PERFORMANCE OF CERVICAL SPINE MOBILISATION

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STATEMENT OF ORIGINALITY

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I hereby certify that the work embodied in this thesis is the result of original research, the greater part of which was completed subsequent to admission to candidature for the degree.

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ABSTRACT

Background and Purpose

Physiotherapists commonly use cervical mobilisation to treat neck pain and headaches. Ensuring similar amounts of mobilisation force are applied by different therapists is a necessary first step in establishing optimal parameters for achieving patient outcomes. A series of studies was designed to quantify cervical mobilisation forces applied by physiotherapists and students, explain any differences identified in applied forces, and determine if real-time objective feedback improves consistency in performance of cervical mobilisation techniques.

Methods

To quantify cervical mobilisation techniques, the forces applied by physiotherapists (n = 116) and undergraduate physiotherapy students (n = 120) were recorded using an instrumented treatment table. Each participant mobilised the C2 and C7 vertebrae of one asymptomatic subject using four grades of mobilisation, with one spinal level repeated after 20 minutes. Factors potentially associated with the applied forces, including spinal stiffness, were investigated.

To investigate the effects of real-time objective feedback on cervical mobilisation forces, visual targets based on force data recorded from an expert physiotherapist mobilising 21 asymptomatic subjects were provided to 50 students. They each mobilised one of these 21 subjects on two occasions. Students' forces were recorded before and after practising mobilisations with real-time visual feedback of forces (experimental group) or without (control).

Results

Cervical mobilisation forces varied between individuals (ICC [2,1], therapist vertical mean peak force, 0.32, 95% CI 0.20 to 0.53), but intra-therapist repeatability was high (0.93, 95% CI 0.92 to 0.94). The highest resultant mean peak force was applied centrally on C7 by therapists (91.8 N, 95% CI 83.4 to 100.2), with students generally using lower forces. For both therapists and students, higher forces were associated with male gender (therapist, student or mobilised subject), and lower forces with greater C2 spinal stiffness in the mobilised subject.

Students who received real-time feedback applied forces that were more similar to the expert's peak forces (median difference 4.0 N, IQR 1.9 to 7.7) than did the controls (14.3 N, IQR 6.2 to 26.2, $p < 0.001$), and this difference was maintained one week later.

Conclusions

The quantification of cervical mobilisation forces and explanations of differences in forces, together with the new technology developed, provide objective data about cervical mobilisation techniques, making effective feedback on performance possible. This will support strategies to improve consistency of mobilisation forces between therapists, as well as students. In turn, this approach provides the basis for future research to determine the mobilisation parameters that are optimal for treating a range of cervical spine disorders.

PUBLICATIONS

The following publications were a direct result of the work completed in this thesis:

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CHAPTER 1. Introduction

1.1. Background

1.1.1 Cervical spine mobilisation treatment

Neck pain is prevalent, disabling and costly. Lifetime prevalence of neck pain has been estimated to be 66.7% in a Canadian population (Côté, Cassidy, & Carrol, 1998), and only one-third of those with neck pain obtain resolution of their symptoms (Côté, Cassidy, Carrol, & Kristman, 2004). In The Netherlands, the annual total costs of neck pain have been estimated at US $686 million (Borghouts, Koes, Vondeling, & Bouter, 1999). In Australia, a 20% prevalence of cervical pain was found in a randomly surveyed population (Gordon, Trott, & Grimmer, 2002).

There are many different ways to treat neck pain, or more specifically, mechanical disorders of the cervical spine. One intervention is manual therapy, which includes any technique involving the use of a therapist's hands to apply forces aimed at moving a joint or the surrounding tissues (Mercer, 2004). Manual therapy includes joint mobilisation, joint manipulation, soft tissue massage and other techniques. It is regularly used to treat musculoskeletal disorders of the neck, supported by some evidence of its effectiveness in the management of both subacute and chronic neck conditions (Bronfort, Haas, Evans, & Bouter, 2004; Gross et al., 2004; Gross, Kay, Hondras et al., 2002; Gross, Kay, Kennedy et al., 2002).

A common manual therapy technique used when treating the neck is the posterior-to-anterior (PA) mobilisation technique described by Maitland et al.

(Maitland, Banks, English, & Hengeveld, 2005). According to two surveys of Australian physiotherapists, mobilisation is the most common manual technique they use to treat cervical spine disorders, and it is used more frequently than manipulation (Jull, 2002; Magarey et al., 2004). The PA mobilisation technique can be described as an oscillatory force applied to the spinous (central PA) or articular (unilateral PA) processes of the spine (Maitland et al., 2005). PA mobilisations to the cervical spine are usually applied with the pads of the thumbs, but occasionally therapists use the heel of the hand. Therapists apply mobilisations using one of four grades, described by Maitland et al. (2005) and Grieve (1991), depending on the aim of treatment. There is some evidence for the use of mobilisation in cervical spine treatment. In one randomised controlled trial, cervical mobilisation was more cost-effective for treating neck pain than either exercise or general practitioner care (Korthals-de Bos et al., 2003).

If the forces applied during cervical mobilisation vary between therapists, or if individual therapists apply inconsistent forces, cervical spine treatments may not be consistently effective, and this may affect treatment outcomes. This has been demonstrated in the elbow, where the application of a specific level of lateral gliding force was required to achieve pain free grip (McLean, Naish, Reed, Urry, & Vicenzino, 2002). Furthermore, if forces applied to the cervical spine are excessive, they may possibly harm anatomical structures, such as the vertebral artery (Kerry, 2002; Mann & Refshauge, 2001). Indeed, adverse symptoms such as dizziness and nausea, potentially related to the vertebrobasilar system, have been reported following cervical mobilisation treatment (Magarey et al., 2004). The potential relationship of cervical mobilisation forces to these symptoms is unknown.

To evaluate the clinical effectiveness of this manual technique and ensure consistency of the treatment dose, the parameters of force related to cervical mobilisation should first be quantified. Following this, links between cervical mobilisation force parameters and manual therapy treatment outcomes could then be investigated.

1.1.2 Consistency of cervical mobilisation force parameters

The forces used to execute a particular grade of mobilisation may not be consistent between therapists. Indeed, this has been shown for lumbar spine mobilisation (Cook et al., 2002; Harms & Bader, 1997), but has not been adequately investigated in the cervical spine. Different forces may potentially result in variations in treatment outcomes, reducing effectiveness for some patients. In the cervical spine, there is some information reported on the forces used during manipulation (Herzog, Conway, Kawchuk, Zhang, & Hasler, 1993; Kawchuk & Herzog, 1993; Kawchuk, Herzog, & Hasler, 1992), but mobilisation forces have not been effectively measured. Consistent with this, factors affecting cervical mobilisation techniques that may result in different treatment outcomes or adverse effects for patients have not been investigated. Similarly, factors that may be associated with potential differences in applied forces between therapists, such as spinal stiffness or therapist/patient characteristics, have not been identified. Therapists use their interpretation of a patient’s spinal stiffness to guide their manual therapy treatment (Maitland et al., 2005), so spinal stiffness or a therapist’s interpretation of it may also affect the manual forces applied by different therapists.

1.1.3 Learning cervical mobilisation

Training in the application of manual techniques is a standard part of physiotherapy curricula (Boissonnault, Bryan, & Fox, 2004; Bryan, McClune, Romito, Stetts, & Finstuen, 1997). One report indicated that spinal mobilisation was included in 99% of surveyed U.S. physiotherapy programs (Bryan et al., 1997). Teaching manual therapy usually involves instructor demonstration, followed by student practice of techniques with a partner and instructor feedback (Flynn, Wainner, & Fritz, 2006). The accuracy of student performance after this instruction and the consistency of teaching methods are not known. Graduates of physiotherapy programs are expected to be autonomous practitioners from their first day of clinical practice (Crosbie et al., 2002), so student proficiency and safety in the application of cervical spine techniques is essential.

Learning methods may contribute to some of the variation between therapists. Students usually learn mobilisation techniques without additional objective feedback about their applied force. Research has shown that when students provided verbal feedback about the mobilisation forces applied to them by one of their peers, it was not as accurate as measurements of the applied force recorded by a forceplate (Petty, Bach, & Cheek, 2001). Therefore, it is unlikely that students effectively develop an ability to apply standardised and consistent mobilisation forces using current teaching methods. Strategies to improve student learning of cervical mobilisation techniques which aim to increase the accuracy and consistency of cervical mobilisation forces are warranted.

1.2. Objectives

1.2.1 Equipment development

Instrumented table

The first objective of this research was to develop a method to effectively quantify cervical mobilisation forces. The aim was to develop a tool that can measure forces while physiotherapists perform their usual clinical technique on a person, without any additional instrumentation between their hands and the mobilised subject. Therefore, an instrumented table was designed, constructed and tested. This is described in Chapter 3.

Stiffness assessment device

The published literature on mobilisation techniques applied to the lumbar spine suggests that the forces used by therapists are likely to be highly variable (Cook et al., 2002; Harms & Bader, 1997). Large variation within the forces applied by therapists indicates a large sample size is needed in order to determine the mean forces therapists use with confidence, and to ensure the sample of therapists is representative of therapists practising in Australia. Measuring mobilisation forces applied by a large sample of therapists means that all therapists cannot ethically mobilise the same person. Therefore, when investigating forces applied by individual therapists, the differences between subjects mobilised by the therapists need to be considered.

A key difference between mobilised subjects is their level of spinal stiffness. Therapists are trained to alter the force they apply based on the spinal stiffness they palpate, in accordance with the recommended grades of mobilisation (Maitland et al., 2005). Thus, spinal stiffness is a potential factor affecting a therapist's applied force. To compare differences in forces applied by individual therapists mobilising different subjects, the spinal stiffness of those subjects must be included in the analyses. For that reason, an instrument for measuring spinal stiffness was designed, constructed, and tested. This is described in Chapter 4.

1.2.2 Quantification of cervical mobilisation techniques

Cervical mobilisation applied by physiotherapists

A primary aim of this research was to quantify mobilisation forces applied to the cervical spine. Cervical mobilisation techniques were quantified using three force parameters identified in the published literature as the most relevant. These are the mean peak force, the force amplitude and the oscillation frequency (detailed descriptions of these force parameters are included in Chapter 2). Initially, ten physiotherapists were recruited to pilot the proposed methods of measuring cervical mobilisation forces. This is described in Chapter 5.

A larger sample of physiotherapists (n = 116) was then recruited. They applied posteroanterior mobilisation techniques to the upper and lower cervical spine of asymptomatic subjects while their forces were recorded. Therapists were also asked to repeat one technique for the calculation of intra-therapist reliability. Factors potentially affecting mobilisation force parameters were investigated. This study is described in Chapter 6.

Cervical mobilisation applied by students

It is unknown whether any potential variability in cervical mobilisation forces between therapists is a result of clinical experience (such as the environments, patients or different manual techniques therapists use during their careers), or whether variability is inherent in individuals, even when they have exactly the same training with no additional clinical influences. Thus, differences between the cervical mobilisation forces applied by physiotherapists and those applied by students with no clinical experience were investigated. Students (n = 120) were recruited to apply cervical mobilisations while their forces were recorded, using the same methods as for the therapists. This study is described in Chapter 7. Further analysis of the similarities and differences between the forces applied by therapists and students is described in Chapter 8.

Mobilised subject perceptions about applied forces

Few studies have investigated the perceptions of subjects being mobilised, in particular their perceptions about applied cervical mobilisation forces. Patients' perceptions of pain or discomfort during a treatment session have been reported to predict patient outcomes from manual therapy (Hahne, Keating, & Wilson, 2004; Tuttle, 2005), and therapists regularly use patients' report of pain to guide treatment, as this is more reliable than therapists' palpation (Maher, Adams, & Shields, 1994). However, it is unknown whether the perceptions of pain by patients are affected by differences in the manual techniques applied to them.

Therefore, subjects mobilised by physiotherapists and students were asked to provide comments about the mobilisations they received and rate their level of comfort while being mobilised. The relationships between cervical mobilisation force parameters and subjects' comments and level of comfort were analysed. This is described in Chapter 9.

1.2.3 Use of real-time feedback for cervical mobilisation training

Real-time feedback software

The final key objective of this research was to develop a strategy for improving consistency in cervical mobilisation forces applied by individual therapists. A new software program was developed that can interpret data from the instrumented table and provide real-time feedback to a therapist while mobilising. The display is visually intuitive and provides feedback that is relevant. It has in-built flexibility for learning so that various options can be selected. For example, specific individual force targets for performing different techniques or mobilising different individuals, or feedback on particular force parameters depending on the aim of the learning activity. This software is described in Chapter 10.

Effectiveness of the feedback software

Lastly, the feedback software was evaluated for effectiveness in improving physiotherapy students' ability to apply cervical mobilisation forces similar to an expert clinician's forces. Students were recruited to apply cervical mobilisation techniques to an asymptomatic subject while receiving visual and auditory feedback about their applied force compared to that pre-recorded for the physiotherapist expert. The students' cervical mobilisation forces were measured before and after practice to determine if their forces were more consistent with the expert's and other students after receiving the feedback. A randomised trial compared the effectiveness of feedback compared to identical practice without feedback. These results are presented in Chapter 11.

1.3. Summary

Improving patient outcomes requires interventions that are effective. Determining effective manual therapy interventions for cervical spine treatment requires clear descriptions of the manual therapy techniques used, with consistent performance of those techniques in order to investigate their efficacy. The first step towards this is the development of measurement methods to specifically quantify cervical mobilisation techniques. Then, therapists must perform techniques consistently so they can be systematically investigated in patient populations. This thesis aims to accomplish these first two steps: accurately measuring and quantifying cervical mobilisation techniques, and improving consistency in the application of cervical mobilisation.

CHAPTER 2. Literature review

2.1. Introduction

The current healthcare environment requires health practitioners to consider the scientific evidence when selecting treatment interventions. Systematic reviews have concluded that there is at least moderate evidence for the efficacy of manual therapy in the treatment of low back pain, neck pain and headaches (Bronfort, Nilsson et al., 2004; Gross et al., 2004; Jull et al., 2002; Koes, Assendelft, van der Heijden, & Bouter, 1996; van Tulder, Koes, & Bouter, 1997). One recent review concluded that spinal manipulative therapy results in similar or better pain outcomes in the short and long term when compared with a placebo or other treatments for a mix of acute and chronic low back pain problems (Bronfort, Haas et al., 2004). In addition, a randomised controlled trial with a cost analysis concluded that mobilisation was more effective and less costly for treating neck pain than ‘physiotherapy’ (consisting primarily of exercise treatment) and general practitioner care (Korthals-de Bos et al., 2003).

The evidence concerning manual therapy has two distinct dimensions: clinical efficacy, as noted above, and the biomechanical evaluation of treatment techniques. The focus of this literature review is specifically on the methods used to evaluate and compare manual treatment techniques, an essential part of establishing reliable clinical treatment protocols. Determining the extent to which manual treatment contributes to a clinical outcome requires understanding the properties of the techniques used. This means manual techniques must be described and reproduced accurately in order to assess their efficacy in treating clinical conditions.

Manual therapy includes both mobilisation (low velocity oscillatory techniques) and manipulation (high velocity thrust techniques). Often no differentiation is made between these different types of manual techniques when reporting conclusions about the effectiveness of manual therapy (Hurley, McDonough, Baxter, Dempster, & Moore, 2005). Indeed, 14 of 15 randomised clinical trials of the efficacy of manual therapy in the treatment of low back pain identified in one review did not adequately describe the manual technique used, and sometimes the terms mobilisation and manipulation were used interchangeably (Kotoulas, 2002). Since there is no internationally recognised and standardised terminology in use for manual therapy, the results of clinical trials and systematic reviews may be interpreted differently by different clinicians. Standardised definitions and descriptions of mobilisation and manipulation are necessary to establish clear conclusions about the efficacy of different manual techniques, and to provide more specific guidelines for clinical practice (Kotoulas, 2002).

If definitions of mobilisation and manipulation are to be clearly distinguished and differentiated, there needs to be a way of quantifying them to ensure reliable and consistent usage. Manual therapists need confidence that they are applying the same technique if there is evidence for its effectiveness. At present, even a single manual technique described in the same way among a group of practitioners may be applied differently by each practitioner, with varying levels of force or velocity (Chiradejnant, Latimer, & Maher, 2002; Harms & Bader, 1997; Simmonds, Kumar, & Lechelt, 1995). Therefore, accurate quantification and description of the type and dose of manual treatment is required. This review starts by evaluating how one commonly used spinal mobilisation technique has been quantified in the literature. The aim is to identify the essential parameters that need to be described in order to standardise this manual therapy technique.

A large proportion of the literature on applied manual forces relates to the posterior to anterior (or posteroanterior, PA) spinal mobilisation technique that has been described by Maitland et al. (2005; Scaringe & Kawaoka, 2005). The PA spinal mobilisation technique is one of the most commonly used manual techniques (Jull, 2002; Magarey et al., 2004). This technique requires the therapist to apply a pressure to the spine using either the heel of the hand (pisiform grip, Figure 2.1a) or the thumbs (thumb grip, Figure 2.1b). Forces are usually applied in an oscillating manner over a period of time, commonly for 30 seconds, and the process is repeated three to four times for a treatment application to a single vertebral level (Maitland et al., 2005). Therapists select different grades of mobilisation depending on the aim of the manual treatment and the patient’s problem (Table 2.1). The grade of mobilisation will affect the forces that are applied.

The number of parameters that may be varied when applying a PA mobilisation and the potential for variation in therapists’ interpretations of what they palpate during mobilisation suggest that the clinical application of this manual technique may vary, resulting in inconsistencies in its effectiveness. For example, the magnitude of force applied during PA mobilisation may affect the outcome of the manual treatment. Forces may be too small to produce the

A **B**

Figure 2.1. A. Pisiform grip during PA mobilisation of the lumbar spine. B. Thumb grip during PA mobilisation of the cervical spine.

Table 2.1. Definitions of the grades of mobilisation as described by Maitland et al. (2005).

Grade	**Definition**
I	Small amplitude movement near the start of the range
II	Large amplitude movement within the resistance-free range
III	Large amplitude movement that moves into resistance or stiffness
IV	Small amplitude movement stretching into resistance or stiffness

desired clinical effect, or may be potentially extreme, resulting in undue stress on anatomical structures. Indeed, adverse effects such as dizziness and nausea, potentially related to the vertebrobasilar system, have been reported following the application of both mobilisation and manipulation techniques to the cervical spine (Magarey et al., 2004). Furthermore, excessive manual forces may have detrimental effects on the practitioner, resulting in work-related hand or thumb pain (Snodgrass & Rivett, 2002; Snodgrass, Rivett, Chiarelli, Bates, & Rowe, 2003). Since the use of manual therapy is supported by some clinical evidence for its effectiveness (Bronfort, Haas et al., 2004; Gross et al., 2007; Koes et al., 1996; van Tulder et al., 1997), practitioners will likely continue to use mobilisation in their treatment of patients with spinal disorders, despite possible inconsistencies in its application.

In summary, the focus of this literature review is to identify mechanisms previously used to measure mobilisation forces and the effectiveness of those mechanisms, report previously measured parameters of mobilisation forces, and establish consistent terms for describing mobilisation forces. Specifically, the review will start by assessing the evidence related to the consistency of applied forces among practitioners during the application of spinal PA mobilisations. This is expected to contribute to standardising terminology for describing this manual technique, and provide a background to the research studies described in this thesis. Existing processes for measuring manual forces during spinal mobilisation and the factors that affect the consistency of these forces among practitioners will be critically evaluated.

This review will support the development of a reliable method of measurement for mobilisation forces. This is necessary to determine the forces that therapists apply when performing spinal mobilisation, particularly mobilisation techniques applied to the cervical spine for which little data is available. This can lead to the possibility of establishing mechanisms to assist students to learn to apply mobilisations with consistent forces, through the development of tools to provide students with objective feedback on the forces that they apply.

2.2. Methods

A comprehensive search of the literature was conducted to identify studies that reported the quantification of mobilisation forces. The following complete electronic databases were included in the literature search: MEDLINE, Cumulative Index to Nursing and Allied Health Literature (CINAHL), Physiotherapy Evidence Database (PEDro), Allied and Complimentary Medicine Database (AMED), EMBASE and the Cochrane Database of Systematic Reviews (Cochrane Library, 2005). Search strategies included the following terms which were linked to MeSH subheadings and combined with Boolean operators: manual therapy, mobilisation/mobilization, manipulation, spine, physiotherapy/physical therapy, physiotherapist/physical therapist, chiropractor, force, reliability, validity, palpation and stiffness. Language was restricted to English. In addition to electronic database searches, relevant citations were identified through hand searching of retrieved publications and email contact with authors who had multiple publications in this subject area. Studies that only describe high velocity thrusting manipulation techniques were excluded. All other studies reporting mobilisation forces were included. The selected studies were then critically analysed to facilitate comparisons of mobilisation forces measured in different studies.

2.3. Results

Seventeen articles were identified which describe the measurement of mobilisation forces. These are summarised in Tables 2.2 to 2.4. An additional four studies quantify movements occurring when therapists apply PA mobilisation forces, without reporting force measures (Chester, Swift, & Watson, 2003; Kulig, Landel, & Powers, 2004; McGregor, Bull, Lee, & Wragg, 2004; McGregor, Wragg, & Gedroye, 2001). The diverse methods of measurement used to quantify mobilisation forces prevented any pooling of data for meta-analysis and made comparisons of data difficult. Despite some questions about the quality of some studies (e.g., small samples of manual therapists, limitations of measuring instruments and a lack of detail in reporting the methods used), given the relatively small number of studies that report the measurement of mobilisation forces, all were included irrespective of methodological quality.

Table 2.2. Magnitude of forces recorded during posterior-to-anterior mobilisations of the lumbar spine.

Study	Measurement method	Practitioners	Subjects mobilised	Grip	Vertebral level	Mean peak force in N (SD) – vertical direction			
						Grade I	Grade II	Grade III	Grade IV
Chiradejnant et al. (2002)	Instrumented treatment table	10 PTs* (mean 10 yrs experience)	80 LBP** patients, mean age 53.5 (SD 15.4) yrs	Not reported	L1 (9%) L2 (15%) L3 (22%) L4 (31%) L5 (23%)	50.1 (25.7)	84.9 (33.4)	121.4 (45.7)	194.8 (46.6)
Cook et al. (2002)	Therapist standing on forceplate	23 PTs (mean 6 yrs experience)	1 male and 1 female asymptomatic model	Pisiform	L3	52.16 (36.11)	119.23 (50.96)	179.31 (63.34)	242.25 (69.17)
Petty et al. (2001)	Therapist standing on forceplate	13 PTs	PT participants as models	Pisiform	L1-L5			L1‡: 196 (37) L2‡: 196 (41) L3‡: 206 (43) L4‡: 224 (43) L5‡: 206 (43)	
Harms et al. (1999)	Instrumented treatment table	1 female PT (5 yrs experience)	30 females (mean age 26) 31 females (mean age 55)	Not reported	L3	<10†	~15†	~180†	~200†
Harms & Bader (1997)	Instrumented treatment table	30 PTs (mean 9.4 yrs experience)	26 yr-old asymptomatic male	Therapist choice	L3	37.0¥	53.3¥	134.7¥	156.3¥
Lee et al. (1990)	Plinth on forceplate	2 PTs 22 students 31 students	1 asymptomatic male	Pisiform	L3		33.3 ~42†‡ ~62†‡		
Matyas & Bach (1985)	Therapist standing on forceplate	8 PTs with post-grad qualifications	4 subjects	Pisiform	T9, T11, L1, L3, L5		2.2-46.7		89.2-329.3 (range)

*PTs = physiotherapists
**LBP = low back pain
†Numerical values estimated from graphical representation of data
‡Mean prior to any training/feedback
¥Resultant vector of 3 measured directions of force

Table 2.3. Magnitude of forces recorded during posterior-to-anterior mobilisations of the cervical and thoracic spines.

Study	Measurement method	Practitioners	Subjects mobilised	Grip	Vertebral level	Mean peak force in N (SD) – vertical direction			
						Grade I	Grade II	Grade III	Grade IV
Lee et al. (2005)	Water-filled pressure device	1 PT*	19 asymptomatic models	Not reported	C5			42.2 (10.8)	
Conradie et al. (2004)	Flexiforce transducers	16 PTs (completed 1 yr post-grad course)	21-year-old asymptomatic female	Thumbs	C6	0.498 (0.475)**			
Smit et al. (2003)	Flexiforce transducers	40 students	20 year old asymptomatic female	Thumbs	C6	1.47-1.96**[†] (range)			
Langshaw (2001)	Instrumented treatment table	9 PTs 9 students	2 male and 2 female asymptomatic models	Thumbs	C4	17.0 (5.2)[‡¥] 34.6 (9.9)[¥¥]	33.3 (9.6)[‡¥] 56.5 (14.5)[¥¥]	68.2 (17.3)[‡¥] 79.6 (18.8)[¥¥]	77.7 (18.9)[‡¥] 81.1 (19.1)[¥¥]
Threckeld (1992)	Plinth on forceplate	2 PTs (at least 5 yrs experience)	1 asymptomatic model	Pisiform	Mid-thoracic	91.1-205.8 (range)			231.8-499.8 (range)
Matyas & Bach (1985)	Therapist standing on forceplate	7 PTs with post-grad qualifications	4 subjects	Pisiform	T5, T7, T9, T11		7.6-87.1 (range)		
		8 PTs with post-grad qualifications	4 subjects		T9, T11, L1, L3, L5		2.2-46.7 (range)		89.2-329.3 (range)

*PT = physiotherapist
**Calculated from raw data provided, original data reported in grams
[†]Numerical values estimated from graphical representation of data
[‡]Experienced physiotherapists
[¥]Student therapists
[¥]Standard deviation calculated from standard error provided

Table 2.4. Magnitude of forces recorded during posterior-to-anterior mobilisations on simulated spines (artificial devices).

Study	Measurement method	Practitioners	Grip	Mean peak force in N (SD) – vertical direction			
				Grade I	Grade II	Grade III	Grade IV
Waddington et al. (2007)	Hand-held dynamometer applied to plinth	30 PTs*	Device handle	39.7	70†	105†	170†
Waddington et al. (2006)	Hand-held dynamometer applied to plinth	30 health science students	Device handle		95-120 (range)		170-220 (range)
Bjornsdottir & Kumar (2003)	Mechanical spinal model	10 PTs (mean 19 yrs experience) 10 PTs (<1yr experience)	Pisiform		77.1 (25.9) 61.1 (20.5)		
Snodgrass (2003)	Secured pinch gauge (static reading)	44 PTs (mean 16 yrs experience)	Thumbs				149.1 (53.9)
Simmonds et al. (1995)	Mechanical spinal model	10 PTs (at least 7 yrs experience)	Therapist choice	82.43 (45.79)‡	106.44 (53.16)‡	155.59 (95.10)‡	141.92 (70.75)‡
Hardy & Napier (1991)	Pressure sensitive platform	5 PTs (mean 12.2 yrs experience) and 2 PT students	Thumbs	0.59-30.09 (range)	1.31-37.99 (range)	3.82-50.50 (range)	7.64-122.11 (range)
Watson & Burnett (1990)	Mechanical plunger apparatus	Group of experienced PTs	Thumbs	50 to 235 (range, grades I – IV)			

*PTs = physiotherapists
†Numerical values estimated from graphical representation of data
‡Reported here for one of three stiffness conditions: the medium stiff condition

2.4. Discussion

2.4.1 Quantification of mobilisation forces

Mobilisations are quantified by measurement of both the force applied to the spine and the displacement (movement) that occurs as a result of the applied force. The magnitude of a mobilisation, or how hard the therapist pushes on the spine, is usually reported as the magnitude of force (Bjornsdottir & Kumar, 2003; Chiradejnant et al., 2002; Cook et al., 2002; Harms & Bader, 1997; Harms, Milton, Cusick, & Bader, 1995; Matyas & Bach, 1985; Simmonds et al., 1995). However, the sensations felt by the patient during mobilisation will be affected by the concentration of the applied force, namely, the pressure. Since pressure is defined by force/area, the surface area where the force is applied will affect the pressure measured, and likely the sensation of pressure felt by the patient. For example, a person receiving mobilisation will feel a different sensation if the force is applied over a smaller compared with a larger surface area, such as when a therapist mobilises with a thumb grip versus a pisiform grip (Figure 2.1). In the literature on mobilisation, researchers have usually reported the forces applied without measuring the surface area upon which it is applied (Bjornsdottir & Kumar, 2003; Chiradejnant et al., 2002; Cook et al., 2002; Harms & Bader, 1997; Harms et al., 1995; Matyas & Bach, 1985; Simmonds et al., 1995). Therefore, even though clinicians may tend to use the terms force and pressure interchangeably, in this discussion the term force will be used when describing mobilisations applied by therapists.

Force parameters include the magnitude (peak or trough), oscillation frequency and amplitude of force (Figure 2.2a). Displacement parameters include the maximum movement (distance) recorded when a force is applied and the amplitude of displacement (Figure 2.2b). These parameters are used to quantify the characteristics of mobilisation techniques applied by practitioners. Each of these parameters has been used to make comparisons between applications of force by different clinicians (Chiradejnant et al., 2002; Harms &

Bader, 1997), at different vertebral levels (Viner, Lee, & Adams, 1997) or for different clinical applications (Chiradejnant et al., 2002; Harms et al., 1999).

