institute, 2016) to assess accuracy and speed of performing left/right discrimination tasks of the back and the Fremantle Back Awareness Questionnaire (FreBAQ) (Wand et al. 2014b) to assess back perception.

Differences between the pain and control groups FreBAQ scores were significantly different but scores for accuracy and response times from the left/right discrimination tasks were not. Although the results from the two measures appear conflicting, it may be that they were measuring different aspects of body schema and this might explain the differences. If considering both sets of results with regards to the null hypothesis, the findings must be considered inconclusive.

6.3.2.1. Body schema - Left/right discrimination tasks

The NOI Recognise® tool accuracy scores (percent of correct answers) differed from those reported by the two studies within the systematic review (Chapter Two) but it is worth noting that Stanton et al. (2013) used a subset of the CLBP and control group data from Bray and Moseley (2011) as part of their larger chronic knee and back pain study. Consequently, similar results were to be expected from both research teams.

The Bray and Moseley (2011) and Stanton et al. (2013) pain groups' accuracy in correctly differentiating between left and right images was considerably less than their control groups. Their methods of analysis differed but the pain groups of Bray and Moseley (2011) achieved between 53-67% (SD 45-62% for the bilateral pain group and SD 60-74% for the unilateral pain group) and those of Stanton et al. (2013) were 80% (SD 17.6%) accurate. However, all of their groups scored less than the >90% scores for accuracy achieved by the pain and control groups in this study and the variation seen in the Bray and Moseley (2011) and Stanton et al. (2013) pain groups was also greater than that seen in this study's accuracy scores.

This study's results were perhaps even more unexpected when considered in relation to a large study from Bowering et al. (2014) which used an online version of the NOI Recognise® tool to measure left/right discrimination of back images. Their study used

questionnaires to collect data from over 1000 participants on demographics, activity level, general health and pain related data. They recruited participants from the Neuro Orthopaedic Institute (<http://www.noigroup.com>) database and readers of the Body in Mind research group website (<http://www.bodyinmind.org>) which has readers in 100 countries. Participants were divided into groups; healthy (no back pain), current back pain, a history of back pain, and both (current back pain and a history of back pain). Their results demonstrated that those in pain at the time of completing left/right tasks were significantly less accurate than those who were back-pain free. Additionally, those who were pain free at the time, but reported historical back pain, were less accurate than those who had always been back pain free. Overall, there were no differences in response time for any of Bowering et al's (2014) groups and all of their groups were approximately 15-18% less accurate than the pain and control groups within this study.

There are several reasons why this disparity might have occurred. Based on evidence from previously published studies, such as Bray and Moseley (2011) and Stanton et al. (2013), finding this study's pain group to be highly and equivalently accurate to the control group was unexpected. That this study's results did not match those already published might be explained if the participant characteristics were different from those in of Bray and Moseley (2011) and Stanton et al. (2013). However, aside from Bray and Moseley's (2011) pain group reporting almost twice the current pain score than this study's pain group (3.7 versus 1.9 on a pain scale of 0-10), both scores would be classified as 'mild' pain (Jensen et al. 2001) and the reported characteristics appear similar in each study.

Persistently incorrect responses in left/right discrimination tasks are suggested to indicate an impairment within the working body schema or premotor cortical functions (Schwoebel et al. 2001; Moseley 2004c). Therefore, the highly accurate scores seen from this study's groups implied participants body schemas to be unimpaired.

A second reason for the differences could be due to small group sizes in the Bray and Moseley (2011) and Stanton et al. (2013) studies. Bray and Moseley (2011) included 21 CLBP and 14 control group participants and Stanton et al. (2013) used a slightly smaller subset of this dataset but neither reported a sample size calculation. For this study, sample sizes were calculated using the TPDT data from the tool reliability study in Chapter Four (based upon two means and equal group sizes). The calculation determined that 31 participants per group were necessary to achieve a power of 90%, where power was the probability that a statistical test would correctly reject the null hypothesis when the null hypothesis was false.

By using smaller group sizes, the studies of Bray and Moseley (2011) and Stanton et al. (2013) may have been underpowered and greater error could have been introduced to the statistical analysis (Ioannidis 2008; Button et al. 2013). The variation seen in their measures of accuracy were greater than those seen in this study and this may be because the mean variation from a small sample is more likely to be greater than that calculated from a larger group (Button et al. 2013). As such, it is possible that the significant between-group differences reported by Bray and Moseley (2011) and Stanton et al. (2013) could have arisen as a result of the methodological process. However, that does not explain why this study's findings differed from those of Bowering et al.'s (2014) large study, which concurred with Bray and Moseley (2011) and Stanton et al. (2013). It may be that this study's participants were a sub-group of the wider CLBP population but the traits which sub-grouped them was unknown. Despite attempts to identify multiple participant characteristics in the hope of better understanding the key findings from this study, it is acknowledged that many heterogeneous traits remain unknown and may have influenced the results and their interpretation.

Recognise[®] response times to select the correct answer were also different between Bray and Moseley (2011) and this study's results. The response times from Bray and Moseley (2011) were identical in their pain and control groups (2.4 seconds, 95% CI 2.2 - 2.6 seconds). In this study, there were no differences in response times between groups either but both groups responded in half the time taken by the Bray and Moseley (2011) groups.

An unforeseen methodological issue may have prevented subtle between group differences from being identified. A new version of the NOI Recognise[™] tool (2016 version) was released just before the main data collection began. The new version replaced that used in the pilot study which is reported in Section 3.5.4 in Chapter Three and there were significant changes to the new version which were unknown until after the main study data had been collected. While the pilot version randomly presented participants from a pool of 48 images, the new version drew from a pool of 98 images. This would have increased variability of the images being shown and therefore, in the data and analyses. Such increased variability could have meant the conclusions drawn may not have been reliable. Additionally, with greater variation in the images being shown, the chance of participants having to assess images that were rotated through 180 degrees was increased and higher error rates are known to occur during assessment of these images (Bowering et al. 2014).

Aside from their geographic location and the slightly higher current pain scores reported by the Bray and Moseley (2011) pain group, the participant characteristics reported by both studies were similar. One reason for the differences seen within this study may have been due to the heterogeneity of participant characteristics and this could have resulted from the recruitment strategy.

There were differences in where participants were recruited from between this study and that of Bray and Moseley (2011). It is unclear where they were all the Bray and Moseley (2011) participants were recruited from but some came from private physiotherapy clinics. This study's recruitment campaign targeted a variety of health related venues which included private manual therapy and dental clinics but also university buildings and some sports and fitness clubs. Participants were not asked where they had learnt about the study so it cannot be known whether recruiting from different venues introduced significant bias to the study but one might speculate that those from the sports and fitness clubs may have had higher levels of fitness and performed better in some tasks than those recruited elsewhere. It is suggested that in some athletic populations there is no difference in left/right judgement task ability (Wallwork et al. 2015). However, some weak evidence suggests that those with significant martial arts expertise perform differently in lateral judgement tasks to those without such training (Campos et al. 2001; Torres 2015). It is suggested that experts may not be more accurate than non-experts when differentiating between images of left and right postures but they might respond more quickly. Participants in both of this study's groups responded faster in comparison to participants performing similar tests in earlier studies but because exercise data was not collected from this study's participants, it cannot be concluded that the increased reaction speed was related to any exercise in which they may be involved.

Furthermore, it cannot be assumed that those who volunteered after reading a recruitment poster placed in a sports or fitness club actually undertook regular exercise. Neither can one assume that those recruited from elsewhere did not have high levels of fitness or motor control skills. The absence of recording exercise data has been noted as a limitation of the study. Overall, it might be suggested that anomalies in the data relating to fitness levels and motor skills due to the recruitment strategy are likely to have been present and represented within the results of both groups.

This study used the criteria of CLBP and the presence of activities of daily living (ADLs) that negatively impacted participants' lives to differentiate them into either the pain or control groups. Other studies assessing performance of left/right judgement tasks do not

appear to have used ADLs to differentiate their participants and this may have influenced the differences in the results between studies.

Distractions are known to increase error or a delay in the correct selection of left and right (McKinley et al. 2015) but this was unlikely to have led to the discrepancies because participants were reminded of the need for concentration, speed and accuracy by both research teams.

It was not reported by Bray and Moseley (2011), but over half of this study's pain and control group participants held a university degree. Initially, education was considered to help explain the enhanced accuracy and response rate seen in this study, but the idea was not supported by the literature. Humans normally develop the ability to differentiate between the left- and right-self around five years of age. By 12 years of age, children are adept at the spatial awareness required to identify left and right of a non-self object (Benton 1968; Hirnstein et al. 2009). Therefore, the high levels of post-school age education observed in our groups was unlikely to have significantly altered their ability in discriminating between left and right. However, differences in visuo-spatial awareness are reported between women and men but can be improved through a variety of tasks and skills that demand spatial awareness consideration, manipulation and reasoning (Lord 1987; Hayes and King 2009). It might be suggested that the participants involved in this study (pain and control groups) might be involved in unknown professions or practices which resulted in well-developed spatial awareness and this was the reason for the high accuracy and response scores in the Recognise® left/right discrimination tasks. Participants were asked basic information regarding their professions but not about other their interests so conclusions regarding this theory could not be explored.

Interestingly, only one other study to measure left/right discrimination tasks of the back (NOI Recognise® software) could be located which did not find significant differences in accuracy or response times between their pain and control groups (Linder et al. 2016). Linder et al. (2016) included participants with low back pain of only six weeks duration so their participants characteristics differed from those in this study, yet similar accuracy and response time scores were noted in the pain and control groups of Linder et al. (2016) and this study. It is noteworthy that, all this study's pain group reported their CLBP to exceed three months duration. In fact, over three quarters of the participants reported a history of CLBP which exceeded five years.

It is widely accepted that correctly differentiating between left and right of a non-self object initially involves the selection of the left or right side, using spatial awareness to manipulate the explicit mental rotation of one's own body into the position of the object or

person under consideration (Parsons 1994; Decety 1996; Parsons 2001). Either the mental rotation is met with a match to the initially selected side, or a mis-match occurs, and the process is begun again after selecting the alternative side. Based upon this principle, it might be expected that initially selecting the incorrect side would result in an increase in the time taken to select the correct answer.

Attentional bias, where the selection of one side is favoured over selecting the other, is suggested to be responsible for delays in correctly selecting left or right in people with painful limb conditions (Schwoebel et al. 2001; Moseley 2004c; Moseley 2004b; Hudson et al. 2006). Those with an acutely painful limb are biased towards choosing the painful side of the body during left/right discrimination tasks (Moseley 2004c; Moseley et al. 2005; Hudson et al. 2006). Conversely, those with a chronically painful limb focus on the opposite side of the body, perhaps to ignore their painful limb, so are biased towards selecting the pain-free limb (Schwoebel et al. 2001; Moseley 2004c). Therefore, the response times for those with acute or chronic limb pain would be slower.

In fact, the opposite appeared to occur in this study because response times were much faster for the almost identically performing CLBP and control groups when compared with those of Bray and Moseley (2011). However, unlike chronic limb pain, CLBP is not spatially discrete so identifying biases towards one side are difficult and were certainly not distinguishable within this study. These results highlight that the body schema impairments reported by Bray and Moseley (2011) and Stanton et al. (2013) are not ubiquitous to the wider CLBP population and some sub-groups out-perform others.

Of final consideration, is that in spatial recognition tasks involving the trunk rather than a limb, left/right judgment tasks do not elicit the same pattern of motor imagery that is thought to occur when limbs are being judged. That is, during limb based left/right judgement tasks, motor imagery of the limb is elicited (Parsons 1994; Parsons and Fox 1998). Until recently, it had been assumed that similar processes would be involved and motor functions of the trunk would be elicited during left/right judgement tasks of the trunk (Bray and Moseley 2011). However, recent findings in unimpaired, pain-free, young adults do not support this theory (Alazmi et al. 2018). Images depicting larger magnitudes of movement resulted in faster and more accurate responses than did those depicting smaller movements. Had motor imagery of the trunk been elicited while participants had been mentally rotating their own bodies into the positions shown on the image, the mental imagery would have taken longer for the images depicting movement further away from the midline and the response time should have been slower. There was no compromise between greater speed and reduced accuracy either and Alazmi et al. (2018) suggests

that their participants did not imagine moving their trunks into the positions presented. In fact, they suggest that the critical factor involved in correctly differentiating between left and right in such tasks involving the trunk may be the saliency of visual cues depicting asymmetry in the body. Furthermore, faster response times were also noted for left/right judgement tasks involving images of the neck when compared with response times for images of hands performing (Wallwork et al. 2015). This evidence also appears to support that different processes might be involved when people perform left/right judgement tasks in which they assess different regions of the body, some of which are nearer the body-midline (x -axis).

This chapter discusses the differences in the participant characteristics between those studies that found impaired accuracy in their pain groups (Bray and Moseley 2011; Bowering et al. 2014) and those that did not (this study and Linder et al. 2016), but this recent study from Alazmi et al. (2018) may provide new perspective on why these differences may have occurred. It may be that the neuro-mechanisms behind the performance of trunk judgement tasks differ to those of the limbs and they are not fully understood. This has implications for clinical practice and is discussed in section 0 of this chapter.

6.3.2.2. *Body Schema - Back perception task*

The second measure of body schema, FreBAQ (Wand et al. 2014b), identified significant differences in back perception between this study's pain and control groups. If FreBAQ and the left/right discrimination tasks were assessing the same body schema metric, similar findings would have been expected. However, this was not the case. Finding a statistically significant difference between the groups for FreBAQ but not left/right discrimination suggests that the different metrics assess different aspects of body schema.

Using the FreBAQ scores, back perception was found to be impaired among this study's CLBP group. The CLBP group exhibited perceptual impairments by endorsing significantly more statements regarding a distorted back perception than did the control group. The three most strongly endorsed statements were; 'I need to focus all my attention on my back to make it move the way I want it to', 'I can't perceive the exact outline of my back' and by far the most strongly endorsed statement was 'My back feels lopsided'. It is worth noting that this pattern of statement endorsement was also mirrored

by some participants in this study's control group, and by the pain groups of Wand et al (2014b) and Wand et al (2016).

While the perceptual differences between the pain and control groups concurred with the results previously reported in other populations (Wand et al. 2014b; Wand et al. 2016), it is the first time such findings have been reported in a sample from the UK population.

The finding has clinical importance because therapeutically altering perception modulates pain in healthy people and those with CLBP (Mancini et al. 2011; Wand et al. 2011a). If perception modulates pain and it can be altered therapeutically, it might be suggested that therapeutic interventions designed to target the back-perception impairments identified in this study may modulate CLBP outcomes.

Whether the backs of this study's pain group truly were distorted or not was not part of this study's design. However, it raises important questions regarding the relationship between perceived body schema versus actual body position. Perception relies upon the processing and integration of peripheral sensory mechanisms with higher level (spinal and supraspinal) processing in the CNS. By interpreting meaning from these afferent signals, humans perceive an image of their body and the space around it. Motor function is reliant upon this information to ensure safe movement through our surroundings but it is a two-way relationship because perception relies upon the ever-changing afferent input from the body as it repositions (Shumway-Cook and Woollacott 2007).

6.3.3. Low back Motor function

Motor function of the low back was assessed in two ways; a) Luomajoki's Battery of Tests (Luomajoki et al. 2007; Luomajoki et al. 2008) and b) using the 30-second Chair Stand Test (30-CST). Luomajoki's Battery of Tests was designed to test specific functions of motor control involving flexion and extension of the lumbar spine. The 30-second Chair Stand Test (30-CST) is considered a measure of motor function endurance (Simmonds et al. 1998).

Both motor function tests revealed significant differences between the pain and control groups, with the pain group participants performing more poorly in both tests.

The Luomajoki's Battery of Test findings were consistent with those of Luomajoki and Moseley (2011) which was the only other article to assess motor function within this study's systematic review.

The 30-CST results identified the pain group to perform less well than the control group and these findings were statistically significant. Although these findings indicate that motor performance by the pain group in this task was impaired, when compared with normative values, both groups performed well (Rikli and Jones 1999). This indicated that neither the pain and control groups were impaired compared with the wider population when performing a common motor functional task; that of rising and sitting down on a chair. One suggestion for this was that the participant recruitment campaign included exercise, sports and dance clubs. Exercise has a positive effect on CLBP outcomes (Liddle et al. 2004; Hayden et al. 2005). Collecting exercise participation data was beyond the scope of this study but it may be that participants who exercised, performed differently to those who did not exercise.

That the CLBP group performed significantly less-well in both of these motor function tasks was expected because people with CLBP move differently to those without back pain (Hodges et al. 2013). Many factors contribute to the altered patterns of motor function frequently seen in those with CLBP (Hodges and Moseley 2003; O'Sullivan 2005; Hodges et al. 2015). One factor of importance to this study is that different motor function patterns of people with CLBP are associated with proprioceptive impairments (Gill and Callaghan 1998; O'Sullivan et al. 2003; Clark et al. 2014). The main reason for including measures of motor function in this study was to identify significant relationships between motor function impairments, TPDT and body schema with the future aim of incorporating new interventions into existing treatments to improve CLBP outcomes.

6.4. CLBP Group Correlations - TPDT, Body Schema and Motor Function

Assessing the relationship between body schema and low back motor function was important because the overarching aim of the study was to identify sensory and low back motor impairments in those with CLBP. By performing correlation analyses, sensory impairments that were related to motor function impairments could be identified with the purpose of highlighting possible targets for future therapeutic interventions.

Only one significant correlation was identified between the key variables of TPDT, body schema and low back motor function, and that was between one aspect of body schema and motor function.

6.4.1. Body Schema and Motor Function

This is the first study to investigate and report the relationship between low back motor function and measures of body schema in a group of UK adults with CLBP and a control group.

In the CLBP group, a statistically significant, positive correlation was identified between back perception, measured by the Fremantle Back Awareness Questionnaire (FreBAQ) (Wand et al. 2014b; Wand et al. 2016) and low back motor control measured by Luomajoki's Battery of Tests (Luomajoki et al. 2007; Luomajoki et al. 2008). This relationship indicates that in adults with CLBP, those who demonstrated greater perceptual impairment were also the poorest performers of Luomajoki's Battery of tests motor function tests.

Similar relationships did not occur between the 30-second Chair Stand test and FreBAQ scores, or between the left/right discrimination scores and any motor function task. There were no significant differences between the pain and control groups ability to perform left/right discrimination tasks, but there was a significant difference between the two groups motor function performance. As such, a correlation between left right discrimination and motor function in this study's pain group was not expected. However, these findings do not support those from other studies. In young healthy adults, faster and more accurate motor imagery performance is associated with motor function, specifically, faster corrections of a limb reaching to a moveable target (Hyde et al. 2013).

Based on Hyde et al. (2013) a negative relationship between this study's pain groups left/right judgement scores (speed and accuracy) and poorer motor performance would be expected. The participants in Hyde et al. (2013) were different to those in this study in that they were, on average, almost 20 years younger and they were pain-free. It may be that a combination of factors was driving this unexpected result.

Those with CLBP move differently to those without back pain so it was expected that those with CLBP in this study would demonstrate impaired motor function. That they were almost as equally fast and accurate than the control group during left/right judgement tasks might be explained by the study's recruitment strategy. Recruitment posters were placed in different sports and exercise venues (martial arts, yoga, health and fitness clubs) in addition to health clinics and university buildings. There is evidence to support that the differences in motor imagery seen in adult populations with and without chronic pain may not occur in some athletic populations. It appears that those regularly engaged with yoga are no faster or more accurate in performing left/right judgement tasks than age and gender matched non-yogis (Wallwork et al. 2015). As the recruitment campaign included sports and fitness clubs, it is likely that some participants saw the posters while at these venues, perhaps indicating that they undertook regular exercise. It may be that varying athletic ability among this study's participants is one factor involved in the contradictory findings of this study. Unfortunately, this cannot be validated because exercise data was not collected as part of this study. This issue is reported in the study limitations section of this thesis.

Luomajoki's Battery of Tests required participants to focus on achieving specific movements of their lumbar spine and pelvis while isolating movement from neighbouring joints. Conversely, the 30-second Chair Stand test demanded the engagement of their whole body to move from a sitting to standing to sitting position. Participants were not guided on how to achieve this, aside from not being allowed to push up using their hands, so the use of different movement patterns and upper body momentum may have allowed them to achieve higher scores than they achieved for the Luomajoki's Battery of Tests. Of course, the high scores may have simply been a result of participants wanting to achieve a high score.

People with CLBP move differently to those who are pain-free and to each other and these movement patterns are associated with proprioceptive impairments (Gill and Callaghan 1998; O'Sullivan et al. 2003; Hodges et al. 2013; Clark et al. 2014). From the study design it cannot be claimed that the motor control impairments caused the

perceptual impairments (or vice versa) but a clear relationship was present where poor performance in one metric was accompanied by poor performance in the other.

Prior to this study, relationships between body schema and low back motor function had not previously been published so comparisons to findings in other populations were not possible. Looking to the wider literature may suggest why the relationship existed between perception of the low back and controlled movement of the same region.

Painful stimuli and pain, or even thinking about painful stimuli, cause changes in motor control (Hodges et al. 2013) and a perceived threat of pain or injury alter trunk range of motion in people with low back pain (Moseley 2004a). It is possible that the CLBP group in this study used altered movement strategies as protective mechanisms from perceived pain.

Clark et al. (2014) assessed the relationship between the perception and supine passive repositioning of the low back in a CLBP and a healthy control group. Although only a small pilot study of seven participants per group, significant differences in passive repositioning between the groups were identified where those with CLBP were more accurate in repositioning their spine than the control group. However, this observation was only noted when participants repositioned to their left side. The side of the location of low back pain was not reported but it was suggested that perhaps differences in laterality of the cortical structures which provided and integrated sensory information within the CLBP group may have behaved differently to those in the control group (Clark et al. 2014).

More recently, a novel study from Stanton et al. (2017) revealed that objective measures of back stiffness were not congruent with perceived back stiffness. Additionally, perceived back stiffness could be modified using sensory input while objective measures of back stiffness were unchanged. Stanton et al. (2017) proposed that “feelings of back stiffness are a protective perceptual construct, rather than a reflection of the biomechanical properties of the back”. These findings are of clinical importance because how a body feels to its owner (body schema) does not necessarily reflect the actual state of that body. In this study, the back-perception impairments may not reflect the participants’ bodies’ true states. Consequently, this sensory incongruity may provide new targets for therapeutic interventions.

It has been suggested that intimate, bi-directional relationships exist between perception and motor function (Stanton et al. 2017). These relationships aid in constructing a sense of body schema (or awareness) that is individual to each person (Haggard et al. 2003).

Body schema relies upon input from numerous sensory systems such as touch, pain and body positioning (Haggard et al. 2003). Joint position receptors and muscle stretch receptors play an important role in the efferent feedback process and in establishing joint position (Collins and Prochazka 1996; Collins et al. 2005). Feedback from skin stretch is also important in accurately establishing joint position sense during passive movements (Mildren et al. 2017). Therefore, it might be suggested that a network of sensory and motor functions is interlinked. For example, impaired biomechanical function may alter the normal proprioceptive afferent input (from joint position, muscle and skin stretch receptors), the efferent feedback processes and the location of joint position.

