Posteroanterior movements of the cervical spine

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Abstract

Posteroanterior (PA) movements are commonly used to assess and treat musculoskeletal neck pain but little is known about their relationship to symptoms or treatment effectiveness.

The general purpose of this research program was to determine relationships between the manual therapy techniques known as PA movements of the cervical spine and symptoms in patients with neck pain. The specific aims of the studies were to:

- Establish a reliable immediate indicator of symptoms in patients with non-acute neck pain that is a good predictor of longer-term change in symptoms.
- Develop and establish the repeatability of a methodology for measuring PA movements of the cervical spine.
- Determine how changes in PA movements are related to:
  - local tenderness as an indicator of potential symptoms in an asymptomatic population and
  - change in symptoms in a population with non-acute neck pain.

In the first two studies change in impairments predicted change in the same impairment both between treatment sessions and by the end of treatment. Change in impairments did not however predict changes in other impairments or activity limitations. Of the impairments considered, change in active range of motion (AROM) was found to be the best predictor of longer-term change in symptoms.

In the third study, the repeatability of a custom made Posteroanterior Movement Assessment Device (PMAD) was assessed using coefficients of multiple determination (CMDs) and adjusted CMDs for inter-rater intra-day (Inter-rater), intra-rater inter-day (Inter-day) and intra-rater intra-day (Intra-rater) repeated measurements. The PMAD was found to produce repeatable measurements of PA movements of the cervical spine and maximum repeatability was achieved if the same operator reassessed the patient on the same day.

In the fourth study PA movements were measured on each side of the cervical spines of ten asymptomatic subjects. Locations with a difference in tenderness to pressure between sides were used for analysis. The tender side demonstrated greater variation of both displacement and stiffness. The tender sides demonstrated greater within-
subject stiffness for all force levels above 12 N. All individual stiffness-force curves of the tender sides were significantly different from the control side. Expected differences in single measures of either displacement or stiffness were not detected. The results suggest that the pattern of stiffness is a more effective method of characterising PA mobility than single measures used in previous studies.

In the fifth study one symptomatic and one asymptomatic location were selected in 20 patients with neck pain of more than two weeks duration. PA stiffness at each location and AROM were measured before and after each of four manual therapy interventions consisting of posteroanterior movements to each location, a general treatment and a control intervention. Following treatment to the symptomatic location, PA stiffness at forces above 8 N demonstrated significant correlations with total AROM. Following manual therapy, increased AROM is related to decreased posteroanterior stiffness in patients with neck pain, but only for the treated location and only when that location had been identified previously as symptomatic.

Overall findings

The results of the studies indicated that change in active range of movement is a good predictor of longer-term change in symptoms. The PMAD provides a repeatable method for measuring PA movements of the cervical spine. Stiffness of PA movements is related to local tenderness in an asymptomatic population. In a symptomatic population, stiffness of PA movements is related to immediate changes in AROM. Immediate changes in AROM are related to between session and end of treatment changes in AROM. Differences in PA stiffness can therefore be considered to be related to symptoms as indicated by local tenderness and changes in PA stiffness can be considered to be related to end of treatment outcomes.
Statement of originality

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

Signed _______________________ Date____________________________

Neil Tuttle
Publications and presentations

The experimental chapters contained in this thesis have been either published or submitted for publication and are listed below:

Chapter 3

Chapter 4

Chapter 5

Chapter 6

Chapter 7
The following conference presentations arose from the studies contained within this thesis:


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<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>AROM</td>
<td>Active range of motion</td>
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<tr>
<td>CMC</td>
<td>Coefficient of multiple correlation</td>
</tr>
<tr>
<td>CMD</td>
<td>Coefficient of multiple determination</td>
</tr>
<tr>
<td>D30</td>
<td>Displacement of PA movement up to a force or 30 N</td>
</tr>
<tr>
<td>FD</td>
<td>Force displacement as in FD curve</td>
</tr>
<tr>
<td>ICC</td>
<td>Intraclass correlation coefficient</td>
</tr>
<tr>
<td>K</td>
<td>Stiffness coefficient or the slope of a FD curve</td>
</tr>
<tr>
<td>LED</td>
<td>Light emitting diode</td>
</tr>
<tr>
<td>NDI</td>
<td>Neck Disability Index</td>
</tr>
<tr>
<td>PA</td>
<td>Posteroanterior as in PA movement</td>
</tr>
<tr>
<td>PMAD</td>
<td>Posteroanterior Movement Assessment Device</td>
</tr>
<tr>
<td>PSFS</td>
<td>Patient Specific Functional Scale</td>
</tr>
<tr>
<td>SAS</td>
<td>Spinal Assessment Simulator</td>
</tr>
<tr>
<td>SCB</td>
<td>Simultaneous confidence band</td>
</tr>
<tr>
<td>SF</td>
<td>Stiffness Force as in SF curve</td>
</tr>
<tr>
<td>SPAM</td>
<td>Spinal Posteroanterior Mobilisation Apparatus</td>
</tr>
<tr>
<td>SPB</td>
<td>Simultaneous prediction band</td>
</tr>
<tr>
<td>SPS</td>
<td>Spinal Physiotherapy Simulator</td>
</tr>
<tr>
<td>TROM</td>
<td>Total range of motion</td>
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Prologue

Polayi coined the term ‘tacit knowledge’ and described it as the stock of professional knowledge that experts possess, that is not processed in a focused cognitive manner but rather lies at a not quite conscious level where the knowledge is accessible through acting, judging or performing…..It is a type of knowledge that is acquired through experience. Polayi called this tacit knowledge because experts were able to act on it but could not always verbalize exactly what they were doing or why. He expressed this concisely in the words ‘we know more than we can tell’ (Fleming & Mattingly, 2000).

When describing the topic of this thesis to friends and colleagues some have been perplexed enough to ask how I, who am so interested in the interactive nature of the therapeutic process, could undertake such a seemingly reductionist project. The contradiction is perhaps not as great as it might initially appear so with the reader’s indulgence, I will take the liberty of briefly telling a story to put the thesis in context.

The story starts in 1975 when, as a recently graduated, but somewhat disillusioned physical therapist I was riding a bicycle somewhere between San Francisco and the Mexican border. Unbeknownst to me and half a continent away, my future ex-housemate Ted Stone blithely signed my name accepting a position to study in Australia. For the following year, Geoff Maitland lent me his tools while I started to learn the craft of manual therapy. In the many years since I have become convinced of the value of being intellectually, emotionally and physically responsive to those who come to me for assistance with their musculoskeletal problems.

When physical manual therapy interventions are performed in a way that I am referring to as responsive, the therapist ceases to impose a technique or intervention on the patient. Rather there is a moment-to-moment interaction where both the therapist and patient continually respond to each other. There is an implicit assumption in this ‘conversation' that the therapist feels and responds to meaningful information. The questions that prompted me to undertake this thesis are not just about the specific
technique of PA movements. Rather the questions are intended to be a first step towards understanding if there is a basis for the two-way physical conversations that manual therapists think we have with our patients or do we simply indulge in complex responses to random physical noise. Do we indeed know more than we can tell?

Reference

Acknowledgements

Nearly thirty years after the story began; I received invaluable advice from Professor Joy Higgs during a brief drive through the canyons of Surfer’s Paradise. It was a conversation from which fragments resurface at irregular intervals, but two points alluding to an economic model were: 1) It is your PhD, so the research question either needs to already be your own or one you are happy to purchase and 2) You ‘employ’ your supervisors on a long contract so hire them carefully. Thank you, Joy. The questions were (almost) all mine.

As for my supervisors, Liisa Laakso and Rod Barrett, you have both been invaluable and impeccable. Thanks Liisa for the structure from the whiteboard and timeline to the final product; for the regular meetings, warmth and encouragement; and for keeping your cards close to your chest while letting me run, but reigning me in just before I was too far astray. Rod, thank you for being a bridge between the scientific and the clinical; for struggling and forcing me to struggle with devils disguised as details; and for always giving the impression of being pleased to get another stack of papers on a Friday afternoon. Now that our ‘contract’ is finished, you both deserve a bonus as well as long-service leave.

I would like to thank: the School of Physiotherapy and Exercise and in particular the head of school, Lewis Adams for his ongoing support; Steve Obst and Lee Barber for assistance with data collection; Judy Waters for assistance with editing and formatting of the final document; and to Andrew Petersen – so long and thanks for all the coffee.

I can’t express sufficient thanks to my family Sue and Nathan. In particular thank you Sue, I don’t know how you have put up with me when my social interactions and contributions to our home and practice have often over the last few years rivaled those of a garden gnome.
Chapter 1
Introduction
1.1. Background

Musculoskeletal conditions are amongst the most common health complaints in Australia and those affecting the cervical spine are second in frequency only to those affecting the lower back (Bogduk, Bolton, Jull, & Bellamy, 2003). Internationally a wide variation of prevalence rates have been reported with a mean point prevalence of 7.6% (range 5.9% to 38.7%), weekly prevalence of 12.5% (range 1.4% to 36%), yearly prevalence of 37.2% (range 16% to 75%), and lifetime prevalence of 48.5% (range 14.2% to 71%) (Fejer, Kyvik, & Hartvigsen, 2006). In the only recent Australian study the weekly prevalence of neck symptoms was found to be 46% (Gordon, Trott, & Grimmer, 2002), but this may overestimate the true prevalence due to the inclusions in the survey of symptoms on waking including any pain or stiffness involving the neck, upper back, or arm, or headaches. There do not appear to be any estimates of the financial burden of neck pain in Australia, but in the Netherlands the cost has been estimated to be 1% of total health care costs or about 0.1% of the gross domestic product (Borghouts, Koes, Vondeling, & Bouter, 1999).

Physical impairments such as pain and limited movement are among the symptoms exhibited by people with musculoskeletal conditions. However the degree of disability resulting from musculoskeletal conditions of the cervical spine may not be associated directly with physical impairments (Chiu, Lam, & Hedley, 2005), but influenced by a variety of factors included in a biopsychosocial model first described by Engel (1977). Consistent with this model, a multidisciplinary approach to treatment is generally recommended to address both psychosocial and biological factors. Some recent research however suggests a multimodal treatment strategy may only be necessary for the minority of patients who are at high risk of developing chronic symptoms (Gatchel et al., 2003).

Manual therapy is one method of treating spinal musculoskeletal conditions and is taught in all schools of physiotherapy in Australia (Hahne, Keating, & Wilson, 2004). There are various conceptual frameworks within manual therapy, but it is generally considered that the symptoms or impairments targeted by manual therapy are related to limitations of intervertebral mobility (Banks, 1998; Fernandez-de-las-Penas, Downey, & Miangolarra-Page, 2005; Lee, Gal, & Herzog, 2000). Motion testing techniques such as posterioanterior (PA) movements (Fig. 1.1) are intended to evaluate limitations of intervertebral mobility and are used to aid diagnosis and guide treatment application.
Motion palpation is an integral part of the manual therapy paradigm. In this paradigm, motion palpation techniques are intended to assess limitations of intervertebral mobility which result in symptoms or impairments which in turn contribute to reduced functional ability and disability (Figure 1.2). Likewise the paradigm suggests that local manual therapy treatment using techniques such as PA movements reduces stiffness in motion palpation and intervertebral movement resulting in a reduction in symptoms and an increase in functional ability.

Figure 1.1. PA movement applied unilaterally to the mid cervical spine.
Figure 1.2. Manual therapy paradigms. A typical manual therapy paradigm is shown on the left. An abbreviated paradigm that includes only manual motion testing, impairments and treatment is shown on the right.

Motion palpation, impairments and functional abilities are each routinely assessed in the clinical setting. Intervertebral mobility or stiffness on the other hand is inferred, but not directly assessed due to the difficulty in assessing intervertebral movement in vivo without utilising invasive techniques. A shortened manual therapy paradigm can therefore be described, as findings on motion palpation are related to impairments which are in turn related to functional ability. It has been suggested that the relation between impairment and functional ability is predominantly mediated by psychosocial factors and therefore may not be influenced directly by manual therapy (Edwards, Jones, & Hillier, 2006). The resulting abbreviated version of the manual therapy paradigm can then be described only including motion palpation, impairments and treatment.

To date despite years of clinical practice being based on this manual therapy paradigm, the assumed links remain largely unproven. A variety of methods have been proposed
for objectively assessing PA movements particularly of the lumbar spine. As will be discussed in Chapter 3, relationships have been established between some elements of the paradigm for the lumbar spine, but no relationships between PA movements and impairments in the cervical spine have been established. Furthermore, although these methods have been able to detect changes in movement related to a variety of factors, any changes specifically associated with patient impairments have not been isolated (Shirley, 2004).

A relationship between characteristics of PA movements and impairments can be inferred if the particular characteristics change when patient impairments change. Moreover if the relationship between PA movements and impairments only occurs for specific locations of PA movements, and only following treatment directed towards that particular location, it can be inferred that the therapeutic effect of the treatment is localised and specific to the treated location. A strategy that can be employed to investigate this abbreviated paradigm corresponds to a framework for clinical reasoning (Maitland, Hengeveld, Banks, & English, 2005) that is commonly employed in clinical practice (Hahne, Keating, & Wilson, 2004). In this clinical reasoning framework changes in active movements immediately following treatment are used as an indicator of change in impairments. The advantages of employing this method in research are not only that it corresponds to clinical practice, but because the short time between reassessing PA movements and active range of movement (AROM) minimises the effect of extraneous factors on both measures and thereby maximises the likelihood of detecting relevant relations. Furthermore it is known that improvement in impairments including AROM and pain occur immediately following manual therapy treatment (Cassidy, Lopes, & Yong-Hing, 1992; Fernandez-de-las-Penas, Palomeque-del-Cerro, Rodriguez-Blanco, Gomez-Conesa, & Miangolarra-Page, 2007; Whittingham & Nilsson, 2001), but it is not known if such changes are indicative of longer-term improvement in impairments.

The manual therapy paradigm proposes that both PA movements and patient impairments are related to intervertebral mobility. There are a number of theories regarding which structures might be responsible for altered intervertebral mobility and each of the structures would be expected to affect intervertebral mobility in specific ways. For example it is known that alterations in segmental mobility occur in the cervical spine and such alterations can be detected by motion palpation (Fernandez-
Introduction

de-las-Penas et al., 2005). It is not known what causes such alterations or for certain if altered segmental mobility is related to the presence or production of impairments.

Various authors suggest different causes for altered segmental mobility. It has been suggested that increased intervertebral stiffness can result from increased muscle activation secondary to pain responses (Zusman, 1986), altered joint surfaces or shortened ligamentous structures (Banks, 1998; Powers, Kulig, Harrison, & Bergman, 2003; Threlkeld, 1992). Some authors suggest that disc degeneration, known as a potential source of symptoms, results in increased intervertebral stiffness (Colloca, Keller, Moore, Gunzburg, & Harrison, 2007; Kawchuk et al., 2001); while others have suggested that disc degeneration results in increased mobility (a reduction in stiffness or a larger ‘neutral’ zone) (Cholewicki, Crisco, Oxland, Yamamoto, & Panjabi, 1996; Panjabi, 2003; Zhao, Pollintine, Hole, Dolan, & Adams, 2005). Furthermore the various structures that have been implicated as possibly altering segmental mobility would be expected to affect intervertebral mobility in different ways. For example, static muscle contraction might be expected to result in an increased intervertebral stiffness throughout the range of movement (Keller, Colloca, Harrison, Moore, & Gunzburg, 2007) while a larger neutral or lax zone might result in an elongation of the normal non-linear pattern of intervertebral stiffness.

Not only is it not known how intervertebral stiffness might be related to impairments, but it is also not known how PA movements are related to intervertebral stiffness. An increased understanding of the relation between PA movements and patient impairments may therefore provide some information on the relation between intervertebral stiffness and impairments.

1.2. Problem

PA movements are commonly used to assess and treat musculoskeletal neck pain but little is known about their relation to symptoms. Previous investigations of relationships between PA movements and symptoms have been hampered by a lack of reliable and valid means of measuring either PA movements of the cervical spine or patient symptoms.
1.3. Aims

The general purpose of this research program was to determine the relation between the manual therapy techniques known as PA movements of the cervical spine and symptoms in patients with neck pain. At the outset reliable methods of assessing either PA movements of the cervical spine or meaningful indicators of changes in symptoms had not been established. Therefore, prior to being able to determine if there is a relationship between the PA movements and symptoms in patients with neck pain it was necessary to determine appropriate methods of measuring both PA movements and symptoms.

The specific aims of the studies were to:

1. Establish a reliable immediate indicator of symptoms in patients with non-acute neck pain that is a good predictor of longer-term change in symptoms.
2. Develop and establish the repeatability of a methodology for measuring PA movements of the cervical spine.
3. Determine how changes in PA movements are related to
   a. local tenderness as an indicator of potential symptoms in an asymptomatic population and
   b. change in symptoms in a population with non-acute neck pain.

Hypotheses in relation to the aims were:

1. Pain location, pain intensity and range of active movement have all been advocated as indicators of symptoms in patients with musculoskeletal symptoms. It was not known which of these measures of impairments would be a better indicator of symptoms in patients with non-acute neck pain.
2. An a priori hypothesis was not considered appropriate for a repeatability study.
3. It was hypothesized that changes in at least some regions of stiffness would be related to local tenderness and change in indicators of symptoms in a population with non-acute neck pain.

1.4. Significance

Recent literature has placed significant emphasis on the psychosocial aspects of musculoskeletal conditions that are known to predominate in the development and persistence of chronic symptoms (Gatchel et al., 2003) with some authors suggesting
that treatments should target behavioural and psychosocial rather than biological factors (Asenlof, Denison, & Lindberg, 2005). It is important, however, to not diminish the significance of the biological components particularly in the acute and sub-acute stages of musculoskeletal conditions. Interventions such as manual therapy may not have been shown conclusively to affect long term outcomes of musculoskeletal conditions to a chronic stage, but manual therapy has been clearly demonstrated to increase the speed of recovery of patients with a variety of musculoskeletal conditions (Bisset et al., 2006; Bronfort, Haas, Evans, & Bouter, 2004).

The importance of PA movements can be considered to be due mainly to their relationship to patient symptoms. A greater understanding of this relationship has the potential to lead to more effective assessment and treatment for patients with spinal musculoskeletal conditions in three main ways. First, PA movements are commonly used to assist diagnosis and to determine subsequent treatment. Even though there is currently no objective basis for their interpretation (Fernandez-de-las-Penas, Downey, & Miangolarra-Page, 2005; Lee et al, 2000; Riddle, 1992), PA movements continue to play not only a significant role in the assessment of spinal musculoskeletal conditions in professions employing manual therapy such as physiotherapy, osteopathy and chiropractic, but are used also in medical and surgical assessment of spinal conditions. Often motion palpation including PA movements is used to localise the source of a patient’s symptoms on the basis of a single parameter such as the total amount or ‘endfeel’ of the movement (Brandt, Sole, Krause, & Nel, 2006). In some systems more detailed characteristics of PA movements are also considered and used to guide the application of manual therapy treatment (Abbott et al., 2007). An increased understanding of the relation between PA movements and patient symptoms is important, therefore, not only to enable accurate localisation and diagnosis of spinal musculoskeletal conditions, but also to ensure that treatments can be consistently selected and applied. If PA movements are indeed able to assist in characterisation as well as localisation of the source of patients’ symptoms, an increased understanding of PA movements may also assist the identification of patient subgroups to be used in future research into musculoskeletal conditions of the spine.

Second, a greater understanding of the relation between PA movements and symptoms could result in improvements in the teaching of manual therapy skills. Manual therapy skills are recognised as some of the most difficult for students and
practitioners to develop (Lewit & Liebenson, 2003). Some of the difficulties are illustrated by the wide variety of subjective descriptors used to describe findings on motion palpation, the limited agreement on meanings of the descriptors (Maher, Simmonds, & Adams, 1998), and the lack of a known relationship between objective findings and impressions from palpation (Petty, Maher, Latimer, & Lee, 2002). An understanding of the physical characteristics of PA movements that relate to patient symptoms would facilitate student learning through more accurate conceptualisation, communication, and feedback. Furthermore, an understanding of how PA movements are related to specific conditions could assist in the development of mechanical or electronic haptic simulators to assist skill acquisition and provide objective palpation benchmarks for students and instructors.

Third, an understanding of PA movements may assist in increasing the understanding of the structures and mechanisms involved in the production of musculoskeletal symptoms of the cervical spine, thereby aiding the search for more effective interventions. An increased understanding of the characteristics of PA movements occurring with specific patient symptoms may therefore be able to assist in understanding which structure or structures are involved in altered segmental mobility and symptom production.

1.5. Thesis structure

A literature review is presented in Chapter 2 focusing on prior knowledge related specifically to the study including: 1) passive movements, 2) measurement of passive movements, and 3) methods of interpretation of PA movements. Chapters 3 to 7 are manuscripts as submitted or published from the studies, and as such contain an introduction placing each study within the context of the scientific literature as well as including methods, results and discussion for each study. Chapter 8 consists of a discussion of the overall findings, a summary, and conclusions.

The aims of the first study described in Chapters 3 and 4 were to: 1) confirm that immediate changes in pain and/or active movements occur in patients with non-acute neck pain; and 2) determine whether changes in pain or AROM are better predictors of longer term changes in symptoms.

The posteroanterior movement assessment device (PMAD) was developed to assess PA movements of the cervical spine and the aim of the study described in Chapter 5
was to establish the repeatability of the PMAD. Local tenderness to PA movements is considered an indicator of patient symptoms so the study described in Chapter 6 was a pilot study aimed at determining how PA movements to tender locations differed from less tender locations in the cervical spine of asymptomatic subjects.

The aim of the final study, described in Chapter 7, was to determine how PA movements are related to symptoms in patients with non-acute neck pain by determining if differences in symptoms and PA stiffness following treatment by PA movements to the cervical spine are dependent on the treated location, and more importantly, if there is a relation between improvement in symptoms and changes in characteristics of PA stiffness. The final study was intended also to provide some indication of possible mechanisms underlying the effectiveness of manual therapy treatment.
References


Introduction


Introduction


Introduction


Chapter 2
Literature review
The general purpose of this thesis was to determine the relationship between the manual therapy technique of PA movements of the cervical spine and symptoms in patients with neck pain. Some of the vast body of literature related to aspects of manual therapy and neck pain will be discussed in the chapters, that follow, but the depth of coverage is limited by the constraints of journal publication. The role of immediate indicators of treatment effectiveness in the clinical setting and their relation to other outcome measures is discussed in Chapters 3 and 4. A discussion of novel statistical methods for assessing the repeatability of and performing comparisons between curve data of PA movements is contained in Chapters 5 and 6. The relation between PA movements and symptoms is discussed in Chapter 7. The following review is a more in-depth discussion of a limited number of topics directly related to the main aims of the thesis, but contains some degree of overlap with material in the individual chapters. Section 2.1 extends the discussion from Chapters 3 and 4 to the place of interactive treatment approaches in the context of evidence-based medicine, while section 2.2 is concerned specifically with the measurement and interpretation of passive movements.

2.1. Interactive treatment approaches and evidence-based medicine

2.1.1. Evidence-based medicine and musculoskeletal problems

The mainstay of evidence-based medicine is the randomised control trial (RCT) and ideally every intervention would have its efficacy tested through such trials. The classical form of RCT compares two or more experimental groups one of which may receive a placebo intervention. Again ideally, the groups are homogeneous, the interventions are repeatable and the outcomes can be measured validly. There are, however, a number of difficulties in the application of this type of study to musculoskeletal conditions: the groups are rarely homogeneous; the interventions lack consistency; and there is lack of consensus on how best to measure outcomes (Koes, 2004).

2.1.2. Variation within groups and interventions

In musculoskeletal conditions it is generally not possible to determine a specific pathology (Wainner, Whitman, Cleland, & Flynn, 2003) so experimental groups are likely to contain a variety of subgroups that may respond differently to interventions. In
addition manual therapy interventions have not been shown to have good repeatability. For example, the force used by physiotherapists intending to perform the same technique and grade of mobilisation has been found to vary by a factor of 5 (ranging from 63 N to 347 N for one technique) between practitioners and by up to 34% for repeated applications by a single practitioner (Harms & Bader, 1997). Similarly, forces used by chiropractors performing a specific manipulation technique have been found to vary from just over 100 N to over 800 N (Forand, Drover, Suleman, Symons, & Herzog, 2004). Both the musculoskeletal conditions and the interventions used for treatment therefore often lack homogeneity.

2.1.3. Outcome measures

Three levels of limitations have been identified in relation to musculoskeletal symptoms; impairments, functional limitations, and disability (Hermann & Reese, 2001). Impairments include pain or limitations of movement and are quantified by pain scales, muscle strength, or active range of movement. Functional limitations are limitations of the person’s ability to function in their daily tasks and can be measured either by assessment of physical tasks such as lifting, walking, or carrying, or by questionnaires such as the patient specific functional scale (PSFS). Disablement is a reduced ability to perform socially-expected functions and can be measured by return to work status, financial cost to the community, or instruments such as the neck disability index (NDI). Although a direct relationship between impairment, functional limitation, and disability might be expected, in practice the relationship is less clear. Studies have described relationships between measures of impairment and disability in groups of patients with neck pain ranging from weak (Chiu, Lam, & Hedley, 2005) to strong (Hermann & Reese, 2001). Importantly, these studies consider the relationship between impairments and other outcome measures within a group rather than comparing change scores for the different outcome measures over time.

When comparing change scores, a strong relationship was demonstrated between subjective and objective measures after two months in patients following lumbar spine surgery (Mannion, Dvorak, Muntener, & Grob, 2005). On the other hand Pengel, Refshauge, & Maher (2004) compared change in impairments and function to individual global perception of change, and found the results to be more variable.

As a result RCTs can fail to detect significant results if experimental groups contain
subgroups that have opposing responses to a particular intervention, if there are aspects of the intervention that are not adequately controlled, or if the variables being measured do not necessarily reflect the parameters of interest (Koes, 2004; Kotaska, 2004). Other types of studies looking, for example, at individualised responses to treatment therefore may be suited to investigating some aspects of treatment of musculoskeletal conditions.

2.1.4. Investigations into individual responses

There is a growing body of literature related to predicting individual treatment responses and the effectiveness of individualised treatment programs. Psychosocial factors have been shown to be up to 90% accurate in predicting which patients with low back pain will progress to develop a chronic condition (Pulliam, Gatchel, & Gardea, 2001). Genetic factors are thought to account for over 40% of the incidence of low back pain (Hestbaek, Iachine, Leboeuf-Yde, Kyvik, & Manniche, 2004) and risk factors including smoking, age obesity, and diabetes are associated with a greater likelihood of development of symptoms and a poor prognosis once symptoms occur (Borenstein et al., 2001; Takala & Viikari-Juntura, 2000; Webb et al., 2003). A generally better or worse prognosis associated with pre-existing factors may impact on the appropriate allocation of resources to an individual (Gatchel et al., 2003), but does little to assist the manual therapist in treatment selection.