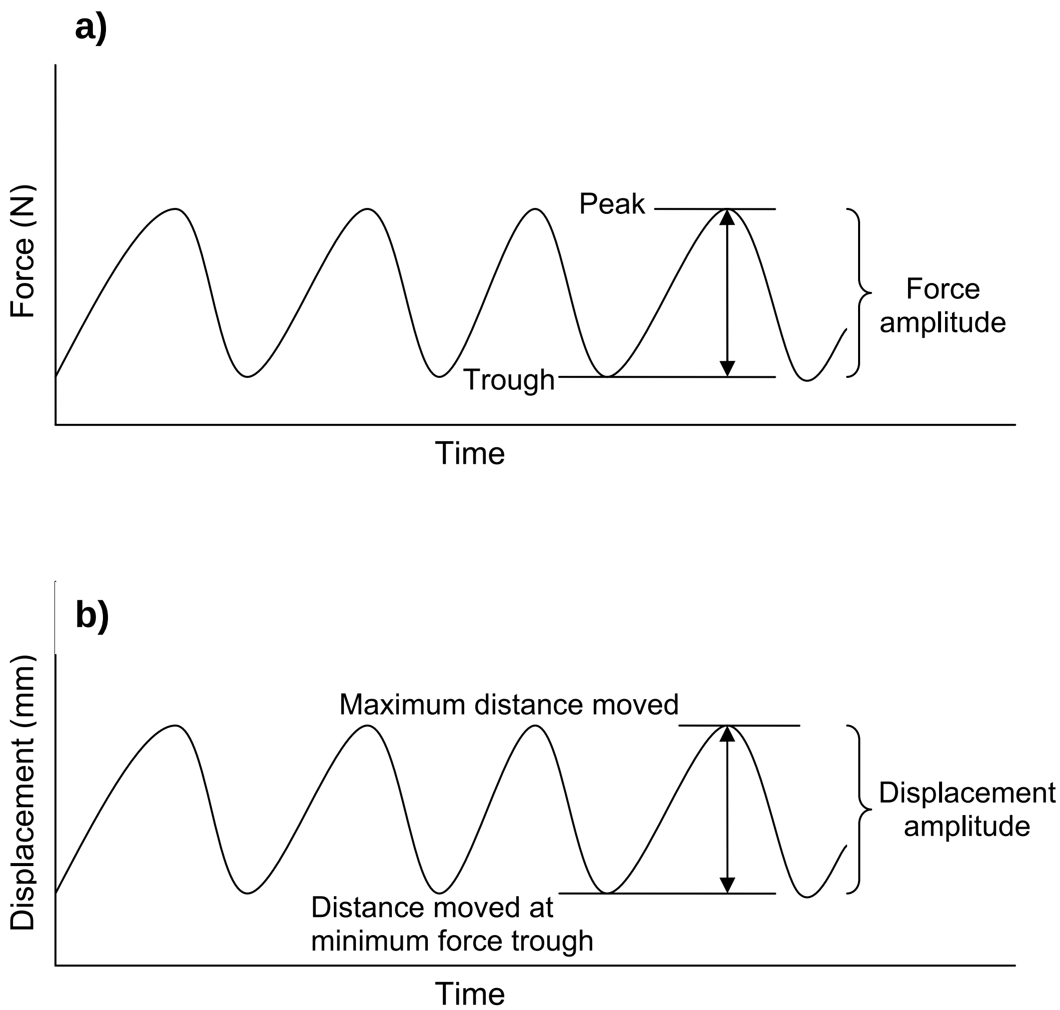

Figure 2.2. Typical representation of a posterior-to-anterior mobilisation with respect to force (a) and displacement (b).

2.4.2 Magnitude of force

The magnitude of applied manual force is defined as the amount of force applied by the practitioner. For oscillatory PA mobilisation techniques, the maximum magnitude of applied force is usually reported as the mean of the force peaks that occur during a specified time period (Chiradejnant et al., 2002; Harms & Bader, 1997; Harms et al., 1999). Likewise, the average of the force troughs during a time segment of recorded data usually represents the minimum force (Figure 2.2a). Force magnitudes have been measured for mobilisation techniques applied to the lumbar spine, and to a lesser extent, the thoracic and cervical spines (Table 2.2 and Table 2.3). Mean peak forces recorded during mobilisation have been reported as extremely variable between different clinicians when applying the same grade of mobilisation (Chiradejnant et al., 2002; Cook et al., 2002).

For PA mobilisations applied to the lumbar spine, the average peak forces applied for a grade I mobilisation are reported to range from approximately 10 to 50 N, a grade II from approximately 15 to 120 N, a grade III from approximately 120 to 225 N, and a grade IV mobilisation from approximately 90 to 240 N (Table 2.2). This summary of mean peak forces is derived from studies that measured PA mobilisation forces applied by experienced clinicians and students, with sample sizes ranging from 1 to 51 participants (Table 2.2). PA mobilisation forces measured in the lumbar spine include forces applied to the spines of both patients and asymptomatic individuals. There is a general pattern of increasing force with higher grades of mobilisation.

Two studies report PA mobilisation forces applied to the thoracic spine (Matyas & Bach, 1985; Threlkeld, 1992). The data from these studies is conflicting. The forces applied during a grade I thoracic mobilisation by two therapists ranged from 91 to 206 N in one study (Threlkeld, 1992). These values are much higher than the range of average peak forces for a grade II mobilisation (7.6 to 87.1 N) reported in a second study (Matyas & Bach, 1985). Factors that might contribute to this discrepancy are differences in the way the techniques were applied by therapists in each study, different methods of measurement and small sample sizes (Table 2.3).

Four studies report PA mobilisation forces applied to the cervical spine (Conradie et al., 2004; Langshaw, 2001; Lee et al., 2005; Smit et al., 2003) (Table 2.3). In all studies, mobilisation forces applied to the cervical spine tend to be somewhat lower than mobilisation forces applied to the lumbar or thoracic spines. Grade II and grade IV mobilisations were measured in only one study, which reported differences in applied forces between experienced therapists and novices (Langshaw, 2001) (Table 2.3). For grade I and grade III cervical mobilisations, the peak forces reported in the literature vary considerably. Mean peak forces for grade I PA mobilisations were much smaller when measured using a flexible force transducer positioned on C6 under the thumbs of the therapist, 0.5 to 2 N (Conradie et al., 2004; Smit et al., 2003), than when an instrumented table was used to measure forces applied to C4, 17 N for experienced therapists and 35 N for novice therapists (Langshaw, 2001). Likewise, grade III mobilisations of C5 measured using a water-filled pressure device, 42 N (Lee et al., 2005), were less forceful than grade III mobilisations of C4 measured with an instrumented table, 68 N for experienced therapists and

80 N for novice therapists (Langshaw, 2001). The pressure device measured the change in water level within a clear plastic hose open to atmospheric pressure at one end and connected to a pressure pad under the therapist's thumbs. When it was used, the frequency of mobilisation was slowed to about 0.25 Hz (1 oscillation per 4 seconds) so that MRI images could be taken (Lee et al., 2005). The slower rate may have reduced the force recorded when a similar amount of movement occurred, since spinal stiffness is less at slower loading rates (Lee & Svensson, 1993). Stiffness is a measure of force and displacement, so less stiffness would correspond to less recorded force for a specific amount of movement. However, factors related to the measuring instrument or participant samples could also potentially contribute to these large discrepancies in reported force magnitudes.

2.4.3 Frequency of oscillation

For PA mobilisations, the rate of oscillation of repeated applications of force is described as the frequency of oscillation (Chiradejnant et al., 2002; Harms & Bader, 1997; Harms et al., 1999; Lee et al., 2005; Petty et al., 2001). The frequency of the oscillating force during mobilisation is another potential source of variation between manual therapists, or when therapists repeat techniques on subsequent occasions. Maitland et al. (2005) recommend applying mobilisations at a rate ranging between one oscillation every two seconds to two to three oscillations per second, depending on patient factors. Most data indicate that therapists apply PA mobilisation forces at a rate of 1 to 1.5 Hz, that is, 1 to 1.5 oscillations per second, regardless of grade of mobilisation or spinal level (Chiradejnant et al., 2002; Conradie et al., 2004; Harms & Bader, 1997; Petty et al., 2001).

2.4.4 Amplitude of force

Force amplitude is the difference between the minimum and maximum forces applied during mobilisation. That is, it is the difference between the force recorded at the trough and the force recorded at the peak of an applied oscillatory force on a force-time curve (Figure 2.2a). For PA mobilisation, force amplitude is usually reported as the average force amplitude for a series of oscillations (Chiradejnant, Maher, & Latimer, 2001; Harms & Bader, 1997; Harms et al., 1999; Petty et al., 2001). This is calculated by averaging the differences between minimum and subsequent maximum forces for repeated oscillations. Amplitudes for PA mobilisation forces are usually greater for grades II and III than grades I and IV (Chiradejnant et al., 2002; Cook et al., 2002; Harms & Bader, 1997). This is consistent with the definitions of the grades of mobilisation, which indicate that grades II and III require the therapist to move a vertebral segment through a greater portion of its total range (Maitland et al., 2005; Petty, 2004). When moving a vertebra through a greater portion of range, there will likely be a greater difference between the minimum force applied at one end of the mobilised range and the maximum force applied at the other end.

Amplitude of force is not the same as vertebral displacement because the resistance provided by the vertebra is not linear with respect to incremental changes in its displacement (Shirley, 2004). For example, a grade II mobilisation, according to the Maitland et al. (2005) grading system, is performed in that part of the range that is free of any resistance perceived by the therapist. The resistance-free range may be greater in a person with a mobile spine than in a person with a stiffer spine, so the amount of resistance-free movement or displacement during a grade II mobilisation may be greater in the mobile spine. However, the difference between the minimum and maximum forces applied for a single grade II oscillation, that is, the force amplitude, might be similar in both cases. Thus, the force amplitude, a measure of force, is not the same as the joint displacement, a measure of distance.

Existing studies report average force amplitude in different ways. Some report raw data in Newtons (Chiradejnant et al., 2001; Petty et al., 2001), some describe force amplitude as a percentage of the maximum amplitude (Harms & Bader, 1997; Harms et al., 1995), and some only display amplitude information graphically (Harms & Bader, 1997; Harms et al., 1995; Threlkeld, 1992). One study that provides force amplitude data in Newtons reports the amplitude for a grade I PA mobilisation to L3 as 16.6 N, grade II 48.4 N, grade III 102.4 N, and grade IV 32.9 N (Chiradejnant et al., 2002). Another group of researchers reported a somewhat higher force amplitude for lumbar PA mobilisation, with the average for different lumbar vertebrae ranging from 110 to 140 N for grade III mobilisations (Petty et al., 2001). Different methods of measurement possibly contribute to this difference: instrumented table (Chiradejnant et al., 2002) versus therapist standing on forceplate (Petty et al., 2001).

2.4.5 Displacement

Displacement is the amount of movement that occurs during PA mobilisation. It has been measured by quantifying either the spinal movement or the movement of the therapist's hand during the application of oscillatory PA force. The method used to measure displacement determines how it is described. When referring to spinal movement occurring as a result of applied force, displacement corresponds to the distance between an initial starting point representing the vertebral position prior to any movement occurring, and an end point representing the position after the movement has occurred (Edmondston et al., 1998; Latimer, Lee, Goodsell et al., 1996; Lee & Evans, 1992; Shirley, 2004). When displacement refers to the movement of the therapist's hands, it is defined as the distance between the initial starting position of the hand contact point on the skin surface (or simulated skin surface) and the position of the hand contact point when maximum force is applied (Chester et al., 2003; Simmonds et al., 1995; Watson & Burnett, 1990). Displacement can be reported as the maximum (peak) displacement (average of the peaks of oscillating movement during a period of time), the minimum displacement (average of the troughs of oscillating movement), or the amplitude of displacement (average difference between maximum and minimum values, Figure 2.2b).

One way of quantifying displacement is by measuring the movement of spinal tissues at the skin surface when force is applied by a mechanical device (Edmondston et al., 1998; Latimer, Lee, Goodsell et al., 1996; Lee & Evans, 1992). A controlled force is applied to the skin surface and displacement is calculated by measuring the distance that the tip of the applicator probe (touching the skin surface) moves in response to an applied force (Latimer, Lee, Goodsell et al., 1996; Shirley, 2004). A selection of known forces is applied so that the mechanical response of spinal tissues to known forces can be determined. Studies that describe measures of tissue displacement in the lumbar spine during mechanised force applications report displacements of 4.3 to 5.9 mm with the application of 30 N of force (30 N represents the estimated end of the non-linear portion of the force-displacement curve, Figure 2.3) (Latimer, Goodsell et al., 1996; Latimer, Lee, Adams, & Moran, 1996;

Nicholson, Maher, Adams, & Phan-Thein, 2001; Nicholson, Maher, & Adams, 1998; Shirley, 2004; Shirley, Ellis, & Lee, 2002). Maximum displacement when 150 N was applied to the lumbar spine was reported in one study as ranging from 10.9 to 13.0 mm for one group of individuals (Lee & Evans, 1992). The application of known incremental forces demonstrates that displacement increases as greater forces are applied, but displacement is also affected by the rate, angle and point of force application, skinfold thickness and body mass index (BMI), the position of the spine, pelvis and ribs, and the stiffness of the pelvis and ribs (Caling & Lee, 2001; Chansirinukor, Lee, & Latimer, 2001, 2003; Lee, Steven, Crosbie, & Higgs, 1996; Lee & Svensson, 1993; Lee & Evans, 1992; Viner & Lee, 1995). This method of displacement measurement provides information about the responses of tissues to known forces, but not to a therapist's manually applied force.

Another limitation of the displacement measure discussed above is that although a measurement is taken at the therapist-patient interface, it is not known how much of the total displacement is spinal movement and how much is compression of soft tissues. Three of the studies identified used MRI images to identify the amount of spinal displacement during a PA mobilisation (Kulig et al., 2004; McGregor et al., 2004; McGregor et al., 2001). Passive spinal movement was quantified by the change in extension angle at various vertebral levels. PA mobilisations to the lumbar spine resulted in approximately three to four degrees of lumbar extension at the target vertebra relative to the adjacent vertebrae, and a general pattern of extension throughout the lumbar spine (Kulig et al., 2004).

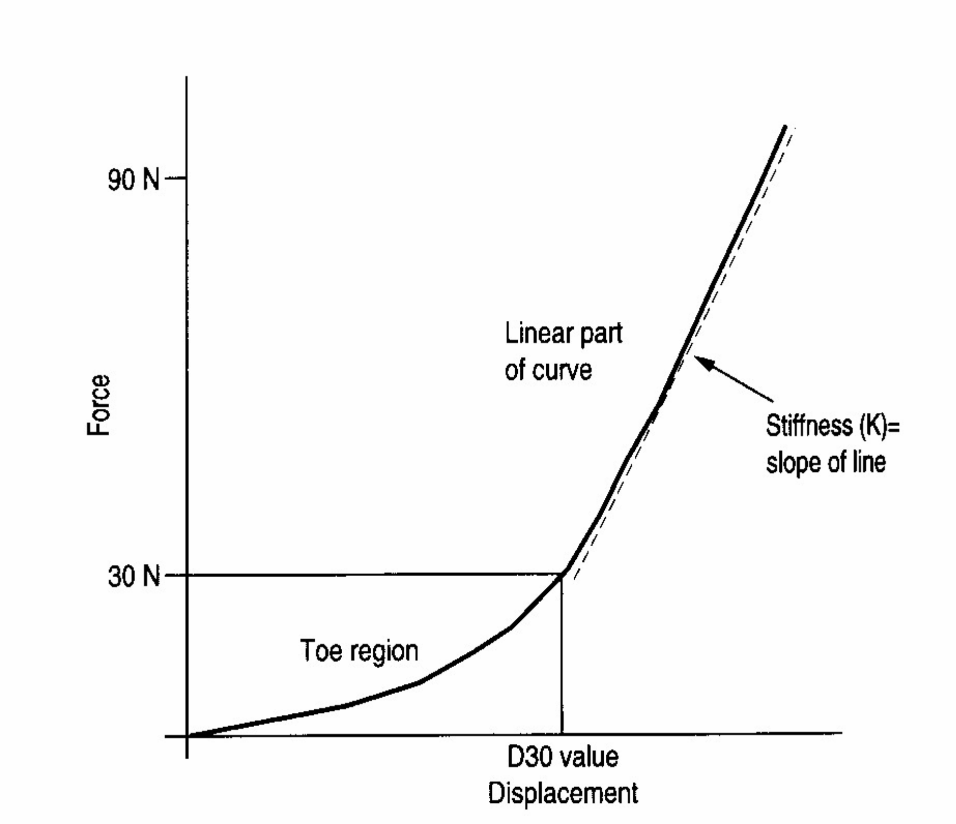

Figure 2.3. Typical force-displacement curve for spinal stiffness.

Represents a vertebra's resistance to applied force up to 90 N. The toe region is the non-linear portion of the curve. D30 value is the displacement occurring between 2 and 30 N of force. Reproduced from Shirley et al. (2002).

In the cervical spine, one study reports little or no vertebral movement (intersegmental movement or translation) on MRI during PA mobilisation, but there was substantial compression of soft tissues (McGregor et al., 2001). Another study that investigated cervical spine movement during grade III PA mobilisations to C5 indicates that C2/3 and C3/4 extended, C7/T1 flexed, and other cervical segments either extended or flexed. Mean movements for all segments ranged from 0.1 to 3.8 degrees (Lee et al., 2005).

The results of MRI studies of the cervical and lumbar spines indicate that displacement of spinal vertebrae during PA mobilisation is small, that PA mobilisation at one vertebral level causes simultaneous movement at other vertebral levels, and that the response to PA force applied to the spine is generally multi-level spinal extension, with minimal anterior gliding of the target vertebra being mobilised (Kulig et al., 2004; Lee et al., 2005; McGregor et al., 2004; McGregor et al., 2001). This is consistent with previous research conducted using mechanised applications of PA mobilisation forces with simultaneous measurement of skin displacement at multiple adjacent vertebral levels in the lumbar and lower thoracic spines (Lee & Svensson, 1993).

In contrast to measuring the spinal movement occurring during mobilisation, displacement is also quantified by measuring the movement of the therapist's hand. The displacement occurring at the contact point of the therapist's mobilising hand has been measured by having therapists perform PA mobilisations on devices designed to simulate the human spine. These artificial devices measure the amount of displacement within the movable portion of the device in response to the therapist's applied force. Displacement values measured by the devices were compared to readings from instruments with known accuracy [vernier (Simmonds et al., 1995) or digital callipers (Bjornsdottir & Kumar, 2003), or an engineer's height gauge (Chester & Watson, 2000)] to ensure validity. Displacement values reported for the application of oscillatory techniques ranged from 1.7 to 1.9 mm for grade I, 1.8 to 5.8 mm for grade II, 2.1 to 8.2 mm for grade III, and 2.0 to 9.2 mm for grade IV (Bjornsdottir &

Kumar, 2003; Chester et al., 2003; Simmonds et al., 1995). The wide range of displacement values for most grades may be due to differences in the properties of the mechanical devices used, differences in hand positions (thumb or pisiform grip), or differences in therapist samples.

Displacement of the therapist's hand was also measured in vivo by one group of investigators using a motion detection device positioned on the thumb interphalangeal joint of a physiotherapist mobilising the lumbar and cervical spines (Watson, Burnett, & Dickens, 1989). They recorded slightly higher values for displacement during lumbar mobilisation (up to a mean maximum of 11 mm for grade IV) using their method compared to mobilisation on simulated spines. Displacement of the physiotherapist's thumb during cervical mobilisation was even greater, with the average displacement measuring 13.25 mm for grade II mobilisation. A confounding factor acknowledged by the authors is the potential for extraneous movement of the thumb joints while the displacements were recorded.

2.4.6 Amplitude of displacement

Amplitude of displacement is calculated when an oscillatory displacement is measured over time. Displacement amplitude is the distance (mm) between a position of maximum movement from the initial starting point on the skin surface (or device surface) to a position that is the smallest distance from the starting point during an oscillating PA movement (Figure 2.2b). Measurements of the amplitude of displacement during mobilisation suggest that therapists generally adhere to the definitions of grades of mobilisation described by Maitland et al. (2005) when determining how far to move a vertebra, since the amplitudes of displacement for grades II and III are reported to be larger than the amplitudes for grades I and IV (Chester et al., 2003; Watson et al., 1989). Mean displacement amplitudes measured when therapists performed PA mobilisations on a mechanical simulated spine using a thumb grip ranged from 0.6 mm for grade I mobilisations to 3.9 mm for grade III mobilisations (Chester et al., 2003). When displacement amplitude was measured using a sensor placed on a therapist's thumb during in vivo mobilisation, mean amplitudes ranged from 1.5 mm (grade IV) to 2.8 mm (grade III) for mobilisation applied to L4, and from 2.2 mm (grade I) to 3.3 mm (grade II) for mobilisation applied to C5 (Watson et al., 1989).

2.4.7 Issues when comparing studies

The values reported for mobilisation parameters, including magnitude, frequency and amplitude of force, and the amount and amplitude of displacement suggest that clinicians differ in their application of mobilisation. There are a number of potential reasons for this variability. Mobilisation parameters may be affected by many factors including the method of measurement, the grade of mobilisation, the hand position used to mobilise, the vertebral level mobilised, the patient's spinal stiffness, the therapist's perception of that stiffness, and factors relating to the therapist (somatotype, training) or to the person receiving mobilisation (age, symptoms, somatotype). No single study of mobilisation forces provides complete descriptions of all of these factors. Therefore, some of the variation in manual forces observed when comparing data from different studies may be attributable to potential unknown contributions from these factors.

Different methods of force measurement

Variations in measurement methods should be considered when comparing reported manual forces. The different methods used to measure mobilisation forces include forceplates positioned under the therapist (Cook et al., 2002; Matyas & Bach, 1985; Petty et al., 2001) or under the treatment table (Lee et al., 1990; Threlkeld, 1992), flexible transducers positioned between the therapist's hand and the skin over the spinous process (Conradie et al., 2004; Smit et al., 2003), instrumented treatment tables (Chiradejnant et al., 2002; Harms & Bader, 1997; Harms et al., 1999; Langshaw, 2001) and artificial devices simulating the spine (Bjornsdottir & Kumar, 2003; Hardy & Napier, 1991; Simmonds et al., 1995; Snodgrass, 2003; Watson & Burnett, 1990). The magnitude of recorded manual force can be affected by the measurement method and how the forces are calculated and reported. This means that comparing the manual forces reported in different research studies requires consideration of the measurement method used.

Therapist standing on a forceplate

The earliest studies that measured PA mobilisation forces were described by Matyas and Bach in 1985 (Matyas & Bach, 1985). Physiotherapists applied PA mobilisation techniques to the lumbar and thoracic spines while standing on a forceplate. Applied force was calculated using a mathematical formula based on the change in the therapist's body weight on the forceplate as the force was applied. Validity of this forceplate measure has been tested by having a therapist apply manual PA mobilisations to a digital pinch gauge on the surface of a treatment table while simultaneous measures were recorded by the forceplate (Petty & Messenger, 1996). Compared with the digital pinch gauge, the forceplate slightly overestimated average peak force and underestimated force amplitude, with the error less than 3 to 4%. This method of measurement continues to be used (Cook et al., 2002; Petty et al., 2001).

Table on a forceplate

A second method of manual force measurement utilising forceplates positioned the treatment table on a platform attached to a forceplate, rather than having the therapist stand on the forceplate (Lee et al., 1990; Threlkeld, 1992). Forces recorded with the treatment table on the forceplate were somewhat lower than forces calculated with the therapist standing on the forceplate for the same grade of mobilisation at the same spinal level. For example, average peak forces for grade II PA mobilisations to L3 applied by experienced physiotherapists were 33 N when the treatment table was on the forceplate (Lee et al., 1990) but 119 N with the therapist standing on the forceplate (Cook et al., 2002). One factor affecting these measures may have been the area contacting the forceplate when forces were applied, since applying force over a larger area will reduce its magnitude at any one point within the area under the applied force. However, a discrepancy of this size is unlikely to be entirely attributable to measurement method alone. This raises the possibility of whether other factors, such as differences between the participant samples, contributed to this discrepancy in force magnitude.

Flexible force transducer

In two studies, a flexible force transducer was used to measure manual forces during PA mobilisations (Conradie et al., 2004; Smit et al., 2003). Ultra-thin (0.13mm), flexible independent variable resistance force transducers were positioned under each thumb of the therapist on the skin overlying the C6 spinous process. Both studies report grade I PA mobilisation forces (Conradie et al., 2004; Smit et al., 2003). The recorded forces ranged from approximately 0.1 to 5 N (converted from original data, 11 to 500 g, on the assumption that force was applied in a smooth continuous manner as would be expected for a grade I mobilisation). However, the flexible force transducer used in these two studies had a maximum limit of 500 g, and 15% of the participants in one study (student physiotherapists) exceeded its capacity, resulting in loss of data (Smit et al., 2003). Another limitation of the flexible force transducer, as with the forceplate methods, is that only forces that are applied perpendicular to the measuring instrument are recorded (Herzog et al., 1993). For example, if a therapist applies a substantial amount of force that is not perpendicular to the measuring instrument during data collection, the magnitude of the recorded force (perpendicular direction only) will be underestimated (Herzog, 1991). This would limit the accuracy of comparisons of force data between manual therapists.

Instrumented treatment table

Mobilisation forces have been measured in three planes using an instrumented treatment table (Chiradejnant et al., 2001; Harms et al., 1995). Load cells fitted under the surface of an instrumented table quantify the forces applied to the table. As a therapist applies manual forces to the spine of a person lying on the table, the load cells record forces transferred to the surface of the treatment table. One argument against the use of an instrumented treatment table is that its design dictates that the forces measured are those absorbed by the table, rather than the forces that are applied at the patient-therapist interface. This means that the recorded forces represent only those transmitted to the table surface by the patient's body, not how much force was directly applied at the point of application. Despite this limitation, the use of an instrumented table allows the therapist to perform manual techniques using the same palpatory cues they would use in normal clinical practice, without being hindered by instrumentation between their hands and the patient's skin. Some research on applied manual forces has accounted for possible force discrepancies by using geometric equations with vector quantities based on an anatomical coordinate system to estimate the forces acting on the vertebral segment of interest (Triano & Schultz, 1997).

For the PA mobilisation technique, instrumented tables have been used to record manual forces applied to the lumbar and cervical spines (Chiradejnant et al., 2001; Harms & Bader, 1997; Harms et al., 1999; Langshaw, 2001). Three studies report PA mobilisation forces applied to L3 (Table 2.2) (Chiradejnant et al., 2001; Harms & Bader, 1997; Harms et al., 1999), and one reports PA forces applied to C4 (Table 2.3) (Langshaw, 2001). When forces in three directions were recorded during PA mobilisations to L3 and C4, researchers found that the majority of force was applied in the vertical direction (Chiradejnant et al., 2002; Harms & Bader, 1997; Langshaw, 2001). Forces recorded in the mediolateral and caudad-cephalad directions were very small, as little as 3% of the total force in one study measuring lumbar mobilisations (Harms & Bader, 1997), and approximately 6 to 12% of the vertical component of force in a study measuring cervical mobilisations (Langshaw, 2001). The way that mobilisation forces were reported varied between studies. One study reported data for each direction of force (Chiradejnant et al., 2002), one reported only the vertical component of force (Langshaw, 2001), and the other two studies reported the magnitude of the resultant vector of force (Harms & Bader, 1997; Harms et al., 1999). Each of these studies reported greater forces for higher grades of mobilisation, but the average peak forces for each grade of mobilisation varied considerably between studies (Tables 2.2 and 2.3).

Devices simulating the spine

Forces measured using methods that involve a practitioner-patient interface can be confounded by variables relating to the person receiving the mobilisation force. Furthermore, when measuring manually applied forces in vivo, it is difficult to collect additional useful information such as the simultaneous displacement of the patient's tissues during the force application. Therefore, other researchers have developed artificial devices to simulate the human spine (Bjornsdottir & Kumar, 2003; Chester & Watson, 2000). When manual therapists apply force to an artificial device, researchers can reduce the number of potentially confounding variables when comparing applied manual forces among therapists, since the additional variability between different patients is removed. In addition, the use of such devices allows for the simultaneous measurement of both force and displacement during an application of a manual technique (Simmonds et al., 1995).

Two devices used to measure manual PA forces were identified in the recent literature (Bjornsdottir & Kumar, 2003; Chester & Watson, 2000), which are modified versions of previously reported devices (Simmonds et al., 1995; Watson & Burnett, 1990). One, consisting of a rubber plunger apparatus, was used to measure oscillatory displacement using a thumb grip (Chester et al., 2003). The other device consisted of a single vertebrae mounted in a springresisted housing and covered with padding. This device was used to measure both oscillatory forces and displacement using the pisiform grip (Bjornsdottir & Kumar, 2003) or therapist's preferred grip (Simmonds et al., 1995) (Table 2.4).

The use of an artificial device may change the way a therapist applies force because the resistance provided by the device is likely to be different than the resistance provided by the spine and soft tissues (Chester & Watson, 2000). When force is applied to the spine, the amount of resistance to the applied force does not increase linearly as force increases (Latimer, Lee, Goodsell et al., 1996; Shirley, 2004). As a therapist initially applies force to the spine, little resistance to movement is present as the soft tissues covering the spine are compressed (Lee & Evans, 1992). Following this, resistance to movement steadily increases as increased force is applied (Latimer, Lee, Goodsell et al., 1996; Lee & Evans, 1992). This nonlinear resistance to movement, or stiffness of the spine, is not easily replicated by artificial devices that measure force (Chester & Watson, 2000). Whether the resistance perceived when applying force to an artificial device is comparable to that experienced when applying force to spinal tissues is a matter of debate (Chester et al., 2003; Chester & Watson, 2000; Simmonds et al., 1995). Nevertheless, even though therapists might alter the way they apply force since palpatory cues will be different, artificial devices provide standardised mobilising stimuli that facilitate comparisons of forces between therapists.