The impaired patterns of motor function and back perception, as a measure of body schema, seen in this study's pain group could be two aspects of this conceptual network of sensory and motor function changes. This theoretical concept is illustrated in Figure 6-2 (those without CLBP) and Figure 6-3 (those with CLBP).

Experimentally creating altered motor strategies in the hands of healthy participants by restricting finger movement initiated reversible cortical reorganisation (Stavrinou et al. 2007). Perhaps cortical re-organisation occurs similarly in those with an altered lumbopelvic motor control strategy, which is common in those with CLBP (Hodges and Moseley 2003).

The structure and function of the primary motor cortex (M1) differs between those with and without CLBP. However, research in this area is in its infancy and although the differences do not appear to relate linearly to motor or sensory characteristics, the differences are not well understood (Schabrun et al. 2015a; Elgueta-Cancino et al. 2018).

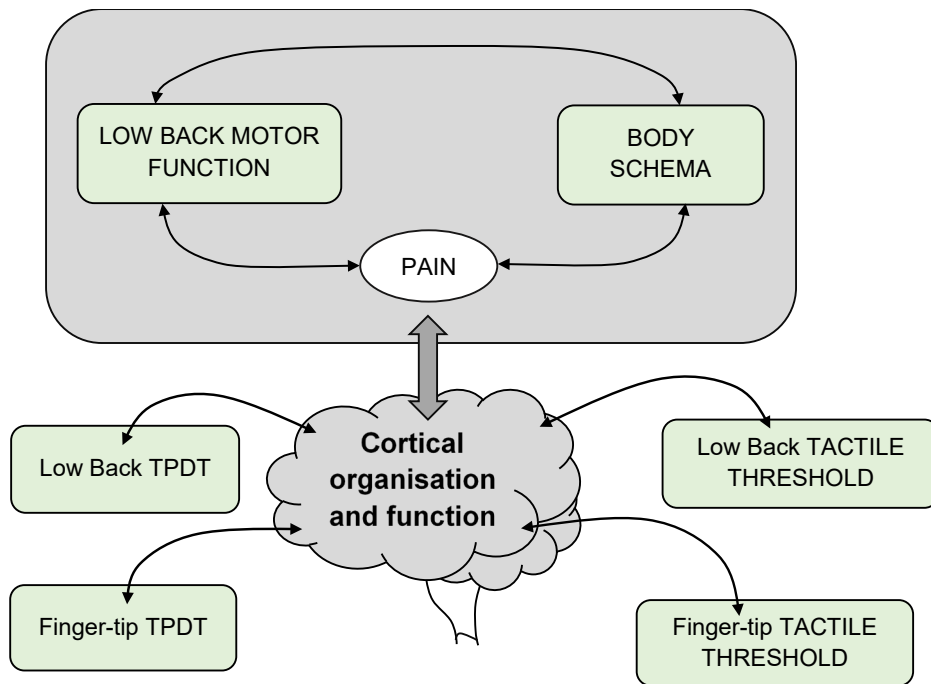


Figure 6-2 - Illustration to show conceptual interactions between the key study elements in the control group (adults **without** chronic low back pain that affected their activities of daily living)

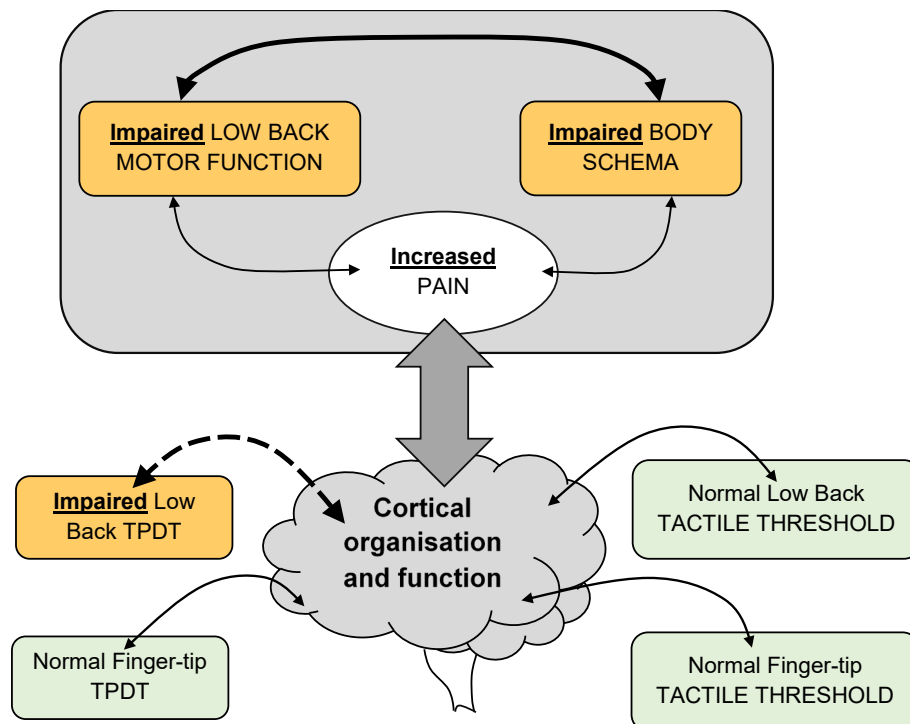


Figure 6-3 - Illustration to show conceptual interactions between the key study elements in the CLBP group (adults **with** chronic low back pain that affected their activities of daily living) (darker solid arrows denote significant correlations identified between altered key elements, darker broken arrows denote suggested altered relationships)

6.4.2. TPDT and body schema or motor function

Measures of low back TPDT at L5 and L3 did not significantly correlate with any of the measures of body schema in the pain group. This was due to the consistently high accuracy scores and rapid response times recorded for all the pain group when performing left/right discrimination tasks. Conversely, the TPDT scores were not similarly distributed and were less accurate in those with higher typical pain scores.

These results did not match those of Stanton et al. (2013), who reported the only other low back TPDT and comparable body schema results in those with CLBP. Stanton et al. (2013) assessed left/right discrimination using Recognise® and low back TPDT and identified a statistically significant correlation where when identifying left and right images of the back, diminished accuracy correlated with impaired low back TPDT. Stanton et al. (2013) also reported a similar significant relationship in their control group, albeit scores were diminished to a lesser degree.

Additionally, Luomajoki and Moseley (2011) reported a significant correlation between low back TPDT and motor function (using Luomajoki's Battery of Tests) in a CLBP group. Where, as TPDT impairment increased, motor function performance decreased. Again, the equivalent TPDT and motor function correlation analysis for this study did not concur with the findings from Luomajoki and Moseley (2011).

Conversely, this study found no significant correlations between low back TPDT, at L5 or L3, and either of the study motor function test scores. The discrepancy between this study and that reported by Luomajoki and Moseley (2011) may be related to participant disability scores, which Luomajoki and Moseley (2011) reported to be over four times greater in their pain group than the equivalent group in this study. Despite this study's pain group reporting less disability than Luomajoki and Moseley (2011), this study's groups motor function scores using Luomajoki's Battery of tests were almost identical to the scores of the more disabled pain group of Luomajoki and Moseley (2011).

There was no significant correlation between TPDT and disability in this study but the differences in results between these two studies from different populations also supports that disability scores are not related to Luomajoki's Battery of Tests scores. However, despite poor motor function and impaired low back TPDT occurring in both CLBP samples from different populations (Luomajoki's were from Switzerland and this study recruited from the UK), the different correlation results indicated that variation existed between the two heterogeneous CLBP groups.

The 30-second Chair Stand Test did not significantly correlate with the low back TPDT scores in this study. Other studies including similar metrics could not be located so it was unknown whether these results were similar in other CLBP populations.

Nevertheless, relationships between motor function and TPDT have been reported elsewhere. One study which may help to explain these findings was from Lissek et al. (2009). It identified impaired TPDT, altered motor function and associated changes to cortical reorganisation using functional magnetic resonance imaging (fMRI) during temporary immobilisation of the arm with a plaster cast following wrist or arm fracture. Lissek et al. (2009) identified contralateral S1 cortical changes related to TPDT on the fingers and hand of the immobilised arm. Cortical reorganisation was most prominent in participants with severely impaired TPDT but it restored when the arm became more mobile with the removal of the plaster cast four to six weeks later. Within two to three weeks of limb remobilisation, the TPDT impairments and cortical function were restored.

However, there were differences in TPDT acuity according to limb use and dominance. The rate of use, and therefore the movement, of the healthy, non-plaster casted limbs was increased during the immobilisation of the contralateral limb. If the dominant arm was immobilised, TPDT on the healthy, non-dominant and non-plaster casted arm improved significantly during the immobilisation period and this superior acuity remained for at least two weeks (when the study ended) beyond the plaster cast being removed and TPDT returning to normal on the dominant arm (Lissek et al. 2009).

The study from Lissek et al. (2009) indicates that decreased limb use results in TPDT impairment alongside its associated cortical reorganisation. Additionally, that increased limb use enhances TPDT acuity. It is plausible that similar phenomena might occur elsewhere in the body.

That low back TPDT and motor function were impaired but not correlated, might suggest that performance in both tasks may fluctuate over different periods of time in those with CLBP. Perhaps rapid fluctuations in motor function performance, such as those from participants wanting to perform well during research studies, meant that although motor function results showed impairments when compared with the control group, the motor function of the pain group may not have reflected their typical functional level. Rapid changes to TPDT acuity are probably unlikely, so sudden and short term changes in motor performance (as might occur between the 'typical' and test performance) may not correlate with measures of TPDT made at a single point in time. It should also be considered that the neural pathways and functionalities involved in TPDT and motor function perform as separate entities. Perhaps in the absence of significant disability, one

may be altered without significant impact upon the functionality of the other but when severe disability occurs, such as the immobilising of an entire joint for a period of weeks (Lissek et al. 2009), both motor function and TPDT become impaired. Such impairments may then be related or could occur in isolation.

That this study's low back TPDT scores did not correlate with low back motor function may have been related to participants determination to perform well on the day of data collection. Without further research, this idea remains conjecture but that the determination of the participants to perform well may help explain why some of the other findings do not concur with previous work.

To summarise, in this study only one statistically significant correlation existed between the key variables of TPDT, body schema and motor function and these results differed to previously published work. The observational study design did not allow for greater interpretation but perhaps unknown characteristics within this sample were significantly different from those in the samples of previous studies and these differences may be related to the variation seen.

This is the first time that body schema has been explored in relation to motor function in a CLBP and control group. That a significant positive correlation between impaired back perception and impaired low back motor function in those with CLBP was identified is a new contribution to this field of study.

6.5. Correlations between TPDT, Body Schema and Clinical Outcome Measures

Further analysis of the pain group data was conducted to address the hypotheses for questions three and four. As a reminder, these were *'there is no correlation between low back two-point discrimination threshold and clinical or psychosocial outcomes in adults with chronic low back pain'* and, *'There is no correlation between body schema and clinical or psychosocial outcomes in adults with chronic low back pain'*.

6.5.1. TPDT and clinical outcome measures

In the pain group, no significant correlations were identified between TPDT (at any low back location) and age, current back pain, back pain duration, back width, disability, kinesiophobia or the risk of developing persistent disabling symptoms in those with back pain.

Two significant correlations to low back TPDT were identified. Firstly, a large and significant correlation between TPDT at L5 and gender was identified where greater acuity was associated with the female participants. This finding cannot be explained by physiological differences such as the density of tactile receptors in relation to skin surface area, or by the smaller back width of females versus males because a similar correlation did not occur between TPDT at L3 and gender. Other studies have reported or refuted TPDT to be affected by gender differences where smaller thresholds favoured women (Weinstein 1968; Davey et al. 2001; Bowden and McNulty 2013; Shibin and Samuel 2013). This study's findings do not help to clarify the relationship between TPDT and the female gender. It is possible that either the L5 and/or the L3 results could have been due to chance and are probably of little clinical importance.

Secondly, a moderate significant and positive correlation was identified between the pain groups L5 TPDT and their typical pain score, where increased pain scores were associated with greater TPDT impairments. No such correlations were identified between the typical pain score and TPDT at L3, or between pain scores on the day of testing and TPDT either at L3 or L5.

These findings might be explained by the cortical reorganisation model discussed earlier in this chapter and illustrated in Figure 6-1. Few studies relating to temporal changes in TPDT exist but it might be argued that if TPDT alters alongside cortical reorganisation (Lissek et al. 2009), the processes involved in such changes might not fluctuate as rapidly

as the frequently changing levels of pain experienced by those with CLBP as highlighted by this study's reported differences in 'typical' and 'today's' CLBP pain scores.

The significant correlation between TPDT at L5 and participants 'typical' pain scores, but not pain scores on the day, were similar to the findings of Pleger et al. (2006) where mean sustained pain scores (equivalent to this study's 'typical' pain scores) correlated with TPDT on the painful limb of those with upper limb CRPS. These findings are important because sensory therapeutic interventions, such as retraining TPDT acuity to restore the impairments on the painful limb were accompanied by a reduction in CRPS pain and disability (McCabe et al. 2003; McCabe et al. 2004; Moseley 2004b; Moseley 2005b, 2006). As part of a small, intensive and complex sensorimotor intervention study with three CLBP participants, Wand et al. (2011b) included tactile acuity training and achieved significant and clinically meaningful improvements between pre- and post-treatment pain intensity and pain interference (with tasks) on a scale of 0-10 (3.92, 95% CI 1.56-6.27 and 4.33, 95% CI 1.8-6.87 respectively) and disability on a scale of 0-24 (9.66, 95% CI 4.23-15.04). Of further interest were the improvements were maintained during a one month follow up phase to the study. Although the small number of participants indicates these results should be treated with caution, they suggest that tactile acuity training as part of a wider sensorimotor intervention programme improves CLBP pain and disability.

6.5.2. Body Schema and clinical outcome measures

A significant medium-sized correlation was identified between back perception (FreBAQ) scores and age, where back perception was more greatly impaired in older participants. Such correlations have not previously been reported so it is not possible to compare the results with those from other studies.

Many sensorimotor functions of the body are involved in constructing a working body schema. As such, there are many factors that might be involved in understanding body schema characteristics. Joint position, muscle and skin stretch receptors play an important role in the efferent feedback process and in establishing joint position (Collins and Prochazka 1996; Collins et al. 2005; Mildren et al. 2017). Reduced physical activity is associated with reduced sensory input so a reduction in back perception may be related to the decreased physical activity levels reported to occur with increasing age (Clarke et al. 2017). However, it should be noted that this study did not include any assessment of physical activity so this hypothesis regarding age and physical activity cannot be supported or refuted.

Many somatosensory and perceptual functions, such as touch, sight and taste perception, are also reported to diminish with increasing age (Mojet et al. 2001; Kalisch et al. 2008). No such correlation was observed between age and the sense of touch in this study but that may have been because this study's participants were much younger than those in other studies (Mojet et al. 2001; Kalisch et al. 2008). As sensory functions are widely reported elsewhere to decline with age, it is conceivable that other perceptual functions may also decline, leading to a reduction in perceptual awareness. Importantly, with a few hours of simple training some of the age-related impairments (tactile, haptic and fine motor function) have been improved for up to four days. Providing simple rehabilitation tasks that can be performed autonomously at home helps preserve independent living for elderly populations (Kalisch et al. 2008). It may be that similar retraining can help to restore back perception impairments or at least prevent further decline, although the impact this may have on activities of daily living in adults of working age or in the elderly are beyond the scope of this study.

The second statistically significant correlation between body schema and clinical outcome measures in the pain group were between the left/right discrimination task speed of response and CLBP duration. Those with pain of longer duration were faster in selecting the correct answer and these results did not concur with those from other chronic pain studies, although those studies focused on chronic limb pain conditions. A detailed discussion relating to these findings is presented at the end of section 6.3.2.1.

It is suggested that in those with chronic pain, more time is taken to select the correct answer during left/right discrimination tasks. Therefore, the response time is slower. Slower response rates might indicate that during the mental rotation of the participants body part to match the test image, participants mentally select the incorrect side (showing attentional bias) and are forced to reselect the correct side prior to the mental image being congruent. Attentional bias can result from chronic pain and choosing the correct answer the first time is reliant upon an absence of attentional bias (Schwoebel et al. 2001; Moseley 2004c). Had such biases been present in this study's pain group, they would have been revealed by differences between the groups in left/right discrimination task accuracy scores (see section 6.3.2.1).

The pain group in this study achieved high accuracy scores which were almost identical to the control group, both of which were higher than results from similar studies (Bray and Moseley 2011; Stanton et al. 2013). However, in this study, the fastest correct responders experienced CLBP for the longest duration which indicated that the aspects of body schema assessed by the left/right discrimination tasks were functioning similarly in both

the pain and control groups. It may be that those with CLBP of longer duration in this study's pain group had developed better coping mechanisms and were able to tolerate their pain better than those with shorter pain durations. However, this theory was beyond the scope of this study and might benefit from a future qualitative research enquiry to gather a deeper understanding of these findings.

6.6. Clinical Implications

CLBP affects over 20% of the global working age population but approaches to treatment that target impaired biomechanics or supposed pathologies are ineffective in the long term (Machado et al. 2006; Meucci et al. 2015; Maher et al. 2017).

CLBP is associated with other musculoskeletal problems, digestive issues, higher rates of depression, sleep impairment and insomnia, high work absenteeism, poor socioeconomic conditions, poor social engagement and reduced physical activity (Vlaeyen et al. 1995; Woolf and Pfleger 2003; Currie and Wang 2004; Holmberg et al. 2005; Leeuw et al. 2007; Briggs et al. 2011; Bahouq et al. 2013; Thais et al. 2013; Karos et al. 2017; Buchbinder et al. 2018). Clearly, CLBP is complex and its manifestation involves modifiable components such as behaviour, beliefs and emotions, life-style and psychological factors, and structural and functional changes at the cortical level (Wand et al. 2010a; O'Sullivan et al. 2014; O'Sullivan et al. 2016). Many treatments focus on pain reduction and improving motor function, yet one approach proves no better than another (Bogduk 2004; Chou and Huffman 2007; Ferreira et al. 2007; Hayden et al. 2010; Van Middelkoop et al. 2011; Garcia et al. 2013; Maher et al. 2017).

This study confirmed that changes occur to different sensory systems in some people with CLBP. The changes included impairments to tactile perception, back perception and motor function. All of these were noted either on the low back or relation to the low backs of those with CLBP. Taken together with previously reported findings (discussed throughout this thesis), these findings have clinical implications in that important information regarding CLBP is probably not known by clinicians or shared with patients. It is apparent that much remains unknown about the emerging CLBP characteristics. In fact, sensory perceptual impairments are increasingly being identified in those with CLBP and other chronic pain conditions but much is not yet understood as to the meaning these findings. Especially within the wider context of chronic pain and human biology but this new knowledge could eventually change the approach in managing chronic pain conditions including CLBP. For example, a number of small studies have successfully improved clinical outcome measures by incorporating cognitive or behavioural therapies to identify sub-groups of the wider heterogeneous CLBP population (Sullivan et al. 2005; Adamczyk et al. 2017b; Maher et al. 2017; Nishigami et al. 2019).

Currently, ensuring that those involved in clinical practice, including healthcare students and patients, have access to updated knowledge. They need to understand that conditions which were probably considered to result from non-radicular, localised,

recurring, inflammatory, sprain/strain or 'wear and tear' injuries of the low back tissues and joints are probably products of a complex, multidimensional, cortical body matrix dysfunction. As a result, there may be new approaches in managing these conditions although these new approaches are far from clear. Setting this ground-work in place would enable clinicians to prepare their patients for slightly unusual approaches to treatment that might exist in the future.

It is predicted that encouraging people to engage with positive health practices, such as a healthy diet and increased activity levels, can reduce the period of disability at the end of life by six to nine years (O'Donnell 2012). Educating patients to have a better understanding of how their bodies function may help them to engage with better self-management of long-term conditions such as CLBP. It may be difficult for patients to understand how their bodies sense touch, interpret and move through the world and how maladaptive actions might hinder their progress in recovering from or managing their CLBP.

Participants in this study were fascinated by their TPDT results, particularly those from the CLBP group who had large differences in TPDT. Using TPDT to demonstrate how tactile discrimination differs in those with CLBP might provide a way to engage patients more in their care. Ideally, showing them the TPDT changes might help them understand that CLBP has wider implications than the pain and disability they experience. It might also encourage better engagement with self-managing their CLBP or with their following the advice of clinicians. Patients might also feel more involved with their care and be empowered to ask more questions about what they can do themselves to improve clinical outcomes.

For patients to receive better health education, their clinicians must be open to change in the way they interact with patients. They need to be willing and able to invest the time and knowledge in improving their own and their patients understanding of CLBP.

Differences in back perception were identified in this study, with the CLBP group reporting higher perceptual impairments. Perceptual rehabilitation techniques are not widely reported in CLBP but there is some evidence that they have improved sensory and motor judgement tasks in healthy groups and in those with CLBP (Morone et al. 2012; Paolucci et al. 2012; Vetrano et al. 2013; Paolucci et al. 2014; Paolucci et al. 2015). Therefore, incorporating perceptual treatments into CLBP care may provide patients with faster pain relief and enable better participation in functional rehabilitation exercises. Gaining a better understanding of perceptual disturbances might allow better subgrouping of the

heterogeneous CLBP population to explore whether such treatment approaches are better for some than others. This has recently been demonstrated by a small proof of concept pilot where differences in back perception was one of the differences noted between two CLBP participants whose response to a perceptual illusion task varied significantly (Nishigami et al. 2019).

Additionally, clinicians and patients should be educated in that the thoughts and feelings patients experience during a painful CLBP episode will influence future experiences. Encouraging clinicians and patients to use positive language, explanations and education materials will help to create a positive experience for the patients. This in turn will influence whether patient related tasks, activities or future episodes might be perceived as positive or negative and this could affect their clinical outcomes (Gifford 2013). Although this might be a difficult concept for patients to understand, especially when they are in severe pain, it is important that changing perception can change their thoughts and feelings about their CLBP, they may be able to change their CLBP outcomes such as pain and disability, or the way they allow it to affect their quality of life (Houde et al. 2016).

Other sensory cues, such as auditory cues when combined with motor function tasks, appear relevant to improving motor functional deficits (Stanton et al. 2017). This adds to the evidence that manipulating sensory factors can improve physical motor function which strengthens the argument that sensory factors might also prove beneficial in improving clinical outcome measures in CLBP, once they are better understood.

From a physiological perspective, structural and functional cortical changes in the somatosensory and motor cortices of those with chronic pain, including CLBP, are widely reported through the use of brain imaging studies (Grachev et al. 2000; Apkarian et al. 2004; Schmidt-Wilcke et al. 2006; Apkarian et al. 2011; Tsao et al. 2011; Baliki et al. 2012; Hashmi et al. 2013; Meier et al. 2013; Smallwood et al. 2013; Hotz-Boendermaker et al. 2016). Sensory and motor cortical reorganisation has been suggested as one of the central process mechanisms involved in CLBP (Flor et al. 1997; Wand et al. 2009; Tsao et al. 2010; Tsao et al. 2011; Wand et al. 2011c; Moseley and Flor 2012b).