Ideally, a priori predictors could be known for a particular individual with a specific presentation of a particular condition. The most effective combination of interventions for that individual could then be selected confidently and outcomes predicted accurately. In one study an experimental group of patients with low back pain who were classified on the basis of their individual signs and symptoms and received specific treatment protocols achieved better results than a second group who received a standardised protocol (Fritz, Delitto, & Erhard, 2003). Asenlof, Denison, & Lindberg (2005), using a different classification method and applying treatment programs with a more psychosocial bias, also found that individually tailored treatment programs produced better results than a ‘one size fits all’ approach. Although not compared with other interventions, patients with neck pain whose treatment was individualised by a decision-making algorithm demonstrated better outcomes than a control group placed on a waiting list (Wang, Olson, Campbell, Hanten, & Gleeson, 2003).
In these studies the group allocations were based on theoretical criteria rather than on experimental evidence. That is, interventions intended to influence a particular clinical pattern were assigned to patients whose presentation was considered to represent that pattern. Experimentally-based prediction rules, on the other hand, determine experimentally which patient characteristics predict specific outcomes. The predictive ability of these rules is then evaluated in the same way as for theoretically-based rules.

In one application of experimentally-based prediction rules, a combination of pre-treatment symptom duration and location, patient beliefs and hip and lumbar mobility were found to predict positive outcomes to manipulation for patients with low back pain after two treatments (Childs et al., 2004; Fritz, Childs, & Flynn, 2005). The inverse of these factors combined with symmetry of hip medial rotation and a negative Gaenslen sign predicted a poor response to two treatments by manipulation in the same population (Fritz, Whitman, Flynn, Wainner, & Childs, 2004). Another study by the same group (Hicks, Fritz, Delitto, & McGill, 2005) developed a clinical prediction rule for patients with low back pain likely to respond to stabilising exercises. Tseng et al. (2006) developed a rule to predict immediate improvement in response to cervical manipulation. It is interesting that both groups of researchers describing experimentally based prediction rules had previously published studies into the effectiveness of theoretically allocated individualised treatments.

There is an important distinction between the cause and effect relationships that RCTs attempt to establish and the predictive value of particular combinations of signs and symptoms. If one assumes the absence of any incidental relationships then RCTs are considered to be able to determine cause and effect relationships between interventions and outcomes (Herbert, Jamtvedt, Mead, & Hagen, 2005). Prediction rules predict, but cannot be considered to establish a cause and effect relationship. Although the cause and effect relationship is vitally important for the researcher, it can be argued that an accurate predictor is more useful for the clinician and important to the patient. For example the clinician and patient may be more satisfied with a known outcome from an uncertain mechanism than an uncertain outcome from a known mechanism.

2.1.5. Interactive approach related to treatment response

The preceding discussion was concerned with the initial selection of a treatment
Literature review

A few authors advocate that the evidence should pre-determine a course of treatment that should be altered only when the patient demonstrates a ‘very poor’ response (Herbert et al., 2005). Most authors, however, support a more individualised, interactive treatment approach using repeated reassessments of their patient’s progress not only as a means to modify and refine their treatment application, but also to determine as quickly as possible whether that treatment is worthwhile for that particular individual (Banks, 1998; Jones, Jensen, & Edwards, 2000; Maitland, 1964; Werneke & Hart, 2003). An interactive approach can be applied whether the initial intervention is determined from a fixed protocol, a prediction rule, or a more complex decision-making algorithm. Decisions about further interventions are then influenced by the patient’s response to the preceding interventions. The author is aware of only one controlled trial that investigated this method. Fritz, Delitto, & Erhard (2003) reported patients had better results when the therapist was allowed to adjust the treatment individually than when the patient’s treatment followed a predetermined protocol.

One of the main assumptions underlying an interactive approach is that changes experienced by the patient or assessed by the therapist are indicative of longer term changes in a patient’s symptoms. Maitland, Hengeveld, Banks, & English (2005) describe at least four levels of reassessment that are used to monitor a patient’s response to treatment: during the application of the intervention; between application of interventions within a given treatment session; between treatment sessions; and over the course of treatment.

Perhaps the majority of the research into the ability of treatment responses to predict outcomes has been in relation to the centralisation phenomenon as described by the McKenzie method. Centralisation is defined as ‘a favorable change in the location of pain from a distal or peripheral location to a more proximal or central spinal position’ (Werneke, Hart, & Cook, 1999) in response to repeated movements. The repeated movements are considered part of the assessment process, but are included in this review as similar repeated movements are also used as the treatment intervention in the McKenzie approach. Centralisation prior to commencement of treatment has been demonstrated to be a reliable method of classification (Kilpikoski et al., 2002) and has been claimed to be able to predict both positive and negative outcomes to conservative management for patients with low back pain (Skytte, May, & Petersen, 2005; Werneke & Hart, 2001, 2003; Werneke et al., 1999). The conservative management used in
these studies, however, consisted primarily of movements similar to the repeated movements performed as assessments. It can perhaps be more appropriately concluded, as pointed out by Walsh (2001), ‘that the lack of centralisation predicts a lack of response to McKenzie treatment, not necessarily a poor outcome.’ In either case, the predictive ability of centralisation improved if the response was considered over a number of treatments (Werneke & Hart, 2003). In one other study, Hahne, Keating, & Wilson (2004) found that immediate changes following manual therapy to the lumbar spine predicted between session changes in pain and active movement but did not extend these findings to include end of treatment outcomes.

2.1.6. Summary

There are difficulties in obtaining and applying evidence from RCTs to the wide variety of musculoskeletal conditions and treatments used in clinical practice. While clinical prediction rules are able to provide some guidance for treatment selection, they are generally not applied after the initial selection of treatment. In clinical practice the patient’s response is repeatedly reassessed and treatment altered accordingly. To date there is only limited evidence supporting this method of adjusting treatment in response to reassessment of the patient.

2.2. Passive movements

The Maitland method describes passive movements as those produced by the therapist without active assistance from the patient and divides passive movements into two categories; passive physiological movements and passive accessory movements (Maitland et al., 2005).

*Passive physiological movements* are defined as movements that although produced passively, could be produced actively. Movements about a single anatomic axis (flexion/extension, lateral flexion or rotation) are therefore passive physiological movements, but the term also refers to combinations of movements around multiple axes. The second category, *passive accessory movements*, is defined as movements not able to be produced in isolation by the individual. Passive accessory movements are predominantly translational rather than rotational. An example of an accessory movement in a peripheral joint is the posterior to anterior glide that occurs during Lachman’s test of the anterior cruciate ligament of the knee.
Movements considered to be passive accessory movements of the spine (passive accessory intervertebral movements or PAIVMs) are generally described according to the location and direction of the force used to produce the movement. That is, a posterior to anterior (PA) force applied to the midline is referred to as a central PA movement while a posterior to anterior force applied to one side of the midline is referred to as a unilateral PA movement. The direction of application of force used in practice is influenced by a number of factors and can be inclined in any combination of superior-inferior and medial-lateral directions. Other manual therapy systems also include assessment and treatment techniques that have similarities to PA movements, but may vary in terminology as well as details of application (Basmajian & Nyberg, 1993). The focus of the current research is PA movements of the cervical spine, but much of the relevant research has been conducted in relation to the lumbar and thoracic spines so the findings from these studies will also be considered in the following discussion.

2.2.1. Spinal posteroanterior movements

Originally PA movements were thought to produce a localised accessory glide of one vertebra on another and the response felt by the therapist to be an accurate indicator of this movement (Figure 2.1). It is now clear from both in vivo (Caling & Lee, 2001; Kulig, Landel, & Powers, 2004; Lee & Evans, 1997; Lee, McGregor, Bull, & Wragg, 2005; McGregor, Wragg, Bull, & Gedroyc, 2005; Powers, Kulig, Harrison, & Bergman, 2003) and in vitro studies (Gal, Herzog, Kawchuk, Conway, & Zhang, 1997a; Gal, Herzog, Kawchuk, Conway, & Zhang, 1997b; Sran, Khan, Zhu, & Oxland, 2005) that the movement occurring when a PA force is applied is not purely or even predominantly accessory movement (Figure 2.2). In addition to PA movements not producing accessory movements, they are not limited to a single intervertebral segment but span a number of intervertebral levels and are influenced by a number of non-vertebral factors (Caling & Lee, 2001; Chansirinukor, Lee, & Latimer, 2003; Kawchuk & Fauvel, 2001; Lee, Gal, & Herzog, 2000; Lee, Steven, Crosbie, & Higgs, 2000; Lee & Evans, 1997). The movement produced by the application of a PA force therefore does not directly correspond to local segmental movement and the segmental movement that does occur only includes minimal true accessory movement.
Figure 2.1. Early concept of movement occurring with PA movements. The movement produced by a PA was considered to be a translational glide localised to one intervertebra moving on another. For reference, grades of movement are shown on the lower right. (From Grieve, 1981 p 421.)
Figure 2.2. MR images of a sagittal section of the cervical spine while a PA force is applied to C6 and a: a) grade I; and b) grade IV PA movement (McGregor, Wragg, & Gedroyc, 2001). Comparing the images shows the intervertebral angle, the generalised movement of the cervical spine and the lack of a significant intervertebral translation that occur with the PA movements.
2.2.2. Manual assessment of PA movements

Notwithstanding that vertebral movements produced by PA movements do not correspond with the original conceptualisations, motion palpation including PA movements form an important component of physical examination (Bullock-Saxton et al., 2002) and manual assessment of passive movements has been shown to have clinical utility. For example symptomatic locations (Jull, Bogduk, & Marsland, 1988), the location of reduced segmental movement (Fernandez-de-las-Penas, Downey, & Miangolarra-Page, 2005) and the location of congenital fusion (Humphreys, Delahaye, & Peterson, 2004; Marcotte, Normand, & Black, 2005) have been reliably detected by manual motion palpation. In a clinical study, the lumbar spines of patients were classified by findings on manual palpation as hypo- or hyper-mobile. Patients who received corresponding treatment – manipulation to increase segmental mobility to the hypo-mobile group and stabilisation exercises to counteract excessive mobility in the hyper-mobile group – had better outcomes following treatment than those receiving randomly allocated treatment (Fritz, Whitman, & Childs, 2005).

The interpretation of manual motion palpation is typically subjective with Maher and Adams (1998) having listed more than forty descriptors used to describe intervertebral movement which were broadly divided into a small number of groups relating to either the quantity or quality of movement. There was limited agreement between practitioners on the meaning of individual terms and any relation between the subjective descriptors and measurable physical characteristics has not been established. Maitland (1964) attempted to relate what was felt during PA movements to mechanical principles when he advocated constructing movement diagrams as a means of communicating not only the mechanical but also the pain behaviour of PA movements (Figure 2.3). Movement diagrams are subjectively referenced force displacement (FD) curves that also include an indication of the pain behaviour during the movement. That is, they are qualitative representations intended as teaching and communication tools to provide more specific information than purely subjective descriptions (Chesworth, MacDermid, Roth, & Patterson, 1998). Although movement diagrams produced by practitioners or students may be able to represent total range of movement accurately (MacDermid, Chesworth, Patterson, & Roth, 1999), they have
not been shown to represent other movement characteristics, such as quality of the movement or point of onset of stiffness (referred to as R₁), accurately (Petty, Maher, Latimer, & Lee, 2002).

Figure 2.3. A movement diagram of a passive movement. Displacement is on the horizontal axis while the vertical axis is the relative magnitude of pain (P) and resistance (R). R₁/R₂ represents the behaviour of resistance while P₁/P₂ represents the behaviour of pain. (Cook, 2003)

The usefulness of spinal passive movement tests such as PAs has been brought into question by findings of limited repeatability (Hollerwoger, 2006; Pool, Hoving, de Vet, van Mameren, & Bouter, 2004; Smedmark, Wallin, & Arvidsson, 2000) and the ability of clinicians to agree on ranking or grading stiffness of PA movements in vivo has not been conclusively demonstrated. When only tactile information is available to the
therapist the repeatability has been found to be poor to fair (Troyanovich, Harrison, & Harrison, 1998; van Trijffel, Anderegg, Bossuyt, & Lucas, 2005). When the practitioners receive common training or additional information is available to the therapist (such as the production of discomfort or information about the patient’s symptoms), the results improve significantly (Lewit & Liebenson, 2003). The limited repeatability of assessment by PA movements may be due to methodological weaknesses (Bullock-Saxton et al., 2002; Hollerwoger, 2006) or to manual palpation lacking the sensitivity necessary to detect relevant differences (Bullock-Saxton et al., 2002), it being unclear what characteristics of the movement are related to patient symptoms or segmental dysfunction (Maher & Adams, 1995a; Najm et al., 2003; Nicholson, Adams, & Maher, 2003; van Trijffel et al., 2005).

A way of quantifying the sensitivity of clinicians’ perceptions is the size of a just noticeable difference (JND) which is typically defined as the size of difference that can be detected accurately 75% of the time. As the size of the JND is related to the magnitude of the stimulus, Weber fractions (defined as the ratio of a JND to the stimulus intensity expressed as a percentage) are used as a measure of sensitivity independent of stimulus magnitude. The Weber fraction for stiffness appears to have a consistent value of 7–8% for the range of stiffness that is relevant to PA movements of the lumbar spine (Nicholson, Adams, & Maher, 1997).

Other authors have suggested that the time-dependent or viscous component of stiffness to PA movements may be important and assessed the Weber constants for the rate dependent component of stiffness to be 14.7% (Nicholson et al., 2003). Caution is required when applying the values of Weber constants to in vivo assessment of PA movements as the values were determined using mechanical devices with constant stiffness or viscosity rather than the more complex patterns found in biological tissues. In spite of these limitations, the Weber constants described above (differences of stiffness greater than 8% or of viscosity of greater than 15%) are able to provide a working approximation of size of differences that practitioners would be able to detect reliably. Many of the differences in PA stiffness that have been found in in vivo studies, therefore, would be expected to be detectable by manual palpation (Shirley, 2004). Percentage differences in viscosity of PA movements, on the other hand, have not been determined so it is unclear if such differences are likely to be detectable by manual palpation.
The clinical utility of manual assessment of PA movements may seem at odds with the reported lack of repeatability. Wainner (2003), however, provides a comprehensive explanation of how clinical utility and poor repeatability are conceptually compatible. Some of the lack of repeatability that has been reported for manual assessment of PA movements may be related to methodological issues, but the question remains of how accurately clinicians are able to manually assess PA movements. Assessment by its nature is a ‘decisional process’ that includes measurement and interpretation (Tesio, 2007). It is not certain whether the difficulty for clinicians is in an inability to measure (perceive) reliably the characteristics of PA movements that are related to patient symptoms or whether the difficulties are in the clinicians’ ability to interpret the characteristics they perceive.

2.2.3. Instrumented assessment of PA and intervertebral movements

Due to the difficulties outlined above, a number of researchers have developed methodologies to measure and interpret PA movements more objectively than is possible with manual assessment. In measurement of PA movements, two main sources of systematic variation can be considered to be device variables and subject variables (Kawchuk & Fauvel, 2001). Device variables including the methods of interpretation of the measurements will be discussed in Section 2.2.4.1 while subject variables will be considered in Section 2.2.4.2.

2.2.4. Methods for measuring PA or intervertebral movements

A range of devices and methodologies that have been developed for measuring passive intervertebral movement and their repeatability are summarised in Table 2.1.
Table 2.1. Repeatability of devices used to measure PA movements. K represents stiffness or a linear approximation of the force displacement curve of a PA movement. D is the distance or displacement of the PA movement occurring in response to a specific force. SPS is Spinal Physiotherapy Simulator (M. Lee & Svensson, 1990), SAS is Spinal Assessment Simulator (Latimer, Goodsel et al., 1996), and SPAM is Spinal PA Mobilisation apparatus (Edmondston, Allison, Althorpe, McConnell, & Samuel, 1999)

<table>
<thead>
<tr>
<th>Study/Device name</th>
<th>Measurements</th>
<th>Method of force application</th>
<th>Subjects</th>
<th>Location</th>
<th>Frequency</th>
<th>Variables</th>
<th>Comparison</th>
<th>Indentor</th>
<th>Repeatability</th>
</tr>
</thead>
<tbody>
<tr>
<td>M. Lee &amp; Svensson, 1990 / Spinal Physiotherapy Simulator (SPS)</td>
<td>Force and displacement</td>
<td>Mechanical</td>
<td>Metal beam</td>
<td>11 normal</td>
<td>L3</td>
<td>0.5 Hz</td>
<td>Linear fit for forces above 15 N</td>
<td>Repeated measures on separate days</td>
<td>720 mm²</td>
</tr>
<tr>
<td>R. Lee &amp; Evans, 1992</td>
<td>Force and displacement of test level plus level above and below</td>
<td>Mechanical</td>
<td>28 normal</td>
<td>L3</td>
<td>1-2 Hz</td>
<td>Relative displacement of L4 (L4-L5/2-L3/2)</td>
<td>Repeated cycles</td>
<td>Interday ICC = 0.95 to 0.99</td>
<td>Max error = 0.7 to 0.8 mm</td>
</tr>
<tr>
<td>Latimer, Goodsel et al., 1996 / Spinal Assessment Simulator (SAS) Similar to SPS, but portable</td>
<td>Force and displacement</td>
<td>Mechanical</td>
<td>Metal beam</td>
<td>L3</td>
<td>0.5 Hz</td>
<td>D30 (0.5 N - 30 N) K (20 N or 30 N to 105)</td>
<td>Repeatability after 15 min</td>
<td>720 mm²</td>
<td>Max error = 2.5 % stiffness ICC=.96 CI (0.95 to -.98) D30: ICC = 0.89 (0.76 to 0.95)</td>
</tr>
<tr>
<td>Latimer, Lee, &amp; Adams, 1998 /SAS</td>
<td>Force and displacement</td>
<td>Mechanical</td>
<td>25 normal</td>
<td>0.5 Hz</td>
<td>K (six regions of stiffness from 30 N to 200 N)</td>
<td>Stiffness at different forces</td>
<td>720 mm²</td>
<td>ICC = 0.39 to 0.67 better for larger force intervals</td>
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### Literature review

<table>
<thead>
<tr>
<th>Study/Device name</th>
<th>Measurements</th>
<th>Method of force application</th>
<th>Subjects</th>
<th>Location</th>
<th>Frequency</th>
<th>Variables</th>
<th>Comparison</th>
<th>Indentor</th>
<th>Repeatability</th>
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<tr>
<td>Shirley, Ellis, &amp; Lee, 2002/ SAS</td>
<td>Force and displacement</td>
<td>Mechanical</td>
<td>18 normal</td>
<td>L4</td>
<td>0.5 Hz</td>
<td>K (30 N to 90 N D30 (2N to 30 N)</td>
<td>Repeated measures</td>
<td>720 mm²</td>
<td>ICC=0.88, SEM = 1.03 N/mm</td>
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<tr>
<td>Edmondston, Allison, Althorpe, McConnell, &amp; Samuel, 1999/ Spinal PA Mobilisation Apparatus (SPAM)</td>
<td>Force and displacement</td>
<td>Mechanical</td>
<td>T4, 7, 10 and sternum</td>
<td>0.5 Hz</td>
<td>K (30 N - 80 N) Preloaded to 25 N</td>
<td>Repeated measures</td>
<td>300 mm²</td>
<td>ICC3,1 = .81, 0.87 SEM = 1.1 N/mm, 1.21 N/mm</td>
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<tr>
<td>Kawchuk &amp; Elliott, 1998</td>
<td>Force and displacement</td>
<td>Mechanical with ultrasound transducer to assist localization</td>
<td>Inanimate phantom Lumbar spine</td>
<td>1-2 Hz</td>
<td>Displacement</td>
<td>Repeated measures</td>
<td>Mean error = 14 to 22%</td>
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<td>Kawchuk, Fauvel, &amp; Dmowski, 2000</td>
<td></td>
<td>Bovine spine in vitro</td>
<td>Direct measure of bone</td>
<td>Accuracy = 12.73%</td>
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<tr>
<td>Kawchuk, Fauvel, &amp; Dmowski, 2001</td>
<td></td>
<td>Porcine spine in vitro</td>
<td>Optical tracking</td>
<td>ICC = .99 to 1 Error 0.81 to 13.62</td>
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<tr>
<td>Beneck, Kulig, Landel, &amp; Powers, 2005</td>
<td>Change in intervertebral angle</td>
<td>MR imaging during manual grade 4 PA</td>
<td>35 subjects, 28 with painful segment</td>
<td>Lumbar spine Quasi-static</td>
<td>Change in Intervertebral angle on MRI</td>
<td>Repeated Measures Manual</td>
<td>ICC = 0.95-0.99 SEM 0.40 – 0.66 degrees</td>
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<td>Study/Device name</td>
<td>Measurements</td>
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<tr>
<td>Brown, Holmes, Heiner, &amp; Wehman, 2002</td>
<td>Force, displacement</td>
<td>Mechanically separate spinous processes during surgery</td>
<td>298 spinal patients during surgery</td>
<td>Lumbar spine</td>
<td>N/A</td>
<td>K (22 N to 90 N) Tested to 134 N</td>
<td>Disc degeneration</td>
<td>ICC = 0.954</td>
<td></td>
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<tr>
<td>Squires, Latimer, Adams, &amp; Maher, 2001 Modified SAS</td>
<td>Force and displacement</td>
<td>Mechanical</td>
<td>36 Normal</td>
<td>L3</td>
<td>0.25 Hz 0.5 Hz, 2 Hz</td>
<td>D (0.5N to 30 N) K (30N to 90 N)</td>
<td>3 sizes of indentor and 3 frequencies</td>
<td>300 mm2, 720 mm2, and 1564 mm2</td>
<td>ICC 0.98 (0.97-0.99)</td>
</tr>
<tr>
<td>R. Y. W. Lee, Tsung, Tong, &amp; Evans, 2005</td>
<td>Force plate under bed, electromagnetic tracking</td>
<td>Manual</td>
<td>20 Normal</td>
<td>L4</td>
<td>Mean 1.2 Hz</td>
<td>Change in angle between ASIS and T 7/8</td>
<td>Repeated measures same day</td>
<td>Hand</td>
<td>ICC 0.98</td>
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<tr>
<td>Owens, DeVocht, Wilder, Gudavalli, &amp; Meeker, 2007</td>
<td>Force and 3D position</td>
<td>Manual</td>
<td>52 measures from 36 LBP patients</td>
<td>L1 to L5</td>
<td>0.5 Hz to 1 Hz</td>
<td>K (last 20 N of movement up to 80 N or limit due to pain)</td>
<td>Intraexaminer same day repeated measures</td>
<td>314 mm2</td>
<td>ICC = 0.79</td>
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<tr>
<td>Snodgrass, Rivett, &amp; Robertson, 2007/ Cervical Spine Stiffness Assessment Device</td>
<td>Force (subtract friction of device from reading) and displacement</td>
<td>Mechanical</td>
<td>67 normal</td>
<td>Foam</td>
<td>1 Hz</td>
<td>K (7 to 40 N)</td>
<td>Repeated measures on different days</td>
<td>15 mm diameter tapered 2.5 mm edge</td>
<td>ICC = 0.99 (CI 0.93-1.00)</td>
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<td>C2 and C7</td>
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<td>ICC = 0.84 when five outliers (~8%) were excluded</td>
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</table>
Lumbar spine

Several instruments have been constructed with the intention of measuring PA movements of the lumbar or thoracic spines in a manner similar to when the movements are produced and perceived manually. Three similar devices, the Spinal Physiotherapy Simulator (SPS) (Lee & Svensson, 1990), the Spinal Assessment Simulator (SAS) (Latimer, Lee et al., 1996) and the Spinal PA Mobilisation Apparatus (SPAM) (Edmondston, Allison, Althorpe, McConnell, & Samuel, 1999), each consist of an indentor that is mechanically advanced along a linear trajectory while simultaneously measuring force and displacement. Although each was based on PA movements performed during manual palpation, there are differences between these devices that could influence their measurements. The indentor for each was intended to be similar to the contact of the hand used during manual PA movements, but the indentors were of different sizes and unlike the human hand, were flat and rigid. In addition, the frequency of movement for each device was within the range used in manual application of PA movements but varied from 0.5 Hz to 2 Hz.

Squires et al. (2001) investigated the effect of the different indentor sizes and application frequencies used in the three devices described above and found both frequency and indentor size influenced the PA movements. In addition, there was an interaction between frequency and indentor size such that for a small indentor a decrease in stiffness occurred with increasing rate, but the reverse was true for a large indentor. Even with the similarity of these three devices, their measurements are dependent on aspects of the device and the methodology.

The reproducibility of a location is another potential source of variation that can be addressed by device design. Kawchuk, Fauvel, & Dmowski (2001) reported an improvement in reproducibility of indentor position when incorporating an ultrasound transducer into the indentor of a device similar to the three discussed above. The location of the indentor was perhaps more critical in this study because the transverse processes were targeted that are deeper and more difficult to locate accurately than the spinous process targeted in most other studies.

Two other devices have been described that produce PA movements manually and provide three-dimensional information on the position of the indentor while simultaneously measuring force. Lee, Tsung, Tong, & Evans (2005) applied a PA force...
by hand and used electromagnetic tracking sensors on the pelvis and thoracic spine to indirectly measure the movement under the PA force. The spine was considered to behave as a beam under three-point load enabling the angles of the pelvis and thoracic spine to be used to estimate the displacement at the target location. Force was recorded simultaneously using a force plate below the treatment bed. This method enabled a PA movement to be produced exactly as it would be performed in clinical practice, but included potential sources of error from the indirect method of measuring displacement and from a time delay before the force registered on the force plate due to the non-elastic properties of the body. Another device was described recently by Owens, DeVocht, Wilder, Gudavalli, & Meeker (2007) that also used manual application of force and electromagnetic tracking. In this case the force was measured as it was applied through the indentor and the location of the indentor was tracked.

Methods have also been described that measure intervertebral movements of the lumbar spine in ways less directly relevant to movements that are produced and perceived during manual assessment. Radiological (Lee & Evans, 1997) or magnetic resonance images (McGregor, Anderton, Gedroyc, Johnson, & Hughes, 2001; Powers, Kulig, Harrison, & Bergman, 2003) have been used to measure the amount of intervertebral movement resulting from PA movements to the lumbar spine. The imaging of static positions during the manual application of PA movement provides detailed information on the relative positions of the vertebra. The time required to run a scan and the difficulty in simultaneously measuring force, however limit the ability of these methods to provide the detailed simultaneous dynamic position and force data that would be perceived by a clinician.