2.4.8 Different ways measures are reported

In addition to the method of measurement, the way that forces are reported may be different, even when the instrumentation is similar. For example, devices that measure mobilisation forces in three directions may report a single force direction or a resultant force (Chiradejnant et al., 2002; Harms & Bader, 1997; Harms et al., 1999). Any calculations using the raw force data prior to reporting should be noted, as well as the specific parameter of force reported. For instance, the average force applied over a period of time, including the peaks and troughs that occur during oscillations, will be different to the average of the peak forces during a set period of time or the maximum peak force that is applied at any one point in time (Chiradejnant et al., 2002). Most frequently, force data for mobilisation is reported as the average of the peak forces in a series of oscillations applied by a therapist over several seconds (Chiradejnant et al., 2002; Cook et al., 2002; Harms & Bader, 1997; Petty et al., 2001). The number of seconds of data recorded for oscillatory forces varies in different studies; e.g., 10 seconds (Chiradejnant et al., 2002), 30 seconds (Conradie et al., 2004; Smit et al., 2003), and 50 seconds (Harms & Bader, 1997; Harms et al., 1995). This may also potentially contribute to variations in average peak forces reported in different studies.

2.4.9 Selected technique and grade

The selected manual technique and the grade that the therapist applies should also be noted. For PA mobilisation techniques, forces can be applied either centrally on the spinous process or unilaterally on the transverse process or facet joint (Maitland et al., 2005). In all of the identified studies that measured manual forces during PA mobilisation, central techniques were performed.

The recorded PA forces will be affected by the mobilisation grades applied (Chiradejnant et al., 2002; Harms & Bader, 1997; Harms et al., 1999). The system of mobilisation grading most commonly used in studies that report mobilisation forces is that defined by Maitland et al. (2005) (Table 2.1). Some researchers have provided these mobilisation definitions to the participant therapists prior to their performance of the manual technique in an effort to try to increase consistency among therapists (Chester et al., 2003; Simmonds et al., 1995). Other researchers have allowed therapists to use their usual clinical technique, without providing specific instructions (Chiradejnant et al., 2002; Harms & Bader, 1997). Even if standardised definitions for mobilisation grades are provided to participants in the research setting, it is not known whether clinicians routinely adhere to these definitions in daily practice. Habits formed during clinical practice may affect a therapist's selected level of applied force when applying a particular grade of mobilisation in a research situation.

2.4.10 Hand position

The hand position used to apply the manual force may also affect the magnitude of forces applied (Bjornsdottir & Kumar, 2003; Hardy & Napier, 1991). When applying a PA spinal mobilisation, therapists tend to use one of two hand positions (Maitland et al., 2005), the pisiform grip or the thumb grip (Figure 2.1). Most studies have reported data where participants used the pisiform grip (Bjornsdottir & Kumar, 2003; Cook et al., 2002; Lee et al., 1990; Petty et al., 2001; Threlkeld, 1992), although in some studies the thumb grip was used (Chester et al., 2003; Conradie et al., 2004; Hardy & Napier, 1991; Smit et al., 2003) and others allowed therapists to choose their preferred grip (Harms & Bader, 1997; Simmonds et al., 1995). Other studies failed to report the hand grip used (Harms et al., 1999); for example, when mobilisations were applied to patients in the clinical setting and therapists used their preferred hand grip (Chiradejnant et al., 2002). If the forces reported by two studies measuring the same grade of mobilisation applied to simulated spines using different hand grips are compared, it appears that larger forces might be applied when using the pisiform grip as opposed to the thumb grip (Bjornsdottir & Kumar, 2003; Hardy & Napier, 1991). Hand position has been shown to affect a therapist's perception of stiffness (Maher & Adams, 1996a), and since stiffness is expected to influence the choice of applied force and displacement when mobilising the spine (Shirley, 2004; Threlkeld, 1992), it is likely that the hand position would affect the forces applied.

2.4.11 Vertebral level

The vertebral level that is mobilised may affect the magnitude of applied manual force. Mean peak PA mobilisation forces applied to the cervical spine appear to be lower than those applied to the lumbar spine (Tables 2.2 and 2.3). One possible reason is that therapists apply manual PA forces in different directions on different vertebral levels (Viner & Lee, 1995), adjusting the direction of their applied force in the sagittal plane in relation to the spinal contour. The recorded force may be affected by the direction of application, particularly if the measuring instrument only records forces in one plane (Herzog, 1991).

Additionally, the identification of vertebral levels may affect applied manual forces. For instance, it is difficult to be certain that the reported vertebral level is actually the level that has been mobilised. Inter-therapist reliability for palpating specific vertebral levels has generally been shown to be poor (Downey, Taylor, & Niere, 2003; Harlick, Milosavljevic, & Milburn, 2000; Lucchetti, 1992; McKenzie & Taylor, 1997; Simmonds & Kumar, 1993), and the validity of identification of vertebral levels by palpation has been questioned (Harlick et al., 2000). Even when studies have reported that therapists mobilised pre-marked vertebral levels (Cook et al., 2002; Latimer, Lee, & Adams, 1996), it can only be stated with certainty that the participating therapists mobilised the same vertebral level when mobilising the same pre-marked spine on the same occasion. Without imaging, it cannot be assumed that the mobilised vertebrae were indisputably the reported vertebral levels, since the researchers marking the spine would be unlikely to have completely accurate palpation skills. In addition, spinal stiffness has been shown to vary between spinal levels (Lee & Liversidge, 1994; Lee, Steven, Crosbie, & Higgs, 1998). If therapists are able to perceive these differences in spinal stiffness (Chiradejnant, Maher, & Latimer, 2003), they may alter their applied forces in response to differences in spinal stiffness at different levels (Maitland et al., 2005; Petty, 2004). Reported mean forces for PA mobilisation may therefore vary due to the possibility of some participants' recorded forces having been applied to different vertebral levels if a target spinal level was incorrectly identified.

2.4.12 Variations between therapists and between patients that may affect forces

Patient stiffness

Stiffness of a patient's spinal tissues (including the vertebra, ligaments, joint capsules and tendons, with overlying skin, muscle, fascia and subcutaneous fat) may affect the amount of force therapists apply during a PA mobilisation technique. This is because therapists moderate the movements of their hands according to their perceptions of spinal movement, as palpated by their contacting hand or thumbs (Maitland et al., 2005; Petty, 2004). The selected grade of mobilisation determines the depth to which the therapist attempts to compress the tissues and thus move the spine (Maitland et al., 2005). Tissue stiffness affects the applied mobilisation force because tissues with greater stiffness potentially require a greater force to move to the same extent as tissues with less stiffness (Lee, Gal, & Herzog, 2000). Tissue stiffness will therefore impact on the measurement of forces applied by therapists, as it may differ between patients or measurement sessions (Latimer, Lee, Adams et al., 1996; Shirley et al., 2002), and because stiffness may be perceived differently by individual manual therapists (Chiradejnant et al., 2003; Maher & Adams, 1996a).

Spinal stiffness has been estimated by measuring the resistance to movement of the skin overlying a vertebral level while simultaneously measuring its displacement (Latimer, Lee, Goodsell et al., 1996). The slope of the regression line fitted to the linear portion of the force-displacement curve has been used as one measure representing stiffness (Latimer, Lee, Adams et al., 1996) (Figure 2.3). A substantial body of knowledge about spinal stiffness exists, based on measurements primarily from the lumbar spine. Since therapists use their perception of a spine's resistance to movement to select the amount of manual force they apply during mobilisation, factors known to affect spinal stiffness may alter the magnitude of forces applied (Table 2.5).

Table 2.5. Factors that affect spinal stiffness.

Factor	Effect on stiffness	Study
Variations in applied forces:		
Magnitude	↑ with ↑ magnitude	Lee et al. (1997) Latimer et al. (1998)
Frequency	↑ with ↑ frequency	Lee & Svensson (1993)
Direction	↑ with force directed more caudad at lower lumbar levels	Allison et al. (1998) Caling & Lee (2001)
Variations in person being mobilised:		
BMI*	↓ with ↑ BMI	Lee et al. (1998)
Breathing	↑ when lung volume rises above or falls below functional residual capacity	Shirley et al. (2003)
Muscle activity	↑ with ↑ muscle activity	Lee et al. (1993) Shirley et al. (1999)
Intra-abdominal pressure	↑ with ↑ intra-abdominal pressure	Hodges et al. (2005)
Position	↑ with ↑ lumbar spine flexion or extension position	Edmondston et al. (1998)
Skin fold thickness	↓ with ↑ skin fold thickness	Lee et al. (1998)
Vertebral level mobilised	↓ in mid to upper lumbar spine where there is less support from ribs or pelvis	Lee & Liversidge (1994) Lee et al. (1998)
Tenderness to palpation	↑ where there is ↑ tenderness to palpation compared with less tender locations	Tuttle (2008)
Variations in the environment:		
Rigidity of treatment table	↑ with table more rigid	Maher et al. (1999)

*BMI = body mass index

Clinician's perception of stiffness

Manual forces may also vary because therapists may perceive a patient's spinal stiffness differently and thus choose to apply different manual treatments (Petty, 2004). Physiotherapists have generally been shown to be unreliable when rating stiffness stimuli (Maher & Adams, 1996a; Maher et al., 1994), particularly when evaluating the cervical spine (Cleland, Childs, Fritz, & Whitman, 2006). However, when therapists matched the stiffness they palpated on the spine to a reference stimulus palpated on an adjustable device, their reliability improved (Chiradejnant et al., 2003). Using this method, and controlling factors known to affect therapists' perception of stiffness, inter-rater reliability was high (ICC(2,1) 0.78, 95% CI 0.56 to 0.90) (Chiradejnant et al., 2003). Factors that affect therapists' perception of stiffness include the therapist's visual state: stiffness is perceived to be greater with vision obscured (Maher & Adams, 1996b); the magnitude of force applied: better discrimination of stiffness with higher applied forces (Nicholson et al., 1998); hand contact area: better discrimination with increased hand contact area (Nicholson et al., 1998); and hand position: stiffness perceived to be greater using a thumb grip than a pisiform grip (Maher & Adams, 1996a). Since a therapist's perception of stiffness may alter the amount of force they choose to apply, any of these factors that affect their perception of stiffness may also affect the magnitude of forces applied.

Other patient and therapist factors

PA mobilisation forces can also be influenced by other factors related to the patient or to the manual therapist (Table 2.6). Three in vivo studies have investigated the effects that patient and therapist factors have on the magnitude, frequency and amplitude of force (Chiradejnant et al., 2002; Harms & Bader, 1997; Harms et al., 1999), with some agreement in reported findings. Two studies found that the height and weight of the therapist had no effect on the magnitude of force applied (Chiradejnant et al., 2001; Harms & Bader, 1997). In addition, two studies reported therapists apply greater force amplitudes to younger patients for the majority of mobilisation grades (Chiradejnant et al., 2002; Harms et al., 1999). However, results are conflicting in regards to whether the age of the patient increases or decreases the mean peak forces or frequencies applied (Chiradejnant et al., 2002; Harms et al., 1999). There is also no agreement on whether the frequency of oscillating force is affected by therapist characteristics (Chiradejnant et al., 2001; Harms & Bader, 1997), with one study reporting therapist height, weight and experience had no effect on frequency (Harms & Bader, 1997), and a second reporting several therapist variables were associated with frequency (Chiradejnant et al., 2002). A study that used an artificial device to measure manually applied forces found work-related thumb pain had no effect on the maximum force a therapist might apply during mobilisation (Snodgrass et al., 2003). Table 2.6 lists the patient and therapist factors that have some evidence from at least one study that they affect manually applied forces.

Table 2.6. Factors with some evidence that they affect manual force parameters.

Patient factors	**Therapist factors**
<u>*Increases force magnitude*</u>	
Younger age*	Frequent use of technique*
Older age[†]	Higher academic qualifications*
Higher body weight[†]	Less experience*
Increased lumbar range of motion[†]	
Low disability*	
Larger area of symptoms*	
Leg symptoms less bothersome*	
<u>*Increases frequency*</u>	
Older age (grades I, II and IV forces)[†]	Frequent use of technique*
Younger age (grade II forces)[†]	Lower academic qualifications*
	Male*
	Shorter height*
	Higher body weight*
<u>*Increases amplitude*</u>	
Younger*[†]	Higher academic qualifications*
Low disability*	Less experience*
Male*	
High body mass index*	
Shorter duration of symptoms*	

*Chiradejnant et al. (2002)
[†]Harms et al. (1999)

2.4.13 Summary

Many factors can potentially affect the application of manual forces during PA mobilisation. Those factors include the method of measurement, the selected manual technique and grade, the therapist's hand position, the vertebral level and how it was identified, the stiffness of tissues being mobilised, the therapist's perception of stiffness, therapist factors such as training and somatotype, and factors related to the person receiving mobilisation such as age or symptoms. Previous research has not definitively ruled out the potential effects of any of these factors on the application of mobilisation forces and potential clinical outcomes. Furthermore, spinal stiffness is also a major factor in a manual therapist's decision-making process as to the amount of force to apply. The amount of variation in applied forces that could be attributable to differences in stiffness between mobilised subjects, rather than due to therapist differences, is not known.

2.4.14 Future directions for research

The variations in applied manual forces reported in the literature indicate that manual therapists should continue to search for the best way to consistently apply and measure forces during PA mobilisation. Future research on manual forces should include detailed descriptions of the methods used to measure forces to enable more effective comparisons of reported data. To comprehensively describe a PA mobilisation technique, the following parameters should ideally be quantified and reported: force magnitude, frequency and amplitude, and displacement magnitude and amplitude. However, it is not usually possible to quantify all force parameters. For example, when researchers attempt to measure manual forces in vivo and in real-time, the accurate measurement of spinal displacement is not generally feasible. This will continue to be a limitation of studies that measure manual forces applied to patients until imaging at a rate equivalent to the typical clinical rate of mobilisation is possible, without exposing participants to excess radiation.

Furthermore, there are many factors that might affect the application of manual forces, including the differences in spinal stiffness between mobilised individuals. Comprehensive measurement and recording of as many relevant factors as possible, and the use of a factorial design to determine the contribution of individual factors would considerably add to our knowledge about the reasons for variations in manual forces.

With the majority of studies about mobilisation forces reporting those applied to the lumbar spine, there is a relative lack of information about the manual forces clinicians apply to the cervical and thoracic spines. Measuring the forces that therapists apply to the cervical spine during PA mobilisation may help explain adverse patient reactions reported following cervical mobilisation (Magarey et al., 2004). The reasons that patients sometimes report symptoms such as dizziness or nausea following cervical mobilisation treatment are not entirely clear, although one study suggests that compromised vertebral artery blood flow may be a factor (Magarey et al., 2004). The amount of force applied to the cervical spine may be part of the problem. Therapists may be able to change how they apply manual forces to the neck if evidence clearly supported this, and if methods for training them to apply consistent specific forces were readily available. Future research should therefore aim to determine if the manual forces applied to the cervical spine contribute to any of the adverse reactions sometimes experienced by patients following manual treatment. This would highlight the need for effective training methods for therapists to be able to systematically and consistently apply selected levels and types of manual forces, which may improve standardisation of PA mobilisations among therapists.

When investigating the effects that mobilisation has on clinical outcomes, it should be acknowledged that manual therapists use a number of different manual techniques in clinical practice (Hurley et al., 2005). Therefore, clinical outcome studies should document each manual technique used, and the extent to which each was used, so that specific clinical outcomes for each manual technique and grade of technique can be identified.

2.5. Conclusions

In order to determine the efficacy for the use of PA mobilisation in the treatment of spinal disorders, the technique used must be carefully defined. Defining a mobilisation technique requires a comprehensive description of the parameters of applied manual force, including force magnitude, frequency and amplitude, the amount of displacement and displacement amplitude. In particular, the parameters of forces applied to cervical spine have not been identified. The challenge is to accurately quantify these force parameters while maintaining a true clinical environment.

CHAPTER 3. Equipment development: Instrumented treatment table

3.1. Introduction

The scientific literature suggests that manual forces applied during treatments vary between practitioners and may lead to inconsistent outcomes for patients (Snodgrass, Rivett, & Robertson, 2006). However, the extent of variation between treatment applications and the actual implications of differences between manual therapists are unknown. To investigate these differences and evaluate the clinical usefulness of manual techniques for treating neck pain, it is necessary to first accurately define and quantify them. This requires the measurement of the manual therapy forces applied.

The use of an instrumented treatment table when measuring manual forces allows the research setting to closely replicate the clinical setting. Almost identical to a standard treatment table, an instrumented table permits therapists to perform manual techniques as they would in the clinic. Data can be recorded without the need for any additional instrumentation between the hands of the manual therapist and the patient.

Instrumented tables have been used to measure the manual forces applied to the lumbar and thoracic spines during various mobilisation and manipulation techniques (Chiradejnant et al., 2001; Harms et al., 1995; Triano & Schultz, 1997). The most commonly studied spinal mobilisation technique is the posteroanterior (PA) mobilisation as described by Maitland et al. (2005). PA mobilisation consists of an oscillatory force applied to the spinous or articular processes of the spine, usually performed with the patient lying prone so forces are primarily directed downward towards the treatment surface. This differs from manipulation, which involves a high velocity thrust (Maitland et al., 2005). The aim of this chapter is to report the development of an instrumented treatment table and its calibration for the purpose of measurement of mobilisation forces applied to the cervical spine.

3.2. Methods

3.2.1 Equipment design

The instrumented table used to measure cervical mobilisation forces was modelled on one used primarily for measuring lumbar spine mobilisation forces (Chiradejnant et al., 2002; Chiradejnant et al., 2001). A padded treatment surface from a standard treatment table (SX3 Physioline Series, Model No. 50251, Chattanooga Group, Inc., Sydney, Australia) was fitted to a steel frame (Figure 3.1). The frame was constructed with 65 x 65 mm RHS (rectangular hollow section) steel that was 3 mm thick. This frame was connected to an 8 mm thick solid steel plate via seven biaxial load cells (Xtran, Model S1W, Applied Measurement Australia, Sydney), with a non-linearity of < 0.015% and hysteresis ± 0.02% of their full scale. The steel plate was welded to a stable steel base with adjustable rubber feet, which enabled the surface of the table to be levelled accurately with the frame sitting on any reasonably level surface. Load cells were attached to the frame and base with high tensile precision fasteners that were placed through lubricated ball-bearing joints in the rod ends of each load cell. Precision alignment of the load cells in each plane was ensured during construction using a milling machine that provided a digital readout of position to 0.001 mm (Model DB-001, Daewoo, Seoul, Korea). A 'lean bar' was constructed parallel to the treatment surface and attached to the base, so that therapists could lean against it without adding additional force to the load cells (Figure 3.2; lean bar omitted from Figures 3.1 and 3.3 to allow visualisation of load cells).

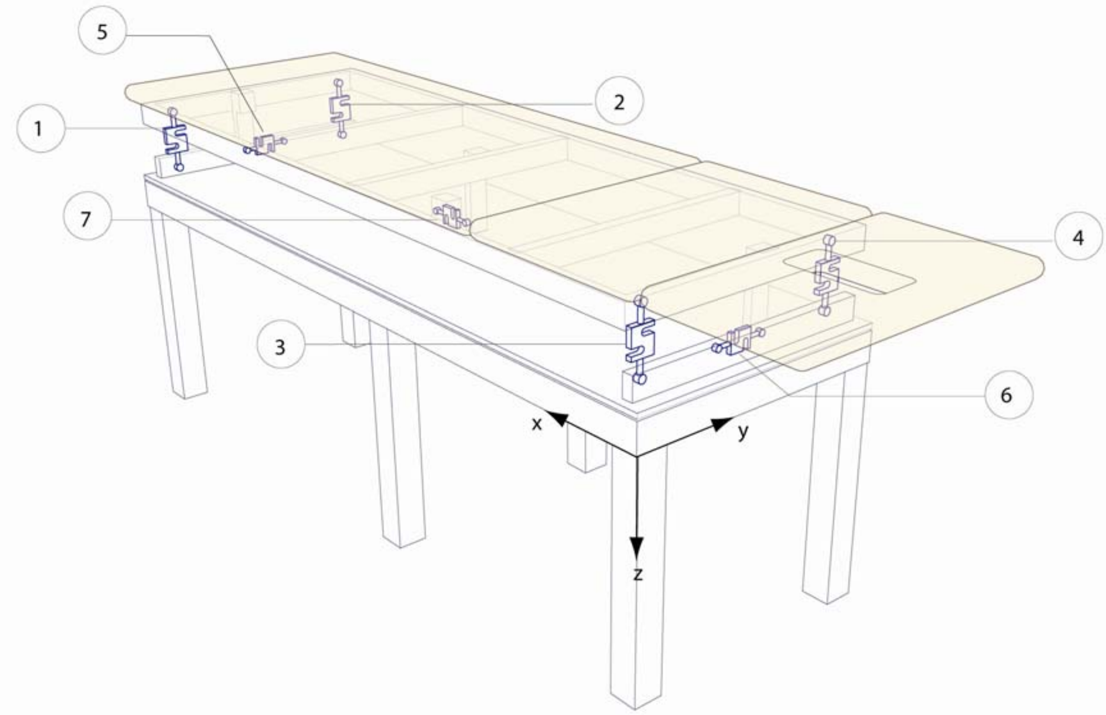

Figure 3.1. Schematic of the instrumented treatment table.

Shows the placement of load cells: load cells 1-4 are positioned to measure vertical force (z-direction), 5 and 6 measure mediolateral force (y-direction) and 7 measures caudad-cephalad force (x-direction).

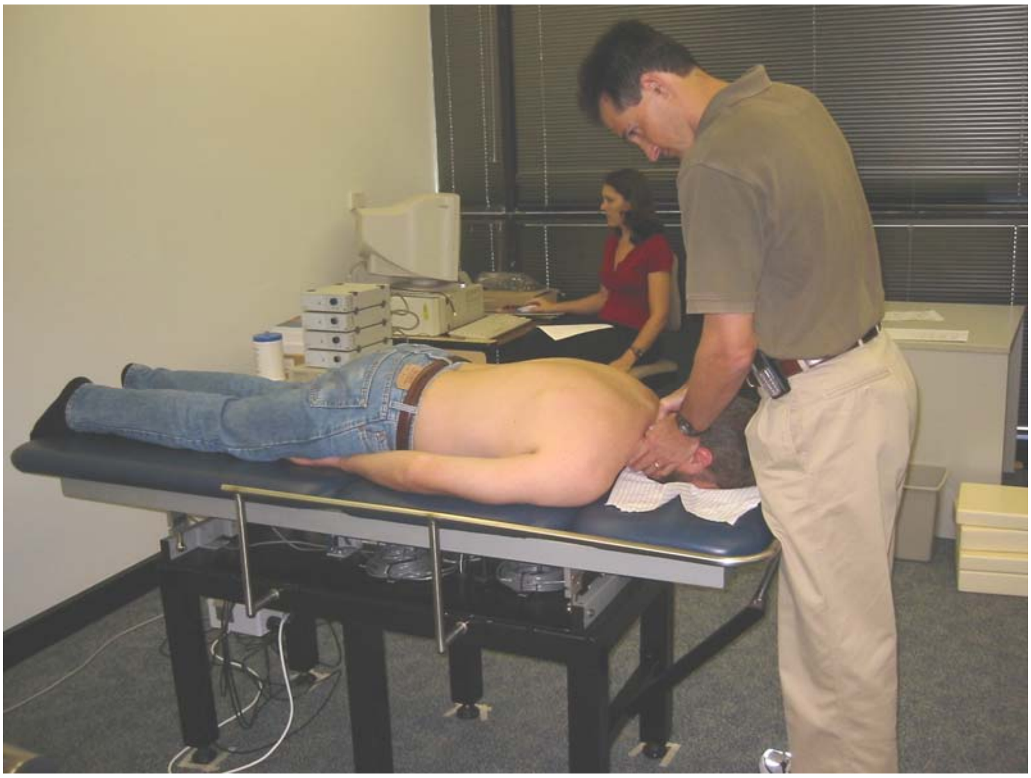

Figure 3.2. Experimental set-up of the instrumented treatment table. Therapist applying cervical mobilisation to a subject lying on the table, showing lean bar in situ.

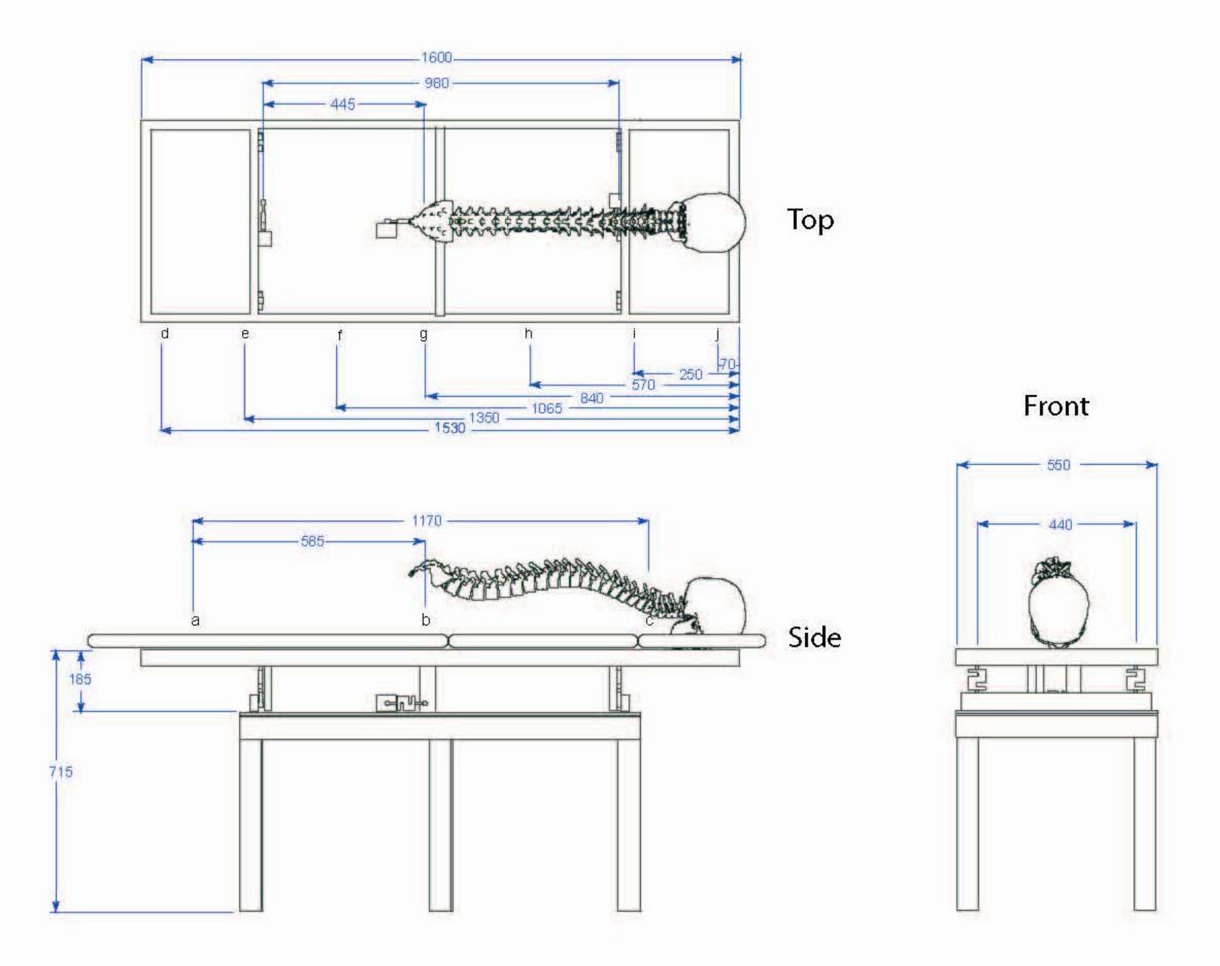

Figure 3.3. Technical drawings of the instrumented treatment table.

Shows side, front and top views of the table with specifications indicating the placement of load cells and the locations used for testing measured forces. The padded treatment surface has been removed in the top and front views, and a simulated skeleton illustrates the relationship of load cell position to location of intended manual force. Labels a through c indicate the locations for vertical force testing. Labels e and i designate the alignment of two hooks attached beneath the surface of the table, centred along the table's width, used for testing both mediolateral and caudad-cephalad forces with a first order pulley. Labels d, f, g, h, and j indicate additional locations for mediolateral force testing using a G-clamp to attach the pulley to the side of the bed frame.

Load cells were positioned to measure forces applied to the table in three directions. Four load cells measure vertical force (z-direction, labelled 1 through 4 in Figure 3.1), two measure mediolateral forces (y-direction, labelled 5 and 6) and one measures caudad-cephalad force (x-direction, labelled 7). The load cells measuring vertical force have a maximum capacity of 750 N, so they can tolerate the body weight of a person lying on the table; the load cells measuring horizontal forces have a maximum capacity of 350 N. Each load cell senses compression and distraction in a single plane and converts this to a voltage signal, negative for compression and positive for distraction. Voltage signals pass through an amplifier (Strain Gauge Signal Conditioner, Model RM-044, Applied Measurement Australia, Sydney) to condition the voltage signal to range from 0 to 10 V, and then through the Powerlab® data acquisition system (ADInstruments, Castle Hill, Australia).

Chart software (Version 4.2.4, ADInstruments, Castle Hill, Australia) was used to convert the amplified voltage signal into Newtons of force, using the appropriate conversions for each load cell (10 V = 750 N for load cells with a 750 N maximum capacity, and 10 V = 350 N for load cells with a 350 N maximum capacity). A sampling rate of 100 Hz was used for each of the seven load cells. All electrical equipment (the distribution box for the amplifiers, Powerlab®, computer and monitor) were routed through a mains muffler (Model 2F2F/4-4, Sigtronic Industries Pty Ltd, Sydney, Australia) to reduce extraneous electrical noise from the mains power supply to the building.

To calculate the force applied for each of the three planes, the following formulas were used:

Vertical force (z-direction) = Load cell 1 + Load cell 2 + Load cell 3 + Load cell 4

Caudad-cephalad force (x-direction) = Load cell 7

Mediolateral force (y-direction) = Load cell 6 – Load cell 5

Chart software combines real time force readings from individual load cells to produce an output for each force direction at 100 Hz. All calculations to determine the force applied in a particular direction are based on the changes in each individual load cell's reading from a baseline of zero (eg. the value for load cell 1 in the above formula equates to the force (N) recorded at a point in time (sampled at 100 Hz) minus the baseline level (N) recorded by load cell 1 prior to any application of manual force). Load cells 5 and 6 are positioned so that when force is applied towards a patient's left (if the patient is lying prone), load cell 6 stretches, recording a positive value, and load cell 5 compresses, recording a negative value (Figure 3.1). For this reason, the difference in the values between load cells 5 and 6 is used, rather than the sum, to quantify the mediolateral force.