Clinically observed characteristics such as TPDT, appear to be related to these cortical changes (Lissek et al. 2009; Tsao et al. 2010). Within chronic pain research, TPDT is a widely accepted clinical signature of cortical reorganisation and studies repeatedly return larger thresholds in those with chronic pain compared with those without pain (Moseley 2008a; Wand et al. 2010b; Luomajoki and Moseley 2011; Moseley and Flor 2012a; Stanton et al. 2013; Spahr 2014; Nishigami et al. 2015; Luedtke et al. 2018).

TPDT remains one of the most commonly used techniques in differentiating 'normal' from 'abnormal' spatial tactile resolution in many pathological conditions and post-surgical procedures (Eryilmaz et al. 2013; Kim et al. 2015; Lai et al. 2015). Within chronic pain research it has become widely accepted as a clinical signature of S1 cortical reorganisation as studies return larger thresholds in those with chronic pain when compared to those without pain (Pleger et al. 2003; Moseley and Flor 2012a; Stanton et al. 2013). The clinical implications that TPDT differs between those with and without CLBP is that tactile training can be improved in primates and humans (Jenkins et al. 1990; Elbert et al. 1994; Chandhok and Bagust 2002). This is important because preliminary studies providing sensory discrimination training in people with chronic low back pain report reduced pain and improved motor function (Wand et al. 2011b; Louw et al. 2015). It is worth noting that TPDT improvements can also be lost if training is discontinued, although the implications on pain and motor function is unknown (Foster and Bagust 2004).

This body of work was conducted because in some chronic pain conditions, the reversal of the cortical reorganisation of neuronal networks is associated with improvements in impaired clinical characteristics. In CRPS, such a reversal of altered neuronal networks occurred alongside improvements to TPDT impairments and reductions in pain and disability (Pleger et al. 2005; Pleger et al. 2006). In CRPS and chronic low back pain the reversal of TPDT and body schema impairments were associated with improved pain and disability (McCabe et al. 2003; Moseley et al. 2008c; Wand et al. 2011b). The reversal of cortical reorganisation in those with CLBP has also been linked to some specific motor function tasks. Tsao et al. (2010) reported that specific motor function task training (isolated voluntary muscle contractions of the deep abdominal muscle, *transversus abdominus*) was related to the reversal of cortical reorganisation of the neuronal networks of the motor cortex. Non-specific motor function tasks, such as self-paced walking, did not achieve the same effect so the relationship between changes in motor function and cortical reorganisation appear to have specific underlying connections. The specificity of this relationship might provide an important target for future rehabilitation techniques although further research is required to understand why specific rather than general activity was necessary to reverse cortical change. In relation to this study, it would be important to establish whether it was the participant focusing on the task or performance of the task itself that altered reversed cortical function. This is discussed in Chapter Seven, in the section on further research.

Some of these findings have occurred in small CLBP studies which means the findings must be interpreted with caution (Button et al. 2013), but the findings of these small

studies shared similarities with the more numerous CRPS studies published in this area of research. In those with CLBP, with better understanding of impaired TPDT and body schema in relation to impaired low back motor function, it may be possible to; 1.) gain a better understanding of the complex CLBP condition and provide solid base line data which may steer future research to identify better CLBP outcomes, and 2.) provide targets for testing new sensory therapeutic interventions and to guide the adaptation of existing interventions which may improve CLBP outcomes.

6.7. Strengths and Limitations of the Study

Strengths

There were several strengths to this study. A unique aspect of this study was that it assessed tactile threshold and TPDT on the painful and a pain-free region of the low back and on the pain-free fingertip. It assessed two measures of body schema and two different motor function tasks in a CLBP and control group recruited from the same UK population. Previous studies explored one or two of the three key variables and none, as far as the researcher is aware, were conducted using participants from the UK.

Studies that have previously reported smaller aspects of this study, recruited participants from multiple clinical and geographical locations. This is important because the heterogeneous nature of CLBP indicates that different characteristics may occur in different populations. By simultaneously assessing all these variables in a CLBP and control group recruited from the same population, CLBP characteristics of this sample may be better understood. Clarifying the relationships between these sensory and motor functions may help in identifying better CLBP outcomes.

This study included a systematic review to understand the area of tactile acuity, body schema and motor function in those with CLBP and this added new knowledge which helped direct the research questions, aims and objectives. The systematic review highlighted disparity in the methods used across the different studies to measure the same variables. It also revealed that the relationships between the key variables were unclear and, in some cases, unknown. It was this finding that determined this study should explore the topic in detail.

Two reliability studies were undertaken to determine the appropriate tool with which to measure TPDT on the back and fingertip and to determine the inter-rater reliability of the Luomajoki's Battery of Tests if raters had not received special motor control assessment training (Luomajoki et al. 2007; Luomajoki et al. 2008).

Following these reliability studies, the main study data was collected directly from a CLBP and control group over a period of three months. A strength of the methods was that all the data collection took place within the same clinic and by the same researcher. Each participant experienced the same environment and the equipment positioning. In fact, tape was used to mark the clinic floor to show bench, chair and tripod positions and by using reference photographs of the correct room set up, an identical room set-up was

recreated before each data collection session. This would have reduced the error from different positioning of the equipment between data collection sessions.

A further strength was the methods themselves. The methods used were researched thoroughly and chosen based on their appropriateness to the task, their reliability, validity, ease of use and to ensure participant interest and comfort. This was a strength because it helped maintain the participants interest and engagement throughout the tasks. The TPDT methods were practised prior to data collection to identify the most appropriate position for the participant and the researcher to ensure good technique. The entire data collection process was piloted and adapted prior to beginning the data collection. These factors were intended to ensure the findings could be compared with the results from other studies that used similar methods, to examine and report detailed methods that were previously unclear and for future studies to be able to replicate the methods used.

Limitations

This study was subject to several limitations. First, this research was undertaken in partial fulfilment of a doctoral programme so time and resource constraints determined the duration and direction of the study. One implication of this was that the researcher collected and analysed all the data so blinding to the participants data collection was not possible. However, in an effort to reduce selection or testing bias, pseudo-blinding was undertaken. This approach enabled the researcher to collect the all data and only then were participants allocated to their group and this allocation was based on the data analysis. It is likely that bias was introduced in the use of pseudo- rather than full-blinding but it is anticipated that by taking this pragmatic approach, the bias was reduced.

Second, the study recruited the CLBP and control groups from the same UK population must be considered a limitation. The study took place in one of the least socioeconomically deprived regions of England (Gill 2015) and the participants probably reflected different socioeconomic, demographic and clinical characteristics than had participants been recruited from a more socioeconomically deprived region of the UK.

Third, participants were divided into either the CLBP or control group based upon their response to questions based on widely reported definitions and criteria that have been adopted by many previous CLBP studies. However, despite not experiencing low back pain on the day of data collection, or not meeting the inclusion criteria for the CLBP group, many of the control group participants reported a history of low back pain. This meant that

some of the CLBP characteristics featured in the pain group may have also been represented in the control group. This effect may potentially have narrowed the margin of any differences between the two groups and could have concealed differences that may have been present if the control group had only included those who had never experienced low back pain. This study highlights the difficulties in recruiting participants who have never experienced low back pain but it also raises important questions for future research. Using participants responses to questions about back pain may not be a reliable method of differentiating them into CLBP and control groups when assessing subtle neurophysiological metric. Recruiting control groups for such studies is important because it reveals a well-rounded view of the findings but in future studies, the mechanism by which the pain and control groups might be divided needs to be reconsidered. This raises important questions for future research.

Fourth, the researcher did not randomise the tests being performed because the need was not identified until the data collection had been completed. Randomising the order of the tests would have counteracted any bias that occurred from the tests themselves, participants expectations of seeing equipment in the room or altered sensitivity through performing the tests. It is likely that learning and sensory expectation may have occurred in some tasks, perhaps heightening or reducing the receptiveness of participants to perform further tasks. This limitation is important because it cannot be ruled out that there was an order effect, namely that findings from one test were influenced by a participant performing the preceding tests. This is problematic if the results are to be interpreted as being influenced by participant characteristics and could lead to the research drawing inaccurate conclusions. This learning will be taken under consideration when designing future studies.

Fifth, with hindsight, the researcher should have contacted the key authors early on in the study design to discover any methodological anomalies they experienced and taken steps to avoid them in this study. It was discovered after the data collection and analysis that a different version of the Recognise[®] tool for backs was used in this study than was used for Stanton et al. (2013) and Bray and Moseley (2011). This study used an 'off the shelf' version which drew 40 images from a pool of 98 images (see Chapter Three, section 3.5.4.3 for more details). Although the tool presented an equal number of left and right sided images to each participant, it may have shown a greater proportion of 90 or 180-degree rotated images to some participants than it did to others. This is important because accuracy and speed of correct response diminishes as the degree of image rotation increases (Bowering et al. 2014; Alazmi et al. 2018). Consequently, participants may have rated images of varying difficulty which could have provided inconsistent results

and this was not considered in the data analysis. Stanton et al. (2013) and Bray and Moseley (2011) used a specially adapted version which presented the same 40 images to each participant, so their results would not have been affected by a similar limitation. Unfortunately, this methodological issue was not discovered until the data collection for this study had been completed and the results analysed. The 'off the shelf' tool may have introduced error into this study's results when compared with the results of Stanton et al. (2013) and Bray and Moseley (2011). As such, it is possible that had any differences in accuracy or speed between the groups existed, the differences could have been masked by this error.

Sixth, Moberg's (1990) technique for TPDT assessment was designed for assessing the volar surface of the hands so when transposing the technique for use on the back, the fine nuances of the technique may have been overlooked by earlier studies. Small commercially produced tools and even opened out paperclips have been shown to be reliable when assessing small areas on the hands and fingertips (Dellon et al. 1987; Crosby and Dellon 1989; Finnell et al. 2004). However, avoiding unwanted vibration when applying the tools is necessary to achieve accurate results. Avoiding vibration is easier when using small tools such as paperclips or the Disk-Criminator™ but it is more difficult when using tools with distances of up to 150mm between the contact tips to assess TPDT on the low back.

Moberg's (1990) technique was critiqued and adapted for use on the low back (See Appendix 9.3.6) but there were occasional difficulties when assessing TPDT on the low backs of those with larger thresholds and these tended to be the participants in the CLBP group. This was because applying the two points of the Vernier calipers simultaneously when they were wide apart was more difficult than when they were closer together. Applying one point, followed quickly by the other, would have been detected by the participant as two separate points of touch, and been reported as "two", but it would have been a false reading because the test demands the correct discrimination between one or two simultaneously applied points. However, the adaptive staircase technique used to collect TPDT data should have limited such measurement bias, so the impact upon the pain group TPDT results may have been small and consequently, the between group analysis should not have been greatly affected (Yarnitsky and Pud 1997; Klein 2001). Recent publications agree that the TPDT method can reliably differentiate between those with and without chronic back pain. However, a standardised procedure is required to enable comparison across different studies (Adamczyk et al. 2018; Ehrenbrusthoff et al. 2018).

Finally, given the importance of exercise and activity within this study and the wider CLBP field, it would have been valuable to gather data regarding the frequency and type of exercise all participants undertook. In addition to university buildings and healthcare clinics, the recruitment campaign advertised the study in sports, dance and martial arts clubs. Data was not collected regarding how participants became aware of the study so it is unclear as to how many were recruited from these organisations. Yet, the implications of exercise and athleticism on some of the variables measured in this study cannot be ignored (Torres 2015; Wallwork et al. 2015). As such, some results may have been subject to a ceiling or floor effect. These effects can occur when a tool of measurement is developed for use in general populations but extreme characteristics, such as high levels of fitness, are strongly but unknowingly represented within the sample population. In this situation, a tool designed to assess the general population may not be sufficiently sensitive to correctly measure people with different abilities and the results may be skewed (Andresen 2000). Despite testing the data for skewness there may have been subtle differences that impacted the findings.

It is possible that this study's participants exercise regimes were different from those in previously reported studies and their engagement with sport or exercise may have influenced the findings. Future CLBP research should collect and analyse exercise and activity data to assess its relationship to other study variables.

6.8. Chapter Summary

This chapter began with a summary of the new findings from this study. It proceeded with a reminder of the research questions and continued to discuss the findings in relation to the questions, the relevant literature and within the context of the theories underpinning this study. The characteristics of the two groups were considered prior to discussing the differences and correlations between measures of tactile acuity, body schema and motor function in the CLBP and control group. The clinical implications of the findings followed and finally, the study strengths and limitations were presented. The following chapter completes this body of work by providing a synthesis of the empirical findings and the key contributions to knowledge. It concludes by suggesting relevant areas of future research based upon the findings from this study.

Chapter 7. CONCLUSION

The purpose of this study was to explore and understand measures of tactile threshold, two-point discrimination threshold (TPDT), body schema and low back motor function when assessed in adults with CLBP of sufficient magnitude to affect activities of daily living with a view to exploring sensory and motor function to inform therapeutic interventions. Changes in sensory and motor function have been noted in other chronic pain conditions and clinicians have been successful in improving outcomes through novel interventions (McCabe et al. 2003; McCabe et al. 2004; Moseley 2004b; Moseley 2005b; Moseley 2005c; Pleger et al. 2005; Moseley 2006). This was important because existing CLBP treatments can result in inadequate outcomes and one approach appears no better than another. Better understanding of CLBP characteristics may help to develop novel treatment approaches and the achievement of better outcomes for patients.

The systematic review identified that each of the included studies had explored only one or two of either TPDT, body schema or low back motor function. None had explored all three. In particular methodological issues were identified in relation to assessing TPDT. Many studies from the systematic review reported using undefined or unknown brands of calipers to measure TPDT (Moseley 2008a; Wand et al. 2010b; Luomajoki and Moseley 2011; Stanton et al. 2013; Nishigami et al. 2015). In the absence of a tool which was validated to measure TPDT on the low back and fingertip, a reliability study was conducted. This identified that there was only partial agreement between measurements of TPDT on the low back when assessed using metal, plastic and modified tipped Vernier calipers. The plastic tipped calipers returned a consistently smaller measurement of TPDT on the low back than other calipers and they were the preferred choice of participants.

A second reliability study assessed the inter-rater reliability of Luomajoki's Battery of Tests when used by chiropractors and an osteopath who had not received the specified motor control assessment training in Luomajoki et al. (2007) and Luomajoki et al. (2008). In this study the single rater and inter rater reliability were good and internal consistency excellent. These results indicated that Luomajoki's Battery of Tests may be reliable in assessing lumbopelvic motor control when used by different registered musculoskeletal healthcare professionals, even if they had not received the specified training.

Several conclusions can be drawn from this study. Tactile threshold and TPDT on the low back had previously been reported by Moseley (2008a) and Wand et al. (2010b) and the findings from this study concurred with their results. Additionally, it added new evidence

by reporting tactile threshold and TPDT measures from participant's fingertips, and painful and pain-free regions of their low backs. This is the first study to do so and it concluded that in samples of UK adults, tactile threshold was equally accurate between the pain and control groups when measured at the fingertip, and on both regions of the low back. However, TPDT was impaired in the pain group within the region of typical low back pain (L5) and to a lesser degree, near to the typically painful region (L3). TPDT was not altered between groups at the distal pain-free fingertip of the dominant hand.

Tactile threshold and TPDT share superficial tactile receptors and neural pathways (Abraira and Ginty 2013). If the impairment seen in low back TPDT was as a result of neural transmission or with the tactile receptor then it might be expected that there would be similar impairments in tactile threshold. As this was not the case, it might be suggested that the impairments were a result of altered central processing within the CNS as suggested by several previous studies (Flor et al. 1997; Pleger et al. 2001; Haggard et al. 2003; Pleger et al. 2003; Pleger et al. 2005; Pleger et al. 2006; Lissek et al. 2009). TPDT is considered a clinical signature of cortical organisation (Pleger et al. 2001; Haggard et al. 2003; Pleger et al. 2003; Pleger et al. 2005; Pleger et al. 2006; Lotze and Moseley 2007; Moseley and Flor 2012b; Catley et al. 2013b). This is of clinical importance because it is suggested that TPDT is a simple and reliable method of clinically assessing the state of the primary somatosensory cortex (S1) (Lotze and Moseley 2007). As the organisation of the S1 alters in those with chronic pain but can be improved through specific training (Flor et al. 2001b), it is suggested that TPDT may be a method to assess the effectiveness of new treatments, or it may provide a target area for future therapeutic interventions.

The results relating to body schema using the two methods in this study suggest they were measuring different aspects of the construct. The FreBAQ results reported in this study in relation to impaired back perception in those with CLBP concurred with earlier studies, i.e. Wand et al. (2014a). However, the results relating to left/right discrimination task scores did not concur with those of Bray and Moseley (2011) or with Stanton et al. (2013). It was noted in this study that both participant groups (CLBP and Control) reported similar scores and when these scores were compared with other studies, both groups were more accurate and faster in their response times than those reported in previous studies, i.e. Bray and Moseley (2011) and Stanton et al. (2013). From this it might be concluded, that measures of body schema differ between different populations of adults with CLBP.

It is widely reported in the literature, clinically and anecdotally that those with CLBP move differently to those without back pain (Hodges et al. 2013). Finding that this study's pain group performed both motor function tasks more poorly than the control group did not lead to any new conclusions. However, a new conclusion could be drawn in that the poorest performers in the Luomajoki's Battery of Tests (Luomajoki et al. 2007; Luomajoki et al. 2008) to assess low back motor control, also had the greatest back perception impairments. As far as the researcher is aware, this was a new finding.

This study differentiated its participants according to the presence of CLBP and whether it negatively impacted their activities of daily living (ADL). Some of the control group reported a history of CLBP but as their ADL's were not affected, they were included in the control group. Therefore, it is possible that differentiating participants using the ADL criteria probably had a profound effect on the groupings although despite this, significant differences in sensory and motor function were identified. It can be concluded that the methods of grouping participants may have influenced the results and possibly been responsible for the differences seen between the results of this study and those previously published. Methods of grouping CLBP participants for neurophysiological studies where the differences may be subtle would benefit from further research.

The relationship between sensory and motor function in CLBP is complex but it can be concluded from this observational study that there is a correlation between altered sensory function and altered motor function in a group of UK adults with CLBP. It is not clear why some of the findings reported in this study differed to those reported in similar studies, but it might be as a result of psychological and social factors associated with empowering patients to take control of their CLBP condition. Assessing such factors was beyond the scope of this study but it is suggested that the psychological and social factors related to empowering patients may vary in communities with differing incomes (Cedraschi et al. 2018). It may be that this study recruited participants from a community with a dissimilar socioeconomic status to those of similar studies. As a result, the degree to which participants in in this study may have differed, therefore this study's CLBP group may have represented a sub-group of the heterogeneous CLBP population when compared with the groups of Bray and Moseley (2011), Luomajoki and Moseley (2011), Stanton et al. (2013) and Nishigami et al. (2015).

This study employed a quantitative methodological approach in assessing sensory and motor function in those with CLBP. It provides new understanding of characteristics and the relationships reported in a population with CLBP recruited from a poster and online social media campaign in the UK. These findings may provide clinicians with a greater

understanding of the altered sensory and motor function that is associated in those with CLBP. This may help clinicians to consider, for example, how they might facilitate improvements in movement and function, and support those with CLBP to engage in self-management strategies.

7.1. Contributions to Knowledge

The aim of the research was to clarify whether sensory impairments existed alongside altered motor function in a sample of adults with CLBP from the UK population. It was anticipated that this new knowledge may guide future sensorimotor therapeutic interventions to support pain management in those with CLBP. Following a systematic review, gaps in the knowledge were identified regarding the characteristics and relationships between TPDT, body schema and motor function in those with CLBP and a control group. Importantly, no previous study had investigated all three variables. Additionally, body schema and motor function had not previously been investigated in those with CLBP. This thesis provides several new contributions to knowledge and these are summarised below.

- This was the first study to investigate tactile threshold, TPDT, body schema and motor function in the same CLBP and control groups. It was also the first to explore these variables in participants from the UK population.

Relating to the Reliability Studies;

- There was only partial agreement between measurements of TPDT on the low back when assessed using metal, plastic and modified tipped Vernier calipers. The disagreement was consistent at different magnitudes of TPDT.
- Modified Vernier calipers with slightly rounded plastic tips consistently returned smaller measures of low back TPDT. Additionally, participants preferred them to 'off-the-shelf' metal or plastic tipped Vernier calipers.
- When used by UK registered chiropractors and osteopaths who had not received specific motor control training, intra-rater reliability of Luomajoki's Battery of Tests (Luomajoki et al. 2007; Luomajoki et al. 2008) was considered 'good' to 'excellent'. Internal consistency when used among this group was also rated as 'excellent'.

Relating to Tactile Threshold and TPDT;

- In this UK sample of adults with CLBP, TPDT was impaired within the typical region of low back pain (L5) and in a nearby region of the low back which was not reported to be painful (L3). This pattern of TPDT impairment was also observed in the control group, where most participants reported at least one historical episode of low back pain.

- Larger TPDT measurements from the ‘typically’ painful low back region moderately correlated with higher levels of ‘typical’ pain.

Relating to Body Schema and Motor Function;

- This is the first study to explore and report the relationship between body schema and low back motor function performance in adults with CLBP. A moderate positive correlation was identified between back perception assessed using the FreBAQ tool (Wand et al. 2014b) and low back motor control measured using Luomajoki’s Battery of Tests (Luomajoki et al. 2007; Luomajoki et al. 2008). Participants with the greatest back perceptual impairment scores performed most poorly in the battery of tests.
- In this group of UK adults with CLBP, correlations between FreBAQ and the 30-second Chair Stand Test, or between the left/right discrimination tasks using Recognise® for backs and either Luomajoki’s Battery of Tests or the 30-second Chair Stand Test were not significant.

7.2. Expected Publications

A list of the conference proceedings at which key stages of this research study were presented is included in Appendix 9.6.1. It is anticipated that at least three peer reviewed articles will be published from this research; the TPDT tool reliability study, the motor control reliability study and the key findings regarding tactile acuity, body schema and motor function in this previously unreported population. Proposed titles are:

- Assessing low back and fingertip two-point discrimination threshold: a reliability study comparing plastic and metal tipped calipers. Suggested journal for publication: *Musculoskeletal Science & Practice*.
- Assessing low back motor control by UK registered manual therapists: a reliability study using Luomajoki’s Battery of Tests. Suggested journals for publication: *BMC Musculoskeletal Disorders*, the *British Journal of Sports Medicine* or *Manual Therapy*.
- Characteristics of sensory and motor function in UK adults with chronic low back pain: an observational exploration of tactile acuity, body schema and low back motor function. Suggested journals for publication: *BMC Musculoskeletal Disorders* or *Manual Therapy*.

7.3. Suggestions for Further Research

To allow better understanding of the wider UK CLBP population, replicating the study with participants recruited from UK regions of differing socioeconomic status is suggested.