Additional methods of measuring intervertebral stiffness in vivo have used perturbations that cannot be produced manually or responses that cannot be perceived by the clinician. Such methods include high speed impulses (Keller, Colloca, & Beliveau, 2002), vibration (Kaigle, Ekstrom, Holm, Rostedt, & Hansson, 1998) and variable frequency vibration (Keller & Colloca, 2007). One additional method was described by Brown, Wehman and Heiner (2002) who assessed intervertebral stiffness by separating the spinous processes when exposed surgically. In addition to this method being impractical for clinical assessment, the authors reported fractures in five out of 298 patients but interestingly did not consider the fractures to be ‘clinically significant’.
Good repeatability was reported for all lumbar spine devices shown in Table 1 with ICCs ranging from 0.79 to 1.00. The one study that reported ICCs as low as 0.39 (Latimer, Lee, & Adams, 1998) compared force intervals that were not intended to be used in further studies. In addition to repeatability, the validity of measures of PA movements was addressed in a small number of in vitro studies where the PA measures were compared with bone movement (Kawchuk, Fauvel, & Dmowski, 2000, 2001; Kawchuk, Liddle, Fauvel, & Johnston, 2006). All of the validity studies reported good to excellent agreement.

Cervical spine

Measurement of PA movements to the cervical spine presents additional difficulties to those encountered in the lumbar spine. The cervical spine is inherently more mobile than the lumbar spine so any applied movement is potentially more difficult to control. The effect of the greater mobility of the cervical spine compared to the lumbar spine is perhaps more pronounced when performing PA movements because the cervical spine is suspended between the head and the trunk rather than being supported on the treatment bed. Further difficulties result from the anatomy of the cervical spine. The location of central PA movements can be determined relatively accurately for C2 and C7 where there are prominent spinous processes. Due to the configuration of the spinous processes of the remainder of the cervical spine, however, it is much more difficult to ensure the contact of an indentor is over a known location or even to ensure that the contact of an indentor is limited to a single spinous process.

As well as central PA movements, unilateral PA movements produced by applying force over the articular pillar or apophyseal joints are commonly used in the assessment of the cervical spine. Measurement of unilateral PA movements presents other difficulties besides those encountered with central PA movements. For unilateral PA movements there is a greater depth of soft tissue between the indentor and the vertebra; the width between the articular pillars varies; and the landmarks used to locate individual vertebrae are less distinct than for central PA moments.

Only recently an instrument using a method similar to the SAM has been described for assessing PA movements in the cervical spine (Snodgrass, Rivett, & Robertson, 2007). The reported repeatability of this device (ICC = 0.84) was comparable to a number of the lumbar devices but only when outliers that occurred for five out of 68 subjects had
been excluded from the analysis. It is important to note that the repeatability of the device was reported only for measuring C2 and C7 which, as described above are perhaps the locations in the cervical spine that are least prone to measurement error.

2.2.5. Interpretation of measures of PA movements

The interpretation of measurements from the devices described above relied on one or two scalar variables from the force displacement (FD) curves of the PA movements. The most common variables used to characterise FD curves of PA movements as shown in Figure 2.4 are: 1) a global measure of stiffness (K) derived from a portion of the force displacement (FD) curve that was considered to be linear (Lee & Svensson, 1990); and 2) the length of the non-linear portion of the FD curve up to a force of 30 N (D30) (Latimer, Lee et al., 1996). The relation between segmental stiffness and either of these measures has not been determined.

The value of K in Figure 2.4 was thought to represent the stiffness of the intervertebral movement and the preceding non-linear toe region thought to represent soft tissue compression (Snodgrass, Rivett, & Robertson, 2007). The portion of the FD curves of the lumbar spine used to calculate K varied considerably across the studies. The lower value of force ranged from 15 N (Lee & Svensson, 1990) to 30 N (Edmondston, Allison, Althorpe et al., 1999; Latimer, Goodsel et al., 1996) and the upper limit ranged from 80 N (Edmondston et al., 1999) to 105 N (Latimer, Goodsel et al., 1996). It is unlikely that the same K value would result from considering different portions of the FD curves as Latimer, Lee, & Adams (1998) demonstrated that both the repeatability and K values varied when different portions of the FD curves were considered. Furthermore, Nicholson Maher, Adams and Phan-Thien (2001) demonstrated that no portion of the FD curves of PA movements could be represented accurately as linear and that an equation including three additional non-linear elements provided a superior method of characterising the curves.
Figure 2.4. Variables used for interpretation of PA movements (Latimer, Goodsel et al., 1996). The graph illustrates a Force displacement curve of a PA movement to the lumbar spine. Two variables extracted from the curve for use in further analysis were K, a linear approximation of the curve from 30 N to 90 N of force and D30, the displacement from 0.5 N to 30 N (D30).
Lee et al. (2005) used a static, rigid body three-point bending model (Figure 2.5) to calculate a single value of PA stiffness from the last 20 N of PA force. Equation 1 was used to represent the relationship between PA force and moment acting at the point of application of the force.

\[ M = P \times a \left(1 - \frac{a}{L}\right) \]  
\text{Equation 1}

Where:
- \( M \) is the moment acting on the beam under the PA force
- \( L \) is the horizontal length between supports (sacrum to T8), and
- \( a \) is the horizontal distance between the sacrum and the point of application of the PA force.

If the dimensional data from the same study are inserted into Equation 1, the relation between PA force and moment becomes:

\[ M \equiv P \times 0.069 \times \left(1 - \frac{0.069}{0.246}\right) \]  
\text{Equation 2}

\[ M \equiv P \times 0.0496 \]  
\text{Equation 3}

In other words, a PA force of 30 N would produce a moment on L4 of approximately 1.5 Nm.
Figure 2.5. Biomechanical model of PA mobilisation (from Lee et al., 2005). The spine is modelled as a beam suspended between the anterior superior iliac spines (ASIS) and spinal level T8/9. \( L \) is the distance between supports, \( a \) the distance from the ASIS to the application of the PA force, \( P \) is the magnitude of PA force and \( M \) is the moment produced. In the example described in the text the magnitude of the moment is calculated under the PA force so distances \( x \) and \( a \) are equal.

When referenced against a moment angle curve of L3/4 (Cholewicki, Crisco, Oxland, Yamamoto, & Panjabi, 1996), a moment of 1.5 Nm would correspond approximately to the end of the toe region of L3/4 (Figure 2.6). This estimate is likely to be conservative however because unlike the data from Cholewicki et al. (Cholewicki, Crisco, Oxland, Yamamoto, & Panjabi, 1996), the spine is not subject to axial loading during PA movements and unloaded spinal motion segments are less stiff than when axial load is applied (Gardner-Morse & Stokes, 2004; Gardner-Morse, Stokes, Churchill, & Badger, 2002). The portion of the PA movement corresponding to the toe region may be clinically significant because differences in both the size and stiffness of the toe region have been demonstrated in relation to disc degeneration (Gay, Ilharreborde, Zhao,
Zhao, & An, 2006; Zhao, Pollintine, Hole, Dolan, & Adams, 2005). Therefore methods of interpretation of PA movements that do not consider stiffness at force levels below 30 N would be unable to detect differences known to occur that are related to disc degeneration.

Figure 2.6. Stiffness curve of L4/5 (from Cholewicki, et al. 1996)) with location of moment produced by a PA force of 30 N.

The variables K and D30 as shown in Figure 2.4 are easily quantifiable and perhaps this explains the number of studies that have used these parameters to describe PA movements of the lumbar and thoracic spines (Brown, Holmes, Heiner, & Wehman, 2002; Brown, Wehman, & Heiner, 2002; Latimer, Lee, Adams, & Moran, 1996; Latimer, Lee, & Adams, 1998; Latimer, Lee, & Moran, 1995; Lee, 1995; Lee, Kelly, & Steven, 1995; Lee & Liversidge, 1994; Lee, Steven, Crosbie, & Higgs, 1998; M. Lee & Svensson, 1993; Lee & Evans, 1997; Maher & Adams, 1995b).

A similar method of determining K was used in the interpretation of PA movements in the only known published study of PA movements of the cervical spine, but in this case the linear portion of the curve was considered to span from seven to 40 N (Snodgrass et al., 2007). An estimation of the toe region for the cervical spine can be calculated using a similar method to that described above for the lumbar spine. If the supports of the three-point bending model are considered to occur at the occiput and T1, then the
moment corresponding to the end of the toe region can be calculated from Equation 1 where:

\[ \mathbf{M} \] is the moment acting on the beam under the PA force
\[ \mathbf{L} \] is the horizontal length between supports (occiput to T4), and
\[ \mathbf{a} \] is the horizontal distance between the sacrum and the point of application of the PA force (occiput to C4/5).

If mean data from US adult females (Pheasant, 1992) are inserted into Equation 1, the relation between PA force and moment at C4/5 becomes:

\[
M = P \times 0.07 \times \left(1 - \frac{0.07}{0.155}\right) \quad \text{Equation 4}
\]

\[
M = P \times 0.038 \quad \text{Equation 5}
\]

A PA force of 7 N would therefore produce a moment of approximately 0.27 Nm. When referenced against a moment angle curve of C4/5 (Panjabi et al., 2001), a moment of 0.27 Nm would again approximate the end of the toe region of C4/5 (Figure 2.7). The toe regions of the FD curves of PA movements and the corresponding stiffness curves of intervertebral movements therefore appear to occur in response to similar levels of PA force.

It is not fully known what characteristics of intervertebral movement might be related to symptoms of either back or neck pain. It is known that degenerative changes in lumbar discs can be related to both stiffness within the toe region (Gay et al., 2006; Zhao et al., 2005) and patient symptoms (Peterson, Bolton, & Wood, 2000). The values of K used in previous studies would not appear to provide an indication of stiffness within the toe region. The length of the toe region (D30, shown in Figure 2.5) used to interpret measures in some studies would provide some indication of stiffness within the toe region, but it is unclear whether a single value is sufficient to characterise differences related to patient symptoms. It would appear therefore that although the methods used to measure PA movements may have been adequate to measure the PA movements, that the single values used by researchers to interpret the measurements may not be sufficient to adequately characterise their findings.
For completeness it is important to recognise that other investigators (Colloca, Keller, Peterson, & Seltzer, 2003; Keller et al., 2002) have suggested alternative methods to characterise intervertebral movement by the frequency response to mechanically produced short duration (~5 ms) high peak intensity (up to 200 N) impulses. The stiffness values at lower frequencies were then extrapolated from the time domain data. Although of academic interest, the characterisation of stiffness by responses to impulses is not directly applicable to the aspects of PA movements perceivable by therapists. Even if impulses of this speed and brevity could be recreated manually, the frequency response could not be perceived manually. In addition, the extrapolation used in these studies from the response to high-speed impulses to a single linear stiffness value is unlikely to provide detailed characteristics of FD movements performed at a slower speed.

2.2.6. Clinical correlates of PA movements

Spinal assessment techniques such as PA movements are intended to provide information about patient symptoms and factors thought to be related to patient symptoms. Attempts have been made, therefore, to establish a relationship between the behaviour of the PA movements and the intervertebral movement that it is intended
to assess. In spite of the shortcomings in current methods of interpreting PA movements, a number of studies have found differences in PA movements with a wide variety of variables (Table 2.2). For example, Kawchuk et al. (2001) were able to detect reduced mobility of spinal segments with induced disc degeneration *in vivo* in the lumbar spine of a porcine model. In an *in vitro* study of the thoracic spine, Srann et al. (2005) demonstrated that differences in segmental sagittal plane mobility between pairs of thoracic vertebrae were related to differences in stiffness of PA movements. A reduction in PA stiffness has been found in individuals with low back pain when their symptoms improved (Latimer, Lee, et al., 1996). Comparisons between groups of symptomatic and asymptomatic subjects have yielded mixed results, with one study (Goodsell, Lee, & Latimer, 2000) not detecting any differences but another (Kulig et al., 2007) finding a greater incidence of hyper-mobility in patients with back pain than asymptomatic controls.

Differences in PA movements have been described also with changes in a number of factors unrelated to patient symptoms or specifically to mobility of the target intervertebral segment (Kawchuk & Fauvel, 2001). Factors including position (Chansirinukor, Lee, & Latimer, 2001; Edmondston et al., 1998), stage of respiration (Shirley, Hodges, Eriksson, & Gandevia, 2003), direction of applied movement (Allison et al., 1998; Caling & Lee, 2001), size of the indentor (Squires et al., 2001), and muscle contraction (Colloca & Keller, 2004; Hodges et al., 2003) have all been demonstrated to be related to differences in stiffness of PA movements.

Some clinical correlates have been found also using high speed impulses. Colloca et al. (2003) found the response to PA impulses to be related to disc height in the lumbar spine and using a similar method Colloca, Keller, Moore, Gunzburg, & Harrison (2007) found PA stiffness increased with disc degeneration.

PA movements have been found to differ in relation to a variety of factors but researchers have not determined whether the effects resulting from the various factors are different. Measurements of PA movements have been found to be repeatable but the usefulness of the assessments appears to be limited by the methods used to interpret the measurements. In order for the interpretation of PA movements to provide more useful information, it may be necessary to apply methods of interpretation and analysis that involve the entire data curves rather than reducing the curves in a pre-determined way to one or two variables.
Table 2.2. Factors affecting PA movements. K represents stiffness or a linear approximation of the force displacement curve of a PA movement. D is the distance or displacement of the PA movement occurring in response to a specific force.

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Faster movement (0.5 Hz) stiffer than quasistatic loads
### Literature review

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<td>R. Y. W. Lee, Tsung, Tong, &amp; Evans, 2005</td>
<td>Force plate under bed, electromagnetic tracking</td>
<td>L4 mean</td>
<td>20</td>
<td>K over last 20 N of force (up to 178 N)</td>
<td></td>
<td>Pelvis good indicator of movement Bending stiffness can be derived from force and change in spinal curve</td>
</tr>
<tr>
<td>Maher, Latimer, &amp; Holland, 1999</td>
<td>SAS</td>
<td>T6, T12, L324</td>
<td>Normal subjects</td>
<td>D30 and K 30 - 90 N</td>
<td>Padded and unpadded plinth</td>
<td>Correlation between padded and unpadded 0.70-0.87</td>
</tr>
<tr>
<td>Powers, Kulig, Harrison, &amp; Bergman, 2003</td>
<td>MRI</td>
<td>Lumbar spine</td>
<td>11</td>
<td>Change in intervertebral angle (10 Kg force)</td>
<td>Tested levels and other levels</td>
<td>PA produced maximum movement under applied pressure (1.2 – 3 degrees), but movement occurred at all levels</td>
</tr>
<tr>
<td>Schmitz-Lesich &amp; Lindemann, 2004</td>
<td>Glass microprobes</td>
<td>Rat sperm</td>
<td>K (not specified)</td>
<td>Vary sodium and calcium concentrations</td>
<td></td>
<td>Stiffness corresponds with active torque production. Bending torque for the Ca(2+) response results from action of the dyneins on outer doublets”</td>
</tr>
<tr>
<td>Kulig, Landel, &amp; Powers, 2004</td>
<td>MRI</td>
<td>Lumbar spine</td>
<td>20</td>
<td>Change in intervertebral angle</td>
<td>Location of PA</td>
<td>Maximum movement occurred under application of force</td>
</tr>
<tr>
<td>Study</td>
<td>Device/ Method</td>
<td>Region/ Subjects</td>
<td>Method of analysis</td>
<td>Comparison</td>
<td>Results</td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------------</td>
<td>-----------------</td>
<td>-------------------</td>
<td>-----------------------------------------</td>
<td>--------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Kulig et al., 2007</td>
<td>MRI</td>
<td>Lumbar spine</td>
<td>Group difference in angle +/- 2SD</td>
<td>Symptomatic vs asymptomatic</td>
<td>Greater incidence of hypermobile in symptomatic group</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 Normal, 45 with LBP</td>
<td></td>
<td>Note mean approximately equal to 2SD so can only be considered hypomobile if immobile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latimer, Lee, Adams, &amp; Moran, 1996</td>
<td>SAM</td>
<td>Lumbar spine</td>
<td>K (30 – 90 N) and D30</td>
<td>Painful and 80% improved</td>
<td>Stiffness decreased by 1.21 N/mm when symptoms improved</td>
<td></td>
</tr>
<tr>
<td>Shirley, Hodges, Eriksson, &amp; Gandevia, 2003</td>
<td>SAS</td>
<td>8 Normal</td>
<td>K 50 - 110 N</td>
<td>Stages of respiration and with glottis open or closed</td>
<td>Stiffness increased with either inspiration or expiration, but not when glottis closed</td>
<td></td>
</tr>
<tr>
<td>Shirley, Lee, &amp; Ellis, 1999</td>
<td>SPS</td>
<td>L4</td>
<td>K (20 - 100 N)</td>
<td>0, 10, 30, 50, 100% of MVC of Lx extensors</td>
<td>Linear increase in stiffness with increasing strength of contraction. Increase by 91% at 100% MVC</td>
<td></td>
</tr>
<tr>
<td>Snodgrass, Rivett, &amp; Robertson, 2007</td>
<td>Cervical Spine Stiffness assessment device CSSAD</td>
<td>C2 and C7 central and unilateral PAs 67 Normal subjects</td>
<td>K (7 – 40 N)</td>
<td>Level, repeated measures on different days</td>
<td>Stiffness C2: 4.58 N/mm, C7: 7.03 N/mm C2 stiffer with increasing age C7 males stiffer than females</td>
<td></td>
</tr>
<tr>
<td>Squires, Latimer, Adams, &amp; Maher, 2001</td>
<td>Modified SAS</td>
<td>36 Normal L3</td>
<td>K (30 – 90 N) D (0.5-30 N) Comfort</td>
<td>3 sizes of indentor and 3 frequencies</td>
<td>With increasing size: Increase K, decrease D30, decrease comfort. Rate and indentor size interact</td>
<td></td>
</tr>
</tbody>
</table>
2.2.7. Statistical analysis

Continuous or time series data such as FD curves require different statistical methods than do scalar values. For interpretation of the FD curves in this thesis, methods of analysis were required that had not been applied previously to PA or other passive movements.

Repeatability

Intraclass correlation coefficients (ICCs) were used in relation to single variables in many of the repeatability studies listed in Table 2.1 and are perhaps the statistical method most commonly used to quantify repeatability. In their simplest form, ICCs are similar to other correlation coefficients and when squared result in a coefficient of determination that indicates the percentage of variance that is accounted for by the other variable. Curve data requires different methods of analysis due both to the large number of samples and the fact that each data point is not independent but related to adjacent data points. Coefficients of multiple correlation (CMCs) are applied to curve data and are analogous to ICCs for individual scalar variables. Similarly the square of a CMC known as a coefficient of multiple determination (CMD) indicates the percentage of the variation accounted for by agreement between the curves. A CMD is defined as:

\[
\text{CMD} = 1 - \frac{\sigma_e^2}{\sigma_g^2}
\]

Equation 6

Where:

\( \sigma_e^2 \) represents the variance from the ensemble average curve, and \( \sigma_g^2 \) represents the variance from the grand mean of the curves.

The more similar the curves being compared, the more \( \sigma_e^2 \) approaches 0 and the CMD approaches 1. Conversely, the more dissimilar the curves, the more \( \sigma_e^2 \) approaches \( \sigma_g^2 \) and the CMD approaches 0.
Just as there are other methods than ICCs to assess the repeatability of scalar measurements, there are also other methods that can be used to assess additional aspects of repeatability for curve data. Systematic bias, as well as the repeatability of variables once any bias is removed, can be important in the assessment of scalar measurements (Bland & Altman, 1999). For curve data, systematic bias is the offset of the curves and is calculated simply as the difference between the grand means of the two curves or groups of curves. In order to compare the overall shape of the curves, adjusted CMDs can be obtained by recalculating the CMDs for each set of curves with the offset removed. In other words, the CMDs quantify the repeatability of the original curves, the offsets indicate any systematic bias as might occur with global movement of the spine, while the CMDs of the adjusted curves compare the overall shape of the curves.

Comparison of curves

Common statistical methods used to compare scalar data are not appropriate when comparing curve data (Lenhoff et al., 1999). The need for and use of bootstrap methods to calculate simultaneous confidence bands (SCBs) and simultaneous prediction bands (SPBs) is discussed in the Statistical Note to Chapter 6. It is important to note that SCBs and SPBs are also one dimensional comparisons and so have important limitations when analysing curve data. For example when applied to FD curves the displacements at a particular force level are compared only with the displacements from other curves at the same force level.

It may not be possible to fully understand the complexity of PA movements without employing even more sophisticated approaches to analysis than SCBs and SPBs. Functional data analysis and artificial neural networks (Ramsay & Silverman, 1997) are two such frameworks. Three of the strategies used in functional data analysis to detect and quantify patterns in continuous or cyclical data are: analysing derivatives of the raw data, identification of landmarks, and normalisation. The first and second derivatives of displacement are velocity and acceleration respectively. When applied to FD data these derivatives become stiffness and rate of change of stiffness. Consideration of derivatives of displacement would facilitate location and quantification of landmarks such as the points of maximum stiffness that cannot be directly compared using SCBs or SPBs. In addition normalising the curves either proportionately across either axis or by aligning specific landmarks could enable a more meaningful comparison between
PA movements where the pattern rather than the values are the characteristics of interest.

2.2.8. Summary

For either manual or instrumented measurement of PA movements to fulfil the intended purpose, it needs to be able to: 1) differentiate between alterations in PA movements related to patient symptoms and those resulting from other, extraneous factors; and 2) reliably localise the source of the altered movement. Manual assessment of PA movements is able to detect clinically useful information and to localise differences in intervertebral mobility, yet has demonstrated only limited repeatability. Instrumented assessment of PA movements on the other hand are repeatable and are able to detect differences in relation to a variety of factors, but have not been able to detect the differentia specific to clinically useful factors or to particular intervertebral locations.

One possible explanation for the differences between manual and instrumented assessment of PA movements is that the characteristics that are relevant to patient symptoms and which inform manual assessment of PA movements may not be the same as those considered in the analysis of instrumented assessment. The current studies therefore did not set out to determine whether predetermined characteristics of PA movements are related to symptoms. Rather the studies set out to identify as yet unknown characteristics of PA movements of the cervical spine that might be specifically related to symptoms.
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Literature review


Literature review


Literature review


Literature review


Literature review
Chapter 3

Do changes within a manual therapy treatment session predict between-session changes for patients with cervical spine pain?
Abstract

Physiotherapists often use within-session changes to provide a guide for refining treatment application. This study tested the validity of within-session changes as predictors of between-session changes for patients with neck pain receiving manual therapy treatment. A total of 70 pairs of treatments from 29 patients with sub-acute non-specific neck pain receiving manual therapy were assessed to determine the relationship between within-session and between-session changes in range of motion (ROM), pain intensity and centralisation. Measurements were taken of ROM of the more limited direction on each axis of flexion, extension, lateral-flexion and rotation and pain (intensity and location), before and after treatment. The same measurements were repeated before the following treatment. Regression analysis demonstrated that within-session change accounted for 26% to 48% of the variability in between-session change for ROM and 6% for pain intensity. The proportion of the within-session change for ROM maintained between-sessions ranged from 42% to 63% (CI 25% to 88%). The odds ratios for within-session improved/not improved categorisation to predict between-session category for ROM ranged from 2.5 (CI 0.6 to 4.3) to 21.3 (CI 10.1 to 96.1), for pain intensity 4.5 (CI 1.2 to 14.4) and for pain centralisation 9.2 (CI 2.2 to 38.7) indicating greater likelihood of between-sessions improvement after within-session improvement. The between-session results for most patients (71 to 83%) could be classified correctly by their within-session category. The results support the use of within-session changes in ROM, centralisation and possibly pain intensity as predictors of between-session changes for musculoskeletal disorders of the cervical spine.
3.1. Introduction

Disorders of the cervical spine are amongst the most common sources of musculoskeletal symptoms (Bogduk, Bolton, Jull, & Bellamy, 2003) with manual therapy being a commonly applied form of treatment. Studies into the effectiveness of manual therapy, however, have demonstrated inconsistent results. Randomised control trials are considered to have significant limitations when applied to complex conditions or when treatments are variable (Kotaska, 2004). The lack of consistent results may thus be partly due to subgroups of patients having different responses to treatment (Christensen, Jones, & Carr, 2002) as disorders of the cervical spine cannot at this point be grouped into functionally homogenous categories (Bogduk et al., 2003) or due to the difficulty in precisely controlling the intervention being applied. Even for surgical interventions precise control of procedures cannot be achieved to the same extent as for drug therapy (Birkmeyer, Weinstein, Tosteson, Tosteson, & Skinner, et al., 2002). For manual therapy, the variation of method and skill is likely to be even greater between practitioners than amongst surgeons making standardisation of interventions even more difficult.

The manual therapy practitioner facing a patient in the clinical setting is concerned with what intervention will be most effective for this particular patient with this particular problem at this particular time. If all members of a group are presumed to be similar and treatments consistent and repeatable, then treatment can reasonably follow set protocols. If, however each patient’s condition is considered to be a unique combination of elements, the treatment needs to be tailored to the individual patient and their response to treatment. The practitioner thus requires a responsive means of gauging the response to their interventions to guide the application and refinement of their interventions.

Early manual therapy texts advocated that effective treatment was gauged by the segmental mobility of the spine, as assessed by the practitioner, being improved to its normal level. The usefulness of relying solely on segmental mobility as an assessment is undermined by its poor reliability (Bogduk et al., 2003) as well as difficulty in ensuring that the reduced segmental mobility is related to the patient’s symptoms and not an incidental finding.
Do within-session changes predict between-session changes?

Immediate changes in the intensity or location of the patient’s pain are commonly used to assess changes in the patient’s condition. Location of symptoms is advocated as an assessment measure in the McKenzie method where centralisation of the patient’s symptoms is considered to be a key indicator of improvement. Several articles have concluded that within-session centralisation of a patient’s symptoms is a valid predictor of treatment success (Aina, May, & Clare, 2004; Werneke & Hart, 2001, 2003; Werneke, Hart, & Cook, 1999). Walsh (2001) however suggested that the results may only demonstrate ‘that a lack of centralisation predicts a lack of response to McKenzie treatment, not necessarily a poor outcome.’