3.2.2 Calibration

Load cells were calibrated by the manufacturer and rated with a non-linearity of ≤ ± 0.015% of the full scale, indicating that if the measured forces were tested through the full capacity of the load cell, the values recorded would deviate ≤ ± 0.015% from the line of best fit. This means that the forces recorded by each load cell, if tested independently, would deviate no more than 0.1 N from the true value. The manufacturer's calibration certificate also provides the measured voltage output at the rated load (or maximum capacity) for each load cell. This was verified for each load cell prior to attachment to the treatment table by comparing the voltage readings from each cell with the predicted voltage based on the calibration certificates. Each load cell was tested at baseline and loaded to half-capacity using known weights. The non-amplified voltage signal from the load cell and the amplified voltage signal were confirmed to be accurate using a multimeter (Fluke 75 Multimeter, Everett, Washington, USA). The voltage signal read by Powerlab® Chart software was confirmed as identical to the amplified voltage signal.

3.2.3 Measurement consistency

The accuracy of the instrumented table was determined by measuring the error due to positional loading with known weights. In the vertical direction, weights were placed on the surface of the table. In the horizontal directions, the weights were suspended from a first order pulley with stainless steel wire and a 1 kg carrier. The pulley was attached to the bed in different locations using either a stainless steel hook fastened beneath the bed surface, or a G-clamp attached to the bed frame. The horizontal portion of the pulley apparatus was verified as level using a single bubble level attached to the wire. A right angle aligned the pulley with the table edge to ensure force was exerted perpendicular to it and only a single planar direction of force was measured. Locations on the table where forces were applied are illustrated in Figure 3.3. Tests of horizontal forces were performed with the table empty (unloaded condition), and with the table loaded with 76 kg arranged to represent the average body weight of a person lying on the table (loaded condition). Seventy-six kilograms is the reference body weight for an adult male in the most recent dietary guidelines for Australia and New Zealand (Australian Government Department of Health and Ageing, 2006). The weights used for these experiments were verified as accurate to within 1-2 grams by weighing them on an electronic scale (PM4800 Delta range top pan digital balance, Mettler-Toledo, Port Melbourne, Australia).

In the vertical direction, a series of weights ranging from 0.25 kg (2.5 N) to 20 kg (196.1 N) were placed in three positions along the centre of the x-axis of the table (positions a, b and c in Figure 3.3). The most cephalad position represented the approximate location where a therapist would apply cervical mobilisation forces, just caudad to the face cut-out on the treatment surface (position c in Figure 3.3). This location was just cephalad to load cells 3, 4 and 6. The second position was located equidistant between the vertical load cells, directly over the ball-bearing joint connecting load cell 7 with the table surface (position b in Figure 3). The third position was just caudad to load cells 1, 2, and 5 (position a in Figure 3.3), replicating the cephalad position at the opposite end of the table (position c in Figure 3.3). As the magnitude of testing weight increased, the size of successive weight increments was increased (0.25 kg increments up to 1 kg, 0.5 kg increments to 2 kg, 2 kg increments to 10 kg, and 2.5 kg increments up to 20 kg). The test weights were selected to identify the level of precision possible when measuring low forces, as previous studies suggested some cervical mobilisation forces would be quite small (Conradie et al., 2004; Langshaw, 2001).

In the horizontal directions, a series of weights ranging from 0.5 kg (4.9 N) to 10 kg (98.1 N) were used to evaluate the accuracy of measured forces (increments of 0.5 kg up to 2 kg, then 2 kg increments). The maximum weight used for testing in the horizontal directions was less than the vertical direction because previous studies of PA spinal mobilisation suggest that forces are mainly vertical, with minimal force applied horizontally (Chiradejnant et al., 2002; Harms & Bader, 1997; Langshaw, 2001).

To assist in attaching the pulley to the treatment table for horizontal force testing, two steel hooks were securely attached to the underside of the treatment surface using steel screws. The hook at the cephalad end was attached in a position corresponding to the approximate location where a therapist would apply a cervical mobilisation force, centred between load cells 3 and 4 and cephalad of load cell 6 (centred along the table's width and aligned with i in Figure 3.3). The second hook was attached at the opposite end of the treatment table in a position that similarly corresponded to the three caudad load cells (centred along the table's width and aligned with e in Figure 3.3). The use of hooks securely fastened to the table was intended to reduce potential extraneous movement that might occur using other means of attaching the pulley to the table.

For evaluating caudad-cephalad forces, the pulley was attached to the hook at the cephalad end for applying cephalad forces, and to the hook at the caudad end for caudad forces. The unloaded and loaded conditions were tested in each direction. Because the aim of testing was to determine accuracy of measurement of cervical mobilisation forces, caudad forces were also evaluated with the pulley attached to the hook at the cephalad end of the table, where mobilisation would be applied.

For mediolateral forces, the two secure hooks were used for testing four directions of force in both unloaded and loaded conditions (one towards each side of the table at both the cephalad and caudad ends, aligned with e and i in Figure 3.3). Further tests of mediolateral forces were performed in an additional five locations along the length of the table by attaching the pulley to the frame on each side of the table using a standard G-clamp. These testing locations can be described for a single side of the table as:

- aligned with the ball-bearing joint connecting load cell 7 to the table surface (position g in Figure 3.3)
- approximately equidistant between position g and vertical load cell 1, and position g and vertical load cell 3 (two locations, positions f and h in Figure 3.3)
- as close as the G-clamp could be attached to the ends of the table frame (two locations, positions d and j in Figure 3.3).

These locations were replicated on the opposite side of the table. The G-clamp was used because the position of other instrumentation (i.e., the load cells, amplifiers and wiring) precluded attaching more hooks under the table. The total number of testing positions for mediolateral forces was fourteen. The testing positions for mediolateral and vertical forces were chosen to include locations both within the rectangle made by the vertical load cells, and outside this rectangle. This is because when the applied force was a composite of recordings from more than one load cell, the behaviour of individual load cells was different depending on the site of applied force, even though the outcome for a single direction of force was the same.

The following procedure was used to record the forces measured by the table from the application of known weights. For each weight applied to the table, a baseline reading from each load cell was recorded prior to the application of the weight. Five-second readings, calculated from 500 data points recorded over 5 second sampling periods at 100 Hz, were taken with the table in equilibrium both before and after the weights were applied. The actual force recorded by the table for each weight was determined by the difference between the before-weight and after-weight mean 5-second force readings for each load cell, using the following formulas:

$$F_{(vertical)} = (F_{a1} – F_{b1}) + (F_{a2} – F_{b2}) + (F_{a3} – F_{b3}) + (F_{a4} – F_{b4})$$

$$F_{(caudad\text{-}cephalad)} = F_{a7} – F_{b7}$$

$$F_{(mediolateral)} = (F_{a6} – F_{b6}) – (F_{a5} – F_{b5})$$

Where:

F is force in Newtons

F_a is the mean 5-second force reading (N) recorded after the application of the weight

F_b is the mean 5-second force reading (N) recorded before the application of weight, and

Numerical subscripts represent the name of the load cell (e.g., F_{a1} is a reading from load cell 1)

To determine if there was any drift in the load cells over time, the 76 kg loaded condition was sustained for 20 minutes. Mean 5-second force readings for each load cell recorded at the start of the 20-minute time period were compared with mean 5-second readings recorded at the end.

3.2.4 Data analysis

Absolute error was used to determine the accuracy of the forces recorded by the table when compared to known weight values. Absolute error was defined as the difference between the known weight value (converted to N from kg) and the force value recorded by the table for a single direction for that particular weight. Values for absolute error could be either positive or negative, depending on whether the recorded value underestimated or overestimated the known weight. For calculating the mean and SD of the absolute errors for each force direction at each weight value, absolute values were used (i.e., the negative sign was dropped for values that were negative). The unloaded and loaded conditions were analysed separately.

Pearson's *r* was used to determine the level of correlation between recorded values and known weights, and linear regression calculations indicated whether recorded forces accurately predicted the known weight applied. Intra-class correlation coefficients (ICCs) are reported to give an indication of the reliability of the table when measuring forces applied in different locations. Although ICCs are usually used for test-retest reliability, the table had to reliably record forces applied in different locations on it. This is because when comparing forces applied to different patients the location of applied force in relation to the table surface will differ with body type, and if a patient's position changes slightly. SPSS 12.0 (SPSS Inc., Chicago, USA) was used for statistical analysis.

3.3. Results

The absolute error of recorded force values was very low for vertical force (mean 1.1 N, SD 1.5, Table 3.1, Figure 3.4) and reasonably low for horizontal forces (Table 3.1, Figures 3.5 and 3.6). Horizontal forces recorded in the loaded condition had slightly higher absolute errors than forces recorded in the unloaded condition. When there was error, the forces recorded by the table usually underestimated the known weight values. Drift in the load cell readings was negligible over 20 minutes of sustained loading. The electrical noise inherent in the system equated to approximately 1 N, and was always less than 2 N. For mediolateral forces, there was no difference in the accuracy of forces measured with the pulley attached to a hook and forces measured with the pulley attached using the G-clamp, so tests of force in the mediolateral directions from all locations have been combined in descriptions of reliability and accuracy (Table 3.1, Figures 3.4-3.6).

Pearson's *r* values were 0.999 to 1.000 for recorded forces in all directions applied in each location, indicating recorded force values correlated with known weights ($p < 0.001$). Linear regression indicated that recorded force values accurately predicted the known weight values in both the unloaded and loaded conditions ($p < 0.001$ for all directions of force applied in each location, Figures 3.4-3.6). ICC (2,1) values for forces recorded in each direction, and for both unloaded and loaded conditions in the horizontal directions, ranged from 0.99 to 1.00 (Table 3.2).

Table 3.1. Accuracy (absolute error in N) of forces measured by the instrumented treatment table.

Known weights were applied in each direction for the unloaded and loaded conditions (absolute error = absolute value [known weight in N – force measured by table in N]).

	Vertical		**Caudad-cephalad**				**Mediolateral**			
	Unloaded		**Unloaded**		**Loaded**		**Unloaded**		**Loaded**	
Weight kg (N)	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
0.25 (2.5)	0.06	0.03	–*	–	–	–	–	–	–	–
0.5 (4.9)	0.16	0.21	1.50	0.54	3.49	1.27	1.04	0.53	1.24	0.38
0.75 (7.4)	0.10	0.09	–	–	–	–	–	–	–	–
1 (9.8)	0.41	0.51	2.13	1.31	6.29	3.56	1.58	0.82	1.97	0.51
1.5 (14.7)	0.16	0.18	–	–	–	–	–	–	–	–
2 (19.6)	0.26	0.22	2.88	0.94	9.63	4.23	2.07	1.01	2.82	1.16
4 (39.2)	0.50	0.50	4.36	1.99	12.49	0.67	2.76	1.05	5.35	2.29
6 (58.8)	0.88	0.82	4.42	0.08	12.95	3.38	2.79	1.46	4.92	1.94
8 (78.5)	1.17	1.04	4.85	1.64	16.86	3.55	4.24	2.63	5.38	2.39
10 (98.1)	1.53	1.31	3.44	1.37	17.02	2.01	5.72	3.53	5.91	2.42
12.5 (122.6)	1.80	1.64	–	–	–	–	–	–	–	–
15 (147.1)	2.38	1.98	–	–	–	–	–	–	–	–
17.5 (171.6)	2.69	2.31	–	–	–	–	–	–	–	–
20 (196.1)	2.95	2.63	–	–	–	–	–	–	–	–

*Indicates there was no data collected for that weight in that force direction.

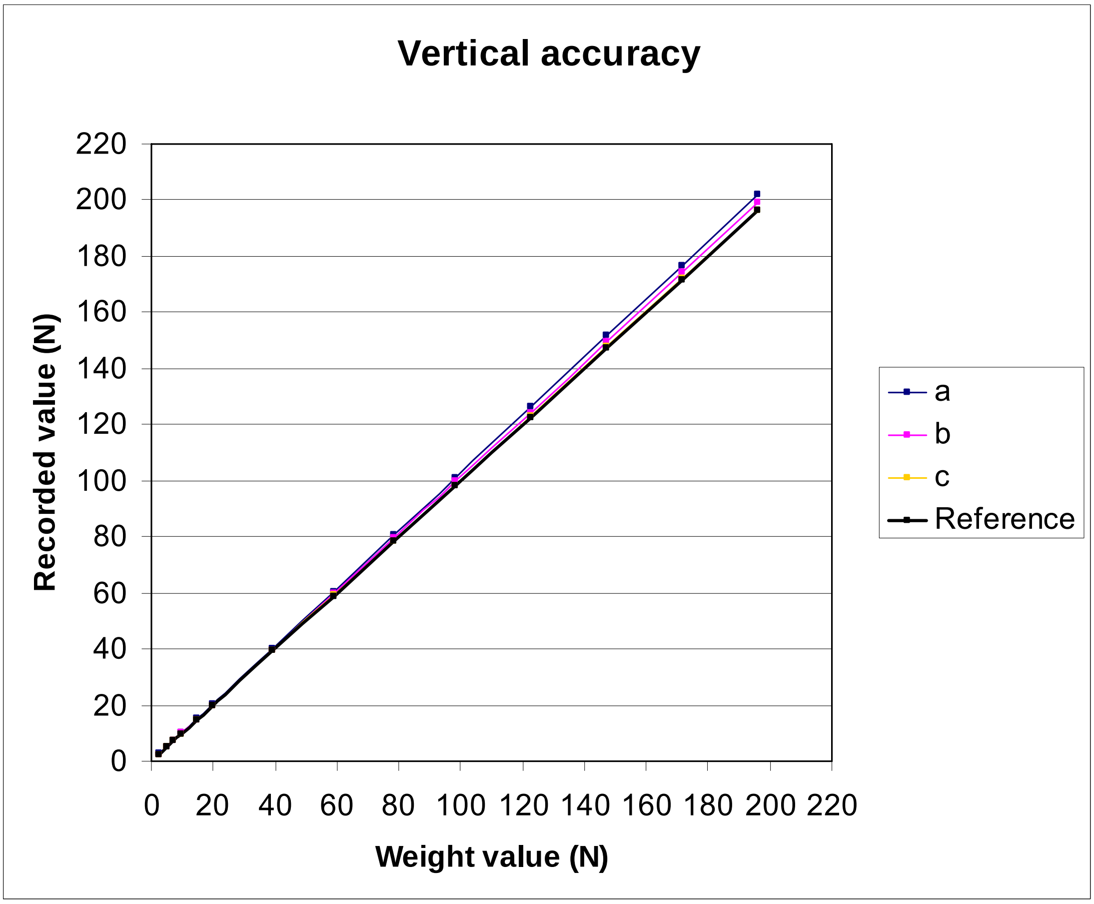

Figure 3.4. Plot of recorded vertical forces against known weight values. Applied in three locations: a = caudad end of table, b = centre, c = cephalad end of table (refer to Figure 3.3). Reference line represents 100% accuracy. Regression coefficients (slope gradients) for the three sets of recorded values ranged from 0.97 to 0.99 (95% CIs ≤ 0.002), $p < 0.001$, Adjusted R^2 for each = 1.000.

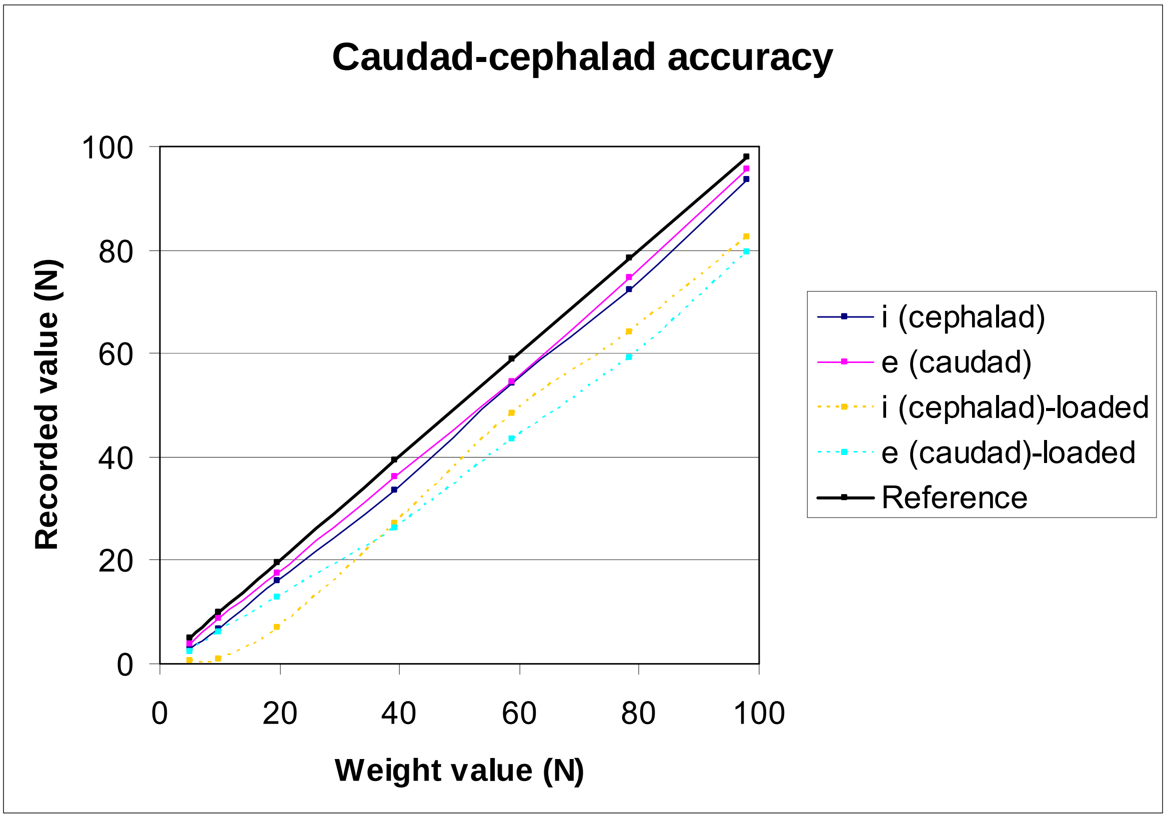

Figure 3.5. Plot of recorded caudad-cephalad forces against known weight values.

Applied in both unloaded (solid line) and loaded (dotted line) conditions in two locations: i = cephalad end of table, e = caudad end (refer to Figure 3.3). The direction of applied force in each location is indicated in brackets. Reference line represents 100% accuracy. Regression coefficients (slope gradients) for recorded values in each direction in each condition ranged from 1.02 to 1.22 (95% CIs ≤ 0.19), $p < 0.001$, Adjusted R^2s ranged from 0.994 to 0.999.

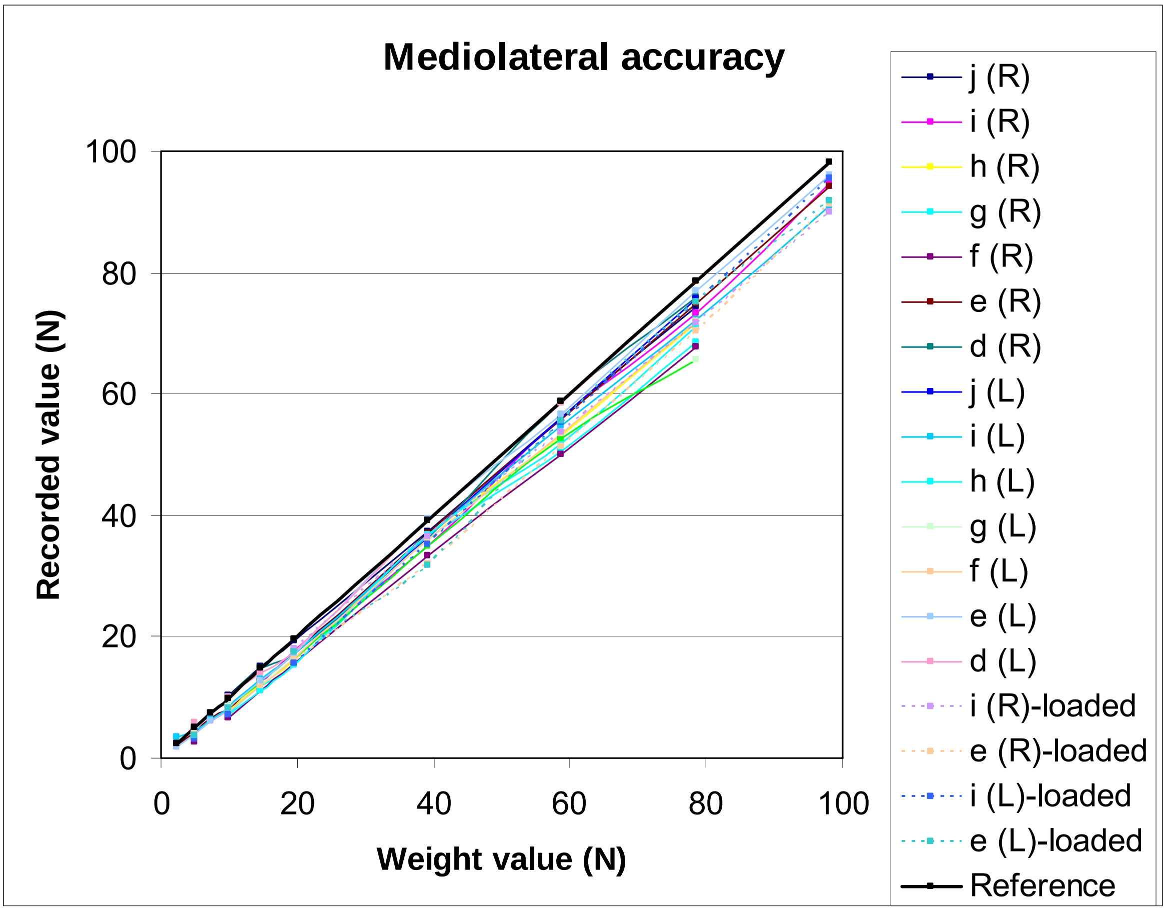

Figure 3.6. Plot of recorded mediolateral forces against known weight values. Applied in both unloaded (solid line) and loaded (dotted line) conditions in 14 locations: d through j = locations along each side of the table (refer to Figure 3.3). The direction of applied force in each location is indicated in brackets: R = right (i.e., to right side of the table, defined by the right side of a person lying prone on the table); L = left. Reference line represents 100% accuracy. Regression coefficients (slope gradients) for recorded values in each direction in both conditions for all locations of applied force ranged from 1.00 to 1.13 (95% CIs ≤ 0.14), $p < 0.001$, Adjusted R^2s ranged from 0.996 to 1.000.

Table 3.2. Reliability of force values recorded by the instrumented treatment table.

Direction of applied force	**ICC (2,1)**	**95% CI**
No pre-load		
Vertical	1.00	1.00 to 1.00
Mediolateral	0.99	0.98 to 0.99
Caudad-cephalad	0.99	0.91 to 1.00
Pre-loaded with 76 kg		
Mediolateral	1.00	0.99 to 1.00
Caudad-cephalad	0.99	0.98 to 1.00

3.4. Discussion

This chapter reports the evaluation of an instrumented treatment table designed to measure the forces applied by practitioners performing manual therapy techniques. Comparisons of the values measured by the table with known weights demonstrate the vertical forces are very accurate. Even with weights as small as 0.25 kg, the absolute error was < 0.1 N (Table 3.1). This high level of accuracy for vertical forces is important, because measurements of manual therapy forces during spinal mobilisation indicate that most force is applied vertically (Chiradejnant et al., 2002; Harms & Bader, 1997; Langshaw, 2001). Previous studies reporting accuracy of other instrumented tables found that the percent error or coefficient of variation decreased as larger magnitudes of weight were applied (Chiradejnant et al., 2001; Harms et al., 1995). For vertical forces measured in the present study, the percent error consistently ranged between 0.1 and 3%, to an upper weight of 20 kg (196 N), indicating a very small amount of error consistent across different magnitudes of applied force. For horizontal forces, the level of accuracy was not as high. The percent error decreased with increased loading in the horizontal directions, though the absolute error (actual number of newtons of error) increased (Table 3.1). A limitation of this method of calibration is the use of uniaxial static forces, when the intended use of the table is for dynamic force measurement at varying angles. Weights were applied to the table in a uniaxial direction because their value and angle of application could be accurately determined, and because there is no gold standard for comparison of dynamic forces. This calibration method is consistent with reported methods used for similar instruments (Chiradejnant et al., 2001; Harms et al., 1995).

The difference between the known weight values and the forces measured by the table in the horizontal directions could not be attributed to a definable error inherent in the table design because the percent error decreased and absolute error increased with greater testing weights. Furthermore, the error did not demonstrate a consistent pattern with the application of increasing magnitudes of force; it was not linear nor a curve with a consistent slope with increasing applied force. Therefore, the differences between known weights and measured horizontal forces could only be described as random error. This error is possibly attributable to a minimal amount of friction or resistance to movement in the eight ball-bearings of the rod ends connecting the vertical load cells to the table surface and base. When force is applied to one side of the table, there is potentially a minimal amount of movement of the table surface in the direction of the applied force. If there is resistance to this movement from the ball-bearings of the vertical load cells, the forces measured by horizontal load cells will be underestimated. The amount of resistance to horizontal movement could change depending on the position of the ball-bearing within the rod end, and the position of the table surface in relation to the base. These positions will change following each applied force in a different direction, making it impractical to measure and account for all possible combinations of resistance to horizontal movement. The resistance to table movement in the horizontal direction appears to increase slightly in the loaded condition (Table 3.1).

The measurement of vertical forces is not affected by any resistance to movement of the table surface in the vertical direction. This is because vertical forces always result in compression of the vertical load cells, never distraction. Therefore, as the ball-bearings of the horizontal load cells do not move up and down in the vertical plane, there is no resistance to movement in this plane which could affect the measurement of vertical forces.

The ball-bearing joints are friction-free according to the manufacturer, and the ability of each ball-bearing to move freely was tested and verified for each individual load cell while not attached to the bed. However, biaxial load cells are usually used independently. When arranged in the configuration shown in Figure 3.1, there is some limitation of the free movement of each load cell as they are connected to each other via the table. However, it was necessary that each load cell remain stationary when in situ because a biaxial load cell does not tolerate excessive force applied in directions other than its single plane for measurement. Also, measuring force in a single plane requires that the load cell remains aligned with that plane. The configuration of the seven load cells in the instrumented table prevents excessive extraneous movement.

Measuring manual therapy forces requires a balance between the accuracy of measurement and the replication of the clinical setting. Often, the more precise and reliable a measure is in the research setting, the less it reproduces clinical practice. By using an instrumented treatment table to measure cervical mobilisation forces, the manual therapist is unencumbered by any instrumentation that might affect their application of force, and the clinical setting is effectively reproduced. However, there are some limitations when using an instrumented table. The table produces a measurement of force in each of three individual planes of movement, resulting in three force values corresponding to separate directions of movement (see sample force-time curves for a cervical mobilisation in Figure 3.7). When manual therapists apply force, they apply a single force at a particular angle that will vary depending on the vertebral level, the technique applied, and the position of the patient and therapist. The measurements recorded for each direction of force can be used to calculate a resultant force, but this is in relation to the table, rather than to the anatomy of the person being mobilised. Furthermore, evaluation of the current instrumented table indicates that forces recorded in the horizontal directions were not as accurate as those recorded in the vertical direction. This may limit conclusions about manual forces that are applied with large components of force at acute angles to the surface of the table.

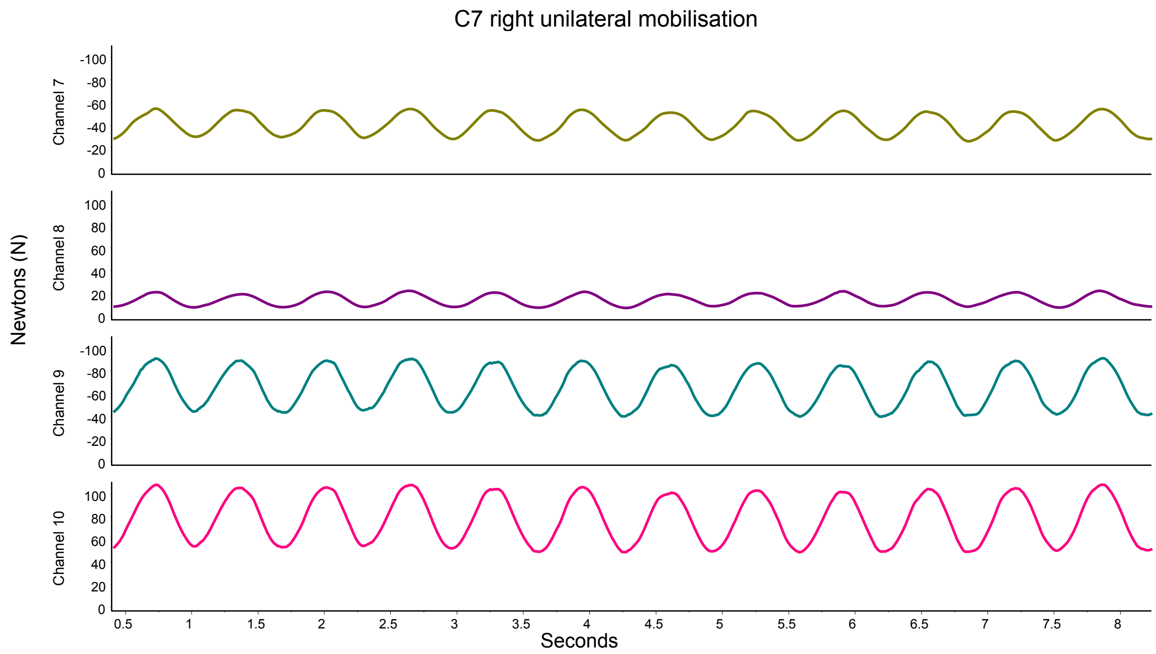

Figure 3.7. Force-time curves for a posteroanterior cervical mobilisation applied to the right articular process of C7.