Only three of the 62 participants had never experienced back pain. It raises the question of what proportion of the adult population is truly back pain free and how many of those with back pain consider their pain to be troublesome? This is not an area that appears to have been discussed in the literature and is an interesting area for future study.

Further observational studies could help to further explore body schema in those with CLBP because there were differences between different measures of body schema in this study. These results did not concur with those previously reported. The two measures of body schema assessed in this study may have been measuring different aspects of body schema so further exploration is necessary into why some with CLBP display left/right discrimination task impairments, when others do not.

It may be that grouping participants based on their FreBAQ scores before assessing sensory or motor differences may reveal that disturbances in body schema might be the reason why some findings differ in apparently similar CLBP studies. For example, in a proof of concept pilot study of two CLBP participants (Nishigami et al. 2019), one CLBP participant presented with a distorted back perception, high pain and disability scores and negative or maladaptive beliefs about his back. Following a visual illusion task which incorporated 'strong' images of his back he reported less pain, less fear and greater perceived strength and confidence. Interestingly the other CLBP participant, who was 36 years younger than the first participant, reported no back perceptual distortion, little maladaptive beliefs and only mild pain and disability, did not respond so positively to the task. This pilot study showed that some people with CLBP might be more likely to benefit from visuomotor illusions than others and they might be distinguishable by self-reported back perception scores. A larger study to investigate these properties is recommended and could be enhanced by incorporating follow up sessions to establish whether if improvements occurred in those with impaired back perception, did they experience an improvement in their symptoms, was it maintained and how did their back perception scores change.

There were issues with the methodology of the left/right discrimination task in this study which used commercial software. This may be the reason why this study's results were different to those previously reported or it may be that this study's participants really were

different. Firstly, this could be explored using a similar sample of those with and without CLBP and a more robust method which included adapted commercial software to ensure every participant was shown the same images. If this study identified a sub-group of the wider CLBP population, attempting to identify how they were different in relation to body schema impairments could help to advance the understanding of the clinical presentations of CLBP. If this study revealed no differences between the groups and highly accurate and fast responses, it may be that this sample reflects a different sub-group within the wider CLBP population.

If so, further information about this group could be collected in an attempt to identify why they might be different. Exercise and activity data were not collected within this study and it is an area where collecting it may have been valuable. However, a few existing studies report motor imagery does not alter in some athletic populations but investigating whether different exercises impact the results might be useful. Particularly as clinical advice often incorporates some form of exercise for those with CLBP.

TPDT was noted to be significantly altered on the backs of those with CLBP in this study and these findings matched those of earlier studies. However, while TPDT is accepted as a clinical surrogate of cortical reorganisation, therefore it is taken as an indicator of cortical change, this has not been confirmed. There are no brain imaging studies which assess TPDT change and cortical function change in those with and without CLBP. If researchers continue to use the tool as a clinical surrogate, it may be beneficial to explore whether it is a reliable measure of cortical change in chronic pain. Additionally, understanding how this relationship over time might change might also be beneficial, particularly if clinicians follow the advice in the clinical implications section of Chapter Six, which advises they use TPDT to demonstrate physiological changes to their CLBP patients as part of an education process.

Longitudinal studies are required to discover whether cortical reorganisation is a driver of the perceptual changes associated with chronic pain or is just a side-effect of the chronic pain process. However, from a clinical perspective, it may not matter whether reorganisation is a driver or a consequence of chronic pain, what does matter is that the training of *specific* motor tasks, rather than non-specific tasks such as walking, appear to improve motor performance and restore cortical reorganisation (Tsao et al. 2010). This may indicate that specific and focused training exercises might offer a better resolution to those with cortical reorganisation and may provide better opportunities for treating CLBP in the future. However, it does present the challenge of reliably identifying those with cortical reorganisation in a clinical setting, without the use of complex equipment. This is

necessary to easily determine those with cortical reorganisation and to assess how it progresses. This reinforces the need for research to confirm the accuracy and reliability of clinical surrogates in those with CLBP.

Activity appears important to CLBP and increasing exercise offers wider health benefits. Exploring the relationship between activity/exercise and the variables measured in this study (particularly back perception and low back motor control) may be important. If body perception disruptions are necessary for people to benefit from illusion type interventions (Nishigami et al. 2019), perhaps body awareness is important for people to experience improvements to their symptoms and back perception issues are a requirement for improving patient outcomes. Therefore, it may be important to investigate the specific benefits of certain activities on CLBP. For example, when participants focus on specific regions of their body moving, their pain improved and cortical reorganisation was restored (Tsao et al. 2010). Further research could investigate whether the focusing of a specific moving body part is linked to back perception, motor function, both or neither. If specific cognitive involvement is important, it may be that patient outcomes can be improved with participants performing other activities while focusing on specific movements. If found to improve patient outcomes, it might be that patients could select an activity of their choice, rather than the clinician's choice and this might encourage their long term engagement with activity and lead to greater improvements in their symptoms. Back perception could frequently be assessed using FreBAQ and activities/focusing tasks might even be specifically designed to improve back perception in the areas where patient scored highly.

Further studies are required to identify the impact of sensory training on tactile acuity, perceptual impairments and CLBP outcomes; and whether these are related to CLBP outcomes from motor training using specific behaviourally related tasks.

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Chapter 9. APPENDICES

9.1. Introduction to Appendices

Appendices are presented in the order they are first referred to within the thesis. Heading 9.2 relates to appendices first mentioned in Chapter 2. Section 9.3 relates to appendices first referred to in Chapter 3, and so on. There are no appendices relating to Chapter 1.

9.2. Appendices for Chapter Two

9.2.1. Tactile Threshold and Two-Point Discrimination Threshold

Definitions

Tactile threshold is the minimum force required for touch to be perceived (Kandel et al. 2013). Two-point discrimination threshold (TPDT) describes a function of touch, also known as tactile spatial acuity or spatial resolution. It is defined as the shortest distance between two points at which a subject can clearly detect two points of contact (Weber et al. 1996; Jerosch-Herold 2005).

The Neurophysiology of Touch

Tactile function is essential in proprioception and allowing interaction with the world around us. The sense of touch is defined as “direct contact between two physical bodies” and involves conscious awareness of the body being touched (Kandel et al. 2013). Passive touch occurs when something else touches your body. It is entirely sensory and is essential in naming objects and describing sensations. When motor function is incorporated, such as the manipulation of an object within the hand, faster and more accurate recognition of the object is achieved. During this sensory-motor action, the cortical integration of afferent sensory and motor signals are inextricably linked and the efferent outputs from the central nervous system are an expression of this linked function. Moberg (1990) states;

‘conscious proprioception and intact manipulative function are impossible in the absence of a proper afferent innervation of the skin in spite of muscle function’

Smooth motion such as picking up a pen from a desk, is only possible if the sensory and motor functions are intact. Afferent impulses from receptors within muscles, tendons, joints and skin control the desired smooth movement by counterbalancing the opposing

muscle groups *and* creating conscious proprioceptive or spatial awareness of the body (Kandel et al. 2013).

9.2.2. Physiology of Tactile Function

It is understood that many neurophysiological processes are involved in tactile threshold and static discriminatory touch, such as TPDT, but much is unknown about the neurophysiological functioning of tactile perception in humans, particularly in hairy skin as studies predominantly involve glabrous (non-hairy skin) like the fingertips or lips.

The same four types of mechanoreceptors detect active and passive touch within glabrous (hairless) or non-glabrous (hairy) skin; Meissner corpuscles, Merkel cells, Pacinian corpuscles and Ruffini endings (see Table 9-1). In non-glabrous skin, the mechanical action of hairs being moved also adds to the detection of touch. Each mechanoreceptor contributes towards the conscious perception of touch as per its shape, structure and location within the skin. They are stretched or distorted according to the displacement incurred from objects being in contact with the skin. The contours of objects coming into contact with the skin effectively create a mirror image within the soft layers of the skin's surface (Goldstein 2008; Kandel et al. 2013).

Mechanoreceptors are innervated by myelinated axons and fall into one of four categories according to the axon type and the size or location of the receptor (see Table 9-1). Superficially located mechanoreceptors are classed as type 1 and those situated deeper in the dermis are type 2 (Johnson 2001). Those innervated by slowly adapting axons (SA) continue to fire in response to steady or constant skin indentation. Mechanoreceptors innervated by rapidly adapting axons (RA) stop firing as soon as the indentation is stationary. As such, SA's detect sustained mechanical input and RA's detect motion across the skin (Dellon et al. 1987; Johnson 2001; Kandel et al. 2013). Table 9-1 summarises the four types of mechanoreceptor.

Table 9-1: Cutaneous mechanoreceptor systems (adapted from Kandel, 2013)

	Neuron Type 1 - superficial		Neuron Type 2 - deep	
Neuron name	Slowly Adapting (SA1)	Rapidly Adapting (RA2)	Slowly Adapting (SA2)	Rapidly Adapting (RA2)
Neuron frequency	Numerous	Numerous	Sparse	Sparse
Mechanoreceptor	Merkel Cell	Meissner Corpuscle	Ruffini Ending	Pacinian Corpuscle
Location	In clusters, in deep epidermis	Singly, In upper epidermis	Singly, in dermis	Singly, in deep dermis
Axon diameter (μm)	7-11	6-12	6-12	6-12
Conduction velocity (m/s)	40-65	35-70	35-70	35-70
Best stimulus	Edges, points	Lateral motion	Skin stretch	Vibration
Response to sustained indentation	Sustained firing with slow adaptation	None	Sustained firing with slow adaptation	None

The mean epidermis thickness is $369.0\mu\text{m}$ (SD 111.9) on the fingertip and $43.4\mu\text{m}$ (SD 12.8) on the back of the trunk (Whitton and Everall 1973) and Merkel cells are distributed in different densities within the epidermis at different sites throughout the body. On the back, $11.8 (\pm 4.8)$ Merkel cells per mm^2 of epidermis occur and that number rises steeply to $103.5 (\pm 13.5)$ per mm^2 on the middle finger pad (Lacour et al. 1991). They are typically situated between 0.5 – 1.0mm deep within the epidermis at the tips of epidermal sweat ridges and form small clusters called touch domes (Snider 1998). Neighbouring touch domes create discrete receptive fields, innervated by separate slowly adapting Type 1 neurons. Each Merkel cell is semi-rigid and it is the compressive force of touch stimulation that triggers their associated neurons. For a review see Tachibana (1995). If one or more Merkel cells within a receptive field is stimulated above its tactile threshold, neurotransmitters are released from the Merkel cell to the terminal of the SA 1 mechanosensory neuron. This action instigates the transmission of information from the peripheral tissues of the skin, towards the central nervous system (CNS).

For simplicity, Mountcastle's (1957) classic work on cats is historically used to convey the idea of how tactile information is transmitted from the periphery to the cortex. Namely, low threshold mechanoreceptors and their associated neurons transmit information via the projection of an axonal neuron branch directly into the spinal dorsal horn, up through the dorsal columns to one of the brainstem dorsal column nuclei. These nuclei are either the gracilis nucleus for low thoracic, lumbar and sacral post-synaptic dorsal column neurons

or to the cuneate nucleus for cervical and upper thoracic post-synaptic dorsal column neurons; both of which are located in the medulla. Here, second-order neurons decussate and ascend through the medial lemniscus pathway, synapsing with the ventral posterior nuclear complex of the thalamus. Third order thalamocortical neurons project out to regions of the somatosensory cortex, where integration with other information takes place, from which an efferent response is derived and transmitted via the descending spinal pathways to the peripheral tissues (Abraira and Ginty 2013). However, Mountcastle's (1957) model is probably too simplistic. A more likely explanation is much more complex and probably involves sensory integration beginning at sub-cortical levels, CNS circuits, complex organisation of low threshold mechanoreceptors and a multitude of ion channel involvement, for a review, see Abraira and Ginty (2013).

9.2.3. Body Schema

Body schema relates to how one's body feels to its owner (Lotze and Moseley 2007; Moseley et al. 2012). It involves how and where we perceive our bodies to be in space in relation to our ability to position ourselves and move within our environment. It also encompasses the complex integration of data from motor, sensory and vestibular cortical maps and can be considered a 'looking out, from within' perspective (Goldstein 2009).

9.2.4. Definition of Motor Function

Within this study, function is defined as the normal or proper physiologic activity of an organ or part; or to perform such activity. Motor is defined as a muscle, nerve or centre that effects or produces movement. Motor function is the normal or proper physiologic movement arising from muscles, nerves or centres that produce motion in adult humans (Dorland 2011).

9.2.5. Definition of Disability

The following definition is adopted from the World Health Organization's definition of disability (World Health Organization 2017)

"Disabilities is an umbrella term, covering impairments, activity limitations, and participation restrictions. An impairment is a problem in body function or structure; an activity limitation is a difficulty encountered by an individual in executing a task or action; while a participation restriction is a problem experienced by an individual in involvement in life situations" (World Health Organization 2017).

9.2.6. Systematic Review Search Strategy based upon PICO

- adapted from Richardson et al. (1995)

Question - 'Is low back two-point discrimination threshold and body schema altered in adults with chronic low back pain when compared with a control group and do these alterations relate to impaired lumbar motor function?'			
Search term 1	Search term 2	Search term 3	Search term 4
P (Population) Chronic Low Back Pain	I (Intervention/Interest) Two-point discrimination Body schema	C (Comparison/Control) Chronic low back pain-free group	O (Outcome) Lumbar motor function
Search term derivatives			
Chronic low back pain Chronic LBP CLBP Chronic pain Non specific low back pain Non-specific low back pain	Tactile acuity Tactile discrimination Two point discrimination Two-point discrimination 2 point discrimination 2-point discrimination 2 PD 2-PD 2PD TPD Sensory acuity Sensory discrimination	Control Comparison Back-pain free Low back pain-free Chronic low back pain-free	Lumbar motor function Lumbopelvic motor* Lumbopelvic movement Lumbopelvic control Lumbo pelvic control Lumbo-pelvic control Low back Low back motor* Low back move* Move* Moment* Motion* Range of motion* ROM Motor Control* Motor funct* Lumbar
475,586 results	1,890,934 results	N/A	20,299,291 results
Search Dates	Jun 2015, Feb 2016, Dec 2016, Aug 2017, Jan 2018 and May 2018. NB: the results for May 2018 are shown above and below		

Results from the final search run in May 2018

* (asterisk) represents any string of characters used in truncation

Pain, Two-point discrimination and Body schema

(chronic low back pain OR chronic lbp OR clbp OR Low back pain OR Back pain OR Chronic pain OR Non specific low back pain OR Non-specific low back pain OR Non specific chronic low back pain Or Non-specific chronic low back pain) AND (Tactile acuity OR Tactile discrimination OR Two point discrimination OR Two-point discrimination OR 2 point discrimination OR 2-point discrimination OR 2 PD OR 2-PD OR 2PD OR TPD OR Sensory acuity OR Sensory discrimination) AND (Body Schema OR Body Image OR Body Awareness OR Cortical reorgani* OR Cortical re-organi* OR Appearance OR Self perception OR Self-perception OR Perception of self OR Left Right judgement* OR Left/right judgement* OR Left-Right judgement* OR Motor imagery OR Sensory motor incongruence OR Sensory-motor incongruence OR Sensory/motor incongruence) = **53 results**

Pain, Two-point discrimination and movement

(chronic low back pain OR chronic lbp OR clbp OR Low back pain OR Back pain OR Chronic pain OR Non specific low back pain OR Non-specific low back pain OR Non specific chronic low back pain Or Non-specific chronic low back pain) AND (Tactile acuity OR Tactile discrimination OR Two point discrimination OR Two-point discrimination OR 2 point discrimination OR 2-point discrimination OR 2 PD OR 2-PD OR 2PD OR TPD OR Sensory acuity OR Sensory discrimination) AND (Lumbar motor function OR Lumbopelvic motor* OR Lumbopelvic movement OR Lumbopelvic control OR Lumbo pelvic control OR Lumbo-pelvic control OR Low back OR Low back motor* OR Low back move* OR Move* OR Moment* OR Motion* OR Range of motion* OR ROM OR Motor Control* OR Motor funct* OR Lumbar) = **123 results**

Pain, Body schema and movement

(chronic low back pain OR chronic lbp OR clbp OR Low back pain OR Back pain OR Chronic pain OR Non specific low back pain OR Non-specific low back pain OR Non specific chronic low back pain Or Non-specific chronic low back pain) AND (Body Schema OR Body Image OR Body Awareness OR Cortical reorgani* OR Cortical re-organi* OR Appearance OR Self perception OR Self-perception OR Perception of self OR Left Right judgement* OR Left/right judgement* OR Left-Right judgement* OR Motor imagery OR Sensory motor incongruence OR Sensory-motor incongruence OR Sensory/motor incongruence) AND (Lumbar motor function OR Lumbopelvic motor* OR Lumbopelvic movement OR Lumbopelvic control OR Lumbo pelvic control OR Lumbo-pelvic control OR Low back OR Low back motor* OR Low back move* OR Move* OR Moment* OR Motion* OR Range of motion* OR ROM OR Motor Control* OR Motor funct* OR Lumbar) = **1751 results**

Pain, Two-point discrimination, body schema and movement

(chronic low back pain OR chronic lbp OR clbp OR Low back pain OR Back pain OR Chronic pain OR Non specific low back pain OR Non-specific low back pain OR Non specific chronic low back pain Or Non-specific chronic low back pain) AND (Tactile acuity OR Tactile discrimination OR Two point discrimination OR Two-point discrimination OR 2 point discrimination OR 2-point discrimination OR 2 PD OR 2-PD OR 2PD OR TPD OR Sensory acuity OR Sensory discrimination) AND (Body Schema OR Body Image OR Body Awareness OR Cortical reorgani* OR Cortical re-organi* OR Appearance OR Self perception OR Self-perception OR Perception of self OR Left Right judgement* OR Left/right judgement* OR Left-Right judgement* OR Motor imagery OR Sensory motor incongruence OR Sensory-motor incongruence OR Sensory/motor incongruence) AND (Lumbar motor function OR Lumbopelvic motor* OR Lumbopelvic movement OR Lumbopelvic control OR Lumbo pelvic control OR Lumbo-pelvic control OR Low back OR Low back motor* OR Low back move* OR Move* OR Moment* OR Motion* OR Range of motion* OR ROM OR Motor Control* OR Motor funct* OR Lumbar) = **23 results**

9.2.7. Data Extraction and Critical Appraisal Form

Reference:

Authors:

Publication year:

Journal:

Date appraised:

Total score of study:

Summary of the study:

A	METHODS	Was it assessed? How? Outcome measure?	Complete
	Is the aim clearly stated		
	Type of study (Quant/Qual/Mixed)		
	Type of study - methodology		
	Was study design appropriate?		
	Was the research question stated?		
	Does the study answer question?		
	Duration of study?		
	Sample sizes (n)		
	No./location of centres		
	Type of centre		
	Profession/Training of researcher		
	Was pelvic tilt used for incl/excl criteria?		
	Was systematic bias avoided?		
	Ethical consent obtained?		
	Power calculation?		
	How were missing values dealt with?		
	Method of randomisation		
	Concealment of allocation		
	Level of blinding		
	Blinding of assessors		
	Blinding of participants		
B	PARTICIPANTS		
	Who are they?		
	How were they selected?		
	Adults? Age range?		
	CLBP > 3 months?		
	Incl/excl. criteria stated?		
	Screened for contraindications?		
C	DATA COLLECTION		
Data for inclusion in Literature review			
	Tactile Acuity		

	Body Image a)		
	Body Image b)		
	Motor Control		
Additional data for inclusion in the literature review <i>only</i> if lit review criteria met			
	Pelvic Tilt		
	Pain Intensity		
	Pain Duration		
	Risk of chronicity		
	Pain Location		
	Gender		
	Age		
	Disability		
	Disability		
	Fear		
	Catastrophising		
	Opioid use		
	Socioeconomic status		
	Handedness		
D	OUTCOMES		
	Outcome measures defined		
	Primary outcomes		
	Secondary outcomes		
	Negative outcomes		
	NOTES:		

9.2.8. Checklist for Measuring Study Quality

For randomised and non-randomised studies, adapted from **Downs and Black (1998)**

Author, Date, Short Title:

Scoring:

Yes = 1, No = 0, Unable to Determine = 0 (Except Question 5 where Yes = 2, Partially = 1, No = 0)

	Description of criteria With additional explanation as required, determined by consensus of raters	Scores
Reporting		
1.	Is the hypothesis/aim/objective of the study clearly described?	Yes / No
2	Are the main outcomes to be measured clearly described in the Introduction or Methods section? If the main outcomes are first mentioned in the Results section, the question should be answered no.	Yes / No
3	Are the characteristics of the patients included in the study clearly described? In cohort studies and trials, inclusion and/or exclusion criteria should be given. In case-control studies, a case-definition and the source for controls should be given.	Yes / No
4	Are the interventions of interest clearly described? Treatments and placebo (where relevant) that are to be compared should be clearly described.	Yes / No
5	Are the distributions of principal confounders in each group of subjects to be compared clearly described? A list of principal confounders is provided.	Yes / No / Partially
6	Are the main findings of the study clearly described? Simple outcome data (including denominators and numerators) should be reported for all major findings so that the reader can check the major analyses and conclusions. (This question does not cover statistical tests which are considered below).	Yes / No
7	Does the study provide estimates of the random variability in the data for the main outcomes? In non-normally distributed data the inter-quartile range of results should be reported. In normally distributed data the standard error, standard deviation or confidence intervals should be reported. If the distribution of the data is not described, it must be assumed that the estimates used were appropriate and the question should be answered yes.	Yes / No
8	Have all important adverse events that may be a consequence of the intervention been reported? This should be answered yes if the study demonstrates that there was a comprehensive attempt to measure adverse events. (A list of possible adverse events is provided).	Yes / No
9	Have the characteristics of patients lost to follow-up been described? This should be answered YES where there were no losses to follow-up or where losses to follow-up were so small that findings would be unaffected by their inclusion. This should be answered NO where a study does not report the number of patients lost to follow-up.	Yes / No
10	Have actual probability values been reported (e.g. 0.035 rather than <0.05) for the main outcomes except where the probability value is less than 0.001?	Yes / No
Total Reporting score (max. of 11)		

External validity (generalisability) All the following criteria attempt to address the representativeness of the findings of the study and whether they may be generalised to the population from which the study subjects were derived.		Scores
11	<p>Were the subjects asked to participate in the study representative of the entire population from which they were recruited?</p> <p>The study must identify the source population for patients and describe how the patients were selected. Patients would be representative if they comprised the entire source population, an unselected sample of consecutive patients, or a random sample. Random sampling is only feasible where a list of all members of the relevant population exists. Where a study does not report the proportion of the source population from which the patients are derived, the question should be answered as unable to determine.</p>	Yes / No / UTD
12	<p>Were those subjects who were prepared to participate representative of the entire population from which they were recruited?</p> <p>The proportion of those asked who agreed should be stated. Validation that the sample was representative would include demonstrating that the distribution of the main confounding factors was the same in the study sample and the source population.</p>	Yes / No / UTD
13	<p>Were the staff, places, and facilities where the patients were treated, representative of the treatment the majority of patients receive?</p> <p>For the question to be answered yes, the study should demonstrate that the intervention was representative of that in use in the source population. The question should be answered no if, for example, the intervention was undertaken in a specialist centre unrepresentative of the hospitals most of the source population would attend.</p>	Yes / No / UTD
Total for External validity (Max. of 3)		