Another method of attempting to evaluate the effectiveness of treatment is by the therapist assessing a movement that is limited by the patient’s symptoms. This method initially proposed by Maitland (1964) and still advocated today (Ferrario, Sforza, Serrao, Grassi, & Mossi, 2002) is taught in all post-graduate manual therapy courses in Australia (Hahne, Keating, & Wilson, 2004). In its simplest form the practitioner selects a movement or function limited by the patient’s symptoms that can be easily and objectively reassessed. This clinical test movement is reassessed at the beginning and end of each treatment session and commonly after individual components of the treatment. Changes in the test movement are used to gauge the effectiveness of the intervention and the therapist then modifies the treatment according to the direction and extent of these changes. Changes in ROM take precedence over changes in the person’s level of pain. That is, if a patient has greater ROM but experiences more pain at the limit of this increased ROM; they are considered to be better.

Maitland’s method would seem to have face validity, but there are a number of underlying assumptions. Reduced movement is assumed to be associated with a patient’s symptoms and this is true for at least some types of neck pain (Dall’Alba, Sterling, Treleaven, Edwards, & Jull, 2001). Within-session changes are presumed to occur and several studies have confirmed immediate changes do occur following manual therapy of the cervical spine (Cassidy, Lopes, & Yong-Hing, 1992; Cassidy, Quon, LaFrance, & Yong-Hing, 1992; Whittingham & Nilsson, 2001). A more important assumption is that within-session changes are valid predictors of between-session changes; in other words that there is some lasting change associated with these immediate changes. For the lumbar spine, Hahne et al. (2004) have found that within-session changes in ROM and pain intensity predict between-session changes. It is also
known for the lumbar spine that changes in ROM correlate with changes in other outcome measures (Hagg, Fritzell, Oden, & Nordwall, 2002; Mannion, Dvorak, Muntener, & Grob, 2005). Werneke and Hart (2003) have found that within-session centralisation of pain predicts between-session changes for both the lumbar and cervical spines when using a McKenzie method of treatment. It has not, however been determined whether within-session centralisation or changes in ROM or pain predict between-session changes with manual therapy treatment of the cervical spine.

This study is designed to address the question of whether within-session changes in range of active movement are a valid basis for decision-making when treating musculoskeletal conditions of the cervical spine by manual therapy. In particular, do within-session changes in active ROM or pain predict between-treatment changes in the same parameters?

3.2. Method

Research was approved by Ethics Review Committee, James Cook University.

3.2.1. Subjects

All patients presenting to a private physiotherapy clinic who fulfilled the selection criteria were offered the opportunity to participate in the study. The inclusion criteria were patients with neck pain with or without referral of symptoms into the shoulder or arm that was accompanied by a limitation of neck mobility. It has been demonstrated for patients with a greater than 2 week history of neck pain that less than 50% had achieved spontaneous recovery in 7 weeks (Hoving, de Vet, Twisk, Deville, van der Windt, Koes, et al. 2004). Therefore in order to ensure that the patients’ symptoms had a less than 50% chance of spontaneous recovery, only those whose symptoms had been present more than two weeks were included in the current study. Patients were excluded if they had any condition which contraindicated the use of manual therapy treatments, or had any inflammatory or other medical condition that was likely to impact on their symptoms. Patients were also excluded if their symptoms were subject to compensation, were a result of trauma within the previous six months or if they had received any physical treatment within the previous two weeks. Twenty-nine subjects were recruited over a seven-month period and consisted of 21 females and 8 males with an average age of 55 years (SD = 17, range 28–83).
3.2.2. Procedures

Data from pairs of consecutive treatments were collected up to a maximum of 6 treatments or until the patient or therapist felt that manual therapy treatment was no longer required, other types of treatment were indicated or when greater than two weeks passed between-sessions. A total of 70 pairs of treatments (mean time between treatments 6.1 days, range 2–14) met the criteria and were used for analysis. A staff member other than the treating therapist gave each patient a form before each treatment including two pain measures: 1) an 11-point visual analogue pain scale (VAS) of their current pain ranging from 0 being 'no pain' to 10 being ‘worst pain imaginable’, 2) a body chart (BC) showing the location of their symptoms. The treating therapist set up the instrumented assessments of each patient’s ROM before and after each treatment but did not have access to the resulting measurements. After each treatment the patient filled out a second form similar to pre-treatment. Thus not only were the assessors of the pain scales (VAS and BC) and ROM blind to each other, but the treating therapist was blinded to both measurements.

The patients were treated by one of three physiotherapists (1, 5, and 30 years’ experience). The study was not intended to assess the effectiveness of treatment, but rather the relationship of within-session changes to between-session changes. Therefore no attempt was made to standardise the treatment each patient received except to ensure that the intervention consisted predominantly of manual therapy, but could include within-session exercises. Manual therapy was defined as described by Korthals-de Bos, Hoving, van Tulder, Rutten-van Molken, Ader, et al. (2003) as consisting of ‘hands-on techniques (muscular mobilisation, specific articular mobilisation, co-ordination or stabilisation). Spinal mobilisation was defined as low velocity passive movement within or at the limit of joint ROM. Spinal manipulation (low amplitude, high velocity techniques [were] not provided.’ The therapist did not alter or suggest any alteration in the patient’s medication. Patient education was provided as appropriate, but in order to minimise the influence of factors outside of the actual treatment, advice on exercises was limited to general advice on monitoring activities.

3.2.3. Measurements and apparatus

A variety of methods have been used to measure cervical ROM comparing the relative positions of the head with landmarks intended to indicate the position of the first
Do within-session changes predict between-session changes?

Thoracic vertebrae (Dvir & Prushansky, 2000; Feipel, Rondelet, Le Pallec, & Rooze, 1999; Ferrario, et al., 2002; Hagen, Harms-Ringdahl, Enger, Hedenstad, & Morten, 1997; Jordan, Dziedzic, Jones, Ong, & Dawes, 2000). Although the values obtained with the various methods vary, the repeatability is similar to the results obtained when the trunk is stabilised and the change in the position of the head in space is measured (Castro, Sautmann, Schilgen, & Sautmann, 2000; Ferrario, et al., 2002; Sforza, Grassi, Fragnito, Turci, & Ferrario, 2002). For the current study, the change in ROM was important rather than the absolute value of ROM so the simpler method of ensuring stability of the trunk rather than stability of T1 was used. The patient was seated in a high-backed chair with their shoulders against the backrest and a 3-axis orientation sensor (3DM MicroStrain Inc, 310 Hurricane Lane, Williston, VT) attached to the patient’s head and interfaced with a PC. Purpose-built software, using Labview v6i (National Instruments Corporation, 11500 N Mopac Expwy, Austin, TX 78759-3504), was used for data acquisition at a sampling rate of 10 Hz. The system was zeroed by having the patient look straight ahead and three consecutive readings were averaged. The patient was then asked to perform three movements as far as they could reasonably move in flexion, extension, and to each side in lateral flexion and rotation. The maximum value for each movement was stored automatically and remained unknown to the therapist. Tests for repeatability of the measurements were performed on four asymptomatic volunteers. The mean difference between the first and second repeated measures was –1.2 degrees and the 95% limits of agreement (the range within which 95% of repeated measures would be expected to lie (Bland & Altman, 1999)) was –5.9 to +3.5 degrees. To simplify analysis a slightly larger difference of +5 degrees was considered to be the smallest detectable improvement. The location of the patient’s pain (BC) was assessed at rest and analysed using the method described by Werneke, et al. (1999). A body chart with regions numbered one through six on a clear plastic overlay (Figure 3.1) was placed over each body chart filled out by the patient and the number of the region containing the most distal symptoms was recorded.

3.2.4. Data analysis

For each of the three parameters (ROM, VAS and BC), the within-session change was the difference between the measurements taken before and after each treatment, and the between-session change the difference between the measurements taken before
Do within-session changes predict between-session changes?

one treatment and before the following treatment. When ROM is used to assess change in the clinical setting, typically the direction of movement that is more limited (the so-called asterisk movement (Refshauge & Gass, 2004)) is used for reassessment. Therefore the within- and between-session changes were calculated for the direction of movement that, prior to treatment, was more limited for each axis (Limited F/E, Limited LF and Limited ROT). If the patient received more than one treatment the direction of movement limited before the first treatment was used for future sessions.

Figure 3.1. Overlay body template (adapted from Werneke et al., 1999).

Pearson correlation coefficients were performed to assess the relationships of within-session changes to between-session changes for each ROM variable and VAS. For those pairs where significant relationships occurred a simple linear regression was performed. Confidence intervals were calculated to assist in determining the clinical relevance of the relationships.

Odds ratios, and positive and negative likelihood ratios were calculated to assess the likelihood of simple improvement within-sessions being retained between-sessions for ROM, VAS and BC variables. For ROM, patients were classified as better if they had
an improvement greater than the smallest detectable improvement determined from pilot data (5 degrees). For ease of comparison, improvement in VAS and centralisation were defined in the same way as previous comparable studies where these parameters were assessed (for VAS a reduction of more than one point (Hahne et al., 2004) and for pain centralisation movement proximally by at least one category (Werneke & Hart, 2003; Werneke, et al., 1999). Otherwise patients were classified as not improved. Although reducing the ROM and VAS data to two categories significantly degrades the data and reduces the sensitivity of the analysis, this categorisation enabled a direct comparison between these parameters and BC, as well as enabling a direct comparison with data from other studies (Hahne et al., 2004). A significance level was set at p < 0.05 for all tests. Data analysis was performed using Microsoft Excel 2000, SPSS v12.1, and Vassarstats (Lowry, 2004).

3.3. Results

Descriptive statistics for scalable variables are shown in Table 3.1. All within-session and between-session variables show an improvement in both ROM and VAS. The standard deviation is greater than the mean change in all cases demonstrating the large variability in between-session measures.

**Table 3.1. The mean pre-session values, within-session changes and between-session changes.** For each movement the between-session change is larger than the within-session change. The simple averages shown here give an indication of the small size of the between-session changes in relation to the large between-session variance.

<table>
<thead>
<tr>
<th>Movement</th>
<th>Mean pre-session value (SD)</th>
<th>Mean within-session change (SD)</th>
<th>Mean between-session change (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limited F/E</td>
<td>45.0 degrees (13.5)</td>
<td>4.3 degrees (9.0)</td>
<td>7.6 degrees (14.6)</td>
</tr>
<tr>
<td>Limited lateral-flexion</td>
<td>31.7 degrees (11.1)</td>
<td>1.4 degrees (4.4)</td>
<td>2.2 degrees (11.4)</td>
</tr>
<tr>
<td>Limited rotation</td>
<td>63.4 degrees (10.5)</td>
<td>3.3 degrees (5.0)</td>
<td>5.0 degrees (13.2)</td>
</tr>
<tr>
<td>Pain intensity (VAS)</td>
<td>4.1 points (2.2)</td>
<td>0.9 points (1.6)</td>
<td>0.8 points (1.9)</td>
</tr>
</tbody>
</table>
3.3.1. Within-session changes for each variable

These were related to between-session changes of the same variable. Figure 3.2 (overleaf) shows the relationship between within-session change and between-session change for all ROM variables. The coefficient of determination ($r^2$), intercept and slope values from linear regression analysis for each pair of ROM and VAS variables are shown in Table 3.2 (overleaf). The $r^2$ values indicate that within-session changes accounted for 22% to 48% of the between-session change in each ROM measurement and 6% of the change in pain intensity. The intercepts representing the amount of between-sessions change unrelated to the size of the within-session change were less than 3 degrees for the ROM variables. The slope indicates that 42% to 63% (95% CI 25% to 88%) of the within-session change in ROM was retained between-sessions.

Table 3.2. Regression statistics. Linear regression analysis of the relationships between within-session changes and between-session changes in the limited directions of movement and VAS. The coefficient of determination ($r^2$) is the amount of variance in between-session change that is predicted by within-session change. Slope is the proportion of the within-session change that is maintained between-sessions (a slope of 1 indicates that all of the change within-session was maintained while a slope of 0.5 indicates that 50% of the within-session change was maintained.) The intercept is the change between-sessions that is unrelated to the size of any within-session change.

<table>
<thead>
<tr>
<th></th>
<th>$r^2$</th>
<th>Slope (95% CI)</th>
<th>Intercept (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limited F/E</td>
<td>0.26</td>
<td>0.63 (0.37 to 0.88)</td>
<td>2.79 (0.25 to 5.33)</td>
</tr>
<tr>
<td>Limited LF</td>
<td>0.26</td>
<td>0.42 (0.25 to 0.59)</td>
<td>2.05 (–0.05 to 4.15)</td>
</tr>
<tr>
<td>Limited ROT</td>
<td>0.48</td>
<td>0.43 (0.32 to 0.54)</td>
<td>2.23 (1.33 to 3.14)</td>
</tr>
<tr>
<td>Pain intensity (VAS)</td>
<td>0.06</td>
<td>0.30 (0.01 to 0.58)</td>
<td>–0.48 (–1.00 to 0.04)</td>
</tr>
</tbody>
</table>
Do within-session changes predict between-session changes?

Figure 3.2. The relationship between within-session and between-session change in the limited directions of ROM. All three axes of movement for all patients (n = 210) are shown. Although most within-session changes were within ± 10 degrees, some patients improved by over 15 degrees in a single direction of movement in a single treatment.

3.3.2. Accuracy, odds and likelihood ratios

Table 3.3 shows the ability of each within-session category (improved/not improved) to predict between-session category for the same variable is between 63% and 83%. The likelihood and odds ratios show that for all variables except the limited direction of lateral-flexion, within-session improvements predict between-session improvements. The lack of significance for lateral flexion may be due to the small number of patients who were categorised as improved for this variable.
Table 3.3 Likelihood and odds ratios. Accuracy is the percentage of sessions where the between-session change was correctly categorised by the within session change. The positive likelihood ratio (+LH) is the increase odds of between-session improvement if improvement occurred within-session. The negative likelihood ratio (–LH) is the decrease in odds of between-session improvement if no within-session improvement occurred.

<table>
<thead>
<tr>
<th></th>
<th>Accuracy (95% CI)</th>
<th>+LH (95% CI)</th>
<th>–LH (95% CI)</th>
<th>Odds ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limited F/E*</td>
<td>73% (1.7 to 8.2)</td>
<td>3.7 (1.7 to 8.2)</td>
<td>0.5 (0.3 to 0.7)</td>
<td>8.0 (2.4 to 26.8)</td>
</tr>
<tr>
<td>Limited lateral-flexion</td>
<td>74% (0.7 to 6.2)</td>
<td>2.1 (0.7 to 6.2)</td>
<td>0.8 (0.6 to 1.1)</td>
<td>2.5 (0.6 to 10.1)</td>
</tr>
<tr>
<td>Limited rotation*</td>
<td>83% (2.6 to 9.9)</td>
<td>5.0 (2.6 to 9.9)</td>
<td>0.2 (0.1 to 0.6)</td>
<td>21.3 (4.3 to 96.1)</td>
</tr>
<tr>
<td>Pain intensity (VAS)*</td>
<td>71% (1.3 to 4.6)</td>
<td>2.5 (1.3 to 4.6)</td>
<td>0.6 (0.3 to 0.9)</td>
<td>4.5 (1.2 to 14.4)</td>
</tr>
<tr>
<td>Pain centralisation (BC)*</td>
<td>77% (1.8 to 6.1)</td>
<td>3.3 (1.8 to 6.1)</td>
<td>0.4 (0.2 to 0.8)</td>
<td>9.2 (2.2 to 38.7)</td>
</tr>
</tbody>
</table>

*denotes significance indicated by confidence intervals not crossing 1

3.4. Discussion

Within-session change predicted between-session change for each of the parameters and the size of within-session change was related to the size of between-session change for ROM and pain intensity.

3.4.1. Strengths and weaknesses

The question under investigation was related to methods of assessment rather than a comparison of outcomes between groups so a control group was not necessary. The types of treatment provided, however were restricted as mechanisms and effects of different treatments for musculoskeletal neck pain may vary. Care would need to be exercised in generalising the results of this study to other settings or interventions as treatment was provided in one setting by one of only three practitioners all of whom work in a similar style based on a Maitland approach. Other influences on outcomes may have occurred within the treatment session besides the intended treatment and modalities other than manual therapy were not completely excluded. Therefore it
cannot be certain that within or between treatment changes were related to the manual therapy aspect of the treatment. It is also important to recognise that although within-session changes predict between-session changes, it is not possible to deduce a cause and effect relationship. In addition patients received real-world treatment that was not influenced by their participation in the study except by the treatment being ‘book-ended’ by additional assessment items before and after each treatment session.

There were no significant differences in the ability of the different within-session parameters to predict between-session change. Small between-session changes are difficult to detect when they are superimposed on the large variability that occurs in the between-session measures of ROM and pain. The more precise the measurement, the more likely it would be to be able to detect small changes. In the clinical setting, assessments of pain intensity and centralisation may be able to be more sensitive than the methods used in this study enabling smaller changes to be detected. The results of this study may therefore underestimate the effectiveness of within-session changes in pain intensity and centralisation to predict between-session changes.

3.4.2. Findings in relation to previous studies

The $r^2$ values expressing the proportion of the variation occurring between-sessions that is accounted for by within-session change were consistent with those found for the lumbar spine (Hahne et al., 2004) with ROM accounting for more of the variation than pain. It is important to note that the current study assessed resting pain before and after treatment whereas the study by Hahne et al. (2004) used level of pain with each movement. The relatively small proportion of variation in between-sessions changes accounted for by within-session changes was not unexpected considering the variety of patient’s experiences between sessions that cannot be taken into account in the experimental design. For example, in the current study one patient had a fall and lost consciousness and another cut off part of a finger with a chain saw. The slope of the linear regression is an important aspect of the analysis which does not appear to have been reported on elsewhere. The range of slopes for the regression lines found in this study reinforce the variability of how much within-session change is maintained between sessions.

The odds and likelihood ratios in the current study of the cervical spine were similar, but generally smaller than those found by (Hahne et al., 2004) for ROM and pain in the
lumbar spine. This may be a result of differences between responses of the cervical and lumbar spines or may be due to patients with more acute symptoms being included in the previous study.

Previously it was known that immediate changes in ROM and pain intensity occur following manual therapy treatment. The current study has shown that immediate changes in these parameters relate to between-session changes; at least if one is reassessing the same measurement and considering treatments predominantly by manual therapy. Previously it was known that centralisation of pain assessed using repeated movements was able to predict longer-term changes when treatment was performed according to the McKenzie method. The current study has shown that within-session centralisation was also able to predict between-session centralisation for patients treated with manual therapy.

3.4.3. Implications of results

This study has shown that the direction and the size of between-session changes in ROM and, to a lesser extent, pain intensity are predicted by within-session changes. The results support the use of within-session changes in ROM, centralisation and possibly pain intensity as predictors of between-session changes for musculoskeletal disorders of the cervical spine. These findings combined with similar findings from previous studies of the lumbar spine support the use of within-session changes as a means of predicting the likelihood of a positive outcome. Being able to predict between-session changes in a single parameter as found in this study is of limited practical use unless the between-session changes correspond to longer-term functional outcomes. For example, centralisation of pain within two treatment sessions has been shown in some circumstances to predict treatment outcomes. The next stage in assessing the relative usefulness of ROM, pain intensity and centralisation is to determine each parameter's ability to predict longer-term treatment outcomes. Further analysis of data from the population in this study is currently being undertaken to begin to answer this question.
Do within-session changes predict between-session changes?

References


Do within-session changes predict between-session changes?


and 2 months after lumbar decompression surgery for disc herniation. 


Do within-session changes predict between-session changes?
Chapter 4
Change in impairments in the first two treatments predicts outcomes in impairments, but not in activity limitations, in subacute neck pain: an observational study
Abstract

The aim of the study was to determine whether change in impairments within and between the first two manual therapy treatments predict change in activity limitations by the end of treatment in patients with subacute neck symptoms. A longitudinal, observational study included 29 participants with neck pain for more than 2 weeks who subsequently received ≥ three treatments. Impairments measured were active neck ROM in six directions (total ROM), most limited direction of ROM (limited ROM), pain intensity and pain location. Activity limitations were measured using the Neck Disability Index and the Patient Specific Functional Scale. Patients’ perceptions of change were measured using the Global Perceived Effect Scale. Impairments and patients’ perceptions were measured before and after the first two treatments and before the final treatment whereas activity limitations were measured only before the first and last treatments. All measures improved by the end of treatment. Within and between-treatment changes in limited ROM predicted changes in limited ROM ($r^2 = 0.53$ and 0.57) and total ROM ($r^2 = 0.26$) by the end of treatment. Within-and between-treatment changes in pain location predicted changes in pain location ($r^2 = 0.24$, 0.27, 0.28 and 0.57) by the end of treatment. No significant relationships were found between changes in impairments in the first two treatments and changes in activity limitations by the end of treatment. Change in impairments predicts change in the same impairment by the end of treatment, but not in other impairments or activity limitations. It is recommended that the reassessments used to guide and refine treatment be individualised and related to the specific goals for that patient.
4.1. Introduction

Musculoskeletal symptoms affecting the neck are second in frequency only to those affecting the lower back (Bogduk, Bolton, Jull, & Bellamy, 2003). Altered cervical intervertebral mobility combined with a patient’s neurophysiological responses are thought to result in impairments such as pain or limitation of active neck movement (Banks, 1998). These impairments interact with psychosocial factors and result in activity limitations (Edwards, Jones, & Hillier, 2006).

Manual therapy is a common treatment for symptoms of the cervical spine targeting altered intervertebral mobility (Banks, 1998). Based on a hypothetico-deductive reasoning model, reassessments of impairments after treatment are typically used to monitor the effectiveness of manual therapy and guide treatment selection and application (Edwards et al., 2006). The therapist’s reasoning process relies on an unproven assumption that immediate within-treatment improvement in impairments is predictive of progress towards a reduction in limitation of activities. Although immediate changes in impairments have been found to occur following manual therapy treatment (Cassidy, Quon, LaFrance, & Yong-Hing, 1992; Goodsell, Lee, & Latimer, 2000), and manual therapy can be effective in improving activity limitations (Costello & Jull, 2002), it does not necessarily follow that within-treatment changes in impairments are predictors of that improvement. Within-treatment changes in ROM and pain have been found to predict between-treatment changes in the same parameters for both the lumbar (Hahne, Keating, & Wilson, 2004) and cervical spines (Chapter 3). The possible ability of within-treatment changes in impairments to be predictors of activity limitations could therefore be demonstrated either directly or by establishing a link between between-treatment changes and activity limitations.

To our knowledge, no studies have assessed whether within- or between-treatment changes in impairments are able to predict changes in activity limitations for patients with cervical spine pain receiving manual therapy. Therefore the aim of this study was to determine if change in impairments in the first two manual therapy treatments predicted change by the end of treatment in patients with subacute neck symptoms. Changes occurring in the first two treatments were considered in this study because anecdotal evidence suggests that many clinicians advise their patients that if treatment is going to be successful, some improvement would be expected to occur within the
first two treatments. Outcome at end of treatment were considered to be the clearest indicators of the effect of manual therapy. It was considered that the intention of manual therapy is predominantly to improve symptoms by the end of treatment as distinct from other interventions such as exercises, education and modification of activities that may emphasise longer-term outcomes such as prevention of symptom recurrence. We hypothesised that within-and between-treatment change in impairments in the first two treatments would predict end of treatment outcomes and that change in combinations of impairments would be better predictors of change by the end of treatment than individual impairments.

4.2. Method

4.2.1. Design

Measurements were taken on 5 occasions: prior to and following treatment 1 (Pre 1 and Post 1), prior to and following treatment 2 (Pre 2 and Post 2), and prior to the final treatment (Pre Final). End of treatment was deemed to occur when either: the patient or therapist considered that treatment was no longer required or that other types of treatment were indicated; greater than two weeks had passed between treatments; or a total of 6 treatments had been provided. Treatment consisted primarily of manual therapy as defined by Korthals-de Bos, Hoving, van Tulder, Rutten-van Molken, Ader, et al. (2003) and was unaffected by participation in the study. Research procedures were approved by the Ethics Review Committee, James Cook University. A more detailed description of the method used in this study can be found in Chapter 3.

4.2.2. Participants

Participants were recruited from patients who presented to a private physiotherapy clinic. The inclusion criterion was neck pain of greater than two weeks duration accompanied by reduced neck mobility. Exclusion criteria were a current third party claim, a history of trauma, physical treatment within the past two weeks or presence of any inflammatory or other medical condition likely to impact on symptoms or treatment. A total of 29 patients who fulfilled the selection criteria and subsequently received three or more treatments were included in the study. 21 females and 8 males, aged 55 yr (SD 17, range 28-83) participated. They received 3.4 treatments (range 3-6), 6.1 days apart (range 2–14) within 15 days (range 7–27).
4.2.3. Outcome measures

Impairments measured included ROM and pain. ROM was measured using a head-mounted 3-axis orientation sensor (3DM MicroStrain Inc, 310 Hurricane Lane, Williston, VT). The seated patient was asked to perform three movements in each direction of right and left rotation, right and left lateral flexion, flexion and extension. The maximum value for each movement was electronically recorded without the therapist being aware of the value. The six active neck ROMs were summed to give a total ROM. The most limited direction of movement (limited ROM) was defined as the less mobile direction around the axis in which the difference between the two directions was greatest. Pain intensity was measured on an eleven-point (0 to 10) visual analogue scale such that a higher number corresponded to a greater intensity of pain. Pain location was measured according to Werneke, Hart, and Cook (1999) on a seven point (0 to 6) scale such that a higher number corresponds to a more distal location.

Activity limitations were measured using the Patient Specific Functional Scale and the Neck Disability Index. The Patient Specific Functional Scale scores activities on a visual analogue scale from 0 (unable to perform activity) to 10 (able to perform activity at the same level as before). The scores for individual activities were averaged with lower scores indicating greater activity limitations (0 to 10). The Neck Disability Index is a 10-item questionnaire with 6 responses (0 to 5) for each item. The summed score was converted to a percentage with higher scores indicating greater activity limitations.

Patients’ perceptions of overall change were measured using the Global Perceived Effect Scale designed to assess all factors related to patients’ symptoms in a single integrated measure (Hagg, Fritzell, Oden, & Nordwall, 2002) and was scored on an eleven-point scale where –5 is vastly worse and +5 is completely recovered.