Channel 7 displays the caudad-cephalad force (negative direction is caudad), Channel 8 the mediolateral force (positive direction is towards the patient's left), Channel 9 the vertical force (negative is downward on to the patient), and Channel 10 the resultant force, calculated in real time at 100 Hz using the formula

$$\sqrt{(Channel\ 7)^2 + (Channel\ 8)^2 + (Channel\ 9)^2}\ .$$

In addition, the forces recorded using an instrumented table can be affected by interaction with the patient. A patient's soft tissues, as well as the padding on the table, may absorb some of the force applied. Alternatively, forces applied to the body which are not directed at the target joint, such as the fingers of the therapist resting on the patient, may transfer additional forces to the table surface which are recorded as part of the force applied. Therefore, the measured force should not be described as solely representing the manual force applied to a particular spinal joint, even though the therapist may have been directing their mobilisation at that particular joint. No current non-invasive method can measure the amount of force applied to specific anatomical structures in vivo. The strain on selected structures during manipulation has been estimated, however, using animal models and cadaveric specimens (Kawchuk, Wynd, & Anderson, 2004; Symons, Leonard, & Herzog, 2002), although these are not without significant limitations.

Compared to other instrumented tables used for measuring manual forces applied to the lumbar spine, (Chiradejnant et al., 2001; Harms et al., 1995), the reliability and accuracy of the current instrumented table appears similar. Although the current table could arguably be used to measure multiple types of manual forces in varying anatomical areas, this study focussed on evaluating its use for measuring cervical mobilisation forces by quantifying the error of very small forces (Table 3.1) and of forces applied to the cephalad end of the table. Testing the accuracy of small forces is necessary because the range of forces applied to the cervical spine was expected to be less than previously reported lumbar mobilisation forces, as an early study of cervical mobilisation applied by a small group of clinicians and students suggests (Langshaw, 2001). Although the table was very accurate in recording small forces applied in the vertical direction, forces recorded in the horizontal directions were not as consistent (Table 3.1).

To increase the precision of measurement, future designers of instrumented tables should investigate ways to decrease the effects of individual biaxial load cells on other load cells used in the project, or consider using triaxial load cells. However, triaxial load cells report cross-talk between the three axes of force measurement (3-component force sensor, Type 9016B4, Kistler Instrumente AG, Winterthur, Switzerland; Tri-channel load cell, Model No. 2880, Robert A. Denton, Inc., Rochester Hills, USA). Cross-talk is the effect that a force in one axis has on the force output of the other two orthogonal axes, and it varies between $< \pm 1.5\%$ and $< \pm 5\%$ of the full scale. This means that if a triaxial load cell with a maximum capacity of 750 N in each direction is loaded in one direction, the maximum effect of that force on the force outputs in the other directions could be up to ± 37 N if the cross-talk rating was $< \pm 5\%$ of the full scale. This indicates that there is a small amount of inherent error when measuring forces in multiple planes, even with triaxial load cells. Nevertheless, the results of this study show that the accuracy of the biaxial load cells was very high for vertical forces, though not as high for horizontal ones.

3.5. Conclusion

This chapter has described the construction and testing of an instrumented treatment table designed to measure mobilisation forces in vivo. It can be used for the measurement of cervical mobilisation forces applied by therapists while replicating the clinical setting. It provides objective measurement of tri-planar forces, enabling specific manual techniques to be quantified.

Interpretation of data is limited somewhat by the recorded forces representing forces applied to the table rather than to an anatomical location. There is also some inherent error when simultaneously recording forces in three planes. In the case of the present instrumented table, the error became more apparent for forces measured in the horizontal directions. Nevertheless, the relatively minimal measurement error means this instrumented table can provide potentially useful information to enable the accurate quantification of manual techniques.

This instrumented table also has other possible uses, such as providing objective real-time feedback about force while a therapist applies a mobilisation technique. Feedback about applied forces can potentially be used to train therapists to apply specific levels of force when performing manual techniques. This could improve the consistency of force application between therapists and help to advance clinical practice in manual therapy.

CHAPTER 4. Equipment development: Stiffness assessment machine

4.1. Introduction

This chapter describes the development of a device to measure cervical spine stiffness. Spinal stiffness is a factor which might affect mobilisation forces applied by therapists. The dose of cervical mobilisation is commonly guided by a grading system which is based on a therapist's perception of the stiffness of the vertebra being treated (Maitland et al., 2005). This method of grading in relation to the perceived stiffness provides a possible reason for differences in mobilisation forces between practitioners. Therefore, prior to the quantification of cervical mobilisation forces, a mechanism for measuring stiffness in the cervical spine was developed and tested.

Stiffness in the cervical spine, unlike the lumbar spine, has not been quantified. Doing this is a necessary first stage in attempting to measure the effects of specific manual treatment techniques on different presenting clinical problems. This chapter describes the development of a reliable and safe instrument for measuring cervical spine stiffness. It also documents the stiffness of a group of asymptomatic individuals who were participants in two studies measuring cervical mobilisation forces, described in subsequent chapters.

4.2. Methods

4.2.1 Equipment

The apparatus for collecting cervical spine stiffness data is modelled on three lumbar spine stiffness assessment devices described previously (Edmondston et al., 1998; Latimer, Lee, Goodsell et al., 1996; Lee & Svensson, 1990). Specifically, the equipment was designed to simultaneously measure the excursion at a point on the cervical spine while applying a mechanical force at a constant speed, and the resistance to that force.

The cervical spine stiffness assessment device uses a 12 V direct current (DC) motor (Model No. BM 4023-MA2, Shinko Electric Co. Ltd., Minato-Ku, Tokyo, Japan) to power a gear drive (Figure 4.1). This produces forward and backward movement of a stainless steel rod used as an indenter on the skin of the neck overlying a spinous process. The indenting end of the rod has a head made of firm plastic that is 15 mm in diameter (flat portion), with a 2.5 mm tapered edge (Figure 4.1, D). Movement of the rod is measured with a DC-operated linear variable differential transformer (LVDT, Model No. DC-EC 1000, Schaevitz™ Sensors, Lucas Control Systems, Hampton, Virginia, USA). Resistance to movement is measured using a compression and tension load cell (Model No. UMM-K050, Dacell Co., Ltd., Chungbuk, South Korea). Voltage output from the LVDT and load cell is routed through an amplifier (Strain Gauge Signal Conditioner, Model RM-044, Applied Measurement Australia, Sydney) to a Powerlab® system (ADInstruments, Castle Hill, Australia) at a transfer rate of 100 Hz. Appropriate voltage conversions for the LVDT and load cell are programmed in Powerlab's Chart software (Version 4.2.4, ADInstruments, Castle Hill, Australia), which records output from each instrument simultaneously.

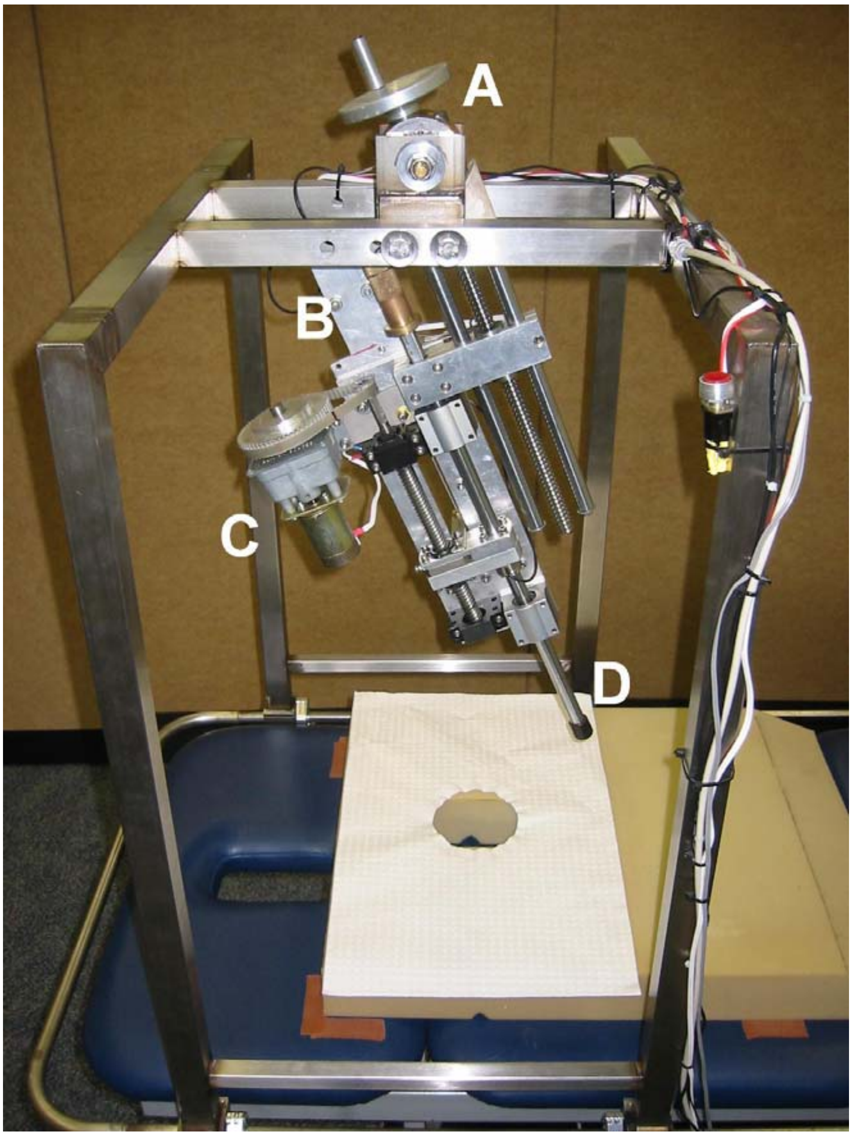

Figure 4.1. Cervical spine stiffness assessment device positioned for C7 testing.

(A) rotary mechanism for positioning device on subject; (B) mechanical stop, positioned to allow maximum displacement; (C) gear drive and motor, (D) indenter probe.

The entire apparatus is mounted on a frame which allows for variations in the sagittal angle of applied force, and changes in the height and position of the device along the length of the treatment table. A power supply (Model 53/2B, Statronics, Hornsby, NSW, Australia) operates the motor that turns the gear drive. It is also linked to an electronic motor controller which allows for variations in the application of the device and safety controls. The motor controller is used to adjust the speed of movement of the rod, the voltage supplied to the motor, and the maximum force that can be applied. It has modes for manual operation and data collection. In manual mode, the motor controller allows the operator to move the rod towards or away from the subject's skin. In the data collection mode, the indenter rod moves forward and back for five cycles, monitored by an electronic counter which is reset by the operator prior to data collection. There are remote safety switches, one held by the subject being tested and one by the operator, which when pressed, automatically move the indenter rod to the position that is furthest away from the subject.

A variable oscillator controls the frequency at which the rod oscillates forward and backward. The available oscillation frequencies range from 0.25 Hz to 3 Hz, in 0.25 Hz increments (Squires, Latimer, Adams, & Maher, 2000). Adjusting the voltage supplied to the motor changes the distance the indenter rod travels while oscillating at the set frequency. The distance the rod travels is also affected by the force exerted back as the tissues are compressed by the indenter head (i.e., the resistive force). If a higher resistive force is encountered, then the traverse of the rod is less, despite the voltage supplied to the motor being the same. This safety feature prevents the rod from continuing to drive the spinous process further into the subject's neck if strong resistance to movement occurs.

To collect comparable values for a group of individuals, the voltage supplied to the motor for all tests is set to a specified level. This needs to be sufficient to collect the required force and displacement data and tolerable for the majority of a range of test subjects. Following pilot trials the voltage used in the present cervical spine stiffness tests was set at 85% of the motor's maximum, 10.2 volts. This level was based on the reported comfort of subjects during trials of different voltages. A physiotherapist with post-graduate manual therapy qualifications and extensive teaching experience indicated the level which he reported felt similar to a physiotherapist applying a grade III mobilisation. This voltage level was selected so that the force applied to the neck would be similar to a clinically applied force, without being excessive. It was then trialled on four asymptomatic subjects, one physiotherapist and three others. All tolerated it well. At the selected voltage level, the rod moves 14 mm both forwards and backwards against a resistance equal to 70 N. If there is a lower resisting force the indenter travels further within a pre-set limit determined by the operator; if greater, it does not travel as far.

For safety reasons, the maximum force and displacement possible can be limited using controls set by the operator. If the motor controller senses the specified maximum force (by detecting the corresponding voltage), the indenter does not move any further towards the subject. The indenter remains stationary for the remainder of the forward cycle (duration depends on the oscillation frequency, e.g., less than 0.5 sec if 1 Hz), before reversing. The maximum safe force was set at 80 N. This level was selected because it was well within the range of force applied to the cervical spine by physiotherapists in a pilot study (Snodgrass, Rivett, & Robertson, 2007), described in Chapter 5, and was considered high enough to collect the necessary data. Previous studies measuring lumbar stiffness have calculated stiffness coefficients in ranges up to 80 N (Edmondston et al., 1998), 90 N (Shirley et al., 2002) and 200 N (Latimer et al., 1998).

The maximum displacement possible is controlled by manually adjusting a mechanical stop (Figure 4.1, B), which contacts an electronic switch if the rod traverses the maximum pre-set distance. Contact with the switch causes the motor to reverse away from the subject and data collection to cease. The maximum displacement available on the existing equipment is 28 mm. This was used in all trials reported here because pilot testing demonstrated large movements occur in the cervical spine without the subjects reporting any discomfort. Previous stiffness devices used for the lumbar spine have reportedly been able to measure maximum displacements of 15 mm (Allison et al., 2001; Edmondston et al., 1998) and 22 mm (Latimer, Lee, Goodsell et al., 1996).

4.2.2 Data collection

Reliability testing

To test the reliability of the stiffness assessment device, repeated measurements were obtained using eight different combinations of foam of varying densities. Foams were selected because their stiffness measurements were in the range of those recorded on the cervical spine in early trials. The foam was positioned under the indenter head and stiffness was measured with the sagittal angle of inclination set to zero degrees. This was repeated without moving the foam being tested.

Cervical spine stiffness measurement

Sixty-seven asymptomatic individuals were recruited and their cervical spine stiffness measured at C2 and C7 on one or two occasions. Ethical approval for the study was granted by the University and local health service Human Research Ethics Committees. Subjects were eligible if they were between 18 and 50 years of age, and they had not had neck pain or headaches for which they sought treatment in the previous 12 months. Subjects were excluded if they had been diagnosed with any condition where PA cervical mobilisation might be contraindicated, such as inflammatory or infectious diseases affecting the neck, nerve root pain, instability, or symptoms potentially related to the vertebrobasilar system such as dizziness or nausea. Prior to the collection of cervical spine stiffness data, each subject's C2 and C7 spinous processes were pre-marked by an experienced physiotherapist researcher using commonly recommended clinical methods (Gross, Fetto, & Rosen, 2002; Hoppenfeld, 1976; Palmer & Epler, 1998). The C2 and C7 vertebrae were then pre-conditioned by applying five manual PA oscillations of force to the spinous process, as a clinician might apply when assessing a joint. During the stiffness test, each subject lay prone with their cervical spine in a neutral position while their head rested on a custom-made piece of foam with a cut-out for the face (Dunlop utility foam AA23-130).

In each case C7 was tested first and then C2. For C7 tests, the sagittal angle of inclination was standardised at 20 degrees caudad, and for C2, 14 degrees cephalad. These angles were based on the average angle of inclination for 252 individuals without craniocervical symptoms, as measured by radiographs in a previous study (Harrison, Janik, Troyanovich, & Holland, 1996). For testing each level, the stiffness measurement device was positioned by winding the mechanical stop to zero and moving the indenter rod to its starting position using the electronic manual mode. The mechanical stop was then positioned to allow maximal movement (28 mm) in testing mode.

Next, the device was manually aligned with the subject. The indenter head was positioned on the mark over the spinous process by sliding the frame in the caudad-cephalad plane and securing it, then positioning the device on the subject's skin using the rotatory mechanism at its top (Figure 4.1, A) which allowed the whole device to move along a coiled thread. Indenter positioning was standardised by moving it toward the subject until it was touching the skin, stopping only when a light indentation first became visible (Figure 4.2).

The stiffness measurement was taken after the subject exhaled a deep breath. The subject was instructed to remain relaxed and to hold their breath (at functional residual capacity) for 5 seconds while data were collected. Subjects were warned that they may feel their head or neck move but to stay relaxed without resisting or tensing any muscles. In lumbar spine stiffness testing, breathing (Shirley et al., 2003) and muscle contractions (Lee et al., 1993) can affect measurements. The implications for cervical spine stiffness measurements are unknown, but at least one set of local muscles, the scalenes, is active during breathing (De Troyer & Estenne, 1984).

Figure 4.2. Subject positioned for stiffness testing with the cervical spine in neutral and the indenter probe on the spinous process of C7.

Stiffness measurements were taken with the oscillatory frequency set at 1 Hz, which corresponds with the mean frequency applied by a group of physiotherapists performing cervical mobilisations (Snodgrass et al., 2007).

Two streams of data were collected for each subject: displacement by time from the LVDT and force by time from the load cell. These data were saved as text files and then extracted using a custom-written program (Appendix 3.2) in IDL software (Version 6.2, ITT Visual Information Solutions, Boulder, Colorado, USA). At this stage, pre-recorded friction (from the linear bearings holding and guiding indenter rod movement) was subtracted from the results, and a force (y-axis) by displacement (x-axis) curve created representing the forward (towards subject) movement for each of the five oscillation cycles of applied force (Figure 4.3). The stiffness measurement (coefficient K) at a single vertebral level was calculated as the mean of the slopes of the linear portions of the force-displacement curves for cycles two through five. The first repetition has usually been excluded in previously reported lumbar stiffness research as it is consistently different than the subsequent four cycles (Latimer et al., 1998; Shirley, 2004; Shirley et al., 2002). The linear portion of the curve is used

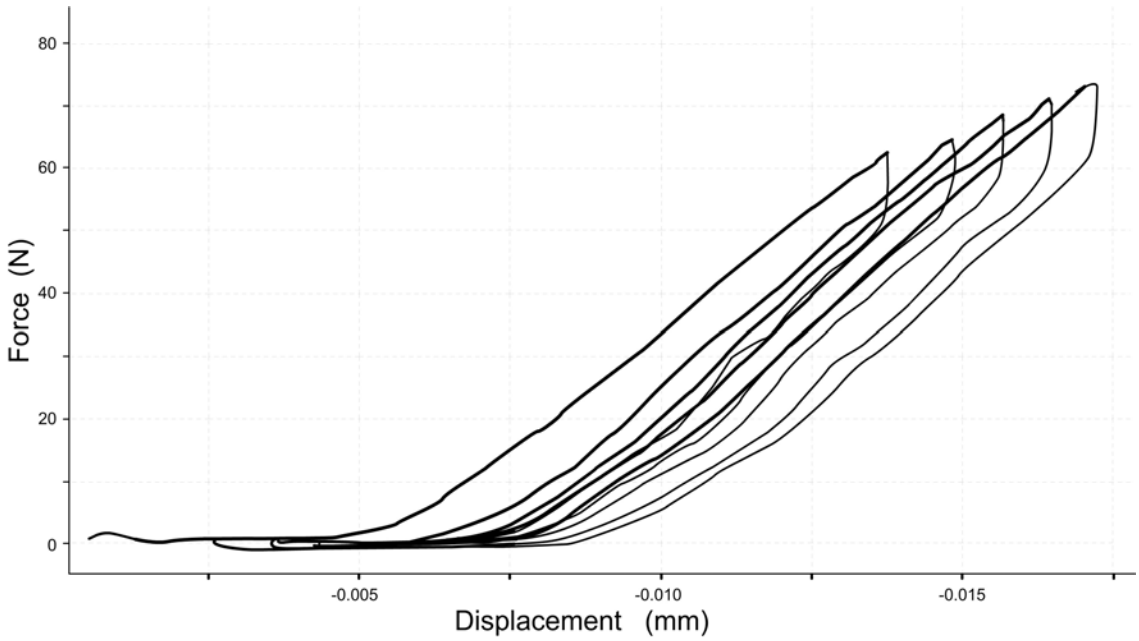

Figure 4.3. Typical force-displacement graph illustrating five cycles of applied force to C7.

The bold portion of each force-displacement curve represents the stiffness device moving in the posterior to anterior direction. This was used for calculating spinal stiffness, which equated to the mean of the slopes of the linear regions of the force-displacement curves for cycles two through five.

because force-displacement curves representing spinal stiffness typically have an initial non-linear region at lower applied forces, and a linear region as higher forces are applied (Shirley, 2004). The initial non-linear or toe region is thought to represent the indenter pressing into the skin and soft tissues; essentially ‘taking up the slack’ of the soft tissues by compression prior to movement of the spinal unit (Latimer, Goodsell et al., 1996; Latimer, Lee, Goodsell et al., 1996).

4.2.3 Analysis

Reliability testing

Stiffness coefficient K for foam types was defined as the mean of the slopes of the linear regions of the force-displacement curves for cycles two through five of applied force. The linear region of the force-displacement curve for each foam type was determined using the mathematical method described below for finding the linear region of the cervical spine force-displacement curves. The corresponding force range for the linear region was used for calculating K. Reliability between repeated measures was calculated using the intra-class correlation coefficient, ICC(2,1).

Determining the linear region of the cervical spine stiffness curve

In the lumbar spine a non-linear toe region of the force-displacement curve typically occurs between 0 and 30 N of applied force. The curve above 30 N of force is considered linear (Shirley, 2004; Shirley et al., 2003). As the properties of cervical spine stiffness were not known, a mathematical method was applied to data from the first 35 subjects to identify the most linear part of the force-displacement curves for C2 and C7 measurements (Appendix 3.1). For each curve representing an oscillation cycle of applied force, a line was fitted to all data points using a y = mx + b model. Then, the endpoint of the curve was selected and y_i = mx + b was fitted to *i* data segments from each point along the curve to the endpoint (approximately 50 data segments, as the force-displacement curve represented one half of an oscillating cycle with data collected at 100 Hz). The linearity of each segment was determined by its sigma value (σ = SD of y about the regression line). If σ for a segment was greater than 0.3, the data point at the start of that segment was considered part of the toe region, rather than part of the linear region. This very small value for σ was selected to best identify the most linear portion of the force-displacement curve. This method assumes that the non-linear portion of the force-displacement curve will always be at the start of the curve. These calculations identified the 'starting point' (x and y coordinates) of the linear portion of the force-displacement curve.

To compare cervical spine stiffness (coefficient K) between individuals, a standard force range for calculating K for all subjects was required. In the lumbar spine, stiffness coefficients calculated in different force ranges within the linear region are significantly different (Latimer et al., 1998; Lee et al., 1997). To select the force range for calculating stiffness of the cervical spine, the mean and 95% CI were calculated for the force values at the 'starting point' of the linear range (y coordinate values) for oscillatory cycles two through five. In addition, the maximum forces applied during each force-displacement curve for cycles two through five were identified, and the mean and 95% CI were calculated. The range for the calculation of stiffness coefficient K was from the lower bound of the 95% CI for 'starting point' forces to the upper bound of the

95% CI for maximum force. Specific ranges were determined for measurements of both C2 and C7.

Stiffness calculation

For stiffness measurements at C2, stiffness coefficient K was calculated from 7 to 40 N, and for C7 measurements from 20 to 70 N. A separate IDL program (Appendix 3.2) was used to calculate slope and linearity (σ) in these specified ranges for each repetition of force application. Stiffness coefficients for cycles two through five were analysed for consistency using one-way ANOVAs with Bonferroni post-hoc tests. Cycles 2 through 5 for each measurement occasion were averaged to determine the stiffness value for each spinal level of each subject. Repeatability of cervical spine stiffness measurements was determined using paired t-tests, standard error of measurement (SEM), and ICC(2,1). Linear regression was used to determine associations between cervical spine stiffness and age, gender, height and weight of subjects. Analysis was performed in SPSS 14.0 (Chicago, IL).

4.3. Results

4.3.1 Reliability testing

The stiffness assessment device was reliable for repeated measures of stiffness of inert materials. The ICC(2,1) for repeated measurements was 0.99 (95% CI 0.93 to 1.00).

4.3.2 Determining the linear region of the cervical spine stiffness curve

The starting point of the linear portion of the force-displacement curve, determined mathematically, varied considerably between individuals and between cycles of applied force. The absolute maximum force applied during any oscillatory repetition also differed between subjects. In order to compare stiffness between individuals, a standard force range representing the linear region was selected. This was based on the means and 95% confidence intervals of the starting points and absolute maximum forces for stiffness measurements of the first 35 subjects.

Selecting the standard force range for calculating the slope of the force-displacement curve (C2: 7-40 N; C7: 20-70 N) meant that not all oscillatory cycles reached the maximum force selected for inclusion. Considering cycles two through five for C2 tests, 80.2% of force-displacement curves were under the 40 N maximum cut-off by a mean of 13.6 N (95% CI 12.4 to 14.7) and 19.8% had data that extended past 40 N, by a mean of 5.5 N (95% CI 4.1 to 7.0). For C7 tests, 76% of oscillatory cycles did not reach the 70 N cut-off, by a mean of 18.4 N (95% CI 16.7 to 20.1), and 19.8% were greater than 70 N by a mean of 17.7 N (95% CI 13.1 to 22.3). Some C7 cases (4.2%) were excluded from this analysis due to noise in the data which skewed the accuracy of determining the linear region using the mathematical method.

The selected regions of the force-displacement curves used for calculating stiffness coefficient K were determined to be reasonably linear (for C2 measures, mean σ = 0.47, SD 0.26; for C7, mean σ = 0.50, SD 0.33). These mean σ values are higher than the original σ value used to select the start of the linear region because a greater amount of each force-displacement curve is included when a standardised force range is used. These σ values indicate that the mean standard deviation of force about the fitted regression line was 0.5 N or less, demonstrating a high degree of linearity for the segments used to calculate the stiffness slope.

4.3.3 Stiffness calculation

The mean stiffness values for cycles two through five (Table 4.1) were analysed for consistency. For C7 measurements, the slopes for individual oscillatory cycles were not significantly different ($F[3, 264] = 0.17$, $p = 0.915$). For C2 measurements, cycle two was different to cycles four and five (mean difference < 0.83 N/mm, $p < 0.05$), but cycles three through five were not significantly different ($F[2,198] = 2.56$, $p = 0.08$). A reliability analysis of C2 measurements determined that the mean of cycles 2-5 was very similar to the mean of cycles 3-5 (ICC[2,1] = 0.98, 95% CI 0.87 to 0.99). Therefore, cycles two through five were used to calculate the average stiffness value for all tests, consistent with previous research measuring lumbar spine stiffness (Latimer, Goodsell et al., 1996; Shirley et al., 2002).

Subjects are described in Table 4.2. Using data from the first occasion of measurement for all 67 subjects, the mean stiffness coefficient K at C2 was 4.58 N/mm (SD 1.13, range 1.95-6.94). At C7 it was 7.03 N/mm (SD 2.20, range 4.15-14.16). Stiffness was reasonably consistent over time. There were no significant differences between measurements for the 31 subjects who returned for repeated testing (Table 4.3). The mean difference for C2 measurements was -0.30 N/mm (95% CI -0.67 to 0.06, $p = 0.102$) and for C7 0.09 (95% CI -0.55 to 0.73, $p = 0.783$). The SEM between the two occasions was 0.53 N/mm for C2 measurements and 0.83 N/mm for C7. ICC(2,1) for all cervical measurements (both levels combined) was 0.75 (95% CI 0.62 to 0.84). There were five outliers that were ± 2 SD from the mean (three measurements at C2 and two at C7). Excluding these outliers, ICC(2,1) was 0.84 (95% CI 0.74 to 0.90).

Table 4.1. Mean stiffness coefficient K for the cervical spine.
Calculated by repetition cycle of applied oscillatory force (n = 67, first occasion of measurement).

Repetition	Mean	SD	95% CI	Minimum	Maximum
C2 measures					
2	4.10	1.27	3.79 to 4.41	1.49	6.91
3	4.47	1.19	4.18 to 4.76	1.54	7.12
4	4.72	1.14	4.44 to 5.00	2.06	7.02
5	4.93	1.16	4.64 to 5.21	2.03	7.12
C7 measures					
2	6.92	2.34	6.34 to 7.49	3.18	14.17
3	7.08	2.49	6.47 to 7.68	3.20	14.58
4	7.21	2.46	6.61 to 7.81	2.96	14.70
5	7.12	2.44	6.52 to 7.72	3.22	14.42

Table 4.2 Description of subjects.

	All	Subjects completing repeated testing
	Mean (SD)	Mean (SD)
N	67	31
Number female	41	17
Age (years)	30.0 (9.5)	29.2 (9.4)
Height (cm)	170.5 (9.0)	170.8 (8.4)
Weight (kg)	73.6 (15.8)	71.6 (13.7)

Linear regression indicated that the age of the subject was positively associated with C2 stiffness (p = 0.01, regression coefficient 0.04, 95% CI 0.01 to 0.07, r^2 = 0.099), but gender, height and weight were not. For C7 stiffness, males were stiffer than females (mean difference 2.20 N/mm, 95% CI 1.23 to 3.17, $p < 0.001$, $r^2 = 0.239$). Height, weight and age were not associated with C7 stiffness. Assumptions of normality, linearity and homoscedasticity were satisfied for the linear regression models.

Table 4.3 Stiffness coefficient K (N/mm) at C2 and C7.