Internal validity - Bias		
14	<p>Was an attempt made to blind study subjects to the intervention they have received?</p> <p>For studies where the patients would have no way of knowing which intervention they received, this should be answered yes.</p>	Yes / No / UTD
15	<p>Was an attempt made to blind those measuring the main outcomes of the intervention?</p>	Yes / No / UTD
16	<p>If any of the results of the study were based on “data dredging”, was this made clear?</p> <p>Any analyses that had not been planned at the outset of the study should be clearly indicated. If no retrospective unplanned subgroup analyses were reported, then answer yes.</p>	Yes / No / UTD
17	<p>In trials and cohort studies, do the analyses adjust for different lengths of follow-up of patients, or in case-control studies, is the time period between the intervention and outcome the same for cases and controls?</p> <p>Where follow-up was the same for all study patients the answer should yes. If different lengths of follow-up were adjusted for by, for example, survival analysis the answer should be yes. Studies where differences in follow-up are ignored should be answered no.</p>	Yes / No / UTD

18	<p>Were the statistical tests used to assess the main outcomes appropriate?</p> <p>The statistical techniques used must be appropriate to the data. For example nonparametric methods should be used for small sample sizes.</p> <p>Where little statistical analysis has been undertaken but where there is no evidence of bias, the question should be answered yes. If the distribution of the data (normal or not) is not described it must be assumed that the estimates used were appropriate and the question should be answered yes.</p>	Yes / No / UTD
19	<p>Was compliance with the intervention/s reliable?</p> <p>Where there was non-compliance with the allocated treatment or where there was contamination of one group, the question should be answered no. For studies where the effect of any misclassification was likely to bias any association to the null, the question should be answered yes.</p>	Yes / No / UTD
20	<p>Were the main outcome measures used accurate (valid and reliable)?</p> <p>For studies where the outcome measures are clearly described, the question should be answered yes. For studies which refer to other work or that demonstrates the outcome measures are accurate, the question should be answered as yes.</p>	Yes / No / UTD
Total for Internal validity – Bias (Max of 7)		

Internal validity - confounding (selection bias)		
21	<p>Were the patients in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited from the same population?</p> <p>For example, patients for all comparison groups should be selected from the same hospital. The question should be answered unable to determine for cohort and case-control studies where there is no information concerning the source of patients included in the study.</p>	Yes / No / UTD
22	<p>Were study subjects in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited over the same period of time?</p> <p>For a study which does not specify the time period over which patients were recruited, the question should be answered as unable to determine.</p>	Yes / No / UTD
23	<p>Were study subjects randomised to intervention groups?</p> <p>Studies which state that subjects were randomised should be answered yes except where method of randomisation would not ensure random allocation. For example, alternate allocation would score no because it is predictable.</p>	Yes / No / UTD
24	<p>Was the randomised intervention assignment concealed from both patients and health care staff until recruitment was complete and irrevocable?</p> <p>All non-randomised studies should be answered no. If assignment was concealed from patients but not from staff, it should be answered no.</p>	Yes / No / UTD
25	<p>Was there adequate adjustment for confounding in the analyses from which the main findings were drawn?</p> <p>This question should be answered no for trials if: the main conclusions of the study were based on analyses of treatment rather than intention to treat; the distribution of known confounders in the different treatment groups was not described; or the distribution of known confounders differed between the treatment groups but was not taken into account in the analyses.</p> <p>In nonrandomised studies if the effect of the main confounders was not investigated or confounding was demonstrated but no adjustment was made in the final analyses the question should be answered as no.</p>	Yes / No / UTD

26	Were losses of patients to follow-up taken into account? If the numbers of patients lost to follow-up are not reported, the question should be answered as unable to determine. If the proportion lost to follow-up was too small to affect the main findings, the question should be answered yes.	Yes / No / UTD
Total for Internal validity - confounding (selection bias) (Max. of 6)		

Power		Score
27	Did the study report/discuss or have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is less than 5%?	
Total for Power (Max of 1)		

Total scores for assessed article (to allow comparison)

	Max. possible score for all questions	Score for paper	% Score	Max. possible score for observational cohort applicable questions	Score for paper	% Score
Reporting	11					
External validity	3					
Internal validity - bias	7					
Internal validity - confounding (selection bias)	6					
Power	1					
Total						

9.2.9. Flow of articles through the systematic review literature search

Search Strategy results from May 2018					
Search No.	Search strategy combinations	Total found in database search (inc duplicates)	No. reviewed by title and abstract screening (duplicates removed)	No. Excluded following title and abstract review	No. included in full paper review
Q1-S1	CLBP	475,586	N/A	N/A	N/A
Q1-S2	TA	139,686	N/A	N/A	N/A
Q1-S3	BS	1,890,934	N/A	N/A	N/A
Q1-S4	MF	20,299,291	N/A	N/A	N/A
Q1-S5	P, TA, BS	53	46	32	14
Q1-S6	P, TA, MF	123	12	12	0
Q1-S7	P, BS, MF	1751	633	630	3
Q1-S8	P, TA, BS, MF	23	4	2	2
		1950	695	676	19
				No. included from hand search	9
				Total included in full paper review	28
	Abbreviation meanings CLBP: Chronic low back pain P: Pain TA: Tactile acuity BS: Body Schema MF: Motor Function			Excluded following full review and quality assessment	21
				Included in the systematic review	7

9.2.10. Articles reviewed and excluded from systematic review

No.	Author & Year	Title	Reason for Exclusion
1	Seltzer and Seltzer (1986)	A comparison of two-point discrimination threshold of tactual, non-painful stimuli between chronic low back pain patients and controls	Assessed Two-point discrimination threshold on the forearms of a CLBP group and a comparison group
2	Peters and Schmidt (1991)	A comparison of two-point discrimination threshold of tactual, non-painful stimuli between chronic low back pain patients and controls	Assessed Two-point discrimination threshold on the forearms of a CLBP group and a comparison group but not on their backs.
3	Catley et al. (2013a)	Assessing tactile acuity in rheumatology and musculoskeletal medicine—how reliable are two-point discrimination tests at the neck, hand, back and foot?	Assessed Two-point discrimination threshold in healthy individuals only.
4	Bowering et al. (2013)	The Effects of Graded Motor Imagery and Its Components on Chronic Pain: A Systematic Review and Meta-Analysis	LBP definition not specific and participants not described well enough to include
5	Catley et al. (2014a)	Is Tactile Acuity Altered in People with Chronic Pain? A Systematic Review and Meta-analysis.	Systematic review but doesn't report any studies not already considered in this review
6	Catley et al. (2014c)	Show me the skin! Does seeing the back enhance tactile acuity at the back?	Assessed Two-point discrimination threshold in healthy individuals only.
7	Trapp et al. (2014b)	A brief intervention utilising visual feedback reduces pain and enhances tactile acuity in CLBP patients.	Did not include a healthy control/comparison group, only another CLBP group receiving different treatment
8	Ryan et al. (2014)	Tactile acuity training for patients with chronic low back	Did not include a healthy control/comparison group

		pain: a pilot randomised controlled trial	
9	Flaherty and Connolly (2014)	A Preliminary Investigation of Lumbar Tactile Acuity in Yoga Practitioners.	Assessed two-point discrimination threshold in healthy individuals only.
10	Bowering et al. (2014)	Do people with chronic pain have impaired executive function? A meta-analytical review	Did not include studies investigating adults with CLBP
11	Rabey et al. (2015)	Somatosensory nociceptive characteristics differentiate subgroups in people with chronic low back pain: a cluster analysis	Assessed two-point discrimination threshold in CLBP group only.
12	Wälti et al. (2015)	Short-term effect on pain and function of neurophysiological education and sensorimotor retraining compared to usual physiotherapy in patients with chronic or recurrent non-specific low back pain, a pilot randomized controlled trial.	Did not include a healthy control/comparison group, only another CLBP group receiving different treatment
13	Zamorano et al. (2015)	Pain sensitivity and tactile spatial acuity are altered in healthy musicians as in chronic pain patients.	Assessed two-point discrimination threshold on the fingertips, not on the back.
14	Gutknecht et al. (2015)	Comparative study: The effect of motor control and tactile acuity training on patients with non-specific low back pain and movement control impairment	Did not include a healthy control/comparison group and CLBP was not defined.
15	Ehrenbrusthoff et al. (2016)	The intra- and inter-observer reliability of a novel protocol for two-point discrimination in individuals with chronic low back pain.	Assessed Two-point discrimination threshold in CLBP group only.

16	Falling and Mani (2016a)	Ageing and obesity indices influences the tactile acuity of the low back regions: A cross-sectional study.	Assessed Two-point discrimination threshold in healthy individuals only.
17	Kälin et al. (2016)	What is the effect of sensory discrimination training on chronic low back pain? A systematic review.	Systematic review of various methods of tactile acuity. Those relevant to this review had already been considered and either included or rejected.
18	Beaudette et al. (2016)	Low back skin sensitivity has minimal impact on active lumbar spine proprioception and stability in healthy adults	Assessed Two-point discrimination threshold in healthy individuals only.
19	Linder et al. (2016)	Using Recognise Online™, compared judgment performance of foot and trunk laterality between people with LBP (with or without leg pain) and healthy controls	Included participants with pain duration of six weeks or longer so does not meet this studies inclusion criteria (CLBP ≥ 3 months duration)
20	Adamczyk et al. (2017a)	Lumbar Tactile Acuity in Patients with Low Back Pain and Healthy Controls: Systematic Review and Meta-Analysis.	Systematic review of low back tactile acuity in adults with CLBP and healthy controls but no new studies were reported.
21	Stanton et al. (2017)	Feeling stiffness in the back: a protective perceptual inference in chronic back pain	Assessed body image/perception using drawings of the back using the method in Moseley (2008a) – excluded due to low quality (specifically selection bias and external validity)

9.3. Appendices for Chapter Three

9.3.1. Participant pack and questionnaires

Sara Glithro

PhD Research Student
Bournemouth
University R313, Royal
London House
Christchurch Road
Bournemouth
BH1 3LT

Thank you for getting in touch and agreeing to take part in the research project called 'Neuroplasticity and Chronic Low Back Pain - An investigation into altered tactile discrimination, body schema and motor function in adults with chronic low back pain'

I enclose the following documents;

- Participant information sheet
- Consent form
- Participant questionnaire

Could I ask that you do the following prior to your appointment at the clinic?

- Read the participant information sheet
- Read and sign the consent form
- Complete the questionnaire
- Bring the signed consent form **and** the completed questionnaire to your appointment

If you have an appointment booked and need to change it, please could you call on or email me on sglithro@bournemouth.ac.uk

Please don't hesitate to get in touch if you have any questions.

I really appreciate you giving up your time to engage with this study.

Kindest regards

Sara Glithro MChiro

sglithro@bournemouth.ac.uk

PARTICIPANT INFORMATION SHEET

Title of the project

Neuroplasticity and Chronic Low Back Pain: An investigation into altered tactile discrimination, body schema and motor function in adults with chronic low back pain.

Research study information

You are being invited to take part in a research study. Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with friends and relatives if you wish to. Ask us if there is anything that is not clear or if you would like more information. Please do take time to decide whether or not you wish to take part.

Who are the researchers of this project?

The research supervisors responsible for this study Dr Carol Clark, Dr Neil Osborne, Dr Dave Newell and Dr Sharon Docherty.

You will meet Sara Glithro who will record and analyse the data collected as part of a doctoral research degree (PhD) which is being undertaken at Bournemouth University in conjunction with the Anglo-European College of Chiropractic.

Although no treatment is being offered as part of this research study, Sara is a practising chiropractor and is registered with the General Chiropractic Council.

What is the purpose of the study?

Low back pain is a common condition affecting most adults at some point in their lives. Between 6-11% of UK adults will continue to experience recurring episodes of back pain which after three months duration is considered chronic. People with chronic low back pain (CLBP) typically report pain and difficulty in moving or performing simple daily tasks. Many of those with CLBP are likely to be absent from work and those that seek care within the NHS utilise more than twice the UK healthcare budget as their pain-free counterparts. The treatment options normally available do not always help resolve the condition.

Your central nervous system, which includes your brain, spinal cord and nerves, is not only responsible for how your body functions, but also how it interprets and responds to the world around you. In people with other chronic painful conditions, parts of their brain change their structure and function and this is called neuroplasticity. These neuroplastic changes manifest as altered sensory functions such as touch and the ability to differentiate between left and right. It may also be that these changes are involved with altered motor (movement) function commonly seen in people in chronic pain.

This study aims to explore these phenomena in volunteer participants with and without CLBP and the researcher hopes that the findings may help guide future treatment possibilities.

Why have I been chosen?

You have been chosen as you meet the criteria for this project of being either;

- An adult aged between 18 and 65 years of age with long term (chronic) low back pain.
- Or, adult aged between 18 and 65 years of age without long term (chronic) low back pain.

Do I have to take part?

Absolutely not. It is up to you to decide whether or not to take part. If you do decide to take part, you will be given this information sheet to keep and be asked to sign a consent form.

Can I withdraw from the study?

You can. If you decide to take part you are still free to withdraw at any time and you don't have to give us a reason.

Part of the study involves you being videoed whilst performing simple movements of the low back. If you agree to be videoed, you can withdraw your video data from the study up until the writing-up of the results takes place.

You may withdraw your non-videoed data (questionnaires, touch assessment etc) from the study providing you notify us prior to the data being anonymised. Once anonymised, removing your data from the pooled group data is not possible. However identification of you from the pooled group data is not possible.

What do I have to do?

Participation in this study requires that you attend one appointment in Bournemouth or Boscombe lasting up to 90 minutes. No further appointments are necessary.

There are a few different parts to this study but all can be completed in one appointment.

- You will be reminded of the procedures involved in this study and asked to sign a consent form.
- You will be asked to complete a set of questionnaires about you and back pain. These may take around 20 minutes to complete. These may be sent to you prior to the appointment, in which case the appointment will last up to 60 minutes.
- A basic health check will be performed to ensure you meet the inclusion criteria. Your height and weight will also be recorded.
- You will be asked to change into your shorts and T shirt (if you brought them with you) or a gown will be provided if you prefer.
- You will be asked to sit comfortably with your writing hand resting palm upwards on a cushion so we can assess your sense of touch on the pad of your middle finger. You will be asked to close your eyes and we will gently touch your finger using a series of fine plastic strands and plastic calipers. You will be asked whether you can feel the strand touching your finger or whether you feel one or two points of the calipers.
- You will then be asked to lie face down on a padded therapy bench and relax for a few minutes. We will measure the width of your low back using a tape measure.
- We will gently touch points on your low back using the fine plastic strands and plastic calipers. Again, you will be asked whether you can feel the strand touching your back or whether you feel one or two points of the calipers. This should take around 10 minutes.



- You will then be asked to sit at a computer screen and undertake a series of tests designed to assess determining left from right. You will be shown a set of images of the back and be asked to decide if the image shows a back turning towards the left side or the right side. You choose 'left' or 'right' by clicking a button. This should take 10-15 minutes.
- Lastly, we will assess your movement. A common task people perform each day is standing from a sitting position or sitting from a standing position. This movement involves the use of the low back, pelvis and lower limbs and we want to assess how it is affected but low back pain. In this part of the study you will be asked to stand up and sit down as many times as you can during a 30 second period, without using your arms to help. If you become too uncomfortable during the task, you may stop at any time.
- You will be shown 6 small but precise movements of the low back and asked if you can repeat them. For this part of the study, the researcher will need to see the skin of your low back and abdomen so if you choose to wear a T-shirt we may need you to tuck it up out the way. Videoing this part of the study would be beneficial to our research however if you would prefer not to be videoed, please do let us know (for more information, please see below). This should take around 10-15 minutes

Will I be recorded and how will the recorded media be used?

Videos of your performance of the low back movements would be of great benefit to our research however we understand if you do not want to be videoed.

If you consent to being videoed, the video recordings of your activities made during this research will be used only for analysis and for illustration in conference presentations and lectures. Your video data may be shared with a panel of health care professionals as part of the study requires their assessment of low back movements in addition to the assessment made by the researcher. No other use will be made of your video without your written permission.

If you provide us with consent to video you, any video of you which is passed to the panel of healthcare practitioners will be sent to them on a USB data stick. No other identifying information about you will be sent to them. All panel members will be asked to keep your video confidential and return the USB data stick once they have completed their assessment however, the nature of sharing the video makes it difficult to safeguard the confidentiality of your data.

What are the possible disadvantages?

It is unlikely but if you have long term or chronic pain, the tests may aggravate your existing level of pain. You will be monitored throughout the study and asked to stop if the researcher feels it appropriate. You are welcome to withdraw from the study at any time.

What are the possible benefits of taking part?

Whilst there are no immediate benefits for those people participating in the project, it is hoped that this work will help us to learn more about one of the most common but least understood conditions which affects millions of people each year. We hope that understanding new aspects of this debilitating condition will enable new approaches to treatments for future pain sufferers.

Will my taking part in this study be kept confidential?

All the information that we collected about you during the course of the research will be kept strictly confidential. All data relating to this study will be kept on a password protected database or in a locked filing cabinet. All data will be kept in accordance with the Data Protection Act 1988. Bournemouth University requires data to be retained for a minimum of five years, after which it can be deleted.

What will happen to the results of the research study?

The results will be anonymised and written up as part of the researcher's PhD thesis which will be put forward for a doctoral (PhD) examination by viva. This is expected to take place by the end of 2018. The anonymised results of this study will be shared with others at national and international conferences and published in several research journals. You will not be identified in any presentation, lecture, report or publication.

Who has reviewed the study?

This study has been reviewed and approved by the Bournemouth University Research Ethics Committee and the Anglo-European College of Chiropractic Research Ethics Sub-Committee.

Contact for further information?

Sara Glithro – sglithro@bournemouth.ac.uk Mobile:

Dr Carol Clark – cclark@bournemouth.ac.uk Office Number:

Both can be contacted in writing at; Bournemouth University, R603 Royal London House,
Christchurch Road, Bournemouth

BH1 3LT

In the unlikely event you wish to complain about any part of this study, please contact:
Professor Vanora Hundley, Deputy Dean of Research, Bournemouth University, Royal
London House, Christchurch Road, Bournemouth, BH1 3LT

Please keep a copy of this information sheet for your future reference Thank you for taking
part in the study

It is important to remind you that no treatment will be offered as part of this study

Participant Consent Form

Full title of project: Neuroplasticity and Chronic Low Back Pain: An investigation into altered tactile discrimination, body schema and motor function in adults with chronic low back pain?

Name, position and contact details of researcher:

Sara Glithro, Post Graduate Researcher - sglithro@bournemouth.ac.uk

Name, position and contact details of supervisor (if the researcher is a student):

Dr Carol Clark, Head of Department Human Sciences and Public Health - cclark@bournemouth.ac.uk

	Please initial each section
I have read and understood the participant information sheet for the above research project	
I confirm that I have had the opportunity to ask questions	
I understand that my participation is voluntary	
I understand that I am free to withdraw <i>up to the point where the data are processed and become anonymous, so my identity cannot be determined, or in the case of videoed data, up until the time the research findings are written up by the researcher.</i>	
During the task or experiment, I am free to withdraw without giving reason and without there being any negative consequences.	
Should I not wish to answer any particular question(s), complete a test or give a sample, I am free to decline.	

<p>I give permission for members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the outputs that result from the research.</p>	
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<p>I agree to be featured in any film taken during the project and for this film to be shared with a panel of healthcare professional outside of this research team specifically for the purpose of analysing the back movements captured in the video.</p>	
<p>I agree to take part in the above research project.</p>	

Name of Participant	Date	Signature
---------------------	------	-----------

Name of Researcher	Date	Signature
--------------------	------	-----------

This form should be signed and dated by all parties after the participant receives a copy of the participant information sheet and any other written information provided to the participants. A copy of the signed and dated participant agreement form should be kept with the project's main documents which must be kept in a secure location.

It is important to remind you that no treatment will be offered as part of this study

Clinical assessment

Patient ID: _____ **Date:** _____ **Age** _____

today: Gender: Male / Female

A brief history of back pain:

First incidence: _____ Age at onset: _____ Onset: Sudden /

Insidious Participants reason for onset:

Recurrence: _____ times per week/month/year Lasting: _____
 _____ days/weeks/months Any recent change to pain: _____ ADLs affected: _____

Sleep: _____ Night pain/sweats: _____

General history

Corticosteroid history: _____ History of fractures: _____

Fever: _____ Unexplained weight loss: _____

Generally feeling unwell: _____

History of illness/managed

conditions: Thoracic pain: No /

Yes

Widespread neurological signs/symptoms: No / Yes If yes, give

details: Local neurological signs/symptoms: _____

Any known spinal structural deformity: _____

Other Exclusion criteria

1. Pregnant or within 6 months of giving birth? No / Yes
2. Any major neurological conditions? No / Yes If yes, details _____
3. Spinal surgery within the previous 2 years? No / Yes
4. Any current spinal pathologies including spinal stenosis, nerve root lesions?
5. Any major medical conditions such as:
 - a. Rheumatic disease
 - b. Rheumatoid arthritis
 - c. Osteoarthritis – if yes, which joints affected?
 - d. Ankylosing spondylitis
 - e. Cardiovascular disease
 - f. Any other major systemic conditions

Neuroplasticity and Chronic Low Back Pain: An investigation into altered tactile discrimination, body schema and motor function in adults with chronic low back pain

ID N°: Date form completed: Are you: Male or Female

Date of Birth: Age: Which hand do you usually write with: Left or Right

Height:

Weight:

SECTION 1

Low back pain is defined as **pain or discomfort** in the **shaded** region shown in the picture below.