4.2.4. Data analysis

The mean and standard deviation was calculated for each variable at each occasion. The relationships of interest involved change over time, so the differences between measurements were used for analysis. Change scores were calculated as change within-treatments (Post 1 minus Pre 1 and Post 2 minus Pre 2), change between-treatments (Pre 2 minus Pre 1 and Post 2 minus Pre 1) and change by the end of treatment (Pre Final minus Pre 1).
Change in impairments in the first two treatments predicts outcomes

The significance of changes was assessed using one-tailed paired-sample t-tests for each time period. Spearman’s rank order correlation coefficient \( \rho \) was used to assess relationships between all changes in variables in the first two treatments and those between the beginning and end of treatment. The coefficient of determination \( r^2 \) was reported rather than \( \rho \) as \( r^2 \) represents the proportion of the variance accounted for by the relationship and was thus more useful in indicating the clinical significance of the findings. Because of the large number of comparisons performed (~100), a family wise error corrected p value \( p < 0.01 \) was used to control the false discovery rate (Howell, 2002, pp. 336-338). Multiple regression analysis was used to explore more complex relationships between changes during the first two treatments and activity limitations. Possible predictors of changes in activity limitations with \( p < 0.10 \) were entered stepwise into a regression model and were retained if their coefficients were significant at \( p < 0.05 \). All statistical analysis was performed using SPSS version 14.

4.3. Results

All impairments and activity limitations improved by the end of treatment (Table 4.1). Furthermore, most impairments improved within the first treatment or, if not, improved between the first and second treatment (Table 4.1). In addition, patients perceived that they had improved (Table 4.1).

The coefficients of determination between change in the first two treatments and change by the end of treatment are shown in Table 4.2. In summary, change in outcome measures in the first two treatment sessions were only ever able to predict change in the same outcome measure by the end of treatment. Between-treatment changes in limited ROM predicted changes in limited ROM \( (r^2 = 0.53 \text{ and } 0.57) \) and total ROM \( (r^2 = 0.26) \) by the end of treatment. Within-and between-treatment changes in pain location predicted changes in pain location \( (r^2 = 0.24, 0.27, 0.28 \text{ and } 0.57) \) by the end of treatment. Patients’ perception of change within the first treatment predicted their perception of change \( (r^2 = 0.32) \) by the end of treatment.

No change in impairments in the first two treatments predicted change in activity limitations by the end of treatment (Table 4.2). Furthermore, stepwise addition of within-or between-treatment change in impairments into multiple regression analyses did not demonstrate any improved ability of combinations of impairments to predict change in activity limitations beyond those found with single impairments.
Change in impairments in the first two treatments predicts outcomes

Table 4.1. Mean (SD) of score and mean (SD) of change score for all outcomes.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Score</th>
<th>Change score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre 1</td>
<td>Post 1</td>
</tr>
<tr>
<td>Total ROM (deg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>259.5 (49.4)</td>
<td>281.9 (52.4)</td>
</tr>
<tr>
<td>Limited ROM (deg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>38.1 (16.6)</td>
<td>46.7 (18.9)</td>
</tr>
<tr>
<td>Pain intensity (0 to 10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.9 (2.1)</td>
<td>3.3 (1.8)</td>
</tr>
<tr>
<td>Pain location (0 to 6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.0 (0.9)</td>
<td>2.3 (1.1)</td>
</tr>
<tr>
<td>Neck Disability Index (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>28.1 (13.2)</td>
<td>16.6 (10.4)</td>
</tr>
<tr>
<td>Patient Specific Functional Scale (0 to 10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.3 (1.4)</td>
<td>7.2 (1.9)</td>
</tr>
<tr>
<td>Global Perceived Effect Scale (-5 to +5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.8 (2.0)</td>
<td>1.6 (1.5)</td>
</tr>
</tbody>
</table>

* indicates a significant difference between occasions of measurement (p < 0.01)
Table 4.2. Spearman coefficients of determination ($r^2$) between change in the first two treatments and change by the end of treatment.

<table>
<thead>
<tr>
<th>Treatment 1 and 2</th>
<th>Pre Final minus Pre 1</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
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<tr>
<td>Impairments and global perceived effect</td>
<td>Impairments</td>
<td>Activity limitations</td>
<td>Patients' perceptions</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td>Total ROM</td>
<td>Limited ROM</td>
<td>Pain intensity</td>
<td>Pain location</td>
<td>NDI</td>
<td>PSFS</td>
</tr>
<tr>
<td>Total ROM (deg)</td>
<td>Post 1 minus Pre 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.18</td>
<td>0.07</td>
<td>0.08</td>
<td>0.00</td>
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<td>0.00</td>
</tr>
<tr>
<td></td>
<td>p=0.01</td>
<td>p=0.09</td>
<td>p=0.07</td>
<td>p=0.42</td>
<td>p=0.46</td>
<td>p=0.40</td>
</tr>
<tr>
<td></td>
<td>Pre 2 minus Pre 1</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.14</td>
<td>0.18</td>
<td>0.03</td>
<td>0.01</td>
<td>0.00</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>p=0.03</td>
<td>p=0.01</td>
<td>p=0.19</td>
<td>p=0.32</td>
<td>p=0.42</td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td>0.02</td>
<td>0.02</td>
<td>0.09</td>
<td>0.01</td>
<td>0.00</td>
<td>0.06</td>
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<td>p=0.36</td>
<td>p=0.46</td>
<td>p=0.10</td>
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<tr>
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<td>Limited ROM (deg)</td>
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<td>Post 2 minus Pre 2</td>
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<td></td>
<td>0.12</td>
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<td>p&lt;0.001 *</td>
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<td>0.01</td>
<td>0.00</td>
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<td>p=0.09</td>
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<td>p=0.49</td>
</tr>
<tr>
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</table>
Table 4.2 (cont)

| Treatment 1 and 2 Impairments and global perceived effect | Pre Final minus Pre 1 |  |  |  |  |  |  |
|----------------------------------------------------------|-----------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
|                                                          | Impairments           | Activity            | Patients'           |                     |                     |                     |
|                                                          | Total ROM             | Limited ROM         | Pain intensity      | Pain location       | NDI                 | PSFS                | GPES                |
| Pain location (0 to 6)                                    |                       |                     |                     |                     |                     |                     |                     |
| Post 1 minus Pre 1                                       | 0.00                  | 0.00                | 0.11                | 0.27                | 0.04                | 0.01                | 0.00                |
|                                                          | p=0.42                | p=0.38              | p=0.04              | p<0.01 *            | p=0.15              | p=0.31              | p=0.40              |
| Pre 2 minus Pre 1                                        | 0.02                  | 0.00                | 0.04                | 0.24                | 0.03                | 0.00                | 0.04                |
|                                                          | p=0.22                | p=0.47              | p=0.16              | p<0.01 *            | p=0.19              | p=0.47              | p=0.15              |
| Post 2 minus Pre 2                                       | 0.01                  | 0.00                | 0.01                | 0.28                | 0.01                | 0.05                | 0.00                |
|                                                          | p=0.33                | p=0.48              | p=0.28              | p<0.01 *            | p=0.35              | p=0.13              | p=0.41              |
| Global Perceived Effect Scale (-5 to 5)                  |                       |                     |                     |                     |                     |                     |                     |
| Post 1 minus Pre 1                                       | 0.03                  | 0.07                | 0.00                | 0.00                | 0.17                | 0.06                | 0.32                |
|                                                          | p=0.19                | p=0.10              | p=0.49              | p=0.47              | p=0.02              | p=0.10              | p<0.01 *            |
| Pre 2 minus Pre 1                                        | 0.01                  | 0.00                | 0.06                | 0.01                | 0.01                | 0.03                | 0.17                |
|                                                          | p=0.30                | p=0.43              | p=0.11              | p=0.36              | p=0.35              | p=0.18              | p<0.01              |
| Post 2 minus Pre 2                                       | 0.00                  | 0.02                | 0.01                | 0.02                | 0.03                | 0.03                | 0.12                |
|                                                          | p=0.50                | p=0.21              | p=0.35              | p=0.26              | p=0.19              | p=0.18              | p=0.04              |

* indicates a significant correlation (p < 0.01 for the corresponding rho)
4.4. Discussion

This study set out to determine if change in impairments in the first two treatments predicted change in activity limitations by the end of treatment for patients with subacute neck pain receiving manual therapy. All impairments and activity limitations improved by the end of treatment. Change in some impairments in the first two treatments predicted change in the same impairment by the end of treatment, but the expected ability of change in either individual impairments or combinations of impairments to predict change in activity limitations by the end of treatment did not occur.

4.4.1. Strengths and weaknesses

This is the first known study to investigate an assumption underlying clinical reasoning commonly used in manual therapy. The sample size used in this study was sufficient to detect strong relationships, but would not necessarily have been able to detect weak or complex relationships. Repeating the statistical analyses with a significance level of \( p < 0.05 \) to detect type 2 errors did not produce a clinically-significant difference in the results. Although the analysis reported in this paper was limited to correlation and regression analysis, we previously performed other statistical tests, grouping and analysing the variables in a variety of ways but no additional clinically-significant patterns were detected.

The results of this study may not be generalisable to treatment by modalities other than manual therapy, other forms of manual therapy or perhaps even to treatment by other practitioners. The overt interventions used in this study were limited to predominantly manual therapy, but any therapeutic contact impacts on psychosocial factors and potentially has effects that are difficult to predict. In addition, it has been suggested that the hypothetico-deductive reasoning model of clinical reasoning used in this study may not be appropriate when extended beyond the relatively mechanistic constructs of impairment to include factors such as activity limitations where ‘knowledge is socially constructed, context dependent and that there are multiple realities rather than a single truth waiting to be discovered’ (Edwards et al., 2006).
Change in the first two treatments predicts outcome in impairments

4.4.2. Findings in relation to previous studies

Within-treatment (Skytte, May, & Petersen, 2005; Werneke & Hart, 2001; Werneke, Hart, & Cook, 1999) and between-treatment (Werneke & Hart, 2003) changes in pain location have been found to predict changes in various outcome measures by the end of treatment in patients with low back pain when the treatment is according to the McKenzie method (Walsh, 2001). Our findings supported pain location as being a predictor of pain location by the end of treatment but not as a predictor of other outcome measures. The apparent discrepancy between this study and previous studies may be due to treatment in the current study consisting of manual therapy rather than the McKenzie method.

Within-treatment changes in active ROM and pain intensity have been found to predict between-treatment changes in the same parameters both for patients with low back pain (Hahne et al., 2004) and neck pain (Chapter 3) receiving manual therapy. Our current analysis extends these findings to the ability of within-treatment change in some impairments to predict change by the end of treatment, but almost exclusively within the same impairment.

The findings of this study support the notion that change in active neck ROM, in particular, change in the most limited ROM, is a better predictor of change by the end of treatment than change in pain intensity. Previous studies have shown that neck ROM in symptomatic patients tends to decrease with repeated measurement (Lee, Nicholson, & Adams, 2005), but this did not occur in our repeatability assessments nor was it apparent in post treatment data. Differences in the method of measurement may account for these discrepancies, as our participants were not required to maintain an end of range position while measurements were taken.

4.4.3. Clinical implications

The results of this study suggest that although change in impairments in the first two treatments predicts change in the same impairment by the end of treatment, this change is not a good predictor of improvement in activity limitations for patients with subacute neck pain receiving manual therapy. Perhaps most important is the finding of the specificity of predictors for change by the end of treatment in the same parameter.

In order to be useful in guiding the clinician’s application and refinement of treatment, a
reassessment must be responsive and valid. That is, the reassessments must be able to detect small changes and the changes that are detected must be related to changes in the desired outcomes. Measures of activity limitations are not considered responsive to the small changes necessary for day-to-day reassessment whereas measures of impairments used to assess within- and between-treatment effects are responsive, but their relevance is now questionable.

The importance of this study for the clinician is that no single impairment or combination of impairments accurately predicted improvement in activity limitations. It is recommended that in order to assist patients and clinicians to achieve specific goals, the reassessments used to guide and refine treatment should be individualized for that patient and related directly to the goals specific to that patient. Reassessment of one impairment or a set of impairments is unlikely to be effective for all patients. Rather we suggest that an understanding of the patient's goals can assist the clinician to determine a combination of impairments and activity limitations to be reassessed that balance responsiveness and relevance. Changes in the most limited or most painful direction of active movement may be the most responsive impairment for reassessment, but additional assessments of activity limitations may be necessary to ensure their relevance.
## 4.5. Appendix Raw CMD, offset and adjusted CMD data

Change in the first two treatments predicts outcome in impairments

<table>
<thead>
<tr>
<th>Subject</th>
<th>Intra-rater</th>
<th>CMDs</th>
<th>Inter-day</th>
<th>Inter-rater</th>
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<td>Mid</td>
<td>Upper</td>
<td>Low</td>
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<td>0.02</td>
<td>0.90</td>
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</tbody>
</table>

95
Change in the first two treatments predicts outcome in impairments

| Subject | Intra-rater Low Left | Intra-rater Low Right | Intra-rater Mid Left | Intra-rater Mid Right | Intra-rater Upper Left | Intra-rater Upper Right | Inter-day Low Left | Inter-day Low Right | Inter-day Mid Left | Inter-day Mid Right | Inter-day Upper Left | Inter-day Upper Right | Inter-rater Low Left | Inter-rater Low Right | Inter-rater Mid Left | Inter-rater Mid Right | Inter-rater Upper Left | Inter-rater Upper Right |
|---------|----------------------|-----------------------|----------------------|-----------------------|------------------------|------------------------|----------------------|---------------------|---------------------|---------------------|----------------------|----------------------|----------------------|---------------------|---------------------|----------------------|----------------------|
|         | Offset (mm)          |                       |                      |                       |                        |                        |                      |                     |                     |                     |                      |                      |                      |                     |                     |                     |                     |                     |
| 1       | 1.00                 | 0.96                  | 0.99                 | 1.00                  | 0.99                  | 1.00                   | 0.99                 | 1.00                | 1.00                | 1.00                | 1.00                 | 1.00                 | 1.00                 | 1.00                | 1.00                | 1.00                | 1.00                |
| 2       | 0.99                 | 0.96                  | 0.99                 | 0.97                 | 1.00                  | 0.98                  | 0.98                 | 0.96                | 1.00                | 1.00                | 1.00                 | 0.99                 | 0.99                 | 0.99                | 0.99                | 1.00                | 1.00                |
| 3       | 0.99                 | 0.97                 | 1.00                 | 0.82                 | 0.95                  | 0.98                  | 0.95                 | 0.93                | 0.96                | 0.91                | 0.93                 | 0.99                 | 0.99                 | 0.99                | 0.97                | 1.00                | 1.00                |
| 4       | 0.99                 | 0.99                 | 0.99                 | 1.00                 | 0.98                  | 0.99                  | 0.98                 | 0.99                | 1.00                | 1.00                | 1.00                 | 0.99                 | 0.99                 | 0.99                | 1.00                | 1.00                |
| 5       | 0.98                 | 0.93                 | 0.96                 | 1.00                 | 0.99                  | 0.98                  | 1.00                 | 0.93                | 0.99                | 0.98                | 0.99                 | 0.98                 | 0.99                | 0.99                | 1.00                | 1.00                | 1.00                |
| 6       | 0.87                 | 0.94                 | 0.98                 | 1.00                 | 0.99                  | 0.99                  | 0.98                 | 0.96                | 0.99                | 0.99                | 0.99                 | 0.99                 | 0.97                | 0.99                | 0.99                | 0.98                | 0.97                |
| 7       | 0.97                 | 0.65                 | 0.99                 | 0.76                 | 1.00                  | 0.96                  | 0.99                | 0.73                | 0.99                | 0.88                | 0.99                 | 0.96                 | 0.98                | 0.96                | 0.99                | 1.00                | 1.00                |
| 8       | 0.99                 | 0.99                 | 0.99                 | 0.95                 | 1.00                  | 0.88                  | 0.90                | 0.93                | 0.96                | 0.97                | 0.96                 | 0.97                | 0.96                | 0.97                | 0.95                | 1.00                | 0.98                |
| 9       | 0.97                 | 0.97                 | 0.99                 | 0.96                 | 0.99                 | 0.94                 | 0.99                | 0.98                | 0.99                | 0.97                | 1.00                 | 0.95                | 0.98                | 1.00                | 0.98                | 0.99                | 0.97                |
| 10      | 0.90                 | 0.98                 | 0.87                 | 0.98                 | 0.85                 | 0.87                  | 0.98                | 0.98                | 0.97                | 1.00                | 0.95                | 0.98                | 1.00                | 0.98                | 0.99                | 0.97                | 0.97                |

Adjusted CMDs
References


Chapter 5
Posteroanterior movements of the cervical spine: repeatability of force displacement curves
Abstract
The repeatability of instrumented assessments of posteroanterior (PA) movements has been reported previously for lumbar and thoracic spines, but only in relation to limited parameters of the movement. This study describes a device for measuring PA movements of the cervical spine and reports on repeatability of the entire force/displacement (FD) curves. Repeatability was assessed using coefficients of multiple determination (CMDs) and adjusted CMDs (where the mean offsets between the two curves are removed and the shape of the curve can be more directly assessed) for inter-rater intra-day (Inter-rater), intra-rater inter-day (Inter-day) and intra-rater intra-day (Intra-rater) repeated measurements. The mean CMD and mean adjusted CMD for intra-rater measurements (0.90 and 0.99 respectively) were significantly higher than for the other measurement intervals. Inter-rater and Inter-day mean CMDs were 0.76 and 0.73 and mean adjusted CMDs were 0.96 and 0.97. It is concluded that the maximum repeatability is achieved if the same operator reassesses the patient on the same day. It is hoped that the methodology described will form the basis for further research that will enable greater understanding of what characteristics of PA movements inform manual palpation and thereby enable improvement in both manual therapy treatment teaching efficiency of manual therapy skills.
Musculoskeletal disorders of the spine are amongst the most common health problems in Australia (Bogduk, Bolton, Jull, & Bellamy, 2003). Spinal mobilisation is a common form of treatment for spinal musculoskeletal disorders and is based on a presumed relationship between symptoms and intervertebral mobility. Posteroanterior (PA) movements typically produced by the manual application of force to an individual vertebra either on or lateral to the midline are commonly used for assessment and treatment of spinal symptoms (Maitland, Hengeveld, Banks, & English, 2005, pp. 117-128).

During a PA movement, the clinician perceives the relationship between the force applied and the resulting displacement. The PA movement is intended to provide the clinician with information about source of the patient’s symptoms and is often represented by a force-displacement (FD) curve. Although PA movements were once thought to produce localised translational intervertebral movement, it is now clear from both in vivo (Caling & Lee, 2001; Kulig, Landel, & Powers, 2004; Lee & Evans, 1997; Lee, McGregor, Bull, & Wragg, 2005; McGregor, Wragg, Bull, & Gedroyc, 2005; McGregor, Wragg, & Gedroyc, 2001) and in vitro studies (Gal, Herzog, Kawchuk, P. Conway, & Zhang, 1997a; Gal, Herzog, Kawchuk, Conway, & Zhang, 1997b; Sran, Khan, Zhu, & Oxland, 2005) that in addition to segmental movement around a flexion/extension axis, other movement also occurs including regional spinal movement, soft tissue compression, and movement of muscle and connective tissue. There are two challenges to assessing the source of a patient’s symptoms by PA movements. Firstly, it is not known how the characteristics of PA movements are altered in the presence of symptoms. Secondly, the displacement produced by a PA movement is complex including deformation of soft tissues as well as the vertical movement of the vertebra. The vertical movement of the vertebra in turn not only involves the entire cervical spine, but is influenced by other factors including rocking of the head and compression of the padding of the plinth. The difficulty in interpreting the clinically relevant characteristics of PA movements is therefore in being able to extract a symptomatic structure’s as yet unknown influence from a PA movement’s already complex signal.

In spite of the apparent difficulties, clinicians are able to detect clinically useful
information from manual assessments of PA movements. For example, the location of congenital fusion can be reliably detected by manual motion palpation (Humphreys, Delahaye, & Peterson, 2004). In a more clinically relevant study, patients who received treatment corresponding to findings on manual palpation had better outcomes than those receiving randomly allocated treatment (Fritz, Whitman, & Childs, 2005).

Several researchers have attempted to objectively assess PA movements using an indentor to apply a force over part of a vertebra and sensors to measure displacement and force (Edmondston, Allison, Gregg, Purden, Svansson, et al., 1998; Kawchuk, Fauvel, & Dmowski, 2001; Latimer, Goodsel, et al., 1996; Lee & Svensson, 1990; Lee & Evans, 1992). Attempts at characterisation of PA movements from instrumented assessments relied primarily on single values of displacement or stiffness at specified force levels. Lee and colleagues (Latimer et al., 1996; Lee & Svensson, 1990) considered that the FD curve could be considered as consisting of a ‘toe region’ where the slope was non-linear followed by a linear region of the curve over 20 N or 30 N. The slope of the linear portion of the FD curves, the overall displacement and the length of the toe region have all been used to characterise PA movements. Although the rationale for selection of these parameters is not clear, they have been widely used to describe PA movements (e.g. Allison et al., 2001; Chiradejnant, Maher, & Latimer, 2003; Kaigle, Ekstrom, Holm, Rostedt, & Hansson, 1998; Latimer et al., 1996; Lee & Evans, 1992; Shirley, Ellis, & Lee, 2002; Sran et al., 2005).

Differences in single measures of stiffness or displacement of PA movements have been found to be related to factors affecting the target intervertebral structures (Kawchuk et al., 2001; Latimer, Lee, Adams, & Moran, 1996; Sran et al., 2005) as well as factors affecting regional or extraspinal factors (Chansirinukor, Lee, & Latimer, 2003; Colloca & Keller, 2004; Edmondston et al., 1998; Kawchuk & Fauvel, 2001; Shirley, Hodges, Eriksson, & Gandevia, 2003). In spite of the apparent difficulties, clinicians are able to detect clinically useful information from manual assessment of PA movements. Furthermore instrumented assessments have not agreed with clinician’s interpretations from manual assessments (Latimer et al., 1996) and the single measures used to characterise PA movements do not appear to be the same as the parameters that inform manual motion palpation (Maher, Simmonds, & Adams, 1998). As a result, the characteristics of PA movements that clinicians consider during motion palpation remain elusive (Petty, Maher, Latimer, & Lee, 2002).
Findings are emerging suggesting how changes in intersegmental stiffness may be related to pathology and how such changes might impact on PA movements. Gay, Ilharreborde, Zhao, Zhao, & An (2006) found differences in segmental stiffness occurring with lumbar disc degeneration were more pronounced near the neutral position rather than near the end of range. We performed computer-based modelling of PA movements where alterations of the ‘neutral zone’ suggested that effects on PA movements would be complex with the greatest differences likely to occur in the early to middle portion of the PA movement (Tuttle, Laakso, & Barrett, 2006).

The single values of displacement or stiffness used previously may not be the clinically relevant characteristics of PA movements. Other, as yet unknown parameters of the FD relationship may be necessary to adequately characterise PA movements. The repeatability of measurements of the FD relationship of PA movements must therefore be established if measurements of PA movements are to be used to detect the clinically relevant characteristics of PA movements. In order to ensure appropriate experimental design for future studies, it is also important to know whether repeated measures can be reliably performed by the same or different practitioners and on the same or different days.

The purpose of this study was to determine the inter-rater, intra-rater and inter-day repeatability of the Posteroanterior Movement Assessment Device (PMAD) which was developed to assess PA movements of the cervical spine. It was hypothesised that the repeatability would be best for the same operator on the same day and that the variation from the tests being performed on different days would be greater than the variation resulting from different operators.

5.2. Methods

5.2.1. Subjects and experimental design

Subjects were recruited from university staff and students. Inclusion criteria were asymptomatic subjects defined as having no neck symptoms within the past six months that required treatment and no contraindications or precautions to manual therapy assessment or treatment (H. Lee, Nicholson, & Adams, 2004). Ten participants (six females and four males; mean age 37.2, range 21 to 50; mean weight 72.7 kg, range 52 to 92 kg; mean height 169.9, range 155 to 179 cm) were recruited for the study. The
experimental protocol was approved by the Griffith University Human Research Ethics Committee and all individuals provided written confirmation of their informed consent prior to participation.

The procedures were explained and the subjects familiarised with the equipment prior to the first trial. Subjects were assessed by two trials on each of two consecutive days with all trials performed by the same operator except the second trial on day two which was performed by a second operator. Both operators were qualified musculoskeletal physiotherapists with over 10 years experience. Each trial consisted of PA movements to a total of six locations: both sides at each of three levels separated by 12 mm along the long axis of the treatment bed. The intention of this study was to assess the repeatability of the PMAD not to assess the ability to locate anatomical locations. It was therefore not necessary to undertake the imaging that would be required to locate positions anatomically. Rather the positions of the PMAD selected in the first trial were repeated for subsequent trials as it was necessary only to ensure that the indentor and patient were located in the same position for repeated measurements. After the first trial on each day, the subject stood and walked a few steps before adopting the same position for a second trial.

5.2.2. Instrumentation and data collection protocol

‘Unilateral’ PA movements were assessed with the force applied over the articular pillar. In order to maximise the relevance of our instrumented assessment to the clinical setting, our intention was to develop a methodology capable of assessment of PA movements of the cervical spine in a manner as similar as possible to that which occurs during manual palpation of PA movements. In principle, the device was similar to methods reported previously for the lumbar and thoracic regions, but was adapted in two ways. Firstly, the indentor was constructed to be similar in size to the human thumb and secondly, the force was applied manually rather than mechanically. The force being applied manually enables the device to be used in future studies to establish the physical factors corresponding to clinicians’ perceptions. The principal requirements of the PMAD (Figure 5.1) developed for this purpose were identified as being able to:

1. Apply a PA force to repeatable locations.
2. Produce repeatable movements as similar as possible to manual assessment of PA movements.
Repeatability

3. Be perceived by the subject and operator to be as similar as possible to those occurring with manual assessment.
4. Accurately measure the force and displacement characteristics of the PA movements.

The indentor was intended to resemble the human thumb as used in manual assessment of PA movements to ensure maximum subject comfort without the indentor being larger than the contact used by a practitioner or wider than the height of a cervical vertebra. An indentor was constructed of a 25 mm length of 12 mm square aluminum section with edges rounded to a radius of approximately 1 mm.

Figure 5.1. Posteroanterior Movement Assessment Device (PMAD). The device measures force and displacement during movement produced by a force applied manually to the thumb-hold.

The assessment of each location consisted of five gradual applications of force up to 25 N performed at an intended frequency of approximately 1 Hz (actual frequency 0.40
Repeatability

Hz, SD 0.082) which is within the range used in manual assessment (Snodgrass, Rivett, & Robertson, 2006). The force and displacement data were simultaneously recorded while the operator gradually applied force to the thumb-hold until hearing an audible sound produced by the data acquisition program when the force reached 25 N. The five applications of the force were angled medially by 10 degrees and positioned such that the shaft was 15 to 25 mm from the midline when the indentor contacted the subject. The shaft was secured to a linear bearing to ensure smooth repeatable movement and the entire assembly could be repositioned to a corresponding position on the contralateral side. Both the operator and subjects found this combination of indentor size, position and direction most closely approximated the sensations felt during manual assessment of unilateral PA movements.