Measured on two occasions with number of days between repeated measurements for each subject (n = 31).

Subject number*	Days between measurements	C2 trial 1	C2 trial 2	C7 trial 1	C7 trial 2
2	20	6.07	5.82	8.43	9.47
3	14	4.54	4.54	6.04	8.55
4	22	4.28	4.50	6.37	6.23
5	28	3.93	4.64	5.92	5.90
6	0.5	3.92	3.92	7.66	7.14
7	56	3.90	6.56	4.50	5.97
9	124	4.38	5.78	9.16	7.56
10	6	2.30	4.98	9.08	8.02
12	13	5.28	4.96	11.30	6.44
14	7	6.94	5.95	9.83	9.74
15	5	5.40	5.68	5.86	6.81
16	6	2.72	2.75	5.77	6.98
17	5	5.01	5.37	4.67	4.92
23	6	3.60	5.37	4.83	4.89
25	14	4.69	5.26	8.41	7.06
31	22	5.94	5.13	7.99	6.22
34	71	4.59	4.50	5.77	6.78
38	62	5.53	5.68	7.02	10.33
39	54	5.20	4.79	7.09	6.97
44	21	4.92	5.24	9.56	7.42
47	44	5.42	3.35	4.81	6.87
50	20	1.95	2.38	13.63	8.89
51	13	3.62	3.57	7.80	7.80
53	14	3.62	3.83	7.28	7.05
54	16	4.10	5.66	8.90	8.46
55	26	4.99	4.52	6.07	6.27
56	35	3.26	2.87	6.97	6.62
58	20	2.36	3.82	5.01	6.44
60	14	5.76	5.11	8.17	8.50
63	13	2.76	3.58	4.91	5.84
64	12	4.05	4.35	5.28	5.28

*Includes only subjects who returned for repeated testing.

4.4. Discussion

The main findings from this study were that the cervical spine responds differently to mechanical force than the lumbar spine, resulting in lower stiffness values; cervical spine stiffness differs between individuals, though an individual's stiffness remains relatively consistent over two sessions; and cervical spine stiffness is associated with gender and age.

Cervical spine stiffness values (coefficient K) were lower than those measured in the lumbar spine (Shirley et al., 2002) due to increased displacement per unit of applied force compared to that reported for the lumbar spine (Latimer, Goodsell et al., 1996; Shirley et al., 2002). In contrast to the lumbar spine, the linear region of the force-displacement curve began earlier in the range; on some occasions the entire force-displacement curve was linear, with virtually no toe region observed. A possible reason may be differences in the soft tissue covering the cervical and lumbar spines. Another dissimilarity was the force range representing the linear region and used for calculating coefficient K. A lower force range was used for cervical spine measurements compared to that reported for lumbar measurements, because lower forces were generated during cervical testing due to increased displacement. This might relate to the fact that the lumbar spine is anchored by the pelvis and ribcage which have been shown to affect stiffness values (Chansirinukor et al., 2001, 2003), whereas the cervical spine has considerably fewer restraints.

Cervical spine stiffness measurement using this device appears reliable. For the device itself, the accuracy of repeated measurements of inert materials is very high. When using it on the cervical spine of asymptomatic subjects, the absolute differences between repeated measurements are reasonably small

(Table 4.3). On 90% of occasions the differences between repeated C2 measurements was < 1.5 N/mm and for C7 < 2.1 N/mm. This level of agreement is similar to that previously reported for lumbar stiffness measurements (Latimer, Goodsell et al., 1996; Shirley et al., 2002). The SEM of 0.53 and 0.83 N/mm, for C2 and C7 measurements respectively, is comparable to the SEM reported for two instruments used to measure lumbar spine stiffness, 1.03 N/mm (Shirley et al., 2002) and 0.26 to 1.05 N/mm (Allison et al., 2001; Edmondston et al., 1998). The ICC(2,1) of 0.84 for repeated cervical spine stiffness measurements indicates excellent reliability, according to Fleiss (1986). When compared to previously reported ICC values for lumbar spine stiffness measurements, the cervical spine values are similar (Allison et al., 2001; Lee & Svensson, 1990; Shirley et al., 2002; Viner et al., 1997) to slightly lower (Edmondston et al., 1998; Latimer, Goodsell et al., 1996). However, only two of these studies reported reliability for measurements taken on different days (Lee & Svensson, 1990; Shirley et al., 2002), whereas the others reported measurements taken minutes apart without the subject moving from the testing surface. The repeated cervical measurements in the current study were recorded a number of days apart (Table 4.3), which may account for some of the difference in ICC values compared to some previous studies. A future study should investigate the reliability of cervical stiffness measurements taken consecutively on the same day, as well as a standard number of days apart.

C2 stiffness was less than C7, likely because C7 is closer to structures that might provide some additional support or restriction to movement, such as the ribs or the soft tissues about the shoulders and chest. C7 stiffness was associated with gender, with males being stiffer. Studies investigating gender differences in joint mobility agree that females usually display greater joint mobility (Didia, Dapper, & Boboye, 2002; Russek, 1999; Seow, Chow, & Khong, 1999), and one study of patients with low back pain found females were slightly less stiff in the lumbar spine (Owens, DeVocht, Gudavalli, Wilder, & Meeker, 2007). However, a previous study found lumbar spine stiffness was not significantly different between males and females (Lee & Evans, 1992), and gender was not associated with C2 stiffness in the current study. C2 stiffness was associated with older age. This might be expected because the prevalence of osteoarthritis increases with age (van Saase, van Romunde, Cats, Vandenbrouke, & Valkenburg, 1989), and symptoms of osteoarthritis are associated with stiffness (Kornaat et al., 2006). However, the increase in stiffness with age was very small (0.037 N/mm per year older, 95% CI 0.009 to 0.065), and this association with age was not observed in C7 measurements. A potential confounding factor when comparing C2 and C7 stiffness measurements was that C7 measurements were performed before C2 on each occasion. The order of measurements may have had an effect on the amount of preconditioning at each spinal level. Additionally, familiarisation may have reduced possible apprehension about the testing procedure, reducing potential muscle activity in some subjects. Both of these issues might have potentially affected the stiffness values.

There are several possible limitations to the cervical spine stiffness data in this present study. First, the stiffness measurement was designed to quantify the stiffness sensations palpated by a clinician when performing a PA mobilisation, so should not be directly compared to pure segmental stiffness as measured on cadavers (Sran, Khan, Zhu, & Oxland, 2005) or in vivo spinal flexibility measurements (McClure, Siegler, & Nobilini, 1998). To mimic clinical practice, subjects lay prone on a foam support with no additional stabilisation of the head or neck. This likely resulted in both angular rotation (sagittal plane extension) and segmental movement during testing, as would occur when a therapist clinically performs a PA mobilisation (Lee et al., 2005; McGregor et al., 2001). Therapists use information from PA motion assessment to guide manual treatment choices (Maitland et al., 2005). The cervical spine stiffness measurement attempts to quantify this, similar to the way lumbar spine stiffness has been evaluated (Shirley, 2004). In clinical terms, the stiffness measurement objectively quantifies the relationship between the amount of resistance to manually applied force and the movement produced as a result of that force.

Second, measurements were taken with subjects lying on a padded plinth using a custom-made piece of foam to standardise head position. Plinth padding has been shown to decrease stiffness measurements in the lumbar spine (Maher et al., 1999), so the current cervical spine stiffness measurements may be low because of this. A padded plinth was used to replicate the clinical situation. Other potential sources of error were friction within the apparatus and the positioning of the indentor rod on the skin prior to data collection. Error in positioning the rod was minimised by using a standardised process which included observing the probe touching the skin, and then winding it towards the skin until it just lightly indented the skin (Figure 4.2). The amount of friction remained constant, so it would not affect comparisons between subjects or between repeated measurements. However, it could potentially affect comparisons between stiffness values measured by the machine and physiotherapist stiffness assessment. Lastly, there was the potential for error in the palpation of C2 and C7 by the operator. To limit this possibility, the same experienced physiotherapist operator identified the levels in each subject using standardised palpation methods.

4.5. Conclusion

This study introduces a safe and reliable method for measuring stiffness in the cervical spine. Cervical spine stiffness measurements were shown to be less than those in the lumbar spine, with greater displacement per amount of applied force during testing. Cervical stiffness varied between individuals, with a positive association between male gender and C7 stiffness and between older age and C2 stiffness. This information forms the basis for future research that could investigate changes in stiffness as a result of manual therapy treatments and lead to improved patient outcomes. In addition, the measurement of spinal stiffness makes it possible to account for this potentially confounding factor when comparing the cervical mobilisation forces applied by individual physiotherapists to different subjects.

CHAPTER 5. Pilot study

5.1. Introduction

Little is known about the forces applied during cervical mobilisation. Additionally, there is considerable variation in methods and findings of the few studies that do report cervical mobilisation forces (Conradie et al., 2004; Langshaw, 2001; Lee et al., 2005; Smit et al., 2003). Potential variations in applied forces may affect treatment outcomes. In order to determine the effects of manual forces on outcomes, the forces must first be measured and described.

The aim of this pilot study was to quantify the cervical mobilisation forces applied by a group of physiotherapists, and to pilot test the data collection method prior to a larger study (described in Chapter 6). Preliminary findings are reported from ten therapists mobilising a single subject.

5.2. Methods

5.2.1 Equipment

An instrumented table was used to measure the applied cervical mobilisation forces in three directions (vertical, caudad-cephalad and mediolateral). The construction of the instrumented table and the results of accuracy and reliability testing are described in detail in Chapter 3.

5.2.2 Mobilisation force measurement

Ethical approval for the study was granted by the University and local health service Human Research Ethics Committees. Ten physiotherapist clinicians provided written informed consent to participate following the explanation of procedures. Therapists applied PA mobilisation to the cervical spine of a 41-year-old asymptomatic male using their usual clinical technique. Physiotherapists were eligible to participate if they performed cervical mobilisation in clinical practice at least once per week. Therapists' height, weight, age and gender were recorded, and each completed a questionnaire which documented their years of clinical experience, current work setting, frequency of performing cervical mobilisation, training, history of any work-related thumb pain and upper limb injuries, and their definition of the mobilisation grades. For mobilisation definitions, participants were provided with a list of selections based on the definitions described by Maitland et al. (2005) and Grieve (1991). Participants were asked to either tick a box representing their understanding of each mobilisation grade, or write down their definition if it was different to the selections provided. Table 5.1 lists the selection of mobilisation definitions provided for participants.

Each therapist applied four grades of mobilisation to C2 centrally, C7 centrally, C2 unilaterally and C7 unilaterally (one right and one left). The four techniques were selected to include all grades of cervical mobilisation to both the upper and lower cervical spine, both centrally and unilaterally. Therapists used their preferred hand and stance positions, standing on wooden blocks if necessary, as the instrumented table is not height-adjustable. The spinous and articular processes of C2 and C7 were pre-marked by a single physiotherapist researcher, and pre-conditioned with five PA oscillations. While the subject lay prone, the C2 spinous process was identified by palpating in the midline just below the external occipital protuberance.

Table 5.1. Selection of mobilisation grade definitions provided for therapists performing mobilisation.

Grade	Mobilisation definition selections
I	Small amplitude movement near the start of the range. Other________________________________
II	Large amplitude movement that carries well into the range. It can occupy any part of the range that is resistance-free. Large amplitude movement which carries well into the range. It can occupy any part of the range, but does not reach the limit of range. Other________________________________
III	Large amplitude movement that moves into resistance or stiffness. Large amplitude movement that reaches the limit of range. Other________________________________
IV	Small amplitude movement stretching into resistance or stiffness. Small amplitude movement at the limit of range. Other________________________________

The C7 spinous process was identified by counting the spinous processes caudally from C2 and by verifying the level using a commonly recommended cervical extension motion test (Gross, Fetto et al., 2002; Hoppenfeld, 1976; Palmer & Epler, 1998). The articular processes were identified just lateral to the spinous process (Gross, Fetto et al., 2002). This process was systematically repeated on each occasion of data collection. Grade, spinal level, technique, and initial side for unilateral technqiues (right or left) were randomised. Measures were repeated for the first technique performed (all four grades) after approximately 20 minutes.

Prior to recording mobilisation forces for each technique, the subject's neck was placed in a neutral position enabling the therapist to palpate the cervical spine. After a therapist completed palpating, a baseline measurement was taken of the subject's body weight on the table without the therapist touching the subject. The therapist was then instructed to perform each mobilisation grade in a pre-determined randomised order, with each grade recorded for 15 seconds. After each therapist had completed their mobilisation (prior to the repeated measure), the subject rated the therapist on the overall level of comfort experienced during the mobilisation using a 10 cm visual analogue scale anchored with 'very comfortable' at the left end and 'very uncomfortable' at the other end. The visual analogue scale was used because it is valid, reproducible, and commonly used to evaluate pain (Scudds, 2001) as well as comfort and discomfort (de Looze, Kuijt-Evers, & van Dieen, 2003). The subject was mobilised by one to four therapists per session with no more than three minutes between therapists. The four separate mobilisation sessions occurred either one or two weeks apart.

Prior to the extraction of force data from the software, each of the seven load cells was zeroed using the baseline measure taken. Mean peak force, force amplitude and frequency of oscillation were calculated for 10-second intervals for each grade of each technique performed. The 10-second intervals of mobilisation that were analysed began two seconds after a therapist verbally indicated they had started performing a particular grade. Mean peak force was defined as the average of the peak forces over the 10-second interval. Force amplitude was defined as the mean of the differences between the force troughs (points of lowest force magnitude during the mobilisation oscillation) and subsequent force peaks over the 10-second interval. Oscillation frequency, or the rate of oscillation, was represented by the number of force peaks per 10-

second interval and described in Hz. Resultant forces were calculated from forces in three directions (x, y and z, Figure 5.1) using the formula $\sqrt{F_x^{\ 2} + F_y^{\ 2} + F_z^{\ 2}}$. Intra-class correlation coefficients (2, 1) were used to determine the repeatability of applied forces. Group means and standard deviations were calculated, and linear regression was used to determine if certain factors were associated with force characteristics. SPSS 12.0 (SPSS Inc., Chicago, USA) was used for statistical analysis.

5.3. Results

The ten physiotherapist participants were a varied group. Half were female and half had completed formal post-graduate training that included advanced instruction in manual therapy techniques. Five worked in private practice, four in the outpatient departments of public hospitals, and one worked in a private hospital and a private practice. A majority of participants (7) had experienced work-related thumb pain, but only one of these reported experiencing thumb pain more than three times per week. Three participants had changed the way they perform cervical mobilisations because of thumb pain. Other characteristics of physiotherapist participants are listed in Table 5.2.

Only two therapists agreed on the definitions of all four grades of mobilisations. For grades II and III, only four participants were in agreement for either grade. For grade I, nine out of ten participants selected the grade I definition as published by Maitland et al. (2005) and Grieve (1991) “small amplitude movement near the start of the range” (Table 5.1). For grade IV, 7 out of 10 selected Grieve’s definition, stated in the questionnaire as a “small amplitude movement at the limit of range” (Table 5.1). When applying the

Table 5.2. Description of physiotherapist participants (n=10).

Characteristic	**Mean (SD)**	**Range**
Age (years)	33.4 (9.8)	22 to 52
Height (cm)	170.9 (11.9)	154 to 192
Weight (kg)	73.4 (13.4)	53.9 to 94.6
Years as a physiotherapist	12.4 (11.2)	1 month to 36 years
Years practicing manual therapy	10.1 (8.7)	1 month to 26 years
Frequency of performing cervical mobilisation (occasions per week)	12.2 (9.8)	4 to 36

cervical mobilisations, all therapists used their thumbs to apply the force for all techniques except for one therapist, who used the heel of the hand for grades II to IV on C7 centrally.

Evaluation of the mean peak forces in each direction indicated that the vertical forces represented 90.2% (SD 14.4%) of the overall resultant forces for each grade of each technique. Since the horizontal forces were only a small component of the overall force, the following results from this pilot study will refer to the vertical forces.

Intra-class correlation coefficients were high for intra-therapist repeatability of force parameters, but low for inter-therapist repeatability (Table 5.3). Table 5.4 and Figures 5.1-5.3 display the overall averages for the mean peak forces, force amplitudes, and frequencies applied by therapists for each grade of each technique. There was a considerable amount of variation in mean peak forces and force amplitudes between therapists when performing the same technique (Figures 5.1 and 5.2). Oscillation frequencies also varied between therapists, but only within a range of 0.54 to 1.75 Hz (Figure 5.3).

Table 5.3. Repeatability of cervical mobilisation forces.

Repeatability	ICC(2,1)	95% CI
Intra-rater		
Mean peak force	0.93	0.88 to 0.96
Force amplitude	0.89	0.80 to 0.94
Oscillation frequency	0.74	0.46 to 0.87
Inter-rater		
Mean peak force	0.31	0.14 to 0.55
Force amplitude	0.29	0.13 to 0.53
Oscillation frequency	0.10	0.03 to 0.27

Table 5.4. Group means (SD) for mean peak force (N), force amplitude (N), and oscillation frequency (Hz) for each grade of each technique.

Force parameter	**Grade**			
Technique	**I**	**II**	**III**	**IV**
Mean peak force (N)				
C2 central	25.6 (20.0)	40.0 (26.1)	62.5 (33.9)	66.7 (27.7)
C2 unilateral	18.8 (6.9)	29.5 (9.8)	56.4 (16.2)	55.2 (13.4)
C7 central	20.8 (15.9)	36.7 (23.1)	55.9 (32.5)	62.7 (38.9)
C7 unilateral	22.1 (16.0)	34.9 (20.9)	58.1 (28.1)	59.5 (36.4)
Force amplitude (N)				
C2 central	23.1 (17.8)	37.2 (23.6)	52.5 (26.3)	39.5 (14.7)
C2 unilateral	16.2 (7.6)	26.5 (9.1)	48.8 (18.2)	32.6 (15.9)
C7 central	20.4 (11.4)	35.2 (15.4)	47.9 (20.2)	38.1 (17.3)
C7 unilateral	18.8 (10.1)	30.8 (17.3)	51.5 (23.8)	37.2 (18.5)
Oscillation frequency (Hz)				
C2 central	1.00 (0.25)	0.93 (0.23)	0.90 (0.23)	1.16 (0.26)
C2 unilateral	1.03 (0.29)	0.96 (0.28)	0.87 (0.24)	1.12 (0.29)
C7 central	1.08 (0.30)	0.91 (0.2.2)	0.92 (0.20)	1.19 (0.34)
C7 unilateral	1.05 (0.28)	0.97 (0.25)	0.86 (0.24)	1.10 (0.29)

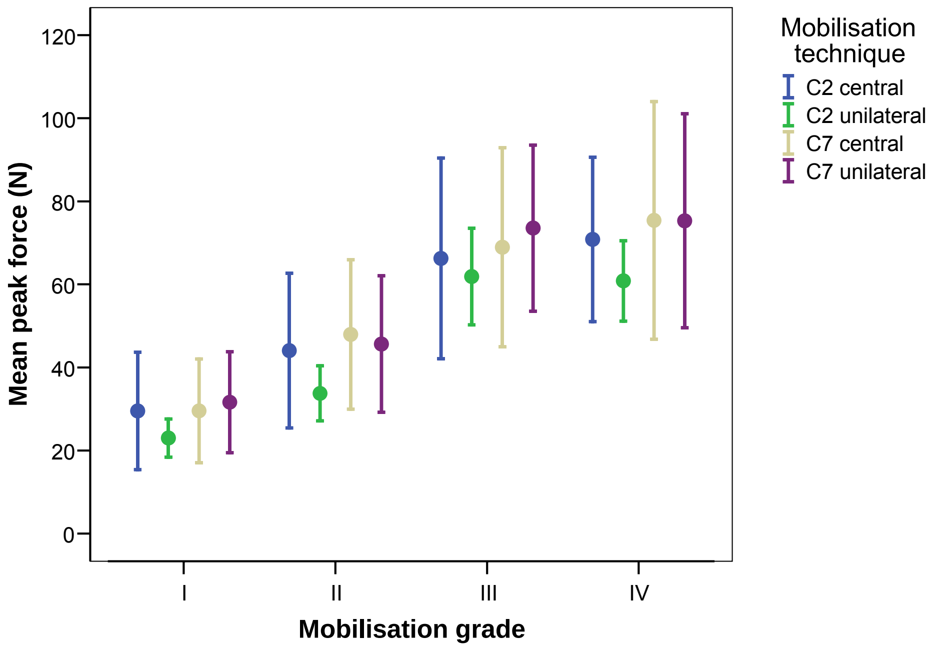

Figure 5.1. Vertical mean peak cervical mobilisation forces (± 1 SD) for each grade of each technique (n = 10).

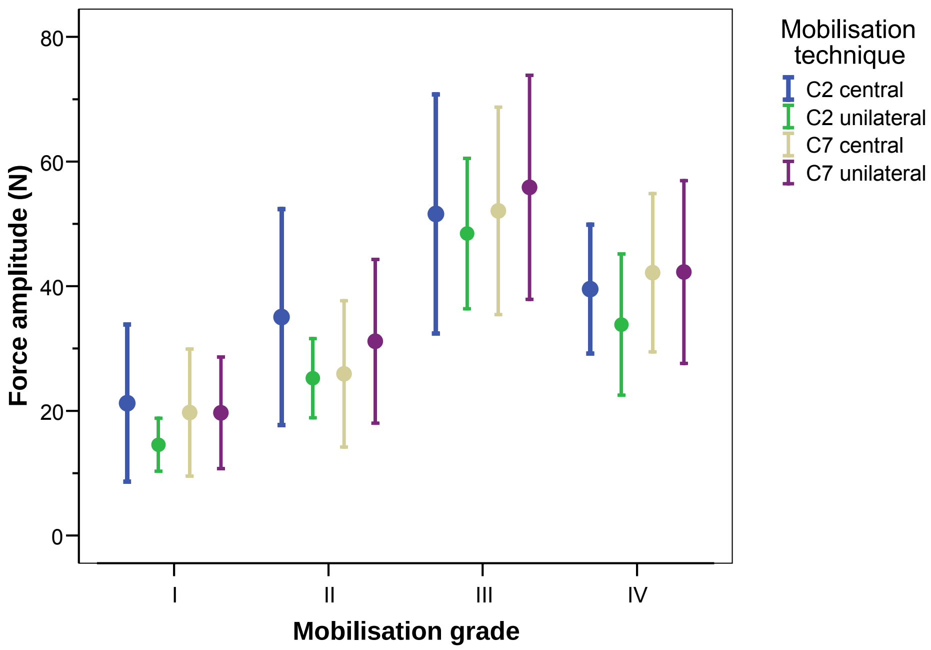

Figure 5.2. Mean vertical cervical mobilisation force amplitude (± 1 SD) for each grade of each technique (n = 10).

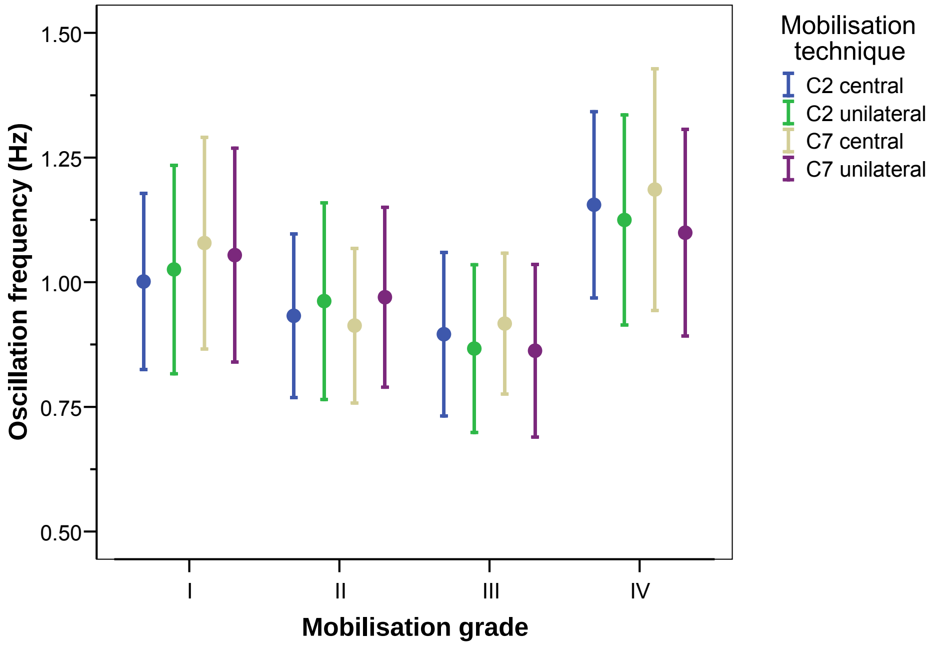

Figure 5.3. Mean cervical mobilisation oscillation frequency (± 1 SD) for each grade of each technique (n = 10).

Due to the small number of physiotherapist participants, the large number of factors that could potentially affect the applied force, and the number of interactions between these factors, none of the therapist factors (age, height, weight, gender, number of mobilisation occasions per week, or history of work-related thumb pain) demonstrated a significant association with any force parameter (mean peak force, force amplitude, and oscillation frequency). In addition, the subject's level of comfort while being mobilised was not associated with mean peak force, force amplitude, or oscillation frequency. The only significant association was between mobilisation grade and mean peak force ($F(3, 156) = 24.6$, $p < 0.001$) and between mobilisation grade and force amplitude ($F(3, 156) = 21.9$, $p < 0.001$). However, mobilisation grade only accounted for about one third of the variance of either peak force or amplitude.

5.4. Discussion

The key findings from this pilot study of cervical mobilisation forces were that manual forces vary widely between therapists, but intra-therapist repeatability is good for mean peak force, force amplitude and oscillation frequency. Mean peak cervical mobilisation forces are considerably less than previously reported mean peak mobilisation forces applied to the lumbar spine, and therapists are generally consistent with the published definitions of mobilisation grades when applying cervical mobilisation techniques. These results define the manual forces applied by a group of therapists, the first step towards optimising cervical spine mobilisation treatment. Further investigation will be required to determine the possible causes of the variations between forces applied by different therapists, as well as the effects of various manual forces on treatment outcomes for neck disorders.

5.4.1 Comparisons with reported mean peak mobilisation forces

Compared to previously reported mobilisation forces, the mean peak vertical cervical mobilisation forces were considerably lower than both vertical and resultant mean peak mobilisation forces applied to the lumbar spine (Chiradejnant et al., 2002; Cook et al., 2002; Harms & Bader, 1997). Only one previous study reported using a similar instrumented table to measure cervical mobilisation forces applied to C4 (Langshaw, 2001). For grades III and IV, slightly higher vertical mean peak forces were reported compared to the present study (by about 10 to 15 N depending on technique), however, grade I and II forces were similar (Langshaw, 2001). Differences in the reported cervical mobilisation forces may be due to the different cervical spine levels mobilised. PA mobilisations to C4 are more likely to be applied perpendicular to the treatment table than PA mobilisations to C2 and C7, because physiotherapists are usually trained to apply PA mobilisations perpendicular to the spinal contour (Maitland et al., 2005). A difference in the angle of applied force will likely affect the magnitude of vertical force recorded. There are no previous studies investigating the angle of applied force during cervical mobilisation. However in the lumbar spine, one study using an instrumented treatment table reported no difference in the angle of applied force measured for mobilisations applied to L1 and L3 by a single therapist (Harms et al., 1999). In contrast, another study which used data from a forceplate positioned under a treatment table reported the sagittal angle of applied force used for assessing lumbar spinal stiffness varied significantly with spinal level (Viner & Lee, 1995).

Others studies that measured cervical mobilisation forces using different measuring devices report different mean peak force values to the current study. A study that examined cervical mobilisation applied by one therapist under magnetic resonance imaging reported slightly lower grade III forces than the present study, mean 42.2 N (Lee et al., 2005). Another study that used a flexible force transducer placed under the thumb to measure grade I cervical mobilisation forces reported much lower forces, mean 0.5 N (Conradie et al., 2004). The differences in values to those of the present study are likely to be due to differences in the measuring instruments.

5.4.2 Comparisons with reported peak manipulation forces

Average peak mobilisation forces for the present study sample were generally lower than the forces that have been previously measured during cervical manipulation (thrust) techniques. The mean peak forces reported for cervical manipulation techniques range from 40 to 280 N, depending on the technique (Herzog et al., 1993; Kawchuk & Herzog, 1993; van Zoest & Gosselin, 2003; Wood, Adams, & Hansmeier, 1994), with a mean peak force of approximately 100 to120 N reported for the majority of techniques (Herzog et al., 1993; van Zoest & Gosselin, 2003). For cervical mobilisations in the present study, the highest group mean peak force was 66.7 N for grade IV mobilisations applied centrally to C2 (Table 5.4). However, the greatest mean peak force recorded for an individual therapist in the present study was 142 N, applied in two instances for centrally applied mobilisations by different therapists, one for a grade III to C2 and the other for a grade IV to C7. This suggests that the magnitude of the mobilisation forces applied by some therapists is comparable to the forces applied during manipulation. Cervical manipulation is commonly considered to carry some risk of vertebral artery injury for some patients (Haldeman, Kohlbeck, & McGregor, 2002; Mann & Refshauge, 2001). Though the actual cause of vertebral artery injury after manipulation is unknown, it may possibly be associated with aspects of the technique applied, such as the position of the head and neck, the velocity at which the technique is applied, or the magnitude of force applied (Mann & Refshauge, 2001; Terret, 2005). Although the amount of the recorded mobilisation force acting directly on the vertebral artery is unknown in the current study, it should be noted that mechanical failure of the distal vertebral artery loop has been experimentally induced in vitro at 8.2 N, SD 3.4 N (Symons et al., 2002). Moreover, if the forces applied during manipulation can be considered a potential cause of vertebral artery injury and stroke (Haldeman et al., 2002), then it is feasible that mobilisation may also involve some risks if the forces are comparable for some applications.