1. Have you **ever** had low back pain?

	Yes
	No

Please answer **all** the questions on each page

Please go to Section 3

2. Has your low back pain persisted or recurred for longer than 3 months?

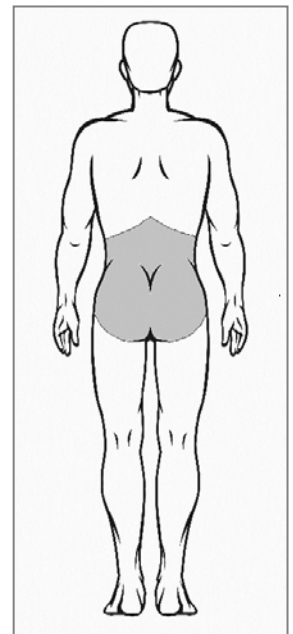
	Yes
	No

3. Does your low back pain interfere with your normal activities of daily living (dressing, washing, work, exercise or social life etc)

	Yes
	No

4. How **long** has low back pain been an ongoing problem for you?

	Less than 1 month
	1-3 months
	3-6 months
	6 months–1 year
	1-5 years
	More than 5 years



5. How **often** has low back pain been an ongoing problem for you over the past 6 months?

<input type="checkbox"/>	Every day or nearly every day in the past 6 months
<input type="checkbox"/>	At least half the days in the past 6 months
<input type="checkbox"/>	Less than half the days in the past 6 months

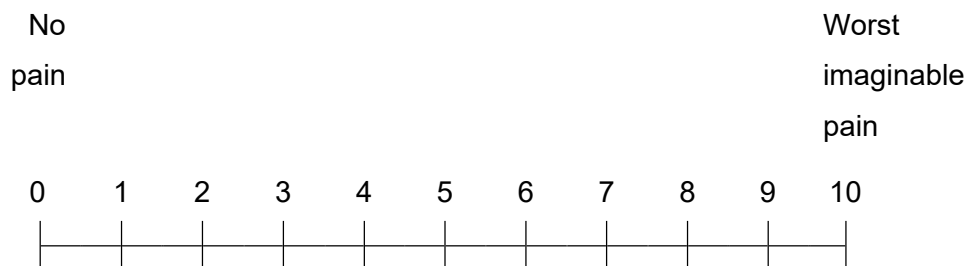
6. When was the **first time** you ever experienced low back pain?

_____ Months Or _____ Years ago

7. Have you had surgery on your low back within the last 2 years?

<input type="checkbox"/>	Yes
<input type="checkbox"/>	No

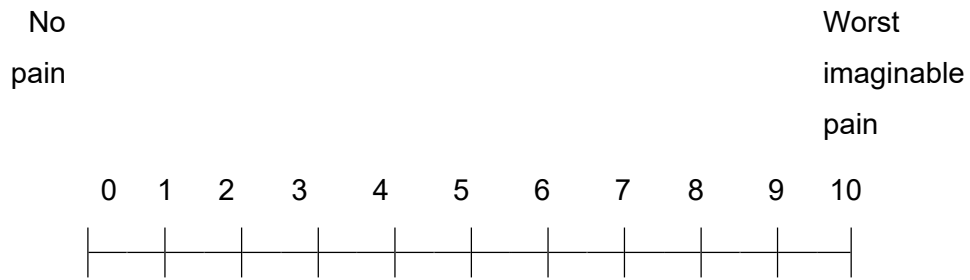
8. If '0' on this chart represents 'no pain' and '10' is 'the worst pain you can imagine', can you indicate the average level of pain during a **typical** back pain episode?



9. Do you have low back pain today?

<input type="checkbox"/>	Yes	Please continue to question 10
<input type="checkbox"/>	No	Please go to question 11

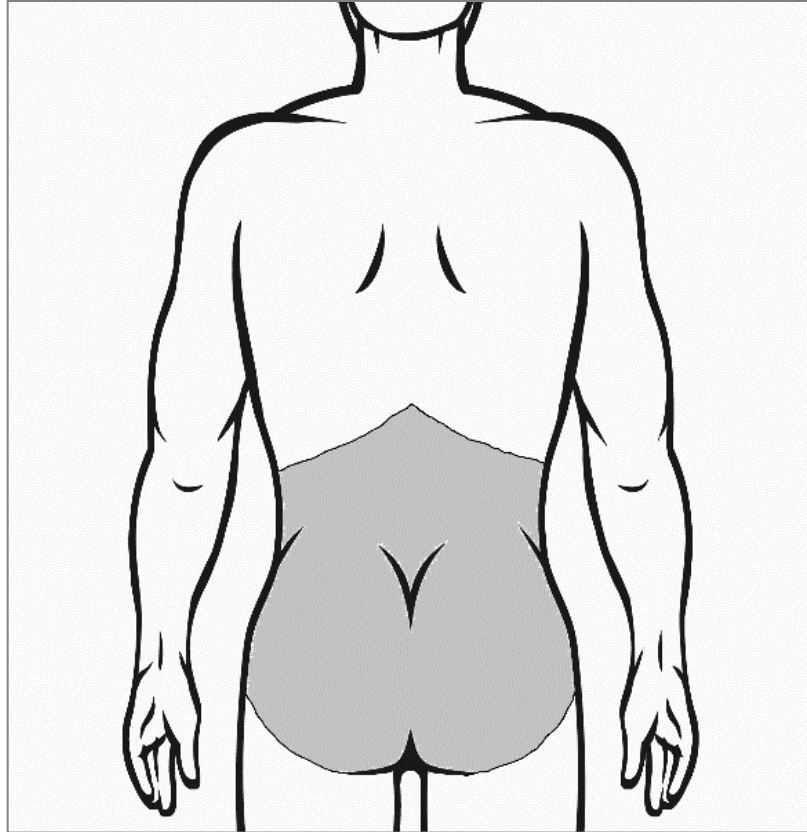
10. What is the level of your low back pain **today**?



11. Have you **ever** had time off work due to low back pain? ('work' includes your normal activities like employed work, homework, childcare, studying,)

Yes	If you select 'Yes', what is the longest period you've had away from work (in one go) _____ Days
No	

12. Please **clearly** mark your **typical** area of low back pain on the image? If it typically covers a large area you may wish to draw an outline around the area or, if it is in one area you might prefer to mark it with an X.



13. Which side of your back is normally more painful than the other?

<input type="checkbox"/>	Left
<input type="checkbox"/>	Right
<input type="checkbox"/>	It changes sides
<input type="checkbox"/>	Same both sides

14. Do you have pain radiating down to one or both legs?

<input type="checkbox"/>	No
<input type="checkbox"/>	Yes, the LEFT buttock/leg
<input type="checkbox"/>	Yes, the RIGHT buttock/leg
<input type="checkbox"/>	Yes, BOTH buttocks/legs

9.3.1.1. Tampa Scale of Kinesiophobia -11 (TSK-11), (Woby et al, 2005)

SECTION 2 - Part A

These 11 questions assess **fear of movement** in relation to your **low back pain**.

Please tick the box that most closely describes your feeling towards each statement as you feel **TODAY**

If you have never experienced low back pain, please go to SECTION 3, page 6

	Strongly Disagree (1)	Disagree (2)	Agree (3)	Strongly Agree (4)
1. I'm afraid that I might injure myself if I exercise	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2. If I were to overcome it (the fear of movement), my pain would increase	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3. My body is telling me I have something dangerously wrong	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4. People aren't taking my medical condition (my low back pain) seriously enough	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5. My accident (or injury) has put my body at risk for the rest of my life	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6. Pain always means I have injured my body	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7. Simply being careful that I do not make any unnecessary movements is the safest thing I can do to prevent my pain from worsening	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8. I wouldn't have this much pain if there wasn't something potentially dangerous going on in my body	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9. Pain lets me know when to stop exercising so that I don't injure myself	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10. I cannot do all the things normal people do because it's too easy for me to get injured	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
11. No one should have to exercise when he/she is in pain	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

9.3.1.2. Roland Morris Disability Questionnaire (RMDQ), (Roland and Morris 1983)

SECTION 2 - Part B

Managing your daily activities – please follow the instructions below

- When your back hurts, you may find it difficult to do some things you normally do
- This list contains sentences that people have used to describe themselves when they have back pain
- When you read them, you may find that some stand out because they describe you **today**
- As you read the list, think of yourself **today**
- When you read a sentence that describes you today, put a tick against it.
- If the sentence does not describe you, then leave the space blank and go to the next
- Remember, only tick the sentence if you are sure it describes you **today**

		Tick if this describes you <u>TODAY</u>
1	I stay at home most of the time because of my back.	
2	I change position frequently to try and get my back comfortable.	
3	I walk more slowly than usual because of my back.	
4	Because of my back I am not doing any of the jobs that I usually do around the house.	
5	Because of my back, I use a handrail to get upstairs.	
6	Because of my back, I lie down to rest more often.	
7	Because of my back, I have to hold on to something to get out of an easy chair.	
8	Because of my back, I try to get other people to do things for me.	
9	I get dressed more slowly than usual because of my back.	
10	I only stand for short periods of time because of my back.	
11	Because of my back, I try not to bend or kneel down.	
12	I find it difficult to get out of a chair because of my back.	
13	My back is painful almost all the time.	
14	I find it difficult to turn over in bed because of my back.	
15	My appetite is not very good because of my back pain.	
16	I have trouble putting on my socks (or stockings) because of the pain in my back.	
17	I only walk short distances because of my back.	
18	I sleep less well on my back.	
19	Because of my back pain, I get dressed with help from someone else.	
20	I sit down for most of the day because of my back.	
21	I avoid heavy jobs around the house because of my back.	
22	Because of my back pain, I am more irritable and bad tempered with people than usual.	
23	Because of my back, I go upstairs more slowly than usual.	
24	I stay in bed most of the time because of my back.	
25	None of these apply to me <u>today</u>	

9.3.1.3. Keele STarT Back Screening Tool, (Hill et al, 2008)

SECTION 3 – Part A

Thinking about the **last 2 weeks** tick your response to the following statements:

		Disagree	Agree
1	My back pain has spread down my leg(s) at some time in the last 2 weeks		
2	I have had pain in the shoulder or neck at some time in the last 2 weeks		
3	I have only walked short distances because of my back pain		
4	In the last 2 weeks, I have dressed more slowly than usual because of back pain		
5	It's not really safe for a person with a condition like mine to be physically active		
6	Worrying thoughts have been going through my mind a lot of the time		
7	I feel that my back pain is terrible and it's never going to get any better		
8	In general I have not enjoyed all the things I used to enjoy		

9	Overall, how bothersome has your back pain been in the last 2 weeks?				
	Not at all	Slightly	Moderately	Very much	Extremely

9.3.1.4. Fremantle Back Awareness Questionnaire (FreBAQ), (Wand et al, 2014)

SECTION 3 – Part B - Back Perception

Please only answer if you have experienced low back pain

If you have never experienced low back pain, please go to SECTION 5, page 10

This list contains sentences that people have used to describe how their back feels when they have back pain.

Please tick the most appropriate response which indicates how your back feels **when you are experiencing back pain**

Never = Never feels like that

Rarely = Rarely feels like that

Occasionally = Occasionally or some of the time feels like that

Often = Often or a moderate amount of time feels like that

Always = Always or most of the time feels like that

		Never	Rarely	Occasionally	Often	Always
1	My back feels as though it is not part of the rest of my body					
2	I need to focus all my attention on my back to make it move the way I want it to					
3	I feel as if my back sometimes moves involuntarily, without my control					
4	When performing everyday tasks, I don't know how my back is moving					
5	When performing everyday tasks, I am not always sure where my back is in space					
6	I can't perceive the exact outline of my back					
7	My back feels like it is enlarged (swollen)					
8	My back feels like it has shrunk					
9	My back feels lopsided (asymmetrical)					

SECTION 4 – About your back pain

Please only answer if you have experienced low back pain

If you have never experienced back pain – please go to SECTION 5

1. Are you involved in a lawsuit or legal claim related to your low backpain?

<input type="checkbox"/>	Yes
<input type="checkbox"/>	No
<input type="checkbox"/>	Not sure

SECTION 5

1. Education - What is your highest educational achievement?

<input type="checkbox"/>	GCSE/CSE/O Level	<input type="checkbox"/>	Diploma
<input type="checkbox"/>	A/AS/A2 Level	<input type="checkbox"/>	Degree
<input type="checkbox"/>	Baccalaureate	<input type="checkbox"/>	Masters
<input type="checkbox"/>	Certificate	<input type="checkbox"/>	Doctorate
<input type="checkbox"/>	BTech	<input type="checkbox"/>	Other _____
		<input type="checkbox"/>	

2. Employment status - Please tick the status that is most applicable to you

<input type="checkbox"/>	Working now
<input type="checkbox"/>	Looking for work
<input type="checkbox"/>	Sick leave
<input type="checkbox"/>	Disabled due to back pain – permanently or temporarily
<input type="checkbox"/>	Disabled for reasons other than back pain
<input type="checkbox"/>	Student
<input type="checkbox"/>	Keeping house
<input type="checkbox"/>	Retired
<input type="checkbox"/>	Other, Specify
<input type="checkbox"/>	Unknown

3. What is your occupation? _____

Thank you for completing this questionnaire

Please bring your completed questionnaire to your appointment

9.3.2. Researcher Data collection sheets

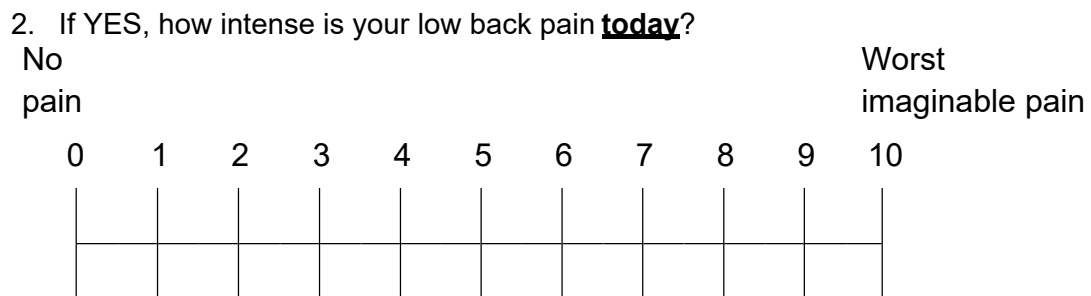
Practical Data Collection sheet for Researcher

Participant ID No: Date: Time: Venue:

	Yes	No	Note s
Health and Safety issues covered			
Questionnaire completed prior to appointment?			
Is questionnaire complete?			
PI issued and read?			
Consent obtained?			
Video consent obtained?			
Clinical Assessment complete?			
Include/Exclude			
Height (cm)			
Weight (kg)			
Width of low back at L3 (mm)			

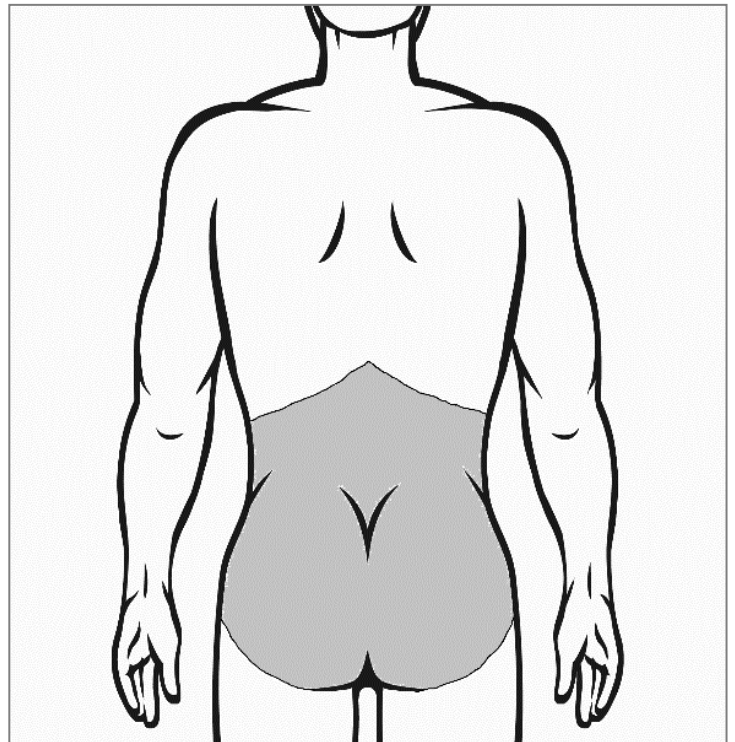
PAIN

1. Do you have low back pain today? YES NO



3. Where is your back pain TODAY?

Please **clearly** mark your **typical** area of low back pain on the image? If it typically covers a large area you may wish to draw an outline around the area or, if it is in one area you might prefer to mark it with an X.



If you do not normally have low back pain, please leave blank and tick here

TACTILE THRESHOLD ASSESSMENT

		L3	Painful level
Level of transverse process (TP) assessment	Control Group	<input type="checkbox"/>	N/A
	Pain Group (Level _____)	<input type="checkbox"/>	<input type="checkbox"/>
	Dominant hand LEFT RIGHT		

Tick the lowest pressure positively sensed

	Aesthesio® Evaluator size	Target Force (g)	Theoretical pressure g/sq.mm	Dom. hand middle finger palp	L3		Painful level	
					Left TP	Right TP	Left TP	Right TP
Green	1.65	0.008	2.53					
	2.36	0.02	4.39					
	2.44	0.04	4.93					
	2.83	0.07	5.53					
Blue	3.22	0.16	8.77					
	3.61	0.40	16.1					
Purple	3.84	0.60	18.4					
	4.08	1.0	24.4					
	4.17	1.4	27.9					
	4.31	2.0	27.4					
Red	4.56	4.0	40.3					
	4.74	6.0	52.6					
	4.93	8.0	61.7					
	5.07	10	68.3					
	5.18	15	82.0					
	5.46	26	106					
	5.88	60	141					
	6.10	100	193					
6.45	180	222						
Orange	6.65	300	292					

TWO-POINT DISCRIMINATION ASSESSMENT (mm) (using modified Vernier calipers)

		L3	Painful level
Level of transverse process (TP) assessment	Control Group	<input type="checkbox"/>	N/A
	Pain Group (Level____)	<input type="checkbox"/>	<input type="checkbox"/>
	Dominant hand LEFT RIGHT		

Middle finger palp of dominant hand

RUN ONE	mm
1 st ascending run	
1 st descending run	
Mean of 1 st run	
Plus 2mm tool correction	

RUN TWO	mm
2 nd ascending run	
2 nd descending run	
Mean of 2 nd run	
Plus 2mm tool correction	

Corrected total palp mean	
---------------------------	--

Low back

RUN ONE	L3 TP's	
	Left	Right
1 st ascending run		
1 st descending run		
Mean of 1 st run		
Plus 2mm tool correction		

Painful level TP's	
Left	Right

RUN TWO	L3 TP's	
	Left	Right
2 nd ascending run		
2 nd descending run		
Mean of 2 nd run		
Plus 2mm tool correction		

Painful level TP's	
Left	Right

Corrected total back means		
----------------------------	--	--

--	--

LEFT/RIGHT DISCRIMINATION OF LOW BACK – Body schema assessment (NOI Recognise™)

Participants to complete two sets of 40 images as a practice prior to trials.

Date of tests: _____

Time tests started: _____

	Noi Recognise - Backs	
	Accuracy (%)	
	Left	Right
Trial 1 (40 images)		
Trial 2 (40 images)		
Mean		

Noi Recognise - Backs	
Speed (s)	
Left	Right

LUMBOPELVIC MOTOR CONTROL – Luomajoki's Battery of Tests assessment

NB: If the movement control improves by instruction and correction and the participant appears to complete the task correctly, score as 'yes'.

Scoring: Movement achieved = 0, movement not achieved = 1

	Task name	Description	Test achieved	Date and time, if videoed
Test 1	Waiters bow	Flexion of the hips in upright standing without movement (flexion) of the low back		
Test 2	Pelvic Tilt	Dorsal tilt of pelvis actively in upright standing.		
Test 3	One leg stance	Measurement of lateral movement of the umbilicus when moving from normal standing to one leg stance. (Start position - feet one third of trochanter distance apart)		
Test 4	Sitting knee extension	Upright sitting with neutral lumbar lordosis; extension of the knee without movement (flexion) of low back. 30-50° Extension of the knee is normal		
Test 5	Quadruped position - Backwards	Transfer of the pelvis backwards and forwards ("rocking") keeping low back in neutral. Starting position 90° hip flexion 120° of hip flexion without movement of the low back by transferring pelvis backwards		
	- Forwards	Rocking forwards to 60° hip flexion without movement of the low back		
Test 6	Prone lying active knee Flexion	Active knee flexion at least 90° without movement of the low back and pelvis		
Total				

30 Second Chair Stand Test (30CST) – No full stands within 30 seconds_____

9.3.3. Locating anatomical landmarks of the lumbar spine

To assess specific anatomical structures, it was essential to locate the same structures within each participant. As a registered chiropractor, the researcher is experienced in human anatomy and palpation techniques.

Locating anatomical landmarks of the spine using palpation alone has been reported to have poor inter-rater reliability, however intra-rater reliability is considered acceptable ($\kappa = 0.4$), (Seffinger et al. 2004). As such, the following technique was adopted from Biel (2014) to locate each participants L3 and L5 lumbar vertebra via static palpation.

The spinous process and transverse processes were located using landmark position assessments with the patient prone. The landmarks of the superior iliac crests were palpated, then the palpatory fingers were moved medially to locate the spinous process of the L4 vertebra, which lies directly between the iliac crests. Moving superiorly while palpating the spinous processes allowed for the location of the L3 vertebra. Using one finger, light contact was maintained over the L3 spinous process while locating its superiorly and laterally positioned transverse processes. The transverse processes of L3 are located laterally to the inferior part of the L2 spinous process. To ensure the correct structure was located, a slight posterior to anterior (P-A) pressure was applied to the transverse process. If correctly positioned, the slight P-A pressure resulted in lateral movement of the L3 spinous process under the finger maintaining contact.

To locate L5 which is positioned medially and inferiorly to the iliac crests, the palpatory fingers were moved medially on a transverse plane, from the iliac crests to the spinous process of the L4 vertebra, then inferiorly to the spinous process of L5. The transverse processes were located using the same two handed approach described above and the knowledge that the L5 transverse processes are situated fractionally superiorly to the transverse plane of the L5 spinous process (Biel 2014). Where participants reported centre of their typical pain region to be level with L4 and the 1st sacral vertebra (S1), positioned directly above and below L5 respectively, similar approaches were used to identifying the relevant vertebrae.

The L3 and L5 transverse processes were marked using a non-permanent marker pen to allow accurate repeated measurements at the same location. The marker pen was removed from the patient's skin on completion of the data collection.

9.3.4. Tactile Threshold method – Middle Fingertip

- a. The participants and assessor were seated with a small table between them.
- b. The assessor explained the process to the participant, taking care not to reveal the expected outcome.
- c. Practise runs were carried out to ensure participants knew what to expect. After several trials on the palms of participant's hands using the 300g von Frey monofilaments (Aesthesio™ Precision Tactile Sensory Evaluators, DanMic Global, LLC) to ensure the procedure was understood, testing began on the fingertip.
- d. The assessor stabilised the participants supinated (upturned) dominant hand and middle finger on a firm foam cushion upon the table at a position comfortable to the participant. The participants elbow and forearm rested on the table.
- e. The researcher held the participant's middle finger, laterally to the palp of the distal phalanges with her thumb and middle finger, gently but firmly against the cushion with her right hand.
- f. The assessor's elbows and wrists were resting on the table throughout. The von Frey filaments were held by the handle with the left hand (the researcher is left hand dominant).
- g. Participants closed their eyes and were instructed to answer "yes" when they perceived a touch stimulus.
- h. Von Frey hairs were applied and removed from the fingertip palp in a uniform manner. Slowly approaching the skin, perpendicularly, from a height of 2.5cm, each filament was permitted to contact the skin and buckle for approximately 1.5 seconds (a count of 2) before being removed directly upward to its start position.
- i. Care was taken to avoid bouncing the filament during contact, as this could increase the force applied. Rapid removal of filaments was also avoided (Weinstein 1968; Bell-Krotoski et al. 1993; Bell-Krotoski et al. 1995).
- j. During testing, filaments were applied in order from the smallest to largest magnitude until participants reported the sensation of being touched.
- k. Threshold was taken to be the recorded as the smallest filament, in grams, perceived by participants.
- l. Steps h.- i. were repeated to confirm tactile threshold and results recorded
- m. To control for attentional effects on localisation accuracy and false positive responses, additional null stimuli were performed in other non-target areas of the hand. These results were not recorded.
- n. Tests with a response delay greater than 3 seconds were considered void and repeated.