The applied force was measured with a load cell (Transducer Technologies MLP-25) between the thumb-hold and the indentor. The corresponding displacements were measured with a linear potentiometer (Hollywell LTS04N04KB5C) attached to the shaft of the PMAD. The non-repeatability of the load cell is reported by the manufacturer to be 0.05% and the linearity of the potentiometer to be ± 0.1%. A two-point linear calibration was performed for both the potentiometer and load cell prior to each day’s testing. Three readings were taken at each of two displacements (separated by 69 mm) and two loads (deadweights of mass 27 and 2362 g). The sensors were connected to a PC through a USB DAQ card (USB-6008, National Instruments) and sampled at 100 Hz. Data collection and storage was performed with custom software written in Labview Version 7i.

A repeatable subject position was achieved by replacing the head section of a standard height-adjustable treatment bed with a specifically designed head-crade lined with 2 mm of high density EVA foam. To determine how much movement was likely to occur as a result of compression of the head-crade and treatment bed an anatomical skull model was placed in the head cradle to represent the subject’s head and a flat plate 20 cm × 20 cm weighing 5 kg was placed on the treatment table as a conservative representation of the subject’s chest. Forces of 12.5 N were applied to each and displacements measured using the PMAD. The measured displacement of the skull model of 0.2 mm and of the plate of 0.4 mm suggested that less than 0.4 mm of the PA movement on subjects would result from compression of the supporting head-crade and treatment table. The reproducibility of positioning of the subject was tested by
measuring the angle of a pointer held between the subject's teeth and the position of the vertex. The angle and position were then re-measured after the subject stood up and repositioned themselves on the treatment bed. The ICC (3,1) were 0.94 and 0.99 for head angle and position respectively and the corresponding 95% limits of agreement (Bland & Altman, 1999) were −1.9 to 1.9 degrees and −1.7 to 1.7 mm, respectively. A sliding frame able to be fixed at 12 mm intervals along the long axis of the bed was fixed to the head cradle to enable repeatable positioning of the device for the three levels to be tested.

5.2.3. Data analysis

Following data collection, the data was processed with custom software using Matlab Version 7.04. Data from the second, third and fourth applications from 0.5 N to 25 N of force were filtered using a second order low-pass Butterworth filter with a cut-off frequency of 2.5 Hz. The displacement at 0.5 N was assigned a value of zero to create a common starting point for further comparisons and the three resulting curves were averaged. In preliminary trials soft tissue occasionally appeared to move under the indentor and the force in the resulting measure did not increase continuously. Therefore, when processing the data, if the force data did not continuously increase through the range being assessed for any of the middle three applications, the fifth and, when necessary, the first applications were used in their place for further analysis. Although data from the first application were used on only three occasions, it is important to note that our preliminary testing did not suggest the need for ‘preconditioning’ the movement as we did not detect any differences between the first and subsequent force applications. Preconditioning may not have been required due to aligning all curves at a force level of 0.5 N rather than at a common location in space. Ninety-nine displacement values corresponding to forces from 0.5 N to 25 N at 0.25 N intervals were then determined using a cubic spline interpolation.

5.2.4. Statistical analysis

The coefficient of multiple correlation (CMC) was advocated by Kadaba, Ramakrishnan, Wootten, Gainey, Gorton, & Cochran (1989) and has since been used extensively to assess the repeatability of curve data related to gait. The adjusted coefficient of multiple determination (CMD) is defined as the square of the CMC and was used in the current study as it indicates the proportion of the variance accounted
for within the data. CMDs have been used to assess the repeatability of measures of both gait (Kavanagh, Morrison, James, & Barrett, 2005) and active spinal movement (Lee, Laprade, & Fung, 2003), but to our knowledge they have not been used for the assessment of the repeatability of passive movements. CMD is defined as:

\[ \text{CMD} = 1 - \frac{\sigma_e^2}{\sigma_g^2} \]  

Equation 1

Where:

\( \sigma_e^2 \) represents the variance from the ensemble average curve, and

\( \sigma_g^2 \) represents the variance from the grand mean of the FD curves.

The more similar the curves being compared, the more \( \sigma_e^2 \) approaches 0 and the CMD approaches 1. Conversely, the more dissimilar the curves, the more \( \sigma_e^2 \) approaches \( \sigma_g^2 \) and the CMD approaches 0.

The offset (systematic bias) in pairs of FD curves was assessed by calculating the difference (in mm) between the grand means of the two curves. In order to facilitate comparison of the overall shape of the curves, adjusted CMDs were obtained by recalculating the CMDs for each pair of FD curves with the offset removed. In other words the repeatability of the original curves considers the curves with a common starting point, the offsets indicate any systematic bias as might occur with altered tissue compliance or muscular contraction while the adjusted curves compare the overall shape of the curves.

The repeatability of the FD curves was assessed by calculating the CMDs for each of the three repeated measures that were assessed: intra-day, inter-rater (Inter-rater); intra-day, intra-rater (Intra-rater); and inter-day, intra-rater (Inter-day). The CMDs were also calculated to compare the repeatability of the shape of the curves with the offsets.
removed. ANOVAs and post hoc Scheffe tests were used to assess main effects of repeated measure interval, side, and level on CMDs, offsets and adjusted CMDs. Statistical significance was set at $p < 0.05$.

### 5.3. Results

Representative data for both sides of one subject showing the raw data and averaged curves are shown in Figures 5A.1 and 5A.2 in the appendix. Representative data of two pairs of repeated measures with the corresponding CMDs, offsets and adjusted CMDs are shown in Figure 5.2. The graph illustrates how the overall displacement and the shape of the FD curves can differ and gives an indication of the extent of agreement between pairs of curves that corresponds with CMD, offset and adjusted CMD values.

![Graph showing forces and displacements](image)

**Figure 5.2.** Representative data from two pairs of repeated measures with corresponding CMDs. The similarity of the Intra-day curves is confirmed by the high CMD. The adjusted CMD indicates the extent of agreement between the curves once the offset is removed. The high adjusted CMDs of both repeated measures indicate close agreement in the shape of the curves.
The CMDs for each repeated measure interval ranged from 0.72 to 0.90 with the Intra-rater mean CMD being 0.90 (Figure 5.3a). There were significant differences between CMDs for the three repeated measure intervals (F = 6.57, dF = 2), with Intra-rater repeatability being greater than Inter-rater by 0.16 (CI 0.03 to 0.28) and greater than Inter-day by 0.18 (CI –0.04 to 0.31). There were no differences in CMDs between sides or levels.

The offsets for the repeated measure comparisons are shown in Figure 5.3b. The mean offsets for the three repeated measure intervals ranged from −0.1 mm to 2.0 mm. There were significant differences in the magnitude of the offsets (F = 8.47, dF = 2) with the Inter-day offsets being larger than Inter-rater by 0.16 mm (CI –0.34 to 2.77 mm) and larger than Intra-rater by 2.22 mm (CI –0.80 to 3.63 mm). There were no significant differences in the offsets between sides or levels.

As shown in Figure 5.3c, the adjusted CMDs for the three retest intervals were higher than the standard CMDs and ranged from 0.96 to 0.99. Again there were significant differences between the three intervals (F = 2.46, dF = 2) with the with Intra-rater repeatability being greater than Inter-rater by 0.03 (CI 0.01 to 0.05) and Inter-day by 0.02 (CI –0.01 to 0.04). There was a small, but statistically significant difference in the adjusted CMDs between sides (F = 4.11, dF = 1) with the left side being greater than the right by 0.01 (CI 0.00 to 0.03), but no differences between levels.
Figure 5.3. Repeatability for each level and side for each repeatability interval. CMDs are shown in a), Offsets (the difference between the ensemble mean values of each FD curve) are shown in b) and the Adjusted CMDs (comparing the shape of the FD curves with the offsets removed) are shown in c).
5.4. Discussion

The purpose of this paper was to report on the repeatability of assessment of PA movements of the cervical spine using the PMAD. To our knowledge this is the first report of the repeatability of assessment of PA movements of the cervical spine and the first study to assess the repeatability of entire FD curves rather than single values for any region of the spine.

5.4.1. Repeatability of PA movements

As expected the best repeatability for all measures occurred for Intra-rater comparisons, where the repeated measures were taken by the same operator on the same day. The expected difference between Inter-rater and Inter-day repeatability was only found in relation to the adjusted CMDs and was most likely too small to be of practical significance. Therefore differences in PA movements would be expected to be easiest to detect if repeated measurements are taken by the same operator on the same day. The instrumentation can be considered to perform equally well regardless of side or level as indicated by the repeatability being comparable across sides and levels.

The adjusted CMDs were consistently larger than the non-adjusted CMDs demonstrating greater consistency in the shape of the curve than when the curves had a common starting point. If only the shape of the curve is being considered, the repeatability of the current instrumentation is excellent with CMDs over 0.96 for all intervals of repeated measures. The reason for or significance of the offsets being larger for intra-day than for the other comparisons is not clear.

Repeatability of FD curves from assessments of PA movements has not been reported previously. Previous studies on in vivo assessment of PA movements have been performed on lumbar, thoracic or animal spines. Lee and Evans (1992) assessed PA movements of the lumbar spine and reported ICCs for inter-day testing of 0.99 and 0.95 for displacement with a maximum error of less than 1 mm. Lee and Svensson (1990) also found good repeatability of the stiffness of the linear portion of the FD curve with ICCs of 0.88. A later device from the same group reported ICCs of 0.89 to 0.96, for intra-day, intra-rater repeated measures performed without repositioning the subject (Latimer et al., 1996). Kawchuk et al. (2001) added an ultrasound transducer to the tip
Repeatability

of the indentor of a similar instrument to reduce possible errors in positioning as well as providing a more direct indication of the depth and movement of the target vertebra. The resulting accuracy for the linear region of the FD curve of porcine vertebrae was 1% to 2% for displacement and 6% for stiffness while for the non-linear region of the curve the corresponding accuracies were 3% to 4% and 14% respectively. It is not possible to make direct comparisons between the current study and previous studies as different measures of repeatability were employed in each study. It could be expected that assessment of the cervical spine may be less repeatable than other regions of the spine as the subject’s position when assessing the cervical spine is less stable and the bony landmarks being assessed more difficult to locate accurately.

5.4.2. Relevance to clinical practice

The PMAD described in this paper was intended to assess PA mobility in a way comparable to that used in manual palpation. Even though PA movements involve the entire cervical spine, their intention is to assess symptomatic structures and it appears that clinicians are able to extract clinically useful information. It is not understood what parameters of PA movement inform the practitioner’s interpretations, but it is clear that single values of displacement or stiffness do not adequately characterize the movements being assessed.

At this time we can only speculate on ways symptoms or pathology might affect FD curves measured using the PMAD. For example, increased muscular contraction might produce a linear change in the entire curve, a difference in the size of an intervertebral ‘neutral zone’ might produce a greater difference in the early part of the PA movement, while alterations in viscosity as suggested by Nicholson, Maher, Adams, & Phan-Thien (2001) might result in rate-dependent differences that are uniformly distributed throughout the PA movement. The potential complexity of aspects of PA movements are further illustrated by Maher et al. (1998) who documented over 40 terms used by practitioners to describe their perceptions of mobility on motion palpation. Ramsay (1996) suggests that the significant features of continuous data are often more apparent when one considers derivatives of the raw data. For example the pattern of stiffness (the first derivative of the FD curve) or the change in stiffness (the second derivative of the FD curve) may be factors considered by practitioners. As the meaning of differences in offsets in the current study is unclear, it is interesting to note that the
offsets are eliminated when derivatives of the data are considered. Changes in stiffness for example may be related to descriptors such as $R_1$ (the point where the first ‘resistance’ to the movement is felt) and end-feel (the change in stiffness at the end of the movement).

Some authors suggest that the difficulty in assessment of PA movements results from practitioners being informed by non-repeatable or idiosyncratic factors (Maher & Adams, 1995). Others have suggested using clinicians who are ‘gold standard palpators, against which others can be calibrated’ (Hansen, Simonsen, & Leboeuf-Yde, 2006). It is hoped that methodologies such as described in this paper will help reduce the subjectivity of motion palpation and enable more objective characterisation of the clinically relevant aspects of PA movements. A clearer understanding of the relevant characteristics of PA movements not only has the potential to improve the effectiveness of manual therapy diagnosis and treatment, but to improve the efficiency of teaching manual therapy skills to students.

It is expected that the repeatability of the PMAD found in the current study would be sufficient to enable studies using this methodology to detect differences relevant to clinical practice regardless of whether the differences are constant, rate dependent or unevenly distributed throughout the PA movements.
5.5. Appendix A. Representative data

Figure 5A.1. Force displacement curves from the right side of one subject. Graphs a), c) and e) are continuous curves from a single trial including loading and unloading of the upper, middle and lower locations respectively. The grey lines in graphs b), d) and f) are smoothed loading curves from three individual indentations of each trial. The black line is the result of aligning and averaging the three loading curves and was used in subsequent calculations of repeatability.
Repeatability

Figure 5A.2. Force displacement curves from the left side of the same subject as shown in Figure 5A.1. Graphs a), c) and e) are continuous curves from a single trial including loading and unloading of the upper, middle and lower locations respectively. The grey lines in graphs b), d) and f) are smoothed loading curves from three individual indentations of each trial. The black line is the result of aligning and averaging the three loading curves and was used in subsequent calculations of repeatability.
### 5.6. Appendix B. Individual CMD, offset and adjusted CMD values

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Table 5A.1. Coefficients of multiple determination for each height and repeatability interval
Table 5.A.3 Adjusted coefficients of multiple determination for each height and repeatability interval

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References


Tender and less tender locations


Chapter 6
Posteroanterior movements in tender and less tender locations of the cervical spine
Abstract

In order to determine how posteroanterior movements (PAs) are related to tenderness and thus possibly to symptom production, we measured PA movements to a force of 25 N on each side of the cervical spines of asymptomatic subjects. From ten subjects (six females and four males; mean age 37.2 years, range 21 to 50), ten locations with a difference in tenderness to pressure between sides were used for analysis. The force-displacement and stiffness-force curves for tender and control sides were compared in four ways: simultaneous confidence bands (SCBs) for each side; width of SCBs for each side; SCBs of the difference between pairs of the tender and control curves; and simultaneous prediction bands (SPBs) from the tender side were compared to individual curves of the controls. The tender side demonstrated greater variation of both displacement and stiffness. The tender sides demonstrated greater within-subject stiffness for all force levels above 12 N. All individual stiffness-force curves of the tender sides were significantly different from the control side. Expected differences in single measures of either displacement or stiffness were not detected. The results suggest that the pattern of stiffness is a more effective method of characterising PA mobility than single measures used in previous studies.
6.1. Introduction

Musculoskeletal symptoms such as neck or back pain are amongst the most common reasons patients seek medical attention (Bogduk, Bolton, Jull, & Bellamy, 2003). Dysfunction of movement between individual intervertebral motion segments is considered to be a potential source of spinal musculoskeletal symptoms (Banks, 1998) and passive movement tests such as spinal posteroanterior movements (PAs) are intended to localise and assess the dysfunctional intervertebral movement (Maitland, Hengeveld, Banks, & English, 2005).

Although many authors advocate motion palpation as an important component of physical examination (Bullock-Saxton, Chaitow, Gibbons, Goosen, & Lee, et al., 2002), the usefulness of passive movement tests such as spinal PAs has been brought into question by inconsistent repeatability (Pool, Hoving, de Vet, van Mameren, & Bouter, 2004; Smedmark, Wallin, & Arvidsson, 2000). In spite of a lack of repeatability, manual assessment of passive movement has been shown to be useful clinically. For example, symptomatic locations (Jull, Bogduk, & Marsland, 1988) and the location of congenital fusion have been reliably detected by manual motion palpation (Humphreys, Delahaye, & Peterson, 2004). In a clinical study, the lumbar spines of patients were classified by findings on manual palpation as hypomobile or hypermobile. Patients who received corresponding treatment (manipulation to increase segmental mobility for the hypomobile group and stabilisation exercises to counteract excessive mobility for the hypermobile group) had better treatment outcomes than those receiving randomly allocated treatment (Fritz, Whitman, & Childs, 2005).

Spinal PAs were previously thought to produce isolated movement between a target pair of vertebrae and the response felt by the therapist was considered to be a direct indicator of the local intervertebral movement (Grieve, 1981, p 421). It is now clear from both in vivo (Caling & Lee, 2001; Kulig, Landel, & Powers, 2004; Lee & Evans, 1997; Lee, McGregor, Bull, & Wragg, 2005) and in vitro (Gal, Herzog, Kawchuk, Conway, & Zhang, 1997; Sran, Khan, Zhu, & Oxland, 2005) studies that in addition to moving the target intervertebral segment, spinal PAs also move other structures including a number of intervertebral levels as well as extra-spinal structures.
In order to clarify the usefulness of spinal PAs, a number of investigators developed instrumented methods to objectively assess PA movements. Interpretation of data from studies discussed in a recent review (Shirley, 2004) relied on single scalar values of displacement or stiffness extracted from the force-displacement (FD) curves of spinal PAs to characterise the stiffness of the entire movement. Using these single values to assess stiffness, instrumented measures of spinal PAs have been successful in detecting differences occurring with segmental dysfunction. For example, differences have been demonstrated with reduction in symptoms in patients with low back pain (Latimer, Lee, Adams, & Moran, 1996), artificially induced disc degeneration in a porcine model (Kawchuk et al., 2001), and local intervertebral stiffness in vitro in human thoracic spines (Sran et al., 2005). Using the same criteria for assessing stiffness, differences have been found also in relation to a wide variety of factors whose influence is extraneous to local intervertebral mobility (Kawchuk & Fauvel, 2001) including subject position (Chansirinukor, Lee, & Latimer, 2001; Edmondston, Allison, Gregg, Purden, Svansson, et al., 1998), stage of respiration (Shirley, Hodges, Eriksson, & Gandevia, 2003), size of the indentor (Squires, Latimer, Adams, & Maher, 2001), and muscle contraction (Colloca & Keller, 2004; Hodges et al., 2003). The methodologies used in these studies are able to detect altered stiffness of spinal PAs resulting from a variety of structures, but are unable to differentiate between alterations resulting from the targeted intervertebral segment and those resulting from extraneous factors.

We therefore set out to identify particular patterns of spinal PA stiffness associated specifically with intervertebral dysfunction (as indicated by local tenderness to pressure) using a protocol similar to that recommended for manual assessment of unilateral PAs (Maitland et al., 2005). That is, we compared PA movements at tender and less tender locations that would otherwise be expected to be as similar as possible; i.e. side-to-side at the same spinal level. Rather than relying on single values of stiffness or displacement, we compared the patterns of displacement and stiffness throughout the PA movement using a bootstrapping method of calculating simultaneous confidence bands (SCBs) and simultaneous prediction bands (SPBs) to detect more specific differences. We hypothesised that, in addition to reduced
displacement and an increase in single values of PA stiffness, more specific differences in the patterns of stiffness throughout the PA movement would correspond to differences in local tenderness to pressure.

By understanding the specific characteristics of PA stiffness related to tenderness (and presumably intervertebral dysfunction) we hope to enable more accurate interpretation of manual and instrumented assessment of PA movements.

6.2. Methods

6.2.1. Subjects and experimental design

Asymptomatic subjects were recruited from university staff and students. Asymptomatic subjects were defined as participants with an absence of current neck symptoms, symptoms within the past six months that required treatment or contraindications or precautions to manual therapy treatment. Asymptomatic subjects as defined above are known to have a significant incidence of low-level symptoms (Lee, Nicholson, & Adams, 2004). As tenderness to PA movements is considered to be an indicator of symptoms, it was expected that PAs to the cervical spine in this population would be tender to pressure at some locations.

Ten subjects (six females and four males; mean age 37.2 years, range 21–50 years; mean weight 72.7 kg, range 52–92 kg; mean height 169.9 cm, range 155–179 cm) were recruited for the study. The experimental protocol was approved by the Griffith University Human Research Ethics Committee and all individuals provided written confirmation of their informed consent prior to participation.

Each subject participated in one session consisting of two trials. The procedures were explained and the subjects were familiarised with the equipment and operation of the pain indicator prior to the first trial. The subjects were instructed that they might experience some pressure pain during the procedures, but they could tell the operator to stop the trial at any time. For each trial, the subjects were prone on a standard treatment bed modified to ensure a reproducible position and on which the Posteroanterior Movement Assessment Device (PMAD) was mounted. Each trial consisted of the application of a unilateral PA force to a total of six locations: the right and left side at each of three levels separated by 12 mm. It is not possible to accurately locate specific anatomical levels without medical imaging so the three levels were
repeateable positions in the mid cervical region that could be accessed by the PMAD (the therapist considered the highest level assessed for any subject to correspond to C2 and the lowest to C6). After the first trial, the subject stood and walked a few steps before the second trial.

The assessment of each location consisted of five gradual applications of force up to 25 N performed at an intended frequency of approximately 1 Hz. The actual frequency when the movements were produced was 0.40 Hz (SD 0.082) which is still within the range used in manual assessment (Snodgrass, Rivett, & Robertson, 2006). The subject rated the maximum intensity of pressure pain experienced during any of the five repetitions and the operator was blind to their response. A single qualified musculoskeletal physiotherapist with over 30 years experience performed both trials.

6.2.2. Instrumentation and data collection protocol

The PMAD (Fig. 1) was designed to be capable of assessing unilateral PAs of the cervical spine in a manner as similar as possible to manual palpation. The PMAD consisted of an instrument for measuring the force and displacement that occurred when an indentor was applied to the subject. The indentor was a 25 mm length of 12 mm square aluminium section with edges rounded to a radius of approximately 1 mm. The operator applied a force through a thumb-hold above the indentor. A linear potentiometer (Hollywell LTS04N04KB5C) measured the displacement and a load cell (Transducer Technologies MLP-25) mounted between the thumb-hold and the indentor measured the force. The device was adjusted such that the medial edge of the indentor contacted the patient 5 to 15 mm from the midline and the movement was directed 10 degrees medially from the vertical. The sensors were connected to a PC through a USB DAQ card (NI 40006, National Instruments) and data were sampled at 100 Hz.
The assembly could be fixed at 12 mm intervals along the long axis of the bed and be repositioned easily to a corresponding position on the contralateral side. A more complete description of the instrumentation and data collection protocol is described in Chapter 5 along with repeatability data for the device.

The pain indicator was a linear array of 20 LEDs located under the bed not visible to the operator, but visible to the subject in the test position. The subject indicated the level of pain with the LEDs acting as a visual analogue scale. No LEDs represented no pain and all LEDs representing the worst pain imaginable. Data collection, storage and operator feedback (an audible sound when the maximum force of 25 N was reached) were performed with custom software written in Labview Version 7.1 (National Instruments).
6.2.3. Data and statistical analysis

Data from test locations were used for further analysis if a difference in the pain rating of at least two LEDs (equivalent to one point on a ten-point scale) was found to occur between sides at the same level during the same trial. In the event that both trials of the same location had a difference of greater than two LEDs, only the one with the greatest difference was used in further analysis. A total of ten pairs of locations from six subjects fulfilled the criteria and were used for further analysis. The median pain level on the tender side was 5.5 points (range 2.5 to 8.5) and for the less tender control side was 3.0 points (range 1.5 to 5.5).

Following data collection, the force and displacement data were processed with customised software using Matlab Version 7.04 (Mathworks, Inc.). Force and displacement values for each trial and each location were filtered using a second order low-pass Butterworth filter with a cut-off frequency of 2.5 Hz. The displacement at 0.5 N was assigned a value of zero to create a common origin for all curves and a single average curve was calculated for each test location. Displacement and stiffness values were extracted from the curves for 100 data points at 0.25 N intervals from 0.5 to 25 N of force (Chapter 5).

Specialised methods of statistical analysis for assessing continuous (time series) data have been used in gait analysis but to our knowledge have not been applied previously to the assessment of passive movement. A detailed description of the type of analysis used in this study can be found in Lenhoff et al. (1999) and the application to the current study is described more fully in the Statistical Note at the end of this chapter. Briefly bootstrap resampling with PopTools (Hood, 2005) was used to calculate simultaneous confidence bands (SCBs) and simultaneous prediction bands (SPBs). SCBs define the band within which the entire mean curve of a group can be expected to lie while SPBs define the band which would be expected to fully enclose the entire length of a given proportion of individual curves from the population.

As it was not known beforehand how differences in spinal PAs between the tender and control sides might affect the FD or stiffness-force (SF) curves, four methods were used to compare the two sides for both types of curves. Firstly, the 95% SCBs were calculated for both the tender and control sides. Portions of the curves were considered to be significantly different when the SCBs for the tender and control sides did not overlap. Secondly, the 95% confidence intervals of the widths of the SCBs of the
tender and control sides were compared to assess for differences in variability between sides. Thirdly, SCBs were calculated for the differences between the tender and control sides and where the bands did not contain zero, the result indicated a significant difference. Finally, the individual FD and SF curves from the tender sides were overlaid on the SPBs for the control side. Portions of the individual curves outside of the SPBs indicated the portion of the curve that was significantly different from the curves of the control side.

6.3. Results

6.3.1. Representative data

The FD and SF curves for tender and control sides from two representative locations are shown in Figure 6.2a and 6.2b, respectively. Although it could be considered to be the independent variable in this study, force is represented on the Y-axis of Figure 6.2a as is the convention for FD curves. The FD curves from the two subjects did not demonstrate consistent differences between the tender and control sides. The SF curves in Figure 6.2b show comparisons of the stiffness data for tender and control sides with the independent variable (force) on the X-axis. The SF curves from the two tender sides shown in Figure 6.2b each have characteristic portions that diverge from the control curves when the applied forces are in the mid and upper range of forces used in the current study.
Tender and less tender locations

6.3.2. Comparisons of sides

The graphs in Figure 6.3a–c compare characteristics of FD curves on the left and SF curves on the right. In Figure 6.3a and 3b the SCBs of the FD and SF curves for the tender and control sides overlap throughout the curves demonstrating that no significant differences were detected between the means of either displacement or stiffness for the two sides at any level of force. The mean width of the SCB of the FD curves from the tender sides was wider than the control sides by 2.00 mm (CI = 1.90 to 2.12) and of the SF curves by 0.52 N/mm (CI = 0.44 to 0.60) demonstrating that there was greater variability of both displacement and stiffness on the tender sides. Figure 6.3c shows the SCBs of the difference in displacement (tender minus control) between the two sides for each level of force. The bands contain zero for all force values indicating the differences were not significant. Figure 6.3d shows that the difference in stiffness between the two sides was significant for all forces above 12 N.