5.4.3 Force amplitude

When performing cervical mobilisation, therapists in the present study generally followed the mobilisation definitions provided by Maitland et al. (2005) in the way they applied the mobilisation grades. This is observed by comparing the force amplitudes and oscillation frequencies for different mobilisation grades (Figures 5.2 and 5.3). Force amplitude was slightly greater for grade II and III techniques than for grades I and IV (Figure 5.2). This is consistent with the mobilisation definitions described by Maitland et al. (2005) which state that grades II and III are large amplitude movements and I and IV are small amplitude movements.

However, the force amplitude for grade II techniques is somewhat smaller and for grade IV techniques somewhat larger than what might be expected based on the description of movement amplitudes for mobilisation grades (Maitland et al., 2005). For grade II techniques, Maitland et al. (2005) suggest that they should be applied within the resistance-free range. Therapists in this study may have only been able to apply a small amount of force before perceiving some resistance to cervical spine movement, which may have reduced the grade II force amplitude. For grade IV techniques, a previous study also found that experienced physiotherapists applied grade IV cervical mobilisations with relatively large force amplitudes (Langshaw, 2001). It was speculated that experienced therapists might use larger amplitudes for grade IV techniques to ease the constant pressure at end of range in order to increase comfort for either the patient or themselves. It is also possible that a small amplitude movement during a grade IV technique, where greater forces are applied, may correspond to a larger force amplitude than a grade II technique, since movement amplitude does not correlate linearly to force amplitude (Snodgrass et al., 2006).

5.4.4 Oscillation frequency

For oscillation frequency, therapists also appeared to adhere to published mobilisation definitions when performing techniques (Figure 5.3). The overall mean for all techniques of 1.00 Hz (SD 0.27) sits well within the recommendations provided by Maitland et al. (2005) of applying between one oscillation every two seconds to three per second. The small range of oscillation frequencies (0.54 to 1.75) could also relate to the fact that all therapists mobilised the same subject and were thus receiving the same palpatory cues. A small amplitude movement is likely to be applied at a higher oscillation frequency than a large amplitude movement, if the actual movement through range is performed at the same speed and the magnitude of range of movement is greater with the larger amplitude. Though not statistically significant, the trend was for grades I and IV to be performed at higher oscillation frequencies than grades II and III.

5.4.5 Therapist interpretation of mobilisation grades

A most surprising finding was the considerable disagreement between therapists on the written definitions of mobilisation grades from the questionnaire results. If therapists do not have the same intentions when applying a mobilisation grade, as prescribed by their definition of the grade, then this may contribute to differences in the way they apply manual forces. Manual therapists might apply cervical mobilisation forces more consistently if they adhered to the same mobilisation definitions and were trained to apply specific levels of forces using objective feedback. Indeed, physiotherapists have demonstrated consistency in rating spinal stiffness when provided with objective feedback using a reference matching device (Chiradejnant et al., 2003).

5.4.6 Limitations

These results should be treated cautiously as they represent pilot data only. There are four main limitations of this study which preclude drawing strong conclusions. First, the reported findings consist of measurements from a sample of ten physiotherapists applying cervical mobilisations to only one asymptomatic subject. This small sample of convenience might not be representative of all physiotherapists. In addition, the small number of therapists precluded any conclusions being drawn about the potential factors affecting cervical mobilisation forces. Due to the variability within the group, no one factor reached statistical significance. A larger sample is needed in order to determine if certain factors, such as therapist gender or their level of training, affect their application of cervical mobilisation forces.

Second, there was possible error in the identification of the spinal levels that the therapists mobilised. However, although the validity of identifying bony landmarks by palpation is questionable (Harlick et al., 2000), there is some evidence for inter-therapist reliability (Downey, Taylor, & Niere, 1999) and greater evidence for intra-therapist reliability when identifying spinal levels

(Lucchetti, 1992; McKenzie & Taylor, 1997). To enhance the reliability of marking the spine in the current study, a systematic procedure was performed by a single experienced physiotherapist. Previous studies that report manual force measurement have also pre-marked the spine (Cook et al., 2002; Latimer, Lee, & Adams, 1996), or have used therapist-nominated levels (Chiradejnant et al., 2002), but none have described their method of palpation. In the absence of any standardised strategy for identifying the spinous and articular processes, the researchers adopted an approach based on recommended clinical practice (Gross, Fetto et al., 2002; Hoppenfeld, 1976; Palmer & Epler, 1998).

Third, there are some limitations when using an instrumented table to collect force data. The forces recorded by the table do not directly represent the manual force applied at the point of hand contact, but rather the forces transmitted by the subject's body to the table. However, the instrumented table was used because it does not rely on any instrumentation between the therapist's hand and the subject that may alter the way a therapist applies manual forces (van Zoest & Gosselin, 2003). When using an instrumented table, extraneous body movement of the subject on the table could potentially confound the force data. The subject was encouraged to remain still while receiving mobilisation, and no excessive movements were noted.

A final limitation is the possibility of changes in the subject as a result of repeated mobilisation by consecutive therapists which could have affected therapists' applied forces. By having all therapists mobilise the same subject, potential differences in palpatory cues or spinal stiffness that might affect a therapist's performance of mobilisation were minimised. However, it was not possible to ascertain if there were changes in the subject's spinal stiffness as a result of the mobilisation. Changes in the subjects' spinal stiffness are unlikely because previous research indicates that spinal stiffness, as defined by the slope of the linear portion of the force-displacement curve or in terms of spinal range of motion, does not change with repeated testing on a single day or within 2 to 8 days (Petty, 1995; Shirley et al., 2002). In the present study, data collection sessions were at least one week apart while one to four therapists applied mobilisations per session, consistent with previous research study designs (Harms & Bader, 1997). There were no systematic variations in the recorded forces that might suggest there was a change in the subject. Nevertheless, future studies might incorporate additional measures of the subject, such as spinal stiffness, on each occasion of data collection in order to determine if there are any changes over time.

5.4.7 Future research

Future research examining the cervical mobilisation forces applied by a larger sample of therapists is needed to determine if therapist and patient characteristics contribute to variability in the application of cervical mobilisation forces. Two previous studies have suggested that patient factors such as age, body weight and gender affect applied manual forces during lumbar mobilisation (Chiradejnant et al., 2002; Harms et al., 1999). In addition, a larger sample would enable findings to be generalised to all Australian physiotherapists, and mean force parameters could be determined with greater confidence. Thus, a large scale study further investigating cervical mobilisation force parameters and the factors that affect them is described in Chapter 6.

5.5. Conclusion

This pilot study provides preliminary evidence that the forces applied during cervical PA mobilisation vary considerably between therapists. However, cervical mobilisation appears to be applied in a manner generally consistent with published mobilisation definitions, and intra-therapist repeatability is high. The small sample in this pilot study precluded any conclusions about the potential factors that might affect mobilisation forces. This suggests a larger physiotherapist sample is warranted.

CHAPTER 6. Cervical mobilisation forces applied by physiotherapists

6.1. Introduction

The previous chapter presented a pilot study measuring the cervical mobilisation forces applied by ten physiotherapists mobilising C2 and C7 of one subject. This provided some evidence of considerable inter-therapist differences in applied cervical mobilisation forces, but left unanswered a number of questions. In particular, it was not possible to determine the relationships between cervical mobilisation forces and potentially associated factors, such as the characteristics of the therapist or the asymptomatic subject. For instance, the results of one published study indicated that a therapist's gender, height, weight, years of experience and academic qualifications were associated with various force parameters when mobilising the lumbar spine (Chiradejnant et al., 2002). This has not been investigated in regards to mobilisation applied to the cervical spine. Identifying these relationships is expected to increase therapists' knowledge about how they apply cervical mobilisation, and lead to the development of strategies to improve therapists' ability to apply these techniques consistently.

Additionally, a greater number of asymptomatic subjects is needed to better represent the variety of different spines that would be encountered when therapists perform cervical mobilisation clinically. Furthermore, wide variations between the forces applied by the small number of therapists in the pilot study made it difficult to ascertain the extent of differences between the forces used for different cervical mobilisation grades and spinal levels. One study reported that mobilisations to higher (more cephalad) lumbar levels were associated with greater force amplitudes applied to patients, but there were no significant associations between the force magnitude used and lumbar level (Chiradejnant et al., 2002). Potential associations between spinal levels and force parameters have not been adequately determined for cervical spine mobilisations.

The purpose of this study is to quantify cervical mobilisation forces applied by physiotherapists in terms of mean peak force, force amplitude and oscillation frequency. Quantifying the forces applied to the neck during this treatment technique is a first step towards determining how and why it may be clinically effective. The specific aims are to determine the i) differences between forces applied to the upper and lower cervical spine, and the spinous and articular processes, ii) consistency of applied forces between therapists and repeatability of forces by individual therapists, and iii) relationships between mobilisation forces and the characteristics of therapists and mobilised subjects, including spinal stiffness.

This study is expected to provide a baseline quantification of cervical mobilisation. This is necessary for subsequent investigations aimed at improving consistency in the application of cervical mobilisation forces, and in future, determining the clinical effectiveness of this common manual treatment technique.

6.2. Methods

6.2.1 Participants

One hundred and sixteen physiotherapists performed cervical PA mobilisation techniques on the C2 and C7 vertebrae of one of 35 asymptomatic subjects. Asymptomatic subjects were used to minimise the sources of variation when comparing differences in forces between therapists, similar to the methods used in the initial investigations of mobilisation forces applied to the lumbar spine (Cook et al., 2002; Harms & Bader, 1997; Harms et al., 1999; Matyas & Bach, 1985).

Eligible therapists were those who performed cervical mobilisation techniques in clinical practice at least once per week. They were recruited by mailing letters to local physiotherapists listed in the yellow pages, and to the heads of departments at hospitals in the area. Mobilised subjects were recruited by posting notices around the university campus where data collection occurred. They were excluded if they had sought treatment for neck pain or headaches within the previous 12 months or if they had any contraindications to cervical mobilisation, which included cancer, inflammatory diseases such as rheumatoid arthritis, infectious diseases affecting the neck, osteoporosis, symptoms of nerve root compromise, instability in the cervical spine, or potential vertebrobasilar symptoms such as dizziness or double vision (Corrigan & Maitland, 1986). The study protocol was approved by the research ethics committees of the university and two area health services.

6.2.2 Equipment

Manual forces were measured in three planes using the instrumented treatment table described in Chapter 3. Measurement accuracy and reliability had been shown to be satisfactory, with the mean absolute error 1.1 N (SD 1.5) in the vertical force direction and $\leq$ 3 N in any force direction (Snodgrass, Rivett, & Robertson, 2008a).

Cervical spine stiffness was measured using the custom-built device, described in Chapter 4, that applied five consecutive mechanical force oscillations with a steel probe at a speed of 1 Hz to the spinous processes of C2 and C7 (Snodgrass, Rivett, & Robertson, 2008b). Stiffness was defined as the mean slope of the linear portions of the force-displacement curves for oscillations two through five. The linear portion of the force-displacement curve was defined as that part of the curve from 7 to 40 N for C2 measurements and from 20 to 70 N for C7. The angle of applied force was standardised by positioning the mechanical probe at 20 degrees caudad for C7 and 14 degrees cephalad for C2, based on the average spinal curvature for 252 asymptomatic subjects in a published radiographic series (Harrison et al., 1996). The stiffness device and calculation methods have satisfactory accuracy and reliability for stiffness measurements of asymptomatic individuals (ICC[2,1] for repeated measures 0.84, 95% CI 0.74 to 0.90) (Snodgrass et al., 2008b).

6.2.3 Data collection

Each therapist performed cervical mobilisation grades I through IV (Grieve, 1991; Maitland et al., 2005) to the C2 and C7 spinous processes (central techniques) and to the C2 and C7 articular processes (unilateral techniques, one right and one left) of one asymptomatic subject. Fifteen seconds of force data were recorded for each mobilisation grade in each position. Therapists were instructed to perform the techniques as they would in the clinical setting, and were not given any standardised definitions of the mobilisation grades. This was done so that therapists would perform techniques as closely as possible to the way they usually applied them in the clinical setting. Therapists were asked to provide their definition of each grade after they completed all of their mobilisations, using a form that provided selections and which also allowed therapists to write their own definitions (Appendix 2.1).

Prior to mobilisation at each session of data collection for a subject, the spinous and articular processes of both C2 and C7 were pre-marked by a single experienced physiotherapist using standardised methods (Gross, Fetto et al., 2002; Hoppenfeld, 1976; Palmer & Epler, 1998). C2 was palpated in the midline just below the external occipital protuberance (Hoppenfeld, 1976). C7 was located by counting the spinous processes from C2 and confirmed using a common cervical extension motion test (Gross, Fetto et al., 2002; Hoppenfeld, 1976; Palmer & Epler, 1998). The articular processes were identified just lateral to the spinous processes (Gross, Fetto et al., 2002). The C2 and C7 central spinous processes were then pre-conditioned with five repetitions of manual PA force prior to stiffness measurement (one C2 and one C7 stiffness measurement per session).

The mechanical probe of the stiffness device was manually positioned over the spinous process prior to measurement. Subjects were asked to exhale, relax, and hold their breath at functional residual capacity without straining while data was collected. Stiffness was measured only once per session because for asymptomatic individuals it was not expected to change after the initial pre-conditioning of the tissues. Spinal stiffness in asymptomatic lumbar spines does not change significantly over eight days (Shirley et al., 2002), and indeed the current data indicate the cervical spine stiffness of individual subjects remains relatively stable over time, described in Chapter 4 (Snodgrass et al., 2008b).

The order that therapists performed the techniques (C2 central, C2 unilateral, C7 central, C7 unilateral) was randomised, as was the order of performance of the four grades for each technique. The first unilateral technique performed was randomly assigned to either the left or right side, followed by the opposite side for the second one. To assess intra-therapist reliability, therapists repeated the first mobilisation technique they performed (all four grades) by applying it again to the same subject after approximately 20 minutes. This procedure ensured a longer time interval between the therapist performing and repeating the initial technique. A subject was mobilised by one to four therapists at a single session in succession (approximately ≤ 3 minutes between therapists), and subjects attended one to three sessions.

Characteristics of therapists and mobilised subjects including age, gender, height and weight were documented. Additional therapist characteristics recorded included their years of clinical experience, post-graduate training, work setting, present frequency of performing cervical mobilisation, history and frequency of any thumb pain, any previous upper limb injury and their interpretation of the mobilisation grades. These factors were identified as relevant following a review of the published literature of mobilisation of the lumbar spine (Chiradejnant et al., 2002; Harms et al., 1999; Snodgrass et al., 2003; Snodgrass et al., 2006). As there were no previous data on the cervical spine, these factors were deemed the most relevant and all needed to be considered due to insufficient evidence to exclude any of them.

6.2.4 Data analysis

Manual forces were quantified in terms of mean peak force, force amplitude and oscillation frequency; three force parameters representing the three dependent variables assessed. Data for each were analysed over 10 seconds of mobilisation, beginning two seconds after the therapist verbally indicated that they were performing the particular grade of mobilisation. Mean peak force (N) was defined as the average of the force peaks. Force amplitude (N) represented the average of the differences between the force troughs (points of lowest force magnitude during the mobilisation oscillation) and subsequent force peaks. Oscillation frequency (Hz) described the rate of applying oscillatory cycles of force.

Cervical mobilisation technique characteristics associated with forces

The independent variables considered were mobilisation characteristics expected to affect the value of the mobilisation force parameters. These included technique (C2 central, C2 unilateral, C7 central, C7 unilateral), grade (I through IV) and force direction (vertical, caudad-cephalad and mediolateral). Each therapist applied one of each technique and grade to an asymptomatic subject in a randomised order. Each force parameter was initially described for each technique, grade and force direction using means and 95% confidence intervals. Resultant mean peak forces were calculated from the mean peak forces for each direction for each therapist. Data were examined for normality prior to the analyses.

The effects of these independent variables (technique, grade and force direction) on each of the force parameters (dependent variables) were assessed using mixed ANOVAs, with technique, grade and force direction as fixed factors. A variance components analysis estimated the contribution of the potential random effects (asymptomatic subject and therapist) to the variance of each force parameter. The therapist contributed substantially to the total variance for all three dependent variables, while the asymptomatic subject had minimal contribution. This was expected because the mobilised subjects were specifically selected to be a relatively homogenous group with respect to their history of neck pain, so that the study focus could be differences between therapists in the forces applied. Only 'therapist' was subsequently included in the final models as a random effect. Differences in force parameters between categories of each of these independent variables (i.e., technique, grades and force directions) were determined using Bonferroni post-hoc tests. Reported p-values are Bonferroni-adjusted.

Consistency of therapists' application of cervical mobilisation forces

To determine the consistency of the application of mobilisation forces between therapists, inter- and intra-therapist reliability were calculated using intra-class correlation coefficients (ICC, 2,1) for each force parameter and direction. The forces applied for each technique and grade for all therapists were used for inter-therapist reliability for each force parameter and direction. For intra-therapist reliability testing, each therapist repeated only one of the four techniques (all four grades), and intra-therapist repeatability was calculated for each force parameter and direction. Further reliability analysis was performed by technique to determine any differences in repeatability between techniques.

Therapist and mobilised subject factors associated with forces

Therapist and mobilised subject characteristics associated with manual force parameters were determined using linear regression. Mobilisation force parameters for individual techniques and grades that were not significantly different, defined as those that did not meet the 0.05 significance level for the Bonferroni comparison, were grouped for these regression analyses. Due to the large number of possible associated characteristics, there was the possibility of a statistically significant association with force due to chance alone. Therefore, prior to entering all factors into the models, univariate regression was performed for each factor to eliminate factors which had minimal association (see complete list of univariate calculations in Appendix 4.2). Characteristics with $p \leq 0.25$ in the univariate regressions were then included in the calculation of regression models for each unique technique and grade group using the backwards elimination procedure (Neter, Kutner, Nachtsheim, & Wasserman, 1996). Regression analyses were examined for commonalities, and only those factors which consistently reached statistical significance across multiple force parameters, directions, grades and techniques are reported (see Appendix 4.3 for data from all final regression analyses, and Appendix 4.4 for the complete list of all statistically significant factors). SPSS 15.0 (SPSS, Inc., Chicago, Illinois, USA) was used for statistical analyses.

6.3. Results

Characteristics of therapists and mobilised subjects are described in Tables 6.1 and 6.2. The mean spinal stiffness of mobilised subjects was 4.7 N/mm at C2 (95% CI 4.3 to 5.1) and 7.3 N/mm (95% CI 6.5 to 8.1) at C7. Means and 95% confidence intervals for mean peak force in each direction are reported in Table 6.3, with force amplitude and oscillation frequency in Table 6.4. Mean peak force significantly increased from grade I to IV for each force direction (vertical $p < 0.001$, Figure 6.1; mediolateral and caudad-cephalad $p < 0.05$, Figures 6.2 and 6.3; except for comparison of grades III and IV in the caudad-cephalad direction where $p = 0.06$). Vertical and caudad-cephalad mean peak forces applied to C7 were greater than those applied to C2 (vertical $p < 0.01$, Figure 6.1; caudad-cephalad $p < 0.001$, Figure 6.2). Mediolateral mean peak forces were greater for unilateral techniques than for central techniques ($p < 0.001$, Figure 6.3). Resultant mean peak forces are depicted in Figure 6.4.

Table 6.1. Description of physiotherapist participants (n = 116).

	Mean (SD) or % (N)
Age	38.5 years (9.8)
Gender	51% female (59)
Height	171.6 cm (8.6)
Weight	73.6 kg (14.2)
Years experience in physical therapy	14.8 years (9.1)
Post-graduate training†	22% post-graduate training in manual therapy (25)
Frequency of performing cervical mobilisation at present	13.7 mobilisation sessions per week (10.2)
Work setting	26% hospital outpatients (30) 68% private clinic outpatients (79) 6% hospital and private clinic outpatients (7)
Frequency of thumb pain in the last 3 months	35% no history of thumb pain ever (41) 5% none (6) 30% rarely (35) 13% sometimes (1-3 episodes/week) (15) 16% regularly/often (3-5 episodes/week) (19)
Change in technique due to thumb pain	35% of sample (> half of those with thumb pain) (41)
Symptoms in upper limbs due to previous injuries	26% of sample (30)
Interpretation of the mobilisation grades‡	Large variation (22 combinations of descriptors)

†Post-graduate training was defined as completion of a formal qualification which included additional learning of manual therapy skills.
‡Therapists were asked to indicate how they defined each mobilisation grade by either selecting a provided description (from Maitland et al., 2005, or Grieve, 1991) or providing their own description.

Table 6.2. Description of asymptomatic mobilised subjects (n = 35).

	Mean (SD) or % (N)
Age	31.5 years (9.9)
Gender	57% female (20)
Height	170.1 cm (9.1)
Weight	71.8 kg (17.2)
Stiffness at C2	4.7 N/mm (1.1)
Stiffness at C7	7.3 N/mm (2.3)

Table 6.3. Average mean peak force applied by physiotherapists (n = 116).

Technique	Grade	Vertical		Caudad-cephalad		Mediolateral		Resultant*	
		Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
C2 central	I	21.62	18.52 to 24.72	2.94	2.25 to 3.64	0.99	.51 to 1.47	22.19	19.06 to 25.33
	II	34.50	30.40 to 38.59	3.84	3.08 to 4.60	1.21	.72 to 1.71	35.05	30.83 to 39.27
	III	55.66	49.88 to 61.45	5.22	4.08 to 6.37	1.78	1.24 to 2.33	56.35	50.42 to 62.28
	IV	64.92	58.16 to 71.68	5.52	4.34 to 6.70	1.91	1.37 to 2.45	65.16	58.33 to 72.00
C2 unilateral	I	21.58	18.78 to 4.38	3.19	2.67 to 3.71	3.74	2.77 to 4.72	22.51	19.60 to 25.43
	II	33.75	30.26 to 37.25	4.49	3.76 to 5.23	5.71	4.60 to 6.82	35.05	31.43 to 38.68
	III	54.24	49.01 to 59.47	6.76	5.67 to 7.86	11.42	9.21 to 13.62	56.52	50.91 to 62.14
	IV	63.34	57.22 to 69.47	7.36	5.91 to 8.81	13.22	10.93 to 15.52	65.64	59.03 to 72.24
C7 central	I	28.98	24.93 to 33.02	14.55	12.48 to 6.61	1.89	1.34 to 2.43	33.52	29.13 to37.91
	II	43.21	38.38 to 48.05	20.36	17.73 to 22.99	2.29	1.83 to 2.75	48.78	43.55 to 54.02
	III	68.75	62.22 to 75.28	33.55	29.45 to 37.66	3.38	2.71 to 4.05	78.06	70.84 to 85.28
	IV	80.37	72.81 to 87.92	39.34	34.51 to 44.17	4.09	3.25 to 4.94	91.80	83.42 to 100.18
C7 unilateral	I	26.96	23.56 to 30.37	13.40	11.65 to 15.16	3.92	3.16 to 4.68	30.96	27.21 to 34.70
	II	40.89	36.64 to 45.15	19.89	17.40 to 22.38	6.85	5.74 to 7.97	46.99	42.16 to 51.83
	III	64.83	58.96 to 70.71	32.19	28.48 to 35.90	12.71	10.72 to 14.70	74.90	68.18 to 81.61
	IV	73.03	66.37 to 79.68	37.57	33.28 to 41.86	15.08	12.84 to 17.32	85.29	77.72 to 92.87

*Resultant mean peak force calculated for each technique from the mean peak forces in each direction using the formula $\sqrt{(vertical)^2 + (caudad - cephalad)^2 + (mediolateral)^2}$.

Table 6.4. Average force amplitude and oscillation frequency applied by physiotherapists (n = 116).

		Force amplitude (N)						Oscillation frequency (Hz)	
		Vertical		Caudad-cephalad		Mediolateral			
Technique	Grade	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
C2 central	I	15.71	13.38 to 18.04	2.85	2.56 to 3.13	1.19	1.08 to 1.30	1.30	1.21 to 1.39
	II	27.25	23.52 to 30.98	3.65	3.25 to 4.04	1.49	1.33 to 1.66	1.18	1.10 to 1.26
	III	43.42	38.37 to 48.47	4.99	4.26 to 5.71	2.02	1.75 to 2.30	1.11	1.02 to 1.19
	IV	35.36	30.00 to 40.72	4.12	3.54 to 4.70	1.83	1.62 to 2.03	1.28	1.19 to 1.37
C2 unilateral	I	14.40	12.51 to 16.29	2.88	2.60 to 3.16	3.68	2.54 to 4.82	1.30	1.20 to 1.40
	II	25.01	22.40 to 27.62	3.67	3.23 to 4.12	5.86	4.69 to 7.03	1.19	1.10 to 1.27
	III	40.55	36.37 to 44.73	5.51	4.72 to 6.30	10.62	8.24 to 13.01	1.12	1.04 to 1.20
	IV	34.14	29.71 to 38.58	4.85	4.04 to 5.66	9.33	7.59 to 11.07	1.33	1.23 to 1.43
C7 central	I	18.39	15.61 to 21.17	7.95	6.66 to 9.24	1.58	1.35 to 1.81	1.32	1.23 to 1.41
	II	30.59	27.01 to 34.16	12.83	10.91 to 14.74	2.15	1.82 to 2.48	1.19	1.11 to 1.27
	III	48.64	43.28 to 53.99	21.43	18.27 to 24.60	3.00	2.46 to 3.54	1.11	1.02 to 1.20
	IV	38.34	33.29 to 43.40	16.58	14.04 to 19.12	2.75	2.27 to 3.22	1.31	1.22 to 1.40
C7 unilateral	I	16.37	14.01 to 18.73	7.36	6.13 to 8.59	3.36	2.78 to 3.95	1.29	1.19 to 1.38
	II	28.22	25.06 to 31.39	12.55	10.76 to 14.34	6.19	5.16 to 7.22	1.18	1.10 to 1.27
	III	45.82	41.05 to 50.59	21.03	18.02 to 24.04	11.01	9.21 to 12.82	1.11	1.03 to 1.19
	IV	35.57	31.09 to 40.05	16.58	13.87 to 19.29	9.05	7.63 to 10.48	1.28	1.18 to 1.38

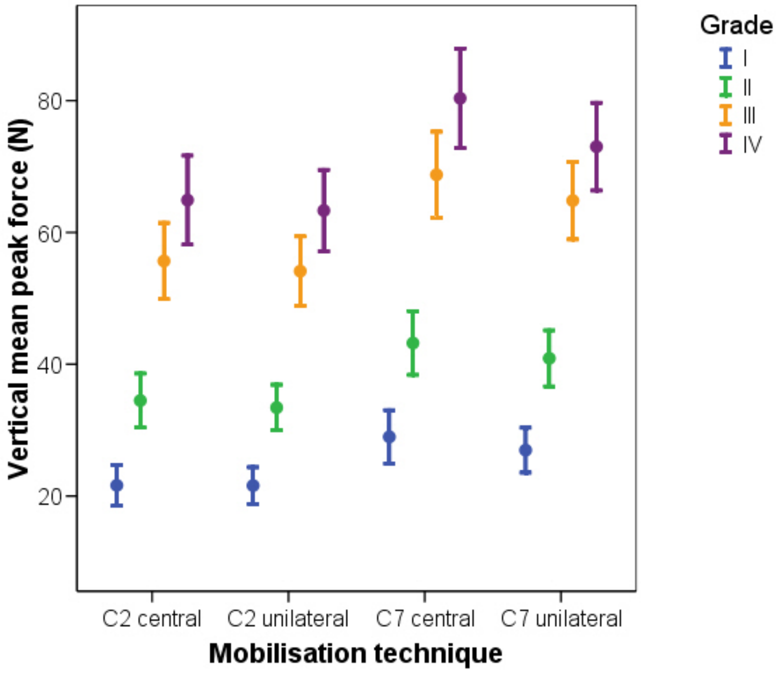

Figure 6.1. Vertical mean peak mobilisation forces (95% CI) applied by physiotherapists (n = 116) for each technique and grade.

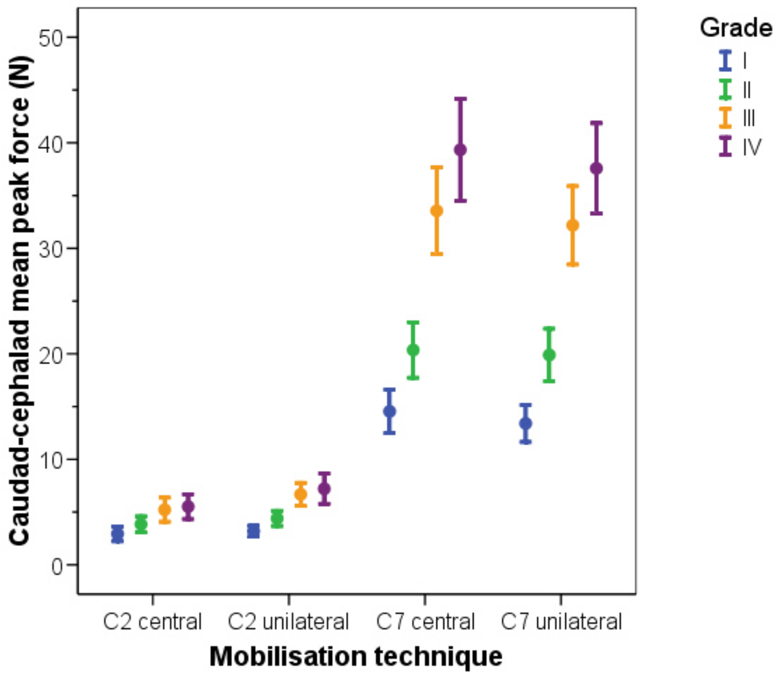

Figure 6.2. Caudad-cephalad mean peak mobilisation forces (95% CI) applied by physiotherapists (n = 116) for each technique and grade.