9.3.5. Tactile Threshold method - Low Back

- a. The assessor explained the process to the participant, taking care not to reveal the expected outcome.
- b. Participants lay prone on a manual therapy bench. To reduce low back tension, a slight knee flexion was created using a bolster cushion under their ankles.
- c. The skin of the low back was exposed and the transverse processes of the L3 and L5 vertebra were located and marked using non-permanent pen and the technique reported in the thesis methodology chapter.
- d. The researcher was seated on stool with wheels which could easily be moved into position. Her elbows were resting on her knees and one hand supported the other wrist during application of the filaments.
- e. Bench height was fully adjustable to ensure the most stable position was obtained for the assessor prior to measurements being recorded.
- f. Participants were asked to report when and where they perceived touch.
- g. Practises were carried out to ensure participants knew what to expect. Using the 300g von Frey monofilament (Aesthesio™ Precision Tactile Sensory Evaluators, DanMic Global, LLC) and the technique reported in point h, participants were asked to identify touch at one of four positions (left L3 = “upper left”, right L3 = “upper right”, left L5 = “lower left” and right L5 = “lower right”). Once participants understood what to expect, tactile threshold was measured and recorded.
- h. Von Frey hairs were uniformly applied and removed from each location on the back. Sites were chosen randomly but all were assessed. Filaments approached slowly and perpendicularly to the skin, from a height of approximately 2.5cm. Each filament was permitted to contact the skin and buckle for approximately 1.5 seconds (a count of 2) before being removed directly upwards, back to its start position.
- i. Care was taken to avoid bouncing the filament during contact, as this could increase the force intended. Rapid removal of filaments was also avoided (Weinstein 1968; Bell-Krotoski et al. 1993; Bell-Krotoski et al. 1995).
- j. During testing, filaments were applied in order from the smallest to largest magnitude until participants reported the sensation of being touched.
- k. Threshold was recorded as the smallest filament, in grams, perceived by each participant, for each location.
- l. Steps h. to i. were repeated to confirm tactile threshold at each location, which were recorded in grams.
- m. To control for attentional effects on localisation accuracy and false positive responses, single-point contacts were randomly included. These results were not recorded.

9.3.6. Adapting Moberg's (1990) TPDT method for use on the back

Moberg's (1990) technique was designed for assessing the volar surface of the hands so when transposing the technique for use on the back, the fine nuances of the technique may have been overlooked in earlier studies. This section reviews Moberg's (1990) technique sequentially (points 1 – 5) and critiques each step regarding its use when assessing low back TPDT. Adaptations to the method are recommended which were adopted during data collection.

1. Unwanted movement from the participant and researcher must be avoided
Moberg (1990)

When assessing the hand, the participant was seated with the limb relaxed, supported and stabilised by resting the hand on a table. The researcher was seated and supported her testing hand by resting the elbow upon the table.

When assessing low back TPDT, her testing hand was supported using the contralateral arm as a brace. This was necessary to reduce unwanted motion when simultaneously bringing the two points into contact with the skin.

Providing skin contact was made when the participants breath cycle changed from inspiration to expiration, or vice versa, stabilising the low back with the patient lying prone was unlikely to be problematic.

However, stabilising the researcher's hands and arms when applying the caliper tips to the back was more difficult. Prior to collecting data, a practice session revealed that only with an adjustable bench height, a wheeled stool and keeping both arms relaxed but braced against her body, could she achieve simultaneous two-point contact with the calipers. Greater measurement bias may have been introduced in the back TPDT measurements because simultaneously contacting the two points to the skin became more difficult as the tips moved further apart.

2. The tool used to measure TPDT should be almost "weightless" and supported near the tips in contact with the skin (Moberg 1990).

Paperclips with a diameter of 0.8 - 0.9mm and the factory-made Disk-Criminator™ provided reliable, valid and repeatable results when assessing TPDT on the hands (Dellon et al. 1987; Crosby and Dellon 1989; Moberg 1991; Finnell et al. 2004). However, a larger tool was required for measuring TPDT on the back because it is less sensitive than the hands and therefore a larger measurement was expected.

Vernier calipers are widely reported in assessing TPDT in regions other than the hands (Moseley 2008a; Wand et al. 2010b; Luomajoki and Moseley 2011; Stanton et al. 2013; Trapp et al. 2014a; Nishigami et al. 2015; Wälti et al. 2015; Adamczyk et al. 2017b). Vernier calipers are at least 150mm in length and as the points became wider apart, gripping them near the two points using one hand was not possible. Holding them further down the length may have fluctuated the contact pressure and introduced false readings.

When assessing the back, the researcher could not rest their forearms or wrists on a stable surface as advised by Moberg (1990). Despite careful positioning and bracing her arms/hands to reduce movement, hand-held tools lacked the ability to control the pressure applied (Bell-Krotoski and Buford 1997). This was particularly a problem when alternating between the application of one (catch trials) and two points (Bell-Krotoski et al. 1993). Manivannan et al. (2015) published a pilot study using a prototype computerised tool which they claimed tackled such issues but building cumbersome laboratory tools was not considered practical in the clinical setting. It was accepted that some measurement bias may be introduced in the measurement of low back TPDT, but with careful technique it could be minimised.

3. The two points should be brought into contact with the skin at the same time and with the application force of approximately 10g. In the fingertips, this corresponded to the very first small “blanching” region seen around the prongs Moberg (1990)

In trialling this technique, the skin tone on the back appears much paler and uneven in colour than on the finger tips and watching for the first “blanching” around the contact points was difficult and subjective. It was unknown whether applying varying force would affect the results, but firmer pressure could be expected to activate additional mechanoreceptors and provide the participant with a variety of tactile information.

Resting the entire weight of the tool on the back was considered but it was too heavy to just blanch the skin at the points of contact. Additionally, within the tool reliability study, which identified the most appropriate Vernier calipers for collecting data within the main study, different tools had different weights and so comparing data from different tools using this technique was not possible. The only alternative was to apply the tips to the skin until the first indentation could be seen.

9.3.7. Two-Point Discrimination Threshold Method - Fingertip

- a) The participants and assessor were comfortably seated with a small table between them.
- b) The assessor explained the process to the participant, taking care not to reveal the expected outcome.
- c) Practise runs were carried out to ensure participants knew what to expect and to ensure the assessor applied the prongs with sufficient pressure for participants to just sense light contact. After several trials on the palms of participant's hands using the modified Vernier calipers discussed in the tool reliability study to ensure the procedure was understood, testing began on the fingertip.
- d) The assessor stabilised the participants supinated (upturned) dominant hand and middle finger on a firm foam cushion upon the table at a position comfortable to the participant. The participants elbow and forearm rested on the table.
- e) The researcher held the participant's middle finger, laterally to the palp of the distal phalange with her thumb and middle finger, gently but firmly against the cushion with her right hand.
- f) The assessor's elbows and wrists were resting on the table throughout. The modified Vernier calipers were held by the prongs with the left hand (the researcher is left hand dominant).
- g) Participants closed their eyes and were instructed to answer "one" or "two" when they perceived either one or two tactile stimuli.
- h) Calipers were applied and removed from the fingertip palp in a uniform manner. Slowly approaching the skin, perpendicularly, from a height of 2.5cm, both tips touched the skin simultaneously for about 1.5 seconds (a count of 2) before being removed directly upwards to the start position. The assessor applied the prongs with sufficient pressure for participants to just sense light contact.
- i) Threshold was recorded as the shortest distance, in mm, between the calipers points at which the participant could correctly identify two points instead of one.
- j) The distance between the calipers tips were increased or decreased by 1mm until two points of contact were reported by the participant. TPDT results were recorded for an ascending/descending run and a descending/ascending run. Testing commenced with a 0mm gap on the calipers digital screen (2mm between the prongs) for ascending runs and 6mm on the digital screen (8mm between the prongs) for descending runs. The sequence for the first assessment was determined by a coin toss.
- k) Raw data results were recorded on paper results sheets. To correct for the tool modifications reported in chapter four, raw data were input to SPSS (version 23.0) and tool corrected means were computed and used in the analysis.

- l) To control for attentional effects on localisation accuracy and false positive responses, additional null stimuli were performed in other non-target areas of the hand. These results were not recorded.
- m) Tests with a response delay greater than 3 seconds were considered void and repeated.

9.3.8. Two-Point Discrimination Threshold Method - Low Back

- a) The assessor explained the process to the participant, taking care not to reveal the expected outcome.
- b) Participants lay prone on a manual therapy bench. To reduce low back tension, a slight knee flexion was created using a bolster cushion under their ankles.
- c) The skin of the low back was exposed and the transverse processes of the L3 and L5 vertebra were located and marked using non-permanent pen and the technique reported in chapter three.
- d) The researcher was seated on wheeled stool which could easily be moved into position. Her elbows were resting on her knees and one hand supported the other wrist during application of the calipers prongs.
- e) Bench height was fully adjustable to ensure the most stable position was obtained for the assessor prior to measurements being recorded.
- f) Participants were asked to report when they perceived two distinct points of touch.
- g) Participants were instructed to answer “one” or “two” when they perceived either one or two tactile stimuli.
- h) Practise runs were carried out to ensure participants knew what to expect and to ensure the assessor applied the modified calipers prongs with sufficient pressure for participants to just sense light contact. To ensure the procedure was understood practices were performed on the low back, away from the areas to be measured. Once the participant understood the process, testing began.
- i) Assessment was made over the transverse processes of the most painful vertebral level first, if one was reported, and secondly over the transverse processes of L3. If a ‘typical’ region of low back pain was not reported, measurements were only recorded from L3
- j) The sequence for the first assessment side (right vs. left side) was individually determined at the beginning of the session by chance (throwing a coin in the air).
- k) Vernier calipers were applied and removed from marked locations on the back, in a uniform manner. The researcher held the calipers near the tips, using both hands. Slowly approaching the skin, perpendicular to the spine, from a height of 2.5cm, both tips touched the skin simultaneously for about 1.5 seconds (a count of 2) before being removed directly upwards to the start position. The assessor applied the prongs with sufficient pressure for participants to just sense light contact.
- l) Threshold was recorded as the shortest distance, in mm, between the calipers points at which the participant could correctly identify two points instead of one.
- m) The distance between the calipers tips were increased or decreased by 5mm until two points of contact were reported by the participant. TPDT results were recorded for an

ascending/descending run and a descending/ascending run. Testing commenced with a 30mm gap on the calipers digital screen (32mm between the prongs) for ascending runs and 100mm on the digital screen (102mm between the prongs) for descending runs. If an ascending run resulted in a measurement of greater than 100mm, this result plus 30mm became the descending runs starting measurement. The sequence for the first assessment was determined by a coin toss.

- n) Raw data results were recorded on paper results sheets. To correct for the tool modifications reported in chapter four, raw data were input to SPSS (version 23.0) and tool corrected means were computed and used in the analysis.
- o) To control for attentional effects on localisation accuracy and false positive responses, single-point contacts were randomly included. These results were not recorded.
- p) Tests with a response delay greater than 3 seconds were considered void and repeated.

9.3.9. Left/Right Discrimination Method as a measure of Body Schema

1. All participants were assessed independently of each other.
2. Participants sat comfortably with their forearms resting on a table, palms down and index finger (whichever they preferred) hovering over the touch screen of an iPad.
3. The task was explained to them as follows;
 - a. You will be shown 40 images of the back, 5 seconds apart
 - b. You should look at the picture and ask yourself 'Is the person turning/twisting or leaning towards their left or their right?'
 - c. Click the button corresponding to your answer (left or right) on the screen
 - d. As soon as you click, or after 5 seconds if you haven't chosen, the image will change to a new image. You should repeat steps b and c.
 - e. After two practices (each of 40 images) and a 2-minute break between each, there will be two more sets of 40 images each and these results will be recorded.
 - f. You should aim to respond as accurately and as quickly as you can.
4. Launch set one of 40 images for the 1st practice
5. Answer any questions during a 2-minute break – Emphasise importance of speed and accuracy
6. Launch set two of 40 images for the 2nd practice
7. Answer any questions during a 2-minute break – Emphasise importance of speed and accuracy
8. Launch set one of 40 images for the 1st TEST
9. Allow a 2-minute break while researcher records the accuracy and time results onto the data collection sheet - Emphasise importance of speed and accuracy
10. Launch set two of 40 images for the 2nd TEST
11. Researcher records the accuracy and time results onto the data collection sheet.

9.3.10. Luomajoki's Battery of Tests performance

The images of **Luomajoki's Battery of Tests performance** are presented in the methods for the reliability study investigating intra-rater reliability for the tool in Appendix 9.4.4

9.3.11. The 30 second Chair Stand Test Method

This method was adapted from that reported by Jones et al. (1999)

A heavy, rubber footed manual therapy bench was placed against a wall to prevent it from moving.

Its height was altered to allow each participant to sit with their hips and knees bent to 90 degrees and rest their feet flat on the floor.

- a) Participants were seated in the middle of the bench (on the shortest side) with their back straight, their feet approximately shoulder width apart and placed on the floor slightly behind their knees.
- b) One foot was placed slightly in front of the other to help maintain balance.
- c) Arms were crossed at the wrists and held against the chest.
- d) The researcher demonstrated the task both slowly and quickly.
- e) The participant performed two practice sit-to-stand-to-sit cycles before beginning the test.
- f) At the signal "go," the participant rose to a full stand (body erect and straight) and then returned to the initial seated position.
- g) Participants were encouraged to complete as many full stands as possible within 30 seconds but must fully sit between each stand.
- h) While monitoring the participant's performance to ensure proper form, the researcher silently counted the completion of each correct stand.
- i) The score was the total number of stands within 30 seconds (more than halfway up at the end of 30 seconds counted as a full stand).
- j) Incorrectly executed stands were not counted as were those where participants used their arms to complete the test

9.3.12. Ethical approval letters

Approval letters from Bournemouth University Research Ethics Committee (Reference ID: 9677) and the AECC Research Ethics Sub-Committee (Approval Number: E71/11/15)

**Research Ethics Checklist**

Reference Id	9677
Status	Approved
Date Approved	25/11/2015

Researcher Details

Name	Sara Glithro
School	Health and Social Care
Status	Postgraduate Research (PhD, MPhil, DProf, DEng)
Course	Postgraduate Research
Have you received external funding to support this research project?	No
Please list any persons or institutions that you will be conducting joint research with, both internal to BU as well as external collaborators.	Anglo European College of Chiropractic (AECC)

Project Details

Title	Neuroplasticity and Chronic Low Back Pain: An investigation into altered tactile discrimination, body schema and motor function in adults with chronic low back pain?
Proposed Start Date	01/12/2015
Proposed End Date	30/11/2018

Summary (including detail on background methodology, sample, outcomes, etc.)
See attached documents

AECC

13 – 15 Parkwood Road
Bournemouth
Dorset, BH5 2DF
UK

T +44 (0)1202 436200
E info@aecc.ac.uk
admissions@aecc.ac.uk
W aecc.ac.uk

Sara Glithro
2 Woodbury
East Overcliff Drive
Bournemouth
BH1 3AD

13 January 2016

Dear Sara,

Re: Neuroplasticity and chronic low back pain: An investigation into altered tactile discrimination, body schema and voluntary lumbopelvic motor control in adults with chronic low back pain and a matched pain-free group

Thank you for submitting an application for ethics approval for conducting the above study which has been approved by the Chair.

May I take this opportunity to wish you every success in the study.

Yours sincerely



Professor J E Bolton, PhD, MA Ed
Chair, AECC Research Ethics Sub-Committee

AECC Ethics Approval Number: E71/11/15



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9.3.13. Participant recruitment poster

Are You:

Back pain-free or suffering from long term low back pain?

Between 18 and 65 years of age?

Able to volunteer and help us learn more about back pain?

Back pain study

I am a chiropractor and a PhD student at Bournemouth University and the Anglo-European College of Chiropractic. The study investigates how chronic low back pain affects the sense of touch, position, movement and the ability to tell left from right. It is hoped that the findings will help future sufferers of this debilitating chronic pain condition.

If you can help please contact **Sara Glithro** for more information
 Email: sglithro@bournemouth.ac.uk
 Phone: **07786 625187**

Tea, coffee and biscuits provided

ANGLO-EUROPEAN COLLEGE OF CHIROPRACTIC

Bournemouth University

Back Pain Study
sglithro@bournemouth.ac.uk
 07786 625187

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 07786 625187

9.3.14. Guidelines for triaging low back pain

Guidelines for diagnostically triaging low back pain are based upon the biopsychosocial model which considers the physical nature of back pain (biological), the psychological impact introduced by the patients beliefs and fears (psychological), and the influence of external factors such as work, family and friends on the ability of an individual and their CLBP (Waddell 2004). Guidelines vary internationally but most recommendations agree that people with low back pain should be grouped into one of three categories with the aim of directing treatment (Waddell 2004; Airaksinen et al. 2006; Van Tulder et al. 2006; Rubinstein and van Tulder 2008; Koes et al. 2010; Lee et al. 2013);

2. Serious pathology (suspected or confirmed), including inflammatory pathologies - These are known as diagnostic 'Red Flags' and should be referred for immediate primary care (Waddell 2004)
3. Simple, ordinary, mechanical or non-specific low back pain
4. Nerve root pain or pain from neuropathic origin

This study included only those meeting the criteria for category two - Simple, ordinary, mechanical or non-specific low back pain – NB: these names are interchangeable within the literature so for this study, the term 'Low Back Pain' has been used to describe this group. Chronic low back pain describes those meeting the criteria for category two and the study inclusion criteria for the pain group.

9.3.15. Insurance certificates

Hasilwood House
60 Bishopsgate
London EC2N 4AW
Tel: 020 7847 8670
Fax: 020 7847 8689



TO WHOM IT MAY CONCERN

20th July 2015

Dear Sir/Madam

**BOURNEMOUTH UNIVERSITY
AND ALL ITS SUBSIDIARY COMPANIES**

We confirm that the above Institution is a Member of U.M. Association Limited, and that the following covers are currently in place:-

1. EMPLOYERS' LIABILITY

Certificate No.	Y016458QBE0115A//044
Period of Cover	1 August 2015 to 31 July 2016
Limit of Indemnity	£50,000,000 any one event unlimited in the aggregate.
Includes	Indemnity to Principals
Cover provided by	QBE Insurance (Europe) Limited and Excess Insurers.

2. PUBLIC AND PRODUCTS LIABILITY

Certificate of Entry No.	UM044/99
Period of Cover	1 August 2015 to 31 July 2016
Includes	Indemnity to Principals
Limit Of Indemnity	£50,000,000 any one event and in the aggregate in respect of Products Liability and unlimited in the aggregate in respect of Public Liability.
Cover provided by	U.M. Association Limited and Excess Cover Providers led by QBE Insurance (Europe) Limited

If you have any queries in respect of the above details, please do not hesitate to contact us.

Yours faithfully

Susan Wilkinson
For U.M. Association Limited



U.M. Association Limited
Registered Office: Hasilwood House, 60 Bishopsgate, London, EC2N 4AW
Registered in England and Wales No. 2731799



CERTIFICATE OF EMPLOYERS' LIABILITY INSURANCE (a)

(Where required by regulation 5 of the Employers' Liability (Compulsory Insurance) Regulations 1998 (the Regulations), one or more copies of this certificate must be displayed at each place of business at which the policy holder employs persons covered by the policy)

1. Name of policy holder Policy No Y016458QBE0115A / 044
Bournemouth University

2. Date of commencement of insurance policy 1st August 2015

3. Date of expiry of insurance policy 31st July 2016

We hereby certify that subject to paragraph 2:

1. the policy to which this certificate relates satisfies the requirements of the relevant law applicable in Great Britain, Northern Ireland, Isle of Man, Island of Jersey, Island of Guernsey, Island of Alderney; or any offshore installations in territorial waters around Great Britain and its Continental Shelf **(b)**; and;
2. (a) the minimum amount of cover provided by this policy is no less than £5 million **(c)**; or
~~(b) the cover provided under this policy relates to claims in excess of [£] but not exceeding [£]~~
3. the policy covers the holding company and all its subsidiaries

Signed on behalf of QBE Insurance (Europe) Limited (Authorised Insurer)

Notes

- (a) *Where the employer is a company to which regulation 3(2) of the Regulations applies, the certificate shall state in a prominent place, either that the policy covers the holding company and all its subsidiaries, or that the policy covers the holding company and all its subsidiaries except any specifically excluded by name, or that the policy covers the holding company and only the named subsidiaries.*
- (b) *Specify applicable law as provided for in regulation 4(6) of the Regulations.*
- (c) *See regulation 3(1) of the Regulations and delete whichever of paragraphs 2(a) or 2(b) does not apply. Where 2(b) is applicable, specify the amount of cover provided by the relevant policy.*

Important

Display will be satisfied if the certificate is made available in electronic form and each relevant employee to whom it relates has reasonable access to it in that form.

QBE Insurance (Europe) Limited, Plantation Place, 30 Fenchurch Street, London, EC3M 3BD - Registered in England No. 1761561
Authorised by the Prudential Regulation Authority and regulated by the Financial Conduct Authority and the Prudential Regulation Authority -
Registration Number 202842

9.3.16. Piloting the main method

The main method was tested with two volunteers. One reported CLBP and one did not. While one volunteer took part in the study, the other made notes on the data collection sheets and timed each stage. Following data-collection, a review of the process took place and necessary changes were made. The results of the timings can be seen in Table 9-2

Volunteers medical histories were known so exclusion screening was not completed during this session.

Table 9-2 - Time taken to complete stages of data collection in pilot

	Cumulative Time (minutes)	Minutes per stage
Introduction, participant information and consent	12	12
Questionnaire completion	35	21
Researcher checking questionnaires were complete	40	<5
Screening	-	-
General data collection – height, weight	45	5
Tactile threshold	50	5
Two-point discrimination threshold	65	15
Left/Right discrimination tasks	85	16
Motor function tasks	100	15

The process took longer than expected but the researcher felt that time could be saved with practice and the completion of questionnaires by participants before their appointment. If they preferred to complete them with the researcher, that could be achieved within 90 minutes.

Volunteers found the tasks interesting to complete but ambiguous wording of some of the previously validated questionnaires was problematic. While the questions themselves could not be changed without re-validation, a sentence introducing each questionnaire would be added to explain who should complete it; those with low back pain or everyone.