Figure 6.2. Representative force-displacement (FD) and stiffness-force (SF) data from two subjects. Red lines represent tender sides; Blue lines represent less tender sides.
Figure 6.3. Simultaneous confidence and prediction bands comparing tender and less sides. Red lines represent painful sides and blue lines represent less tender sides. For solid lines, thick lines indicate means and thin lines indicate simultaneous prediction bands (SPBs). For dashed lines, thick lines indicate simultaneous confidence bands (SCBs) and thin lines indicate curves from individual locations.
6.3.3. Comparisons of individual tender curves to control side

SPBs were plotted to determine if specific areas of individual curves of the tender sides differed from the control side. Figure 6.3e shows that six out of the ten FD curves from the tender sides extended outside of the SPBs for the control sides indicating significant differences from the control sides. There did not appear to be a consistent pattern to the differences as four curves demonstrated less displacement throughout the force range, one less displacement in the latter half and one more displacement in the early half. In Figure 6.3f, all of the SF curves from tender locations extended outside the SPB of the control sides indicating that all of the tender curves were significantly different from the control side. Eight of the tender curves were stiffer either between 12 and 16 N or above 20 N while two were less stiff below 12 N.

6.4. Discussion

The current study set out to determine patterns of movement or stiffness associated with local tenderness during unilateral PAs of the cervical spine. We found several differences in the pattern of the tender sides compared to the less tender control sides. Specifically, the tender side demonstrated greater variation of both displacement and stiffness; the tender sides demonstrated greater within-subject stiffness for all force levels above 12 N; and all individual SF curves of the tender sides were significantly different from the control side. The expected differences between sides in single measures of either displacement or stiffness however were not detected.

The pattern of differences is illustrated by comparisons of the SF curves of the tender and control sides of the representative curves shown in Figure 6.2b. In the middle and latter thirds, the curves from the tender side diverge from the corresponding control curve, reach a peak of maximum difference and then re-approach the control curve.

The effects of a similar pattern can be seen in the shape of the mean SF curves in Figure 6.3b, the differences between tender and control sides in Figure 6.3d, and the areas where the individual tender SF curves are above the SPBs in Figure 6.3f. Variations in the pattern (particularly variations in the force at which the stiffness of the painful side rises away from the control side) are likely to be responsible for single measures of displacement or stiffness as used in previous studies being unable to detect differences between sides in the current study.

Displacement has been used to assess PA mobility in previous studies but no
differences in displacement were detected in the current study. The differences in
displacement may have been too small to be detected by the methods used in the
current study or unilateral PAs on the cervical spine may exhibit different behaviour
than PAs applied to the midline of the lumbar or thoracic spines investigated in
previous studies. Stiffness of Spinal PAs (slope of the latter portion of the FD curve)
expressed as a constant is another parameter that has been used to characterise
spinal PA stiffness. Although visual inspection of the FD curves from the current study
may have suggested the stiffness approached a constant, the SF curves clearly
indicated stiffness continued to change throughout the movement. The lack of constant
stiffness in any region of the SF curves agreed with Nicholson, Maher, Adams, & Phan-
Thien (2001) who found that a linear approximation of stiffness did not provide the best
fit to FD curves from PAs to the lumbar spine. Variations in the force at which the
stiffness of the tender side diverges from the control side may explain why single
measures of displacement or stiffness were unable to detect differences between sides
in the current study.

6.4.1. Clinical implications
The findings in the current study of significant differences in stiffness at forces starting
at 12 N supports the assertion by experienced clinicians of being able to detect altered
PA mobility well before the end of the PA movement. The method used in this study
may have in fact overestimated the minimum force necessary to manually detect
differences. Clinicians will often displace overlying soft tissue to gain closer contact
between their thumbs and the vertebrae being palpated. The indentor in the current
study was applied in a predetermined linear direction without prior displacement of soft
tissue which may have resulted in a thicker layer of soft tissue being compressed than
occurs with manual palpation. A small amount of force being necessary to detect
differences was also demonstrated by Marcotte, Normand, & Black (2005) who found
that the force used by clinicians varied from 1 N to 8 N, but the level of force did not
affect the accuracy of detecting the location of a known intervertebral fusion. In light of
differences being detectable at such low levels of force, it is interesting to note that
many of the previous studies assessing central PA stiffness in the lumbar spine
considered stiffness occurring only in the latter portion of the movement at forces
above 30 N (Edmondston et al., 1998; Latimer, Lee, & Adams, 1996; Latimer, Lee,
Adams, & Moran, 1996; Lee & Liversidge, 1994; Shirley et al., 2003).
Clinicians interpreting manual spinal PAs appear to consider aspects of the PA movements other than or in addition to the single values of displacement or stiffness previously used to describe instrumented assessments (Maher & Adams, 1995a, 1995b). The findings of differences in patterns of stiffness throughout the PA movement may suggest some of the parameters that clinicians consider in their assessments of PA stiffness but the inferences that can be drawn from these findings are limited in several ways. Firstly, it is not known if the patterns of stiffness found in the current study could be differentiated from altered stiffness resulting from extraneous factors not addressed in this study but known to influence PA stiffness (e.g. position, respiration or regional muscle contraction). Secondly, despite the subjects being defined as asymptomatic, the control side could not be considered ‘normal’ but only less tender than the tender side. Both sides used for comparisons were tender to some extent and the sides only differed in pain intensity by an average of 2.5 out of 10 on a visual analogue scale. Finally, although the analysis in the current study was more detailed than that used in previous studies, it may not have been sufficient to determine the essential characteristics of differences in spinal PAs related to altered segmental mobility.

It may be worth suggesting how clinicians’ perceptions might relate to the patterns of stiffness described in the current study. Two common terms used to describe PA movements are $R^1$ (the point thought to correspond with the first onset of resistance) and endfeel. Petty, Maher, Latimer, & Lee (2002) pointed out that there was resistance throughout the PA movement and suggested that $R^1$ did not correspond with a measurable point in PA movements. The point described as $R^1$ may, however, correspond with the point where the rate of increase in stiffness changes rather than the point of first perceptible resistance. In the current study $R^1$ may therefore correspond with the point on the stiffness graphs where the tender side diverges from the control side. Likewise, defining the physical equivalent of endfeel is problematic. There is no clear end of range of PA movements as displacement continues to increase with increasing force. The location, height and shape of portions of the SF curves diverging from the control sides may therefore be parameters of interest in assessing spinal PA stiffness. Additional research is necessary using symptomatic subjects to clarify the relationship between patterns of PA stiffness and symptom production. In addition, further studies relating clinicians’ perceptions to physical
measurements may bring greater objectivity to manual assessment of passive movements.

6.4.2. Conclusions

To our knowledge this is the first study to investigate differences in patterns of stiffness throughout PA movements to the cervical spine. The pattern of stiffness particularly from 12 to 16 N and 20 to 25 N is a more effective method of characterising altered PA mobility in the cervical spine related to intervertebral dysfunction than the single measures of displacement or stiffness used in previous studies. There was a small sample size in this study so the results can only be considered as preliminary but, if confirmed, these findings will assist in determining more objective criteria for characterisation of spinal PA mobility for research, teaching and clinical practice. Future studies investigating assessment and interpretation of spinal PAs may need to consider parameters other than the single values of displacement or stiffness used in previous studies.

6.5. Statistical Note

6.5.1. Calculation of simultaneous confidence and simultaneous prediction bands

Resampling methods such as bootstrapping overcome many of the difficulties resulting from small sample sizes. This study used 1000 simultaneous bootstrap resamples (resampling entire curves) with replication for all analyses.

Simultaneous confidence bands (SCBs) enable the comparison of mean values by enclosing the area around the sample mean curve where, for a given probability, the entire length of the true mean curve can be expected to lie. To determine the SCBs, the sample mean curves from each of the bootstrap resamples for the tender side, the less tender side and pointwise difference between the two sides were calculated. The largest pointwise standardised deviation from the grand mean that occurred on each resample mean curve \( \text{SD}_{\text{max resample}} \) indicated the maximum distance (in standard deviations) from any point on that resample mean curve to the grand mean curve. The 95th percentile (50th largest) \( \text{SD}_{\text{95% resample}} \) was therefore greater than the maximum distance (in standard deviations) between any point on the remaining 95% of the sample means and the grand mean. The width of the 95% SCB around the
grand mean at each point was therefore SD\textsubscript{\textit{95\%_{resample}}} multiplied by the pointwise standard deviation at that point. The difference between SCBs and point wise confidence intervals could be illustrated by probabilities related to the mean curve of any future resample of the original dataset. There would be only a 5% chance that any part of the curve would lie outside a simultaneous confidence band, but as each curve would contain 100 data points one would expect an average of 5 data points to lie outside of a pointwise series of confidence intervals.

Plots of the SCBs of the tender and control sides were then overlaid and any areas where the SCBs did not overlap represented areas of the curves with significantly different means. The mean and confidence intervals of the pointwise widths of the SCBs were calculated for the tender and control group as an indicator of the variance of the curves. The SCBs of the differences between the tender and control sides were graphed and if zero was not contained within the SCBs the difference was considered to be significantly different from zero.

Simultaneous prediction bands (SPBs) differ from SCBs in that, for a given probability, SCBs are expected to fully enclose the true mean curve of the population while SPBs are expected to enclose individual curves from the population. The usefulness of SPBs is that when future individual curves are co-plotted with the SPBs, if any part of the new curve is outside of the SPBs, then the individual curve can be considered to be significantly different from the population used to determine the prediction band. SPBs were also calculated using bootstrap resamples each containing ten curves. The maximum pointwise standardised deviation was calculated for each curve (SD\textsubscript{\textit{max\_curve}}). The average of the 95\textsuperscript{th} percentiles of SD\textsubscript{\textit{max\_curve}} from the bootstrap resamples (SD\textsubscript{\textit{95\% curve}}) is therefore greater than the maximum distance (in standard deviations) between any point on 95% of the individual curves and the mean curve. The width of the 95% SPB of the control group around the grand mean at each point is therefore SD\textsubscript{\textit{95\% curve}} times the pointwise standard deviation at that point. Plots of individual curves of tender locations were overlaid on the SPBs of the control group. If any part of an individual curve from the tender side lies outside of the SPB of the control group, that curve can be considered to be significantly different from the control group.
References


Hodges, P., Kaigle Holm, A., Holm, S., Ekstrom, L., Cresswell, A., Hansson, T., et al. (2003). Intervertebral stiffness of the spine is increased by evoked contraction


Chapter 7
Relation between changes in posteroanterior stiffness and active range of movement of the cervical spine following manual therapy treatment
Abstract

Study design. Repeated measures study of active and passive movements in patients with neck pain.

Objectives. To determine if, following manual therapy: 1) changes occur in active range of movement (AROM) and stiffness of posteroanterior movements, 2) such changes are dependent on the location treated, and 3) there is a relation between changes in posteroanterior stiffness and AROM.

Summary of Background Data. Posteroanterior movements are frequently used to assess patients with neck pain but little is known about how these movements are related to patient symptoms.

Methods. One location deemed symptomatic and hypomobile and one asymptomatic location were selected in 20 patients with neck pain for more than two weeks. Posteroanterior stiffness at each location and AROM were measured before and after each of four manual therapy interventions: posteroanterior movements to each location, a general treatment and a control intervention.

Results. The general intervention had a greater increase in each axis of AROM than the other interventions (F=2.814 to 7.929, DF=3) but there were no differences in posteroanterior stiffness across interventions (F=0.945, DF=3). Differences in posteroanterior stiffness was divided into regions by applied force. Following treatment to the symptomatic location, regions of stiffness at forces above 8 N demonstrated significant correlations with total AROM (R = -0.466 to -0.628).

Conclusions. Following manual therapy, increased AROM is related to decreased posteroanterior stiffness in patients with neck pain, but only for the treated location and only when that location had been identified previously as symptomatic and hypomobile.
Relation between changes in stiffness and active ROM following treatment

7.1. Background

Posteroanterior (PA) movements are one form of motion palpation commonly used by manual therapists to assess and treat spinal pain and are produced by applying a force over a vertebra (Figure 7.1). Although originally intended to produce, and thus enable the clinician to assess, a translational gliding movement of one vertebra on another (Grieve, 1981, p. 421), it is now clear that the spinal movement produced by PA movements is neither localized to one intervertebral level nor predominantly translational (McGregor, Wragg, & Gedroyc, 2001). Nevertheless, according to the manual therapy paradigm, PA movements assess the mobility of the underlying intervertebral segment which is related to impairments such as pain and limitation of active range of movement (AROM) (Magarey, 2002; Maitland, Hengeveld, Banks, & English, 2005, pp. 53-83). A variety of subjective terms are used to describe the findings on manual assessment of PA movements but there is limited agreement on the meaning of even the most common descriptors (Maher & Adams, 1995). Maitland, Hengeveld, Banks, & English (2005, pp. 445-468) advocated the use of subjectively referenced force displacement curves known as movement diagrams as a means to describe and communicate findings from manual motion testing but the validity of movement diagrams has been brought into question (Petty, Maher, Latimer, & Lee, 2002). As an alternative, objective measures of displacement or stiffness have been suggested as more valid indicators of PA movement (Shirley, 2004).

The presumed relation within the manual therapy paradigm between PA movements and underlying intervertebral movement is supported by a limited number of studies. In an in vitro study of the thoracic spine, Sran, Khan, Zhu, & Oxland (2005) found increased PA stiffness corresponded to increased local intervertebral stiffness while Kawchuk et al. (2001) using a porcine model reported increased PA stiffness with artificially induced disc degeneration. There is some support for a relation between PA stiffness and patient symptoms or impairments with one study reporting changes in PA stiffness being related to changes in pain and AROM in the lumbar spine (Latimer, Lee, Adams, & Moran, 1996). Altered PA stiffness as assessed in these studies did not appear to be specific to local or intervertebral factors. Differences in PA stiffness have also been found with factors whose effect would be expected to extend beyond local or intervertebral movement such as patient position (Chansirinukor, Lee, & Latimer, 2001; Edmondston et al., 1998) stage of respiration (Shirley, Hodges, Eriksson, & Gandevia,
Relation between changes in stiffness and active ROM following treatment

2003), direction of movement (Allison et al., 1998; Caling & Lee, 2001), indenteror size
(Squires, Latimer, Adams, & Maher, 2001), rate of movement (Squires, Latimer,
Adams, & Maher, 2001) and muscular contraction (Hodges et al., 2003).

Most studies of PA movement have focused on the lumbar spine (Shirley, 2004) and
used only single values of displacement or linear approximations of stiffness to
characterize PA movements. It has been suggested recently that relations between
applied force and displacement during PA movements are non-linear (Nicholson,
Maher, Adams, & Phan-Thien, 2001). For example in the cervical spine, differences
between tender, potentially symptomatic (Jull, Treleaven, & Versace, 1994) locations
and less tender locations were detected only when non-linear methods were used to
assess differences in PA stiffness (Chapter 6).

When used as treatment techniques PA movements are intended to decrease
intervertebral stiffness and thereby improve impairments (Lee, Gal, & Herzog, 2000). A
relation between PA movements and impairments could be inferred if characteristics of
PA movements change when impairments change. Furthermore, if a relation between
PA movements and impairments occurs only for specific locations of PA movements
and only following treatment directed towards those particular locations, it could be
inferred that the therapeutic effect of the treatment is localized and specific to the
treated location. A strategy for clinical reasoning advocated by Maitland, Hengeveld,
Banks, & English (2005) and commonly employed in clinical practice (Hahne, Keating,
& Wilson, 2004) uses changes in active movements immediately following treatment as
an indicator of change in impairments. The advantage of investigating changes
immediately following treatment is that the timing corresponds to the timing of
reassessments in clinical practice. In addition, the short time between reassessing PA
movements and AROM would be expected to maximize the likelihood of detecting
relevant relationships by minimizing the impact of extraneous factors on measures of
both AROM (Jordan, 2000) and PA movements (Chapter 5). Furthermore, AROM is
known to change immediately following treatment but also has been shown to be a
better predictor of longer-term changes in patient symptoms than other measures of
impairments such as pain intensity or location (Chapters 3 and 4).

An aim of the current study was to determine if differences in AROM and PA stiffness
following treatment by PA movements to the cervical spine are dependent on the
treated location. A second aim was to determine if there is a relation between
improvement in AROM and reduction in PA stiffness. It was hypothesized that following treatment by PA movements to locations deemed to be symptomatic there would be: 1) an increase in AROM; 2) a decrease in PA stiffness at the treated location; and 3) a significant relation between decreased PA stiffness and increased AROM. It was expected that an increased understanding of the relations between PA movements and patient impairments resulting from this study would contribute to a greater understanding of musculoskeletal neck pain and its treatment by manual therapy.

7.2. Method

7.2.1. Subjects

Subjects were recruited by a broadcast email to all staff and students at a university. The inclusion criteria were neck pain for more than 2 weeks and a reported limitation of active neck movements. Exclusion criteria were a current third party claim, a history of trauma within the previous six months, or any contraindications to treatment by manual therapy (Boyling, Palastanga, & Grieve, 2004, pp. 478-479). Twenty subjects (10 females and 10 males) with a median age of 31 years (range 19 – 55 years) who met the criteria volunteered to participate in the study which took place in May and June 2007. The median symptom duration was 2 years (range 3 weeks - 20 years). Over the previous three days, the reported average pain intensity was 3/10 (range 0.5/10 - 7/10) and maximum pain intensity was 4/10 (range 1/10 - 10/10). Investigator A was a titled Musculoskeletal Physiotherapist with over 30 years experience and Investigator B was a registered physiotherapist with 2 years experience.

7.2.2. Design

After providing written confirmation of informed consent, each subject attended a single test session lasting approximately ninety minutes. Investigator A took the patient’s history and performed a physical assessment including active movements and passive motion palpation. Based on his assessment, Investigator A selected two locations limited to a region approximately between C3 and C6 because these segments 1) were accessible by the PMAD and 2) have more similar biomechanical properties than motion segments above or below this region. One location that was assessed as being hypomobile and considered most likely to be contributing to the patient’s impairments was deemed symptomatic. A second location deemed to be asymptomatic was
selected on the opposite side either 12 mm (approximately one intervertebral level) above or below the symptomatic location depending on which location was considered less likely to be a significant contributor to the patient’s impairments. The symptomatic location was located along the articular pillar but the height and lateral position was not defined by a specific anatomical location. Investigator B was informed of the locations but not which site was symptomatic or asymptomatic.

Investigator B assessed AROM and PA stiffness. The subject remained on the treatment bed for a further two minutes. Investigator A performed one of three experimental interventions (standard, placebo or control) for two minutes and the subject remained prone for an additional two minutes. Measures of skin conductance, skin temperature and blood flux were taken during this time, but are not reported in this paper. Investigator B then reassessed AROM and PA movements. The post-intervention assessments formed a baseline for the subsequent intervention. The order in which the first three interventions were performed was determined prior to the first intervention by Investigator A selecting one of 20 pre-printed forms with a random intervention order. The process was repeated for the next two interventions. AROM and PA stiffness at the two locations were measured before and after each of four interventions: 1) a standard intervention consisting of two-minutes of PA mobilization to the symptomatic location as would be performed if the subject were to receive that technique as a clinical treatment; 2) a placebo intervention consisting of the same grade of PA mobilization as on the symptomatic location but performed at the asymptomatic location; 3) a control intervention where the subject simply remained in the same position for two minutes; and 4) a general treatment intervention that consisted of manual therapy not including high velocity thrusts (as defined by Korthals-de Bos, Hoving, van Tulder, Rutten-van Molken, Ader, et al. 2003) to the cervical spine as might occur in a normal treatment setting and not limited in duration or to specific techniques or locations. The general treatment intervention was not restricted to treatment techniques performed in supine so was always the last to be performed. Although Investigator B was not present during the general treatment, they could not be blinded to the timing of the general treatment because it was always performed last.

It was considered that in order for differences in stiffness of PA movements to be clinically useful, they would be detectable by manual palpation and it has been demonstrated that only differences in stiffness greater than 7 to 8% can be detected
Relation between changes in stiffness and active ROM following treatment

manually (Nicholson, Adams, & Maher, 1997). A small correlation therefore, although statistically significant, may lack clinical significance. In the absence of previous specific experimental data, it was estimated that a correlation of 0.40 (difference in PA stiffness accounting for 16% of the differences in AROM) would be sufficient to detect a clinically useful relationship. A power analysis with a significance level 0.05 and the minimum detectable correlation of 0.40 found the minimum necessary sample size to be 18.

7.2.3. Instrumentation and data collection protocol

The Posteroanterior Movement Assessment Device (PMAD) mounted on a repositionable frame was developed to assess unilateral PA movements of the cervical spine in a manner as similar as possible to manual palpation (Figure 7.1). When using the device, an indentor is directed manually along a linear path and measurements of the applied force and the resulting displacement are recorded. Five movements were performed at a frequency of approximately 1 Hz and a single set of force and displacement data was calculated from three of the final four movements. As the entire FD curves from the PMAD were to be considered, repeatability was assessed using coefficients of multiple determination (CMD). The CMD was 0.90 for intra-day, intra-rater repeated measures on an asymptomatic population. A more complete description of the methodology and repeatability is presented in Chapter 5. It was necessary to ensure when PA movements were produced by the operator’s thumb during manual palpation, the standard intervention and the placebo intervention, that the movements occurred in the same location and plane as the PA movements measured by the PMAD. The movement of the operator’s thumb was therefore constrained during these procedures by a gating mechanism attached to the frame of the PMAD (Figure 1).
Figure 7.1. PA movements. The image on the left shows the PA movement produced by the PMAD and the right hand image shows the gating mechanism used during manual PA movement in the current study to ensure a consistent plane and location.

A head-mounted 3-axis orientation sensor (3DM MicroStrain Inc, 310 Hurricane Lane, Williston, VT, USA) was used to measure AROM. The patient was seated in a high-backed unpadded chair with his or her shoulders against the backrest and arms by their side holding the rear chair legs. Investigator B demonstrated the movements to be performed and after zeroing the sensor, the patient was asked to perform three movements “as far as you can reasonably move” in each cardinal direction (Chapter 3). The movements were unconstrained and performed at the patient’s selected speed as would typically occur in the clinical setting. The maximum of the three movements in each direction was used for further analysis. Full axis movements have been demonstrated to be more repeatable than half axis movements (Lantz, Chen, & Buch, 1999) so full axis movements of flexion/extension (FE), lateral flexion (LF) and rotation (ROT) as well as the total range of movement about all three axes (TROM) were used for further analysis. The difference between repeated measures was the variable of interest, so repeatability had been assessed using limits of agreement (Bland & Altman, 1999). For asymptomatic subjects, the 95% limits of agreement were from -5.9 degrees to 3.5 degrees (Chapter 3).
7.2.4. Data and statistical analysis

Stiffness values for PA movements were interpolated to produce 100 data points at 0.25 N force intervals from 0.5 to 25 N and the percentage changes in PA stiffness from pre-intervention to post-intervention were calculated. Rather than dividing the data into arbitrary regions, it was considered that if changes in AROM were related to changes in PA stiffness, such relations would be more likely to occur in regions where PA stiffness changed in response to the standard intervention. A bootstrap re-sampling procedure (Chapter 6) was used to calculate one-tailed 90% SCBs for differences in PA stiffness following each intervention for each side. Levels of force where the SCBs of the differences did not include zero indicated regions where PA stiffness was likely to have decreased. Continuous regions of the SCBs of the differences for the standard intervention that included, and did not include zero were considered separately for further analysis. A 90% criterion was used for determining the SCBs rather than a usual, more stringent 95% criterion because the intention of the regions of PA stiffness was primarily for use in assessing correlations between the regions of PA stiffness and AROM. Repeated measures ANOVA were used to assess within subject changes by intervention for AROM and regional PA stiffness. Type 3 sum of squares, uncorrected pairwise contrasts were used to compare means. In order to limit the number of tests performed and thus reduce the likelihood of type I errors, Pearson correlation coefficients were calculated initially between change in TROM and change in mean PA stiffness for both the symptomatic and asymptomatic sides following each intervention. Significant correlations were then explored further by calculating correlation coefficients between TROM and each region of PA stiffness and between each axis of AROM and the mean PA stiffness. Significance levels for ANOVAs and correlation coefficients were set at p < 0.05.
7.3. Results

Representative stiffness curves for the standard intervention for two subjects showing pre-intervention, post-intervention and differences in stiffness are shown in Figure 7.2.

![Representative stiffness curves](image)

**Figure 7.2.** Representative data from the symptomatic locations of two subjects showing stiffness force curves from pre-intervention and post-intervention PAs and changes in stiffness following the standard intervention.

Mean initial AROM (SD) for FE, LF, ROT and TROM in degrees were: FE = 119 (17); LF = 93 (12); ROT = 137 (16); and TROM = 349 (39). The initial stiffness values for each side and region of stiffness are shown in Table 1.

Table 7.1. Pre-intervention stiffness in N/mm for each region of force. Brackets indicate one standard deviation. There were no significant differences between the symptomatic and asymptomatic sides.

<table>
<thead>
<tr>
<th>Region of stiffness</th>
<th>4 N – 7.0 N</th>
<th>8 N – 13 N</th>
<th>14 N – 17 N</th>
<th>18 N – 25 N</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptomatic Side</td>
<td>1.19 (0.26)</td>
<td>2.23 (0.50)</td>
<td>2.78 (0.84)</td>
<td>3.45 (1.43)</td>
<td>2.36 (0.68)</td>
</tr>
<tr>
<td>Asymptomatic Side</td>
<td>1.17 (0.38)</td>
<td>2.27 (0.83)</td>
<td>2.91 (1.06)</td>
<td>3.32 (1.11)</td>
<td>2.33 (0.76)</td>
</tr>
</tbody>
</table>
The SCBs of percentage changes in PA stiffness following the standard intervention are shown in Figure 7.3. The two regions of PA stiffness at forces where the SCBs did not include zero (4-7 N and 14-17 N) as well as two regions that included zero (8-13 N and 18-25 N) were used for further analysis. The lower boundaries of the SCBs of percentage changes in PA stiffness for both the symptomatic and asymptomatic sides for all other interventions were less than zero for their entire length.