One very important issue emerged; the initial questionnaire did not discriminate between those with or without CLBP. Initially phrased according to the proposed International Classification of Diseases-11 revisions (Treede et al. 2015), which are expected to be finalised in 2018 (World Health Organisation 2015). The proposals classify CLBP as 'persistent or recurrent pain occurring in the low back on more than 50% of the days within the previous 6 months'. The participant with pain reported regular/weekly CLBP. However, her completed questionnaire indicated she had only experienced back pain on 16 days within the previous 6 months. During a discussion after the task, the cause of the mismatch was her concept of what was meant by pain. She found the concept difficult to verbalise and did not consider her 'normal' twinges, aches and discomfort to be pain. It highlighted that without further questioning on pain, answers from self-completed questionnaires could place participants in the wrong groups and lead to distortion of the findings for the entire study.

The pilot helped to revise the questionnaire structure, determine that participants should be given more time to read and understand the participant information sheet and consent form and improve the pain questioning during the clinical exam to confirm or refute participant's responses to the questionnaire pain questions. The questionnaire wording was also amended to ask if participants experienced 'pain or discomfort'.

In the main study, measures were taken to ensure participants received the documents at least 24 hours prior to their data collection appointment.

To ensure that participants reporting 'no pain' really had no pain (within the realms of the study definition) and that different participants were referring to the same experienced sensations, a discussion was included within the medical screen to confirm the information provided on the questionnaire.

9.4. Appendices for Chapter Four

9.4.1. Participant Information Sheet

Title of the project

Movement control tests of the lumbar spine – a reliability study

Research study information

You are being invited to take part in a research study. Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and do ask us if there is anything that is not clear before deciding whether you wish to take part.

Who are the researchers of this project?

The research supervisors responsible for this study Dr Carol Clark, Dr Neil Osborne, Dr Dave Newell and Dr Sharon Docherty.

You will have contact with Sara Glithro who is carrying out this study as part of her doctoral research degree (PhD). This research is being undertaken at Bournemouth University and is funded by Bournemouth University, the Anglo-European College of Chiropractic and the McTimoney College of Chiropractic.

Although no treatment is being offered as part of this research study, Sara is a practising chiropractor and is registered with the General Chiropractic Council.

What is the purpose of the study?

Low back pain is a common condition affecting most adults at some point in their lives. Between 6-11% of UK adults will continue to experience recurring episodes of low back pain. When persisting or recurring for longer than three months it is classified as chronic low back pain (CLBP). People with CLBP typically report pain and difficulty in moving or performing simple daily tasks. Many of those with CLBP are likely to be absent from work and those that seek care within the NHS utilise more than twice the UK healthcare budget as their pain-free counterparts. The treatment options normally available do not always help resolve the condition.

Your central nervous system, which includes your brain, spinal cord and nerves, is not only responsible for how your body functions, but also how it interprets and responds to the world around you. In people with other chronic painful conditions, parts of their brain change their structure and function and this is called neuroplasticity. These neuroplastic changes manifest as altered sensory functions such as touch and the ability to differentiate between left and right. It may also be that these changes are involved with altered motor (movement) function commonly seen in people with chronic pain.

This study aims to explore the altered movement aspect of these phenomena by assessing the low back movements of videoed consenting volunteer participants with and without CLBP.

By including the views of a group of UK registered healthcare professionals who are likely to assess people with and without chronic low back pain, we hope to establish;

- the reliability of a battery of established tests in identifying impaired movement in those with and without chronic low back pain
- the reliability of our own assessments when observing the low back movements of participants within our wider study

Why have I been chosen?

You have been chosen as you meet the criteria for this project as being either;

- A UK practising Chiropractor, currently registered with the General Chiropractic Council (GCC).
- A UK practising Osteopath, currently registered with the General Osteopathic Council (GOC).
- A UK practising Physiotherapist, currently registered with the Health and Care Professions Council (HCPC).

Do I have to take part?

Absolutely not. We would be delighted if you would join our study but it is your decision. If you do decide to take part, you will need to sign and return the consent form prior to receiving the data for the next part of the study taking place.

Can I withdraw from the study?

Yes, you can, providing you notify us *prior* to your data being pooled with other participants and anonymised. Once anonymised, removing your data from the pooled

group data is not possible. However, identification of you from the pooled group data is not possible. You do not have to give a reason for withdrawing from the study.

What do I have to do?

Participation in this study requires you to view and rate the active movement observed in videos of ten participants performing six short lumbopelvic motor control tests (60 tests in all). One video per participant will be provided and each video includes all six tests. The ten videos last between 1 minute 25 seconds and 1 minute 55 seconds each. It is expected that participating in the entire study will take up to 40 minutes.

1. First, you will be asked to print the enclosed consent form (we can post you a paper copy on request) and complete all the grey sections. We need you to initial each statement and to provide your name, mobile phone number and email address, then sign (in ink) and email a scanned copy or photo back to sqlithro@bournemouth.ac.uk Your data will not be shared or used for any purpose other than this study.
2. Once we receive your consent form, we will send an email to the address you provided, which includes a link to the Bournemouth University file transfer service (BU Transfer). By clicking this link, you can securely upload the study videos and documentation to your own computer. Depending upon your data connection, downloading the ten videos may take 10 minutes or so. To protect our participant's personal data, the videos are password protected within a .zip file. To enhance security, the password to access the videos will be texted to the mobile phone number you provide on the consent form.
3. Once you have access to the download files you will first complete a short questionnaire about you and your experience of performing musculoskeletal assessments in adults. This should take less than five minutes to complete.
4. Next, you will be asked to read the instruction sheet which describes six movement control tests of the low back. Written instructions are accompanied by photographs to show correct ('achieved') and incorrect ('not-achieved') performances. The aim is to judge participant's videoed performance of the tests as either 'achieved' or 'not-achieved' based on the instructions.

5. You will also be required to record how many times you viewed each video before making your final decision.
6. Finally, using only the video information and your expertise, we would like you to judge whether you think each participant presents with or without chronic low back pain.

Do I need to download any software?

Some video player software that we tested played videos in a disjointed or jumpy format and it was not possible to see the fine detail of the movements being assessed. All videos should be smooth. If the media player you normally use causes our videos to play in a jumpy, disjointed way, we strongly recommend opening the video files using VLC Media Player which is available for free download at <http://www.videolan.org/vlc/index.en-GB.html> We will include a step-by-step guide to downloading this software in the study download pack. If you have any problems with downloading VLC Media Player, please get in touch with us.

Videoed participant consent

All videoed participants have given their consent for their information to be shared with a panel of registered healthcare professionals as part of this study. We ask that you keep their data confidential and delete all video files on completion of the assessment.

What are the possible benefits of taking part?

It is hoped that this work will help us to learn more about one of the most common but least understood conditions which affects millions of people each year. We have assessed movement alongside numerous sensory and clinical measures and hope that understanding new aspects of this debilitating condition will enable new approaches to treatments for future pain sufferers.

Will my taking part in this study be kept confidential?

All the information that we collected about you during the research will be kept strictly confidential. All data relating to this study will be kept on a password protected database or in a locked filing cabinet. All data will be kept in accordance with the Data Protection Act 1988. Bournemouth University requires data to be retained for a minimum of five years, after which it can be deleted.

What will happen to the results of the research study?

The results will be anonymised and written up as part of the researcher's PhD thesis which will be put forward for a doctoral (PhD) examination by viva. This is expected to take place by the end of 2018. The anonymised results of this study will be shared with others at national and international conferences and published in several research journals. You will not be identified in any presentation, lecture, report or publication.

Who has reviewed the study?

This study has been reviewed and approved by the Bournemouth University Research Ethics Committee and the Anglo-European College of Chiropractic Research Ethics Sub-Committee.

Contact for further information?

Sara Glithro – sglithro@bournemouth.ac.uk Mobile: 07786 625187
Dr Carol Clark – cclark@bournemouth.ac.uk Office Number: 01202 963022

Both can be contacted in writing at; Bournemouth University, R603 Royal London House, Christchurch Road, Bournemouth, BH1 3LT

In the unlikely event you wish to complain about any part of this study, please contact: Professor Vanora Hundley, Deputy Dean of Research, Bournemouth University, Royal London House, Christchurch Road, Bournemouth, BH1 3LT

Please keep a copy of this information sheet for your future reference

Thank you for taking part in the Study

9.4.2. Participant Consent Form

Project Title: Movement control tests of the lumbar spine – a reliability study

Name, position and contact details of researcher:

Sara Glithro, Post Graduate Researcher, Bournemouth University -
sglithro@bournemouth.ac.uk or phone 07786 625187

Name, position and contact details of supervisor (if the researcher is a student):

Dr Carol Clark, Head of Department Human Sciences and Public Health, Bournemouth University cclark@bournemouth.ac.uk

	Please initial each section
I have read and understood the participant information sheet for the above research project	
I confirm that I have had the opportunity to ask questions and have the phone number of Sara Glithro should I have any questions during the study.	
I understand that my participation is voluntary	
I understand that I am free to withdraw <i>up to the point where the data are processed and become anonymous, so my identity cannot be determined.</i>	
During the tasks I am free to withdraw without giving reason and without there being any negative consequences.	
Should I not wish to answer any particular question(s) or complete a test, I am free to decline.	
I give permission for members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the outputs and publications that result from the research.	

Please turn over →

9.4.3. Study instructions

Movement control tests of the lumbar spine – a reliability study

How to complete the study

Read the participant information sheet and consent form. If you are happy to take part in this study, please print the form, initial each section on both sides, complete with your name, mobile phone number, email address and signature. Then return a scanned copy or photograph/s of the completed form to Sara Glithro at sglithro@bournemouth.ac.uk

1. Once we receive your consent form, we will send an email to the address you provided which includes a link to the secure Bournemouth University file transfer service (BU Transfer). BU Transfer automatically scans files for viruses and by clicking this link, you can safely download the study videos and Microsoft Word/PDF documents to your own computer. Depending upon your data connection, uploading the ten videos may take 10 minutes or so. To protect our participant's personal data, the videos are password protected within a .zip file. To enhance security, the password to access the videos will be texted to you on the mobile phone number you provided on the consent form.
2. The documents to be downloaded includes;
 - a. This instruction sheet
 - b. instructions for downloading VLC media player
 - c. a short questionnaire
 - d. ten videos of participants performing low back movement tasks (1.1GB data)
 - e. an answer sheet on which to score your assessments.
3. Read the instruction sheet (this document) in full. Please contact Sara if you have any questions via sglithro@bournemouth.ac.uk or calling her on 07786 625187.
4. Complete the questionnaire about you and your experience in performing musculoskeletal assessments with patients reporting low back pain. This should take less than five minutes to complete.
5. You are then asked to refer to the written instructions and accompanying photographs, on page 3 and 4 of this document, which show example performances of the six low back motor control tests judged to be 'Achieved' and 'Not-Achieved'. The aim is for you to observe ten videoed participants performing the six tests and using the instructions judge their performance similarly.

6. If the media player you normally use causes these videos to play in a jumpy, disjointed way, we strongly recommend using VLC Media Player which is available free of charge at <http://www.videolan.org/vlc/index.en-GB.html> If you need to download it, please see the step-by-step download guide included in the information pack. If you have any problems with downloading VLC Media Player, please get in touch with us.
7. Videos are labelled Participant A to J. Begin with Participant A and work through in alphabetical order to Participant J.
8. Watch the first test for participant A, then pause the video to record your rating as either 'Achieved' or 'not-achieved' based upon the written and photographic instructions for each test.
9. Please also record how many times you viewed the first video before making your final decision.
10. Press play on the media player to proceed to Participant A's second test, recording your ratings as above. Continue until all six tests for participant A are rated.
11. Finally, in the last column on the results sheet and using only the video information and your expertise, record whether you think it is likely that the participant presents with chronic low back pain. We understand that this will be difficult given you have no other information, however we want to identify whether classification based on these tests alone is possible.
12. Move on to participant B's videos and continue until all ten participants have been rated.
13. Once the results sheet is completed, please email it back to sglithro@bournemouth.ac.uk If you have written on a paper copy, please email a scanned copy or legible photo instead.





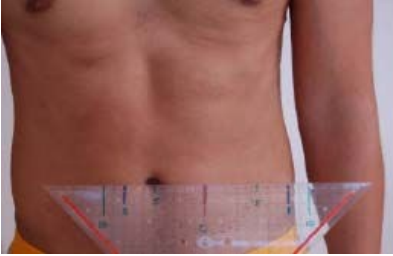



How to complete the results sheet

We recommend completing the results sheet on your computer as a word document so that you can email it back to us. If you prefer to print it out and write on it whilst viewing the videos, you can email us a scanned copy or photographs of the completed form back to us.







We offer an example of how to complete the Results Sheet below and recommend deleting the unwanted 'Achieved' or 'Not-achieved', leaving your chosen rating on the form. We have purposefully left the results sheet as a word document, rather than a PDF, so you can type in the boxes but please do not amend any other information.

Test 1 Waiters Bow		Test 2 Pelvic Tilt		Test 3 One legged stance		Test 4 Sitting knee extension		Test 5 Back & forwards quadruped		Test 6 Prone knee flexion		Reports chronic low back pain?
Achieved		Not- Achieved		Achieved		Achieved		Not- Achieved		Achieved		Yes
Views	1	Views	2	Views	2	Views	1	Views	2	Views	1	

9.4.4. Example performances of Luomajoki's Battery of tests

Test	Achieved	Not Achieved
<p>Test 1 - Waiters bow Flexion of the hips in upright standing without movement (flexion) of the low back</p>	<p>Forward bending of the hips without movement of the low back (50-70° Flexion hips).</p> 	<p>Angle hip Flexion without low back movement less than 50° or Flexion occurring in the low back.</p> 
<p>Test 2 - Pelvic tilt Dorsal tilt of pelvis actively in upright standing.</p>	<p>Actively in upright standing; keeping thoracic spine in neutral, lumbar spine moves towards Flexion.</p> 	<p>Pelvis does not tilt or low back moves towards Extension or compensatory Flexion in the thoracic spine.</p> 
<p>Test 3 - One leg stance From normal standing to one leg stance: measurement of lateral movement of the belly button. (Position: feet one third of trochanter distance apart)</p>	<p>The distance of the transfer is symmetrical right and left. Not more than 2 cm difference between sides.</p> 	<p>Lateral transfer of belly button more than 10 cm. Difference between sides more than 2 cm.</p> 
<p>Test 4 - Sitting knee extension Upright sitting with neutral lumbar lordosis; extension of the knee without movement (flexion) of low back</p>	<p>Upright sitting with neutral lumbar lordosis; extension of the knee without movement of low back (30-50° Extension of the knee is normal).</p> 	<p>Low back is moving in flexion. Patient is not aware of the movement of the back.</p> 

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Test	Achieved	Not Achieved
<p>Test 5 - Quadruped position</p> <p>Transfer of the pelvis backwards and forwards (“rocking”) keeping low back in neutral. Starting position 90° hip flexion.</p> <p>NB: Movement in both directions must be achieved for the test to be scored as ‘Achieved’. If one part is achieved and one not, the test must be rated as ‘not-achieved’.</p>	<p>120° of hip flexion without movement of the low back by transferring pelvis backwards.</p>  <p>Rocking forwards to 60° hip flexion without movement of the low back.</p> 	<p>Hip flexion causes flexion in the lumbar spine (typically the patient not aware of this).</p>  <p>Hip movement leads to extension of the low back</p> 
<p>Test 6 - Prone lying active knee Flexion</p>	<p>Active knee flexion at least 90° without movement of the low back and pelvis.</p> 	<p>Following knee flexion, the low back does not stay neutral but moves in extension or rotation</p> 

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9.4.5. Reliability study Questionnaire

Please complete before watching the videos

Participant N ^o (researcher to complete)					
Gender		Male		Female	
Are you a registered chiropractor, osteopath or physiotherapist?		Yes		No	
Which regulatory body are you registered with?		GCC	GOP	HPCP	Not registered
How many years have you been registered?					
What is your highest qualification?					
Have you undertaken any postgraduate training in musculoskeletal (MSK) assessment of human adults?		Yes		No	
	If yes, what was the course title?				
	How long was the course?				
Do you perform musculoskeletal assessments of adults with low back pain as part of your registered profession?		Yes		No	
Can you estimate the percentage of your work as a registered healthcare professional that includes an MSK assessment of the low back in adults?					

9.4.6. Reliability study Results sheet

Using the instruction sheet guidance notes and photos, rate performances by deleting the unwanted text and write the number of times you viewed each video in the boxes

Video	Test 1 Waiters Bow	Test 2 Pelvic Tilt	Test 3 One legged stance	Test 4 Sitting knee extension	Test 5 Back & forwards quadraped	Test 6 Prone knee flexion	Reports chronic low back pain?
A	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Yes No
	Views	Views	Views	Views	Views	Views	
B	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Yes No
	Views	Views	Views	Views	Views	Views	
C	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Yes No
	Views	Views	Views	Views	Views	Views	
D	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Yes No
	Views	Views	Views	Views	Views	Views	
E	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Yes No
	Views	Views	Views	Views	Views	Views	
F	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Yes No
	Views	Views	Views	Views	Views	Views	
G	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Yes No
	Views	Views	Views	Views	Views	Views	
H	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Yes No
	Views	Views	Views	Views	Views	Views	
I	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Yes No
	Views	Views	Views	Views	Views	Views	
J	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Achieved Not- Achieved	Yes No
	Views	Views	Views	Views	Views	Views	

9.5. Appendices for Chapter Five

9.5.1. Summary of results following Bonferroni calculations

This section reports how the significant findings ($p \leq 0.05$) from the main study altered when the Bonferroni calculation was applied ($p \leq 0.0029$).

The justification for maintaining significance at $p \leq 0.05$ within the main study is reported in the methodology (Chapter Three, section 3.9.5.5). This appendix presents a summary of the Bonferroni corrected results for completeness.

Table 9-3 - Table to show the impact of the Bonferroni Correction on the significant differences between the pain and control group results

	Pain Group	Control Group	P value	Significance	
				$p \leq 0.05$	$p \leq 0.0029$
Any work absence longer than three days due to LBP, n (%)	16 (51.6)	3 (9.7)	0.03 [§]	Significant	Not Significant
Current LBP intensity, NRS (0-10), mean (SD)	1.9 (2.0)	0.0 (0.0)	0.002 ^ω	Significant	Significant
L3 TPDT, mm, median (IQR)	67.7 (58.4, 81.5)	59.8 (52.2, 68.2)	0.031 ^ω	Significant	Not Significant
L5 TPDT, mm, median (IQR)	77.8 (68.3, 93.0)	64.9 (59.3, 73.9)	0.007 ^ω	Significant	Significant
Back perception (FreBAQ), median (IQR)	8.0 (4.0, 11.0)	2.0 (1.0, 4.0)	<.001 ^ω	Significant	Significant
Luomajoki's Battery of Tests, median (IQR), (maximum score = 6)	3 (1, 4)	1 (0, 2)	≤0.001 ^ω	Significant	Significant
30-second Chair Stand Test, median (IQR)	15 (13, 19)	18 (13, 23)	0.04 ^ω	Significant	Not Significant
n = 31 participants per group for all measurements, except for L5 TPDT in the control group where n = 26, LBP: low back pain, %: percentage, NRS: Numerical Rating Scale, mm: millimetres, IQR: Interquartile range, L3: 3 rd Lumbar vertebra, L5: 5 th Lumbar vertebra, [§] Chi-Squared test for nominal data, ^ω Mann-Whitney U test for non-parametric distribution					

Table 9-4 - Table to show the impact of the Bonferroni Correction on the significant correlations between variables in the pain group

	Spearman's Rank Correlation Coefficient (r)	Significance	
		$p \leq 0.05$	$p \leq 0.0029$
FreBAQ and Luomajoki's Battery of Tests scores	$r(31) = 0.362, p = 0.045$	Significant	Not Significant
L3 TPDT (mm) and BMI (kg/m²)	$r(31) = 0.457, p = 0.010$	Significant	Not Significant
L5 TPDT (mm) and Height (cm)	$r(31) = -0.623, p \leq 0.001$	Significant	Significant
L5 TPDT (mm) and sex	$r(31) = -0.609, p \leq 0.001$	Significant	Significant
L5 TPDT (mm) and level of Education	$r(31) = -0.428, p = 0.016$	Significant	Not Significant
Body Schema (Time taken to select the correct answer when identifying left and right sides of the torso/back) and LBP duration (years)	$r(31) = -0.370, p = 0.041$	Significant	Not Significant

n = 31 per group, FreBAQ: Fremantle Back Awareness Questionnaire, TPDT: Two-point Discrimination Threshold, L3: 3rd Lumbar vertebra, L5: 5th Lumbar vertebra, mm: millimetres, BMI: Body mass index, kg: kilograms, LBP: Low Back Pain.

9.5.2. Data collection diary

Notable comments made by participants during two-point discrimination threshold testing on the low back

- “It feels much sharper there”
 - Reported by 15 people during assessment of their typical painful vertebral level. Those with unilateral pain only felt the sharpness on the side of their low back pain. Participants with bilateral pain reported sharpness on either one or both sides of the spine at their typical painful vertebral level.
 - Eight of the 15 people also reported increased sharpness during assessment of the L3 vertebra. All eight reported sharpness on the side of the spine where they rated their pain as more intense.

- “the outside [lateral] point feels like a whisper compared to the inside [medial] one”
 - Six participants used the term ‘whisper’.

- “It feels like something is lying across my back all the time now”
 - 11 people reported altered sensation across their backs by the time four readings had been taken at the point of assessment. If this was the case, a few minutes’ break was allowed before proceeding, at which point the altered sensation had passed.

- “but they feel so close together”
 - Once data was collected, participants were shown the distances between the two points and most participants were surprised to see how far apart the points were.

9.6. Appendices for Chapter Seven

9.6.1. Publications

Glithro S., Clark C., Osborne N., Newell D., and Docherty S. (2017). Tactile acuity, body schema and motor control and clinical outcome measures – A comparison study of adults with chronic low back pain and matched controls. Proceedings of The British Pain Society 50th Annual Scientific Meeting, 3-5th May 2017, Birmingham, UK. British Journal of Pain. 11:(2): Supplement 1. p23-24.

Glithro S. (2017). Chronic low back pain: The source of pain or a symptom? Oral presentation at Bournemouth University 9th Post-Graduate Researchers Conference, 8th March 2017, Bournemouth, UK.

Glithro S., Clark C., Osborne N., Newell D., and Docherty S. (2017). Tactile acuity, body schema and motor control impairment in adults with chronic low back pain – A systematic review and comparison of chronic low back pain and pain free subjects. Royal College of Chiropractors Winter conference, 1st February 2017, London.

Glithro S., Clark C., Osborne N., Newell D., and Docherty S. (2016). Tactile acuity, body schema and motor control impairment in adults with chronic low back pain – A systematic review and comparison of chronic low back pain and pain free subjects. International Association for the Study of Pain 16th World Congress on Pain. 26-30th September 2016, Yokohama, Japan.

Glithro S., Clark C., Osborne N., Newell D., and Docherty S. (2016). Tactile acuity, laterality discrimination and motor control impairment in adults with chronic low back pain - A review. Proceedings of the British Pain Society Annual Scientific Meeting, Harrogate, UK, 10-12th May 2016. British Journal of Pain. 10:(2): Supplement 1. p92-102.