Figure 7.3. Percentage change in stiffness on the symptomatic side following each intervention. The solid line represents the mean percentage change in PA stiffness and the dashed lines the 90% SCBs. Regions of stiffness where the SCBs include and do not include zero are indicated on the graph at the top left.
7.3.1. Changes in stiffness and AROM

One sample t-tests demonstrated that significant increases in AROM occurred for ROT and TROM following the standard intervention ($t = 2.204$ and $2.839$) and for all axes as well as TROM following the general treatment ($t = 2.239$ to $3.369$). Differences did not reach statistical significance for either the placebo or control interventions. The only significant decreases in stiffness following any interventions occurred in the 2.5 N to 8 N region on the symptomatic side following the standard intervention and in the 18 N to 25 N region of the asymptomatic side following the control intervention. Changes in AROM for each intervention are shown in Figure 7.4. The only significant reductions in stiffness occurred following the standard intervention, but there were regions of increased stiffness following the placebo and control interventions. There were significant differences in within-subject changes by intervention for FE, LF, ROT and TROM ($F = 7.291$, $2.814$, $2.970$, and $7.929$; $DF = 3$). The only significant pairwise contrasts for each axis of movement indicated that the differences in AROM were larger for the general intervention than for the other interventions.

![Figure 7.4. Changes in AROM by intervention. Error bars represent one standard error of the mean. Asterisk (*) indicates significant within subject differences across interventions.](image)
Changes in regional stiffness following each intervention are shown in Figure 7.5. There were no significant within subject differences in PA stiffness across interventions (F = 0.945, DF= 3).

**Figure 7.5.** Percentage changes in regional stiffness of the symptomatic and asymptomatic locations following the standard treatment (PA movements to the symptomatic location). Error bars represent one standard error of the mean.
Correlations between stiffness and AROM

The only significant correlation between changes in TROM and mean PA stiffness was for changes in PA stiffness on the symptomatic side following the standard intervention (Table 7.2). Following the standard intervention, the only individual axis of AROM that demonstrated a significant correlation with mean PA stiffness was LF (R = -0.459, p = 0.024). Three out of the four regions of stiffness (8 – 14 N, 14 – 18 N and 18 – 25 N) demonstrated significant correlations with TROM (R = -0.466, -0.528 and -0.628; p = 0.022, 0.010 and 0.002).

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Standard</th>
<th>Placebo</th>
<th>Control</th>
<th>General</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptomatic Side</td>
<td>-0.596 * (0.004)</td>
<td>-0.240 (0.161)</td>
<td>-0.256 (0.145)</td>
<td>-0.107 (0.337)</td>
</tr>
<tr>
<td>Asymptomatic Side</td>
<td>0.379 (0.055)</td>
<td>0.169 (0.252)</td>
<td>-0.384 (0.058)</td>
<td>-0.017 (0.474)</td>
</tr>
</tbody>
</table>

7.4. Discussion

Movement diagrams, single values of displacement and linear approximations of stiffness have been advocated previously to describe PA movements. The current study used a continuous assessment of stiffness to assess PA movements and aimed to determine whether differences in AROM and PA stiffness following treatment by PA movements to the cervical spine were dependent on the treated location, and if there is a relation between improvement in AROM and reduction in PA stiffness.

The expected increase in AROM following the standard intervention was not detected although an increase in AROM did occur following the general intervention. The general intervention was intended to be similar to a typical clinical treatment and the increases in AROM that were found were consistent with other studies of immediate
changes in AROM following manual therapy treatment (Cassidy, Lopes, & Yong-Hing, 1992; Tseng et al., 2006). The general intervention included treatment to several areas of the neck and upper back and the improvement in AROM following the general treatment but not the standard intervention highlights one of the difficulties with manual therapy research. When interventions are pre-selected or pre-specified as for the standard intervention in the current study and as is often required by research designs, the treatment may not be as effective as treatments applied in clinical practice (Fritz, Delitto, & Erhard, 2003). Alternatively, the general intervention always being performed last may have influenced the relative magnitude of the increase in AROM following this intervention.

The decrease in PA stiffness following the standard treatment that would have been expected according to the manual therapy paradigm occurred only at forces from 4-7 N and 14-17 N. Differences in PA stiffness were not detected following treatment in two previous studies of the lumbar spine. One study involved asymptomatic subjects (Allison et al., 2001) and the other involving symptomatic subjects did not detect differences in PA stiffness following treatment in spite of an improvement in pain (Goodsell, Lee, & Latimer, 2000). In both studies however the investigators only considered single values of displacement or stiffness.

The hypothesis of a relation between increases in AROM and decreases in PA stiffness at the symptomatic location following the standard intervention was supported by the results. To our knowledge, this is the first demonstration of a relation between PA stiffness and impairments in the cervical spine. Latimer, Lee, Adams, & Moran, (1996) found decreased stiffness at forces over 30 N and an increased PA displacement up to a force of 30 N in a group of patients with low back pain when their pain had resolved by 80%. Kulig et al. (2007) on the other hand found increased PA mobility in a group of young adults with low back pain compared to asymptomatic controls, but this comparison of group differences would not distinguish between differences related to pre-existing or pre-disposing factors and those related to the source of the patient’s impairments.
Relation between changes in stiffness and active ROM following treatment

The finding that relations between changes in PA stiffness and AROM occurred following only treatment to the symptomatic location and that similar changes in PA stiffness did not occur at an untreated location suggests a localization of the effects of treatment by PA movements. Similarly, Chiradejnant, Maher, Latimer, & Stepkovitch, (2003) found that improvement in pain following treatment by PA movements was greater when the treated location had been selected previously as a likely source of impairments.

One of the main aspects of PA stiffness investigated previously is stiffness at forces near the ‘end of range’ (Maitland, 1964). The findings in the current study of a relation between changes in AROM and PA stiffness at all force regions above 8 N are similar to the results of our previous study where differences in PA stiffness were found between tender and less tender locations of the cervical spine for all forces above 11.5 N (Chapter 6). The changes that were found in stiffness included force levels much lower than forces of up to 100 N that are used by therapists to produce ‘end-of-range’ PA movements in the cervical spine (Snodgrass, Rivett, & Robertson, 2007). The idea that differences in motion palpation can be detected at low forces is supported by previous findings. Marcotte, Normand, & Black, (2005) using motion palpation techniques other than PA movements found that clinicians applying less than five N of force could accurately detect the location of fused cervical vertebrae. The relatively small sample size in the current study was sufficient to determine that local changes in PA stiffness following manual therapy treatment are related to changes in AROM, but it was not possible to fully characterize these changes and in no case did the changes in PA stiffness account for more than 36% of the variation in AROM.

There are a number of elements in the design of the current study that could have influenced the results. Unilateral PA forces are often described as being applied over the apophyseal joints, but this was not specified in this study for two main reasons. Anatomic locations cannot be located accurately without imaging and perhaps more importantly; the apophyseal joints may not be the most appropriate location for applying PA forces. The intervertebral movements produced by PA movements are known to be primarily extension and the axes of rotation of cervical extension are generally through the vertebral body of the lower level of a motion segment rather than
through the apophyseal joints (Bogduk & Mercer, 2000). Even if the location of the application of PA force were to be defined anatomically, it may therefore be more appropriate to do so in relation to centres of rotation rather than apophyseal joints. Subjects with bilateral limitation of movement or multiple areas of symptoms were not excluded, so the symptomatic location was not necessarily the sole source of symptoms. Therefore the subject group could have included subgroups with divergent responses as might occur if their impairments were related to hyper-mobility rather than hypo-mobility. Limitation of movement was self-reported so some subjects may not have had objective limitation of movement. Furthermore, objective determination of limitation of movements is limited by the lack of consensus on norms or reference standards for defining what constitutes a limitation of movement. The subjects being from a university community is a different population with potentially different responses than a clinical population. For example, the mean pain scores of 3.0 in the current study were lower than the 4.9 observed in a population from clinical practice with the same inclusion/exclusion criteria (Chapter 3). The symptomatic and asymptomatic locations being at different intervertebral levels would be expected to be less similar, but more independent than if they were at the same level. The treatment to the symptomatic and asymptomatic locations was intended to be the same grade, but the force applied could not be measured during the application of the treatment. In spite of the elements listed above, the current study was still able to detect a significant relationship between changes in PA stiffness and changes in AROM following the standard treatment.

7.5. Conclusions

Following the standard intervention, the expected increase in AROM did not occur, and the decrease in PA stiffness occurred only in response to certain levels of forces. Change in PA stiffness at locations deemed to be symptomatic and hypomobile were found to be related only to change in impairments following manual therapy treatment to the symptomatic location in patients with neck pain for more than 2 weeks. The findings suggest that at symptomatic locations of the cervical spine there is a relation between AROM and PA stiffness at forces as low as eight N and that the therapeutic effect of treatment by PA movements is related to local PA stiffness.
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Chapter 8
Discussion
8.1. Introduction

Manual therapy techniques such as posteroanterior (PA) movements are commonly used to assess and treat patients with musculoskeletal neck pain. PA movements are thought to be indicative of patient symptoms, but little is known about their relation to symptoms or their mechanism of action. Thus the purposes of this thesis were initially to establish a good predictor of symptom improvement, to develop and establish the repeatability of a methodology for measuring PA movements of the cervical spine and then to use these tools to determine the relation between PA movements to the cervical spine and symptoms in patients with neck pain.

8.2. Indicator of immediate change in symptoms

The first aim of the studies discussed in this thesis was to establish which immediate indicator of symptoms in patients with non-acute neck pain is a better predictor of longer-term change in symptoms. The study described in Chapters 3 and 4 demonstrated that all of the indicators of immediate change in symptoms that were tested had limitations, but immediate change in AROM was the best predictor of changes in symptoms in patients with non-acute neck pain. Specifically, immediate post-treatment changes in individual axis of AROM and total AROM accounted for 26% to 48% of the between-session changes in AROM, and within the first two treatments changes in AROM predicted 26% to 57% of the end of treatment changes. Comparable results found for the lumbar spine by Hahne, Keating, & Wilson (2004) were discussed in Chapter 3.

For pain intensity, within-session changes accounted for only 6% of the between-session changes in pain intensity, and changes in the first two treatment sessions did not predict end of treatment outcomes. Again, these results were comparable to those identified by Hahne et al., (2004) in the lumbar spine and indicate that within-session change in pain intensity is not a good predictor of future outcomes.

For centralisation (change in pain location) within-session changes also predicted between-session centralisation, and between-session centralisation predicted 24% to 57% of end of treatment centralisation. Previous studies suggested centralisation to be better able to predict outcomes, but these studies considered changes in both pain location and intensity in response to repeated movements and only when treatment also consisted of repeated active movements (Werneke & Hart, 2003). Changes in pain
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location, however only occurred for a minority of subjects in the current study, so this measure is unlikely to be useful for the majority of patients.

Changes in measures of function or disability are not necessarily related directly to symptoms but are considered the best measures of the impact of symptoms on the patient and society (Pengel, Refshauge, & Maher, 2004). Functional measures including the patient specific functional scale, neck disability index and individual global perception of change were also assessed in the current study, but none of the changes in impairments predicted changes in functional measures. Indeed few correlations were detected between changes in the different functional measures at the end of treatment, or between changes in any of the measures of impairment at the end of treatment and end of treatment functional measures.

Changes in measures of impairment primarily predicted changes in the same impairment, but not changes in the other impairments or in functional outcomes. Just as there is no single best measure of end of treatment outcomes, there does not appear to be a best immediate indicator or predictor of change in patient symptoms. From the results of this study, immediate changes in AROM were considered the most useful indicator of immediate changes in symptoms because changes in AROM occurred immediately following manual therapy treatment, were responsive to small changes and were the best predictor of future change.

Change in AROM has been called the ‘clinical variable of primary significance’ (Zusman, 1995) and the use of immediate change in AROM is consistent both with current physiotherapy teaching (Hahne et al., 2004) and recommended clinical practice (Maitland, Hengeveld, Banks, & English, 2005; Refshauge & Gass, 2004). Considering that manual therapy interventions specifically target impairments and that psychosocial factors are thought to be largely responsible for how impairments then impact on an individual's functional ability (Edwards, Jones, & Hillier, 2006), it would not seem unreasonable for the clinician to use changes in impairments to assess the effectiveness of manual therapy interventions. It is equally important, however, to recognise that although changes in AROM may be the best available indicator of immediate post treatment change, AROM is an imperfect predictor of changes in impairments generally and a poor predictor of changes in functional abilities. In other words, changes in AROM are perhaps the best predictors of changes in AROM but the clinical usefulness of such changes are likely to be dependent on their relation to the
patient's goals. In spite of the limitations of changes of AROM as an indicator of future change, it appears that out of the measures tested, AROM is the best indicator of future changes in impairments.

8.3. Methodology for measuring PA movements

The second aim was to develop and assess a methodology for measuring PA movements of the cervical spine. The PMAD device that was developed for the current studies and its repeatability for assessing the entire curves of PA movements is described in Chapter 5. As it was not known beforehand what characteristics of PA movements might prove to be important in later studies, it was considered necessary to extend the assessment of repeatability of PA movements beyond the single measures of displacement or stiffness used in other studies. Therefore, methods were employed that had previously been advocated for assessing the repeatability of other time series data (Kadaba et al., 1989) but which were novel for assessing PA or other passive movements. The methods used in the current study included coefficients of multiple determination (CMDs), curve offsets, and adjusted CMDs. The PMAD demonstrated very good repeatability for intra-rater, intra-day measurements with the mean CMD and mean adjusted CMD being 0.90 and 0.99 respectively. At 0.76 and 0.96, inter-rater, intra-day mean CMDs and adjusted CMDs were not as high. Similarly for intra-rater, inter-day repeatability the mean CMDs and adjusted CMDs were 0.73 and 0.97. The best repeatability was achieved by the same operator repeating measurements on the same day so an experimental design that minimised the variability of measurements was used for the final study in this thesis.

The repeatability of the PMAD cannot be compared directly to other devices for assessing the lumbar or thoracic spines as earlier studies only considered single values of stiffness or displacement. Snodgrass, Rivett, & Robertson (2007) recently reported the repeatability of single stiffness values from a newly developed device for assessing PA movements of the cervical spine to have an ICC of 0.84, but again direct comparisons cannot be made with the current study.

The PMAD was devised to assess PA movements of the cervical spine as produced during manual motion palpation. Many of the devices used to assess PA movements of other spinal regions, as well as the one device for assessing the cervical spine (Snodgrass et al., 2007), advanced an indentor mechanically. In contrast the force
application of the PMAD was produced manually, enabling the operator to produce a movement that more closely resembled that used in clinical practice both in terms of rate and technique. It is known that for the lumbar spine the rate of application of PA movements affects the stiffness (Squires, Latimer, Adams, & Maher, 2001). The author recently demonstrated the importance of consistent technique to produce PA movements using real-time ultrasound where marked differences in the intervertebral movement occurred with variations in technique (Tuttle, 2007). For example, the therapist stabilizing the contra-lateral side with their hand (as occurred when using the PMAD, but not for other devices) resulted in a more vertical movement of the underlying vertebra and less soft tissue deformation than occurred without this stabilization. There are still, however, a number of differences between PA movements produced manually and those produced by the PMAD that may influence the resulting PA stiffness. Displacing the soft tissue from between the indentor and the underlying vertebra prior to manual application of PA movements is often used clinically and also affected PA movements (Tuttle, 2007) but was not possible even when using the PMAD. The shape, size (Squires et al., 2001) and angle (Allison et al., 1998; Caling & Lee, 2001) of the indentor affects the stiffness of PA movements of the lumbar spine and would also be expected to affect PA movements of the cervical spine. Although the indentor of the PMAD was designed to be similar to the human thumb, it could not duplicate a thumb. Therapists typically use tactile feedback to adjust their thumb and localise the application of force over the vertebra. This adjustment was not possible when using the PMAD, so the indentor was of necessity a constant shape and was longer in a medial-lateral dimension than the contact likely to be produced manually.

The study discussed in Chapter 6 compared PA movements on opposite sides at the same intervertebral level when there was a difference in tenderness between the two sides. Tenderness has been suggested previously as an indicator of symptoms (Seffinger et al., 2004) so it was hypothesised that in addition to differences in single measures of displacement or stiffness, any specific differences in PA movements related to the tenderness of the location would be similar to differences related to symptoms. Differences between PA movements at more and less tender locations were not detected by single measures of displacement or end of range stiffness. The application of simultaneous confidence and prediction bands as well as use of a bootstrapping method to calculate the bands were novel in their application to PA.
movements. The tender group demonstrated greater variation of both displacement and stiffness. The tender sides demonstrated greater within subject stiffness for all force levels above 12 N. All individual stiffness-force curves of the tender sides were significantly different from the control group.

The PMAD device demonstrated good repeatability and pilot data suggested that consideration of PA stiffness throughout the PA movements was likely to be useful in detecting differences related to patient symptoms. Comparing stiffness of PA movements measured by the PMAD therefore was considered an appropriate methodology for assessing the relation between PA movements and symptoms in the final study involving patients with neck pain. The type of differences in PA movements that could be expected to occur with changes in patient symptoms were not fully understood, nor was it certain what the best statistical method of assessing such differences.

8.4. Relation between changes in symptoms and PA movements

The third aim of the thesis was to determine how changes in PA movements are related to changes in patient symptoms. Previous studies had found differences in PA stiffness related to a wide variety of factors, but had not established if there were specific differences related to symptoms that PA movements are intended to assess. The previous chapters demonstrated the suitability of AROM as a predictor of change in symptoms in patients with non-acute neck pain, that the PMAD is capable of measuring PA movements, and the importance of considering stiffness throughout the movement when assessing PA movements. The aim in the final study could therefore be restated as determining how immediate changes in PA stiffness are related to immediate changes in AROM in patients with non-acute neck pain. The study described in Chapter 7 demonstrated that changes in PA stiffness are related to changes in AROM. As immediate changes in AROM were demonstrated in Chapters 3 and 4 to be related to end of treatment outcomes, a reduction in PA stiffness would appear to be related to end of treatment outcomes in patients with non-acute neck pain.

The characteristics of the changes in PA stiffness that occurred following treatment were complex and it was not possible to determine specifically what characteristics of the PA movements were associated with changes in AROM. Correlations were found
between changes in AROM and PA stiffness at regions of forces from 8 N to 25 N, but changes in any of the regions of PA stiffness did not account for more than 36% of the change in AROM. Although there was a general decrease in PA stiffness of the treated symptomatic location, the pattern of difference varied from subject to subject. The complexity of the patterns suggested that the effect of treatment was perhaps not consistent across subjects. It was therefore not possible to determine if there are the differences in PA stiffness that are specifically related to patient impairments or symptoms.

The finding that change in PA stiffness is related only to changes in AROM at symptomatic locations suggests that the relevant differences in PA stiffness are at least more pronounced at locations deemed to be symptomatic. The finding that relations between changes in PA stiffness and AROM occurred only following treatment to the symptomatic location and did not occur at an untreated location suggests a localisation of the effects of treatment by PA movements. Although a localisation of the effect of PA movements on AROM is consistent with intervertebral movement being affected by the treatment, it does not necessarily exclude other factors, such as neurophysiological or muscular responses, being responsible for the changes.

8.5. Clinical significance

As stated previously, the importance of PA movements as assessment techniques is due largely to their potential relationship with patient symptoms or impairments. This is the first study to demonstrate that stiffness in PA movements is related to impairments in the cervical spine. The ability of clinicians to localise the source of a patient’s symptoms is supported by the finding that the relationships between changes in PA stiffness and changes in AROM only occurred at the locations that had been selected previously by the clinician to be symptomatic. This does not necessarily suggest that the clinician is able to detect a symptomatic location based on palpation findings, as the symptomatic location was not selected solely on the basis of the mechanical characteristics of the PA movements. The investigator had also taken the patient’s history and the symptomatic locations were selected with this information combined with both pain provocation and perceived stiffness during PA movements.

Changes in PA stiffness that were related to patient symptoms were not found in the simple indicators such as total amount of movement or stiffness towards the end of
range advocated by some authors (Brandt, Sole, Krause, & Nel, 2006) and considered in previous studies (Brown, Holmes, Heiner, & Wehman, 2002; Brown, Wehman, & Heiner, 2002; Latimer, Lee, Adams, & Moran, 1996; Latimer, Lee, & Adams, 1998; Latimer et al., 1996; Latimer, Lee, & Moran, 1995; Lee, 1995; Lee, Kelly, & Steven, 1995; Lee & Liversidge, 1994; Lee, Steven, Crosbie, & Higgs, 1998; Lee & Svensson, 1993; Lee & Evans, 1997; Maher & Adams, 1995a). Rather changes in PA stiffness included changes at forces lower than many therapists have been found to use in practice. For example, clinicians performing Grade 1 PA movements, defined as occurring short of the onset of resistance (stiffness), on average applied more than 20 N of force (Snodgrass et al., 2006). In the current study, however, differences in stiffness were detected starting at 8 N, less than half of the force applied by clinicians performing the lowest grade of movement. The complexity of characteristics of PA movements that appear to be related to patient symptoms are perhaps consistent with the wide variety of subjective descriptors that have been used previously to characterise PA movements (Maher & Adams, 1995b).

Another important aspect of PA movements is how differences in PA stiffness might be related to intervertebral movement or pathology. There is some indication in the lumbar spine that differences in the toe region of intervertebral movement occur with disc degeneration and that disc degeneration at least to some extent correlates with patient symptoms (Peterson, Bolton, & Wood, 2000). It is not known if the same occurs for the cervical spine but there is some indication that the presence of degenerative changes does not correspond with patient symptoms (Peterson, Bolton, Wood, & Humphreys, 2003), but it is worth considering how differences in the toe and elastic regions of intervertebral movements might affect PA movements. A theoretical analysis of the relation between PA forces and stiffness curves of intervertebral movement of the cervical spine was provided in Chapter 2. The end of the neutral or lax zone (Crawford, Peles, & Dickman, 1998) of the target intervertebral location would be expected to corresponded to an increase in PA stiffness at a force just above 7 N. Because the largest moment produced by a PA movement occurs under the application of the PA force, the effect of any change in the intervertebral lax zone would occur earliest and be most pronounced when the PA force was applied directly over that axis of rotation. Therefore an increase in the size of the lax zone of the target location would be expected to result in the end of the toe region occurring later in the PA movement or a
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decrease in the stiffness within the lax zone would result in a change in stiffness at forces lower than 7 N. Similarly the effect on PA movements of a difference in the elastic region of an intervertebral motion segment would be more pronounced at forces above 7 N with a non-linear increase in intervertebral stiffness resulting in a non-linear effect on PA stiffness. Unfortunately, even the methods of analysis used in Chapter 7 only compared values of stiffness at the same level of force and would therefore not be well suited to detecting the specific types of differences expected to occur with differences in the intervertebral toe region.

If intervertebral stiffness is responsible for differences in PA movements and intervertebral stiffness is related to patient symptoms, then the location and magnitude of high and low points of the stiffness curves may be the characteristics of interest in PA movements. The development and application of statistical methods such as functional data analysis (Ramsay & Silverman, 1997) capable of considering changes in location and rates of increases in PA stiffness may therefore be necessary to more specifically characterise the types of differences in PA stiffness that are related to patient symptoms.

PA movements are used as treatment as well as assessment techniques and although the thesis did not primarily set out to investigate the mechanisms of treatment effects, there are several observations that are potentially clinically relevant. It has been proposed that the effects of manual therapy treatment are mediated through the sympathetic nervous system with changes in intervertebral mobility being likely to result from altered muscular responses (Pickar, 2002; Sterling, Jull, & Wright, 2001; Vicenzino, 1995; Wright, 2002; Wright & Vicenzino, 1995). The suggestion that changes in PA stiffness are the result of alterations in local muscle contraction secondary to altered pain mechanisms would not appear to be consistent with the current results. Firstly, as occurred in the lumbar spine with electrical stimulation (Hodges et al., 2003; Keller, Colloca, Harrison, Moore, & Gunzburg, 2007), muscle contraction would be expected to produce a change in stiffness throughout the PA movements. Secondly, although not reported in this thesis, measurements were taken during the study described in Chapter 7 of indicators of sympathetic nervous system activity (skin temperature, skin conductance, and blood flux) before, during, and after the active, placebo, and control interventions. Analysis of these data suggested that differences in SNS measures were related to the passive mobilisation being performed,
but not to the therapeutic effect of the technique. That is, differences in SNS activity were not related either to whether the mobilisation was directed to a symptomatic or asymptomatic location or to the effectiveness of the treatment (Tuttle, Laakso, & Barrett, 2007). The results do not support the therapeutic effects of manual therapy being mediated through the sympathetic nervous system. The results in relation to the SNS however need to be interpreted with caution as the two-minute baseline and post-treatment periods used in the current study may not have been sufficient to enable effective comparisons. Alternatively, other methods of assessing SNS function may need to be employed to detect any significant effects from PA movements.

In the current study it was not possible to fully characterise how PA movements are related to patient symptoms or to provide more specific guidelines for selection of patient subgroups or for the selection and application of treatment. Although no firm conclusions can be drawn on how PA movements might be related to intervertebral movement, our findings are consistent with the classical manual therapy paradigm that suggests a relation between impairments and intervertebral movement.

The results of this study can have a rapid impact on the teaching of manual therapy skills. Instructors frequently exhort students to use less force and the results of these studies provide a rationale for using lower forces in the assessment of PA movements than have been found to be employed in clinical practice. In addition the studies suggest the magnitude of forces that may need to be considered and provide a possible explanation of how differences in PA stiffness might be related to intervertebral movements.

Perhaps the most important finding for clinical practice is that immediate change in PA stiffness (regardless of the cause) is related to changes in symptoms. This finding supports the practice by skilled clinicians who vary their technique on a moment-to-moment basis in order to maximise changes in stiffness during the application of manual therapy treatment rather than applying a predetermined dose of a predetermined technique.

8.6. Summary and Conclusions

Immediate changes in AROM following manual therapy treatment to the cervical spine are a good indicator of between treatment and end of treatment changes in AROM. The PMAD is capable of assessing the force-displacement characteristics of PA
movements of the cervical spine. In patients with non-acute neck pain, there is a relation between PA movements of the cervical spine and active range of movement. Change in PA stiffness was only found to be related to changes in AROM at symptomatic locations and relations between changes in PA stiffness and AROM occurred only following treatment to the symptomatic location. The mechanisms underlying the effectiveness of mobilisation with PA movements remain unclear. The effects of treatment by PA movements, however appear to be dependent on and specific to the location treated. The results are consistent with, but insufficient to confirm, the influence of segmental mobility on patient symptoms.

The results demonstrated that stiffness of PA movements of the cervical spine is related to active range of movement in the cervical spine. The exact nature of this relationship however remains unclear and will continue to be the subject of further research.
8.7. References


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