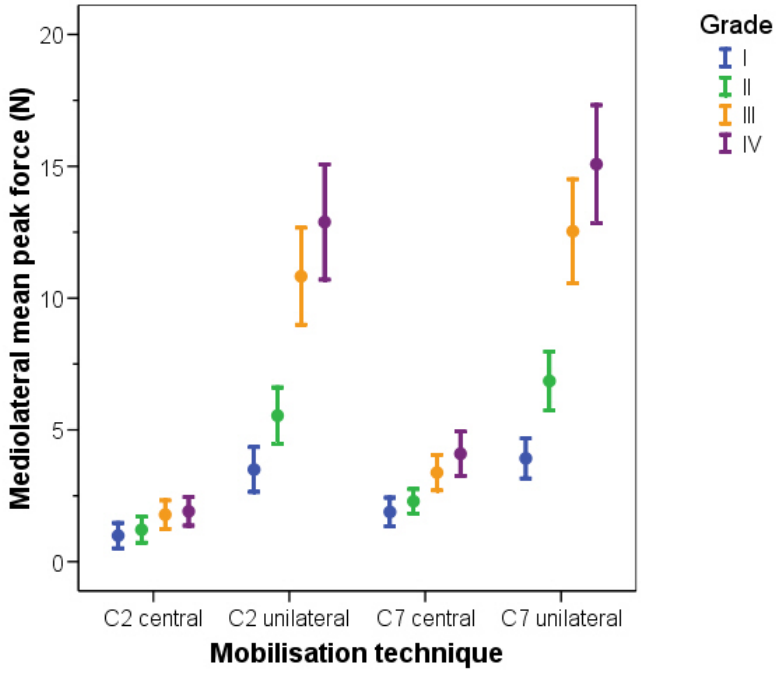

Figure 6.3. Mediolateral mean peak mobilisation forces (95% CI) applied by physiotherapists (n = 116) for each technique and grade.

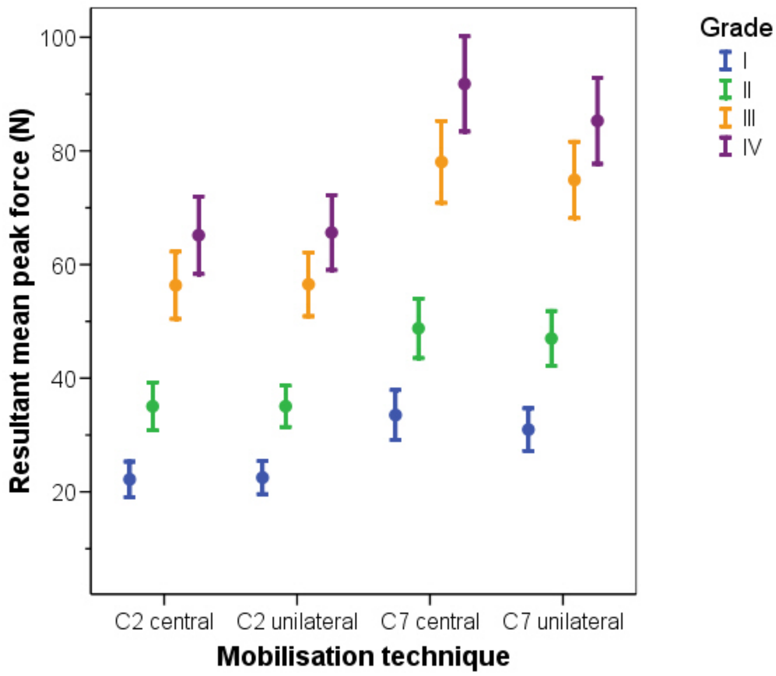

Figure 6.4. Resultant mean peak mobilisation forces (95% CI) applied by physiotherapists (n = 116) for each technique and grade.

The relationship of force amplitude to mobilisation grade was the same for all force directions and techniques. It was greatest for grade III mobilisations, followed by grades IV, II and then I (Figure 6.5). Force amplitude was significantly greater for C7 techniques than C2 techniques in the vertical and caudad-cephalad directions ($p < 0.001$); in the mediolateral direction, force amplitudes were greater for unilateral compared to central techniques ($p < 0.001$). For oscillation frequency, grades I and IV were consistently greater than grades II and III ($p < 0.005$), with no differences between different techniques (Figure 6.6). Grade III mobilisations had the lowest oscillation frequency.

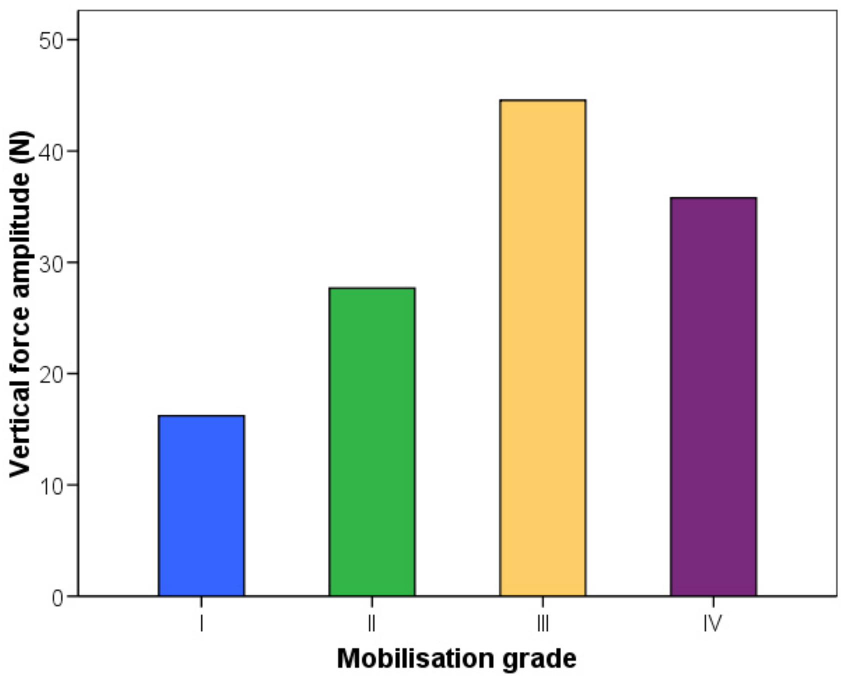

Figure 6.5. Vertical mean force amplitudes applied by physiotherapists (n = 116) for each grade (all techniques combined).

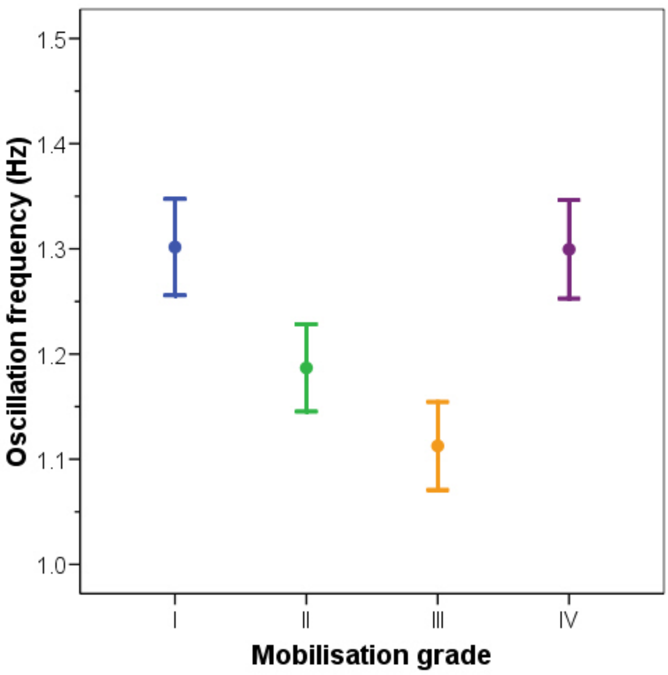

Figure 6.6. Mean oscillation frequency (95% CI) applied by physiotherapists (n = 116) for each mobilisation grade (all techniques combined).

Reliability of the application of manual forces is reported in Table 6.5 for each force parameter and direction. The individual mobilisation techniques were combined to simplify interpretation as there were no differences in reliability for different techniques.

Force parameters were different for the majority of techniques and grades, but those that were not significantly different were grouped for the linear regression analyses. There were 22 unique technique and grade combinations for both mean peak force and force amplitude, and two categories for oscillation frequency (listed in Table 6.6, Appendix 4.1 reports the complete results of calculations determining differences between techniques and grades).

Table 6.5. Inter- and intra-therapist reliability of cervical mobilisation force applications (n = 116).

	Inter-therapist†		**Intra-therapist**‡	
	ICC (2,1)	**95% CI**	**ICC (2,1)**	**95% CI**
Mean peak force				
Vertical	0.32	0.20 to 0.53	0.93	0.92 to 0.94
Caudad-cephalad	0.48	0.33 to 0.69	0.90	0.88 to 0.92
Mediolateral	0.32	0.20 to 0.53	0.84	0.81 to 0.87
Force amplitude				
Vertical	0.20	0.12 to 0.38	0.90	0.88 to 0.92
Caudad-cephalad	0.33	0.21 to 0.54	0.90	0.88 to 0.92
Mediolateral	0.26	0.16 to 0.46	0.87	0.85 to 0.89
Oscillation frequency				
	0.03	0.01 to 0.07	0.88	0.69 to 0.94

†Inter-therapist analysis includes all four techniques (C2 central, C2 unilateral, C7 central, C7 unilateral) and grades (I-IV) performed by each therapist for each force parameter and direction.
‡Intra-therapist includes all four grades performed by each therapist for the initial technique applied and subsequently repeated by the therapist.

Therapist and mobilised subject characteristics associated with manual forces varied with force parameter, force direction, technique and grade (Table 6.7). The most consistent finding across all techniques and grades was that male gender (of the therapist or mobilised subject) was associated with higher peak forces and amplitudes ($p < 0.05$). Other findings were that lower peak forces and amplitudes were associated with post-graduate training, C2 spinal stiffness, and a history of thumb pain ($p < 0.05$). Height and weight of the mobilised subject were associated with forces applied in the caudad-cephalad direction ($p < 0.05$), and therapists who rarely had thumb pain used slower oscillation frequencies ($p < 0.001$). Therapists who defined grade II mobilisations using the term ‘range’ (Grieve, 1991), as opposed to ‘resistance’ (Maitland et al., 2005), applied higher forces for grade II mobilisations ($p < 0.01$, Table 6.7).

Table 6.6. Categories of unique mobilisation techniques and grades used for linear regression analysis.

Force parameters for each category were significantly different to the others (Bonferroni $p < 0.05$).

Techniques	Direction Grade*	Direction Grade	Techniques	Direction Grade
Mean peak force				
	Vertical	Caudad-cephalad		Mediolateral
C2 central & unilateral	I	I	C2 & C7 central	I
	II	II		II
	III	III & IV		III
	IV			IV
C7 central & unilateral	I	I	C2 & C7 unilateral	I
	II	II		II
	III	III & IV		III
	IV			IV
Force amplitude				
C2 central & unilateral	I	I	C2 & C7 central	I
	II	II		II
	III	III		III & IV
	IV	IV		
C7 central & unilateral	I	I	C2 & C7 unilateral	I
	II	II		II
	III	III		III & IV
	IV	IV		
Oscillation frequency**				
All techniques	I & IV			
	II & III			

*Each grade or grade pair listed on a separate line represents a category of mobilisation techniques used for a linear regression model with therapist and mobilised subject characteristics.
**Force direction not applicable for oscillation frequency

Table 6.7. Physiotherapist and asymptomatic mobilised subject characteristics associated with manual force parameters.

Characteristic	Direction-Technique*	Grades†	p‡	B (range)†
Mean peak force (N)				
Male gender (therapist)	V-all	I-IV	< 0.05	4.2 to 19.9
	CC-C7	I-IV	< 0.05	3.7 to 7.7
Male gender (mobilised subject)	V-all	I-IV	< 0.001	8.3 to 28.6
	CC-C7	I-IV	≤ 0.05	2.9 to 14.3
	ML-all	I-IV	< 0.05	0.7 to 6.3
C2 spinal stiffness (N/mm)	V-C2	II-IV	< 0.01	-3.7 to -5.6
	ML-uni	III-IV	< 0.05	-1.3 to -1.6
Post-graduate training	V-all	I-II, III-IV(C2)	< 0.05	-8.5 to -16.1
	ML-uni	I	< 0.01	-1.9
Mobilised subject height (cm)	V-all	II, III-IV (C2)	< 0.05	-0.8 to -1.4
	CC-C7	II-IV	< 0.001	-0.8 to -0.9
	ML-uni	I	< 0.05	-0.1
Mobilised subject weight (kg)	V-all	II(C7), III-IV(C2)	< 0.05	0.4 to 0.5
	CC-C7	I-IV	< 0.005	0.2 to 0.7
	ML-uni	I-II	< 0.05	0.1
History of thumb pain	V-C2	I	< 0.05	-4.4
Current upper limb (UL) symptoms due to past injury	CC-all	III-IV	< 0.05	2.3 to 4.6
No UL symptoms due to past injury	V-C7	IV	< 0.05	-17.5
Defining a grade II mobilisation using range (selecting description from Grieve, 1991)	V-all	II	< 0.005	7.8 to 9.5
	CC-C7	II	< 0.005	5.4
Force amplitude (N)				
Male gender (therapist)	V-all	II(C7), III	< 0.05	5.2 to 7.9
	CC-C7	I-IV	< 0.05	3.7 to 9.1
Male gender (mobilised subject)	V-all	I-IV	< 0.01	4.6 to 19.6
	CC-all	I-IV	≤ 0.05	0.8 to 15.0
	ML-all	I(cen), II-IV	< 0.05	0.7 to 2.5
C2 spinal stiffness (N/mm)	V-C2	I-IV	< 0.05	-1.7 to -3.2
	CC-C2	I, IV	< 0.05	-0.2 to -0.5
Post-graduate training	V-all	IV	< 0.01	-11.0 to -12.2
	ML-all	I	< 0.05	-0.3 to -1.3
Mobilised subject height (cm)	V-C2	III-IV	≤ 0.05	-0.5 to -0.6
	CC-C7	II-IV	< 0.05	-0.7 to -0.9
	ML-uni	III-IV	< 0.05	-0.2
Mobilised subject weight (kg)	CC-C7	I-IV	< 0.005	0.2 to 0.7
	ML-uni	II	< 0.01	0.1
History of thumb pain	V-all	I	< 0.05	-3.7 to -4.5
	ML-uni	III-IV	< 0.001	-11.0
Frequency of thumb pain regular or often	V-all	IV	< 0.05	-9.3 to -12.6
No UL symptoms due to past injury	V-C7	IV	< 0.05	-9.8
Defining a grade II mobilisation using range (selecting description from Grieve, 1991)	V-all	II	< 0.01	6.0 to 7.0
	CC-all	II	< 0.05	0.9 to 5.4
Working in a private clinic	V-C7	I, III	< 0.05	4.9 to 12.0
Oscillation frequency (Hz)				
Post-graduate training	all**	I-IV	< 0.01	0.10 to 0.13
Rarely having thumb pain	all**	I-IV	< 0.001	-0.30
Working in a private clinic	all**	I-IV	< 0.05	0.11 to 0.17

*V = vertical, CC = caudad-cephalad, ML = mediolateral, all = all techniques for that direction, C2 = techniques applied to C2, C7 = techniques applied to C7, cen = central posteroanterior techniques, uni = unilateral posteroanterior techniques; B (range) = range of regression coefficients from the final regression models for each grade, direction and technique; positive values indicate increased force was associated with the characteristic, negative values indicate decreased force.
†Statistical significance applies for all techniques for each grade listed, except when techniques are specified for a particular grade, which indicates the significance only applies for those techniques for those particular grades.
‡Statistics for individual characteristics in the final backwards regression models for each unique technique and grade category.
**Force direction not applicable for oscillation frequency.

6.4. Discussion

This study defines cervical PA mobilisations in terms of mean peak force, force amplitude and oscillation frequency, the baseline mechanical properties which are needed to investigate how, when and why this commonly used manual technique may be clinically effective. Quantifying the force parameters is also the first step toward establishing consistency of cervical mobilisation dose between therapists. Despite variations in forces between therapists, examination of the mean of each force parameter suggests therapists apply cervical mobilisation reasonably consistent with textbook descriptions of the grades of mobilisation (Grieve, 1991; Maitland et al., 2005). For example, greater forces are applied for higher grades of mobilisation, forces are applied perpendicular to the spinal curvature, and greater force amplitudes are used for grades that are described as being ‘large amplitude movements’ (Maitland et al., 2005). In addition, therapists use oscillation frequencies that are between 1 and 2 Hz, consistent with the rate of 1 to 3 per second recommended by Maitland et al. (2005). Factors associated with higher peak forces and force amplitudes include the therapist or mobilised subject being male; while lower forces are used by therapists with post-graduate training or thumb pain, and in the upper cervical spine when spinal stiffness is greater.

6.4.1 Manual forces

In terms of force parameters, the majority of cervical mobilisation techniques and grades were significantly different, indicating therapists differentiate their applications of force for different techniques and grades. Force increases from grades I to IV, unilateral techniques are applied at a medial angle toward the spine (evident in higher mediolateral forces for unilateral techniques, Table 6.3 and Figure 6.3), and C7 techniques are angled caudad (evident in more caudad-directed force with C7 techniques, Table 6.3 and Figure 6.2). Calculating the average resultant peak force from each therapist's mean peak forces only made a substantial difference to C7 techniques, where up to a mean of 39 N was applied in the caudad direction (Table 6.3 and Figures 6.2 and 6.4). Forces in the mediolateral direction were smaller, only up to 15 N (Table 6.3 and Figure 6.3), so they had less effect on the resultant force (Figure 6.4).

The results of this study appear similar to one previous study that measured mobilisation forces applied to C4 (Langshaw, 2001). However, in the current study mean peak forces for grade III and IV mobilisations applied centrally were less at C2 (56 and 65 N) and slightly greater at C7 (69 and 80 N) than those applied at C4. The previous study only reported the vertical component of force (68 and 78 N for grades III and IV) (Langshaw, 2001). The differences between manual forces applied to different areas of the neck suggest therapists apply greater forces to the lower cervical spine than the upper. Cervical spine stiffness at C7 was greater than at C2 (mean difference 2.56 N/mm, 95% CI 1.79 to 3.33, $p < 0.001$), which may be one possible reason why therapists applied greater forces to C7. Compared to mean mobilisation forces applied to the lumbar spine: from 37 N for a grade I (Harms & Bader, 1997) up to 242 N for grade IV (Cook et al., 2002); those applied to the cervical spine are substantially less, even when comparing the resultant cervical forces from the present study with previously reported vertical lumbar forces (Chiradejnant et al., 2002; Cook et al., 2002; Harms & Bader, 1997).

The highest mean cervical mobilisation peak force (i.e., 91.8 N for resultant grade IV forces applied to C7) reported in the present study was somewhat lower than the majority of previously reported mean peak cervical manipulation forces for different techniques (between 100 and 140 N) (Kawchuk & Herzog, 1993; Kawchuk et al., 1992; van Zoest & Gosselin, 2003). However, the maximum mean peak mobilisation force applied by a single therapist in the present study was 220 N for a grade IV resultant force. This is much higher than most manipulation peak forces previously reported (Herzog et al., 1993; Kawchuk & Herzog, 1993; Kawchuk et al., 1992; van Zoest & Gosselin, 2003), but is similar to the forces recorded in one study for the application of a 'Pierce' technique (Wood et al., 1994). Therefore, it appears the forces applied during mobilisation could, at times, be as high as the forces applied in manipulation techniques. On rare occasions, serious complications have occurred following mobilisation (Haldeman, Kohlbeck, & McGregor, 1999; Michaeli, 1993), and it has been suggested that therapists should not assume that the reduced speed of mobilisation techniques (compared to manipulation) means that they are without risks (Childs et al., 2005).

6.4.2 Consistency between therapists

Although there was high inter-therapist variability in the application of cervical mobilisation forces, intra-therapist variability was low, as shown with repetition of a technique (Table 6.5). This is similar to other clinical skills which demonstrate greater intra-therapist reliability than inter-therapist (Huijbregts, 2002; Seffinger et al., 2004). If individual therapists can reliably apply precise mobilisation forces for specific techniques and grades, then it may be possible to increase consistency between therapists by providing uniform objective feedback during training. One possible reason for the differences between therapists was the wide range of descriptors they used to define the mobilisation grades (Table 6.1). Their definition of the grade was significantly associated with grade II forces (Table 6.7), but for other grades the large number of different descriptors precluded any single descriptor reaching statistical significance, even when descriptors were categorised into groups. Nevertheless, if consistency between therapists can be achieved, it would strengthen investigations of the clinical efficacy of mobilisation techniques. Researchers would have greater certainty that a technique being investigated was mechanically the same for each participating therapist.

6.4.3 Factors associated with cervical mobilisation forces

This study found that male therapists tended to use greater force and higher force amplitudes when applying cervical mobilisations (Table 6.7). In addition, higher forces and amplitudes were usually applied when the mobilised subject was male. The possibility of greater joint stiffness in males is discussed in the next section. A previous study investigating lumbar mobilisation forces also reported that greater force amplitude was associated with techniques applied to males, but found no links between gender and mean peak force (Chiradejnant et al., 2002).

The present study found that therapists with post-graduate training in manual therapy used less force and higher oscillation frequencies during cervical mobilisation than those without this training. In contrast, therapists with higher academic qualifications in a previous study tended to use greater force and lower frequencies when applying lumbar mobilisations (Chiradejnant et al., 2002). Differences in the findings between these two studies could be due to variations in therapist and mobilised subject samples, differences in the number and categorisation of investigated characteristics, or differences in the way lumbar and cervical mobilisations are applied. Recognising therapist and patient characteristics associated with applying different levels of manual force should assist in training novice clinicians to apply specific forces during cervical mobilisation.

6.4.4 Spinal stiffness and manual forces

Unlike previous studies investigating manually applied forces in vivo, the current study included a measure of spinal stiffness. This was done to identify a possibly important and relevant difference between mobilised subjects which could affect therapists' mobilisation forces. Therapists are usually trained to differentiate mobilisation grades by whether the technique moves 'into' palpated resistance (Maitland et al., 2005). Thus, the level of resistance or stiffness of the mobilised subjects' tissues would likely affect the level of force applied for particular mobilisation grades. Spinal stiffness was quantified to account for this potentially confounding factor when comparing forces applied by therapists mobilising different subjects.

A possible reason that greater forces were applied to male subjects at C7 was that males in this study were significantly stiffer at C7 (8.91 N/mm) compared to females (6.03 N/mm, mean difference 2.88 N/mm, 95% CI 1.45 to 4.32, $p < 0.001$). However, males were not stiffer at C2 (mean 4.70 N/mm for both males and females), so this cannot account for the greater force applied to males at C2. Participating therapists performed all four techniques (C2 central, C2 unilateral, C7 central and C7 unilateral) on the subject they mobilised, so perhaps their interpretation of the stiffness palpated at C7 affected their application of force at C7 and C2. Alternatively, stiffness measurements at C2 may be less robust than at C7, and thus may not distinguish the subtle differences in stiffness that might be palpated by a therapist.

Greater forces were applied at the C7 spinal level compared to C2. A possible reason for this may be that C7 was stiffer than C2 for this group of mobilised subjects. However, there were no significant associations between C7 stiffness and force applied at C7 in the final regression models. In contrast, increased spinal stiffness at C2 was associated with decreased applied force (Table 6.7), which is contradictory to what one might expect when considering the generally accepted descriptions of the grades of mobilisation (Maitland et al., 2005; Grieve, 1991).

Stiffness, as measured in this study, describes the relationship between applied force and the simultaneous traverse of a mechanical probe travelling at a constant speed (Latimer, Lee, Goodsell et al., 1996; Snodgrass et al., 2008b). Less force with greater traverse represents a lower stiffness value, while greater force with less traverse represents increased stiffness. Therefore, greater spinal stiffness would be expected to be associated with higher manually applied forces if only the mechanical properties of stiffness were taken into account. These findings suggest other factors must also contribute to differences in the level of force applied during human spinal mobilisation. For instance, therapists may reduce the force applied to the upper cervical spine when they palpate strong resistance to movement to avoid possible damage to sensitive or vital structures.

6.4.5 Limitations

These results are limited to asymptomatic mobilised subjects and to the total global forces applied to the neck during mobilisation. The local forces transmitted to a vertebra could not be separated from the overall forces because of the use of an instrumented table for measurements. Using this method, therapists applied techniques as they would normally do clinically, without instrumentation between their hands and the mobilised subject that might have altered their usual technique.

The factors identified here as being associated with cervical mobilisation forces should be interpreted with caution. The large number of factors examined increased the possibility of finding a statistically significant association due to chance alone. However, as this is the first study to investigate the relationship of cervical mobilisation forces to therapist and mobilised subject characteristics, there was no evidence to justify excluding particular factors. Two processes were used to control for this and to increase the accuracy of reporting. First, univariate regressions were performed initially with each factor to exclude some from the final regression models, using a relaxed cut-off of $p \leq 0.25$ to prevent prematurely eliminating possible key factors from the final analyses (Neter et al., 1996). Second, only those factors that were significantly associated with force across multiple force parameters, directions, techniques and grades are reported and discussed.

6.5. Conclusions

The ability to objectively quantify cervical mobilisation forces means that researchers can now begin to explore the relationships between the actual forces applied during a cervical mobilisation technique and its effectiveness for treating specific clinical conditions. Establishing the evidence base for manual therapy is challenging because therapists use specific manual treatments for different disorders and modify their treatment applications for individual patients. Classification of patients with neck pain into subgroups is beginning to be used to identify individuals who will benefit from specific treatments (Childs, Fritz, Piva, & Whitman, 2004; Fritz & Brennan, 2007), such as thoracic manipulation for cervical spine pain (Cleland, Childs, Fritz, Whitman, & Eberhart, 2007). However, therapists applying the 'same' treatment may use different forces. This occurred in the current study when individual therapists applied very different forces while mobilising a single asymptomatic subject using the same technique on the same occasion.

Variations in forces between therapists may result in different outcomes within a patient sample in a clinical trial, weakening conclusions. In addition, previous clinical studies have lacked clear descriptions of manual techniques used (Hurley et al., 2005; Kotoulas, 2002), and usually there is no documentation of the mechanical force parameters.

Quantification of cervical mobilisation forces in future trials will enable investigators to determine the most appropriate, safe and effective levels of force for treating different clinical conditions. The results of this study define the baseline mechanical properties of cervical mobilisation, and this will support further research into improving its clinical application and establishing its effectiveness.

CHAPTER 7. Cervical mobilisation forces applied by students

7.1. Introduction

Quantifying cervical mobilisation force parameters is necessary for establishing the levels of force that are most effective for treating patients with specific cervical spine disorders. In order to investigate which forces are clinically effective, the application of forces must be consistent and reliable. However, when therapists learn cervical mobilisation techniques during training, they do not usually receive any objective feedback about their forces, potentially contributing to the often considerable variation in forces between therapists reported in Chapter 6.

Instructors of manual therapy techniques using traditional teaching methods are currently unable to provide students with objective information about the force parameters of mobilisations applied to a cervical vertebra. Having this knowledge could enable instructors to identify possible irregularities in students' techniques. Making objective information available to students could also help them improve their accuracy and consistency while learning to model their application of techniques on the demonstrations provided by their instructors. In addition, it is unknown whether the variability in applied forces observed between therapists might also be observed between students who receive standard instruction within a single learning environment.

The aims of this study are to objectively quantify the cervical mobilisation force parameters applied by students following standard training to determine i) if manual force applications are consistent between students, and ii) whether they are affected by the characteristics of students or mobilised subjects, such as gender or spinal stiffness.

7.2. Methods

The manual forces applied by 120 physiotherapy students during cervical spine mobilisation were measured in three directions using an instrumented treatment table. The methods used to collect cervical mobilisation force data from students were identical to the methods used with physiotherapists (Chapter 6), with the exception of minor changes to the questionnaire collecting information on student characteristics (Appendix 2.2). Students applied PA techniques to the C2 and C7 spinous (central) and articular (unilateral) processes of one of 32 asymptomatic volunteers, whose cervical spine stiffness was measured prior to mobilisation. The study protocol was approved by the University and local health service Human Research Ethics Committees.

7.2.1 Participants

Physiotherapy students were in years two, three and four of a four-year undergraduate program. Students were recruited through announcements in class, via email and noticeboards. Participation in the study was not required for their coursework, and all gave informed consent to participate. All students had learned cervical PA mobilisation techniques during year two of the program using typical methods. These included lecture instruction plus small group tutorial with demonstration and hands-on practice in student pairs with feedback from a physiotherapist tutor with post-graduate qualifications in manual therapy. Second year students participated in the study within 5 weeks of this initial instruction, while third and fourth year students were tested 7 months to 2 years after initial instruction. Fourth year students had completed at least one four-week musculoskeletal outpatient clinical placement where they may have performed cervical mobilisation techniques on patients.

Mobilised subjects were asymptomatic volunteers who had not sought treatment for neck pain or headaches within the previous 12 months and had no contraindications to cervical mobilisation, including cancer, inflammatory diseases such as rheumatoid arthritis, infectious diseases affecting the neck, osteoporosis, symptoms of nerve root compromise, instability in the cervical spine, or potential vertebrobasilar symptoms such as dizziness or double vision (Corrigan & Maitland, 1986). They were recruited through flyers posted around the university campus and an email announcement sent to staff and graduate students. Asymptomatic subjects were used to minimise the sources of variation when comparing differences in forces between students, as was done in the study investigating the forces applied by therapists, described in Chapter 6.

7.2.2 Data collection

Cervical mobilisation force data were collected using the same method as used with physiotherapists, described in Chapter 6, using the equipment described in Chapters 3 and 4. Each student performed grades I through IV cervical PA mobilisations to the C2 and C7 central spinous and unilateral articular processes (one right and one left) of one asymptomatic subject. The order of application of techniques, grades, and first unilateral side were randomised. After approximately 20 minutes, each student repeated the first technique they performed on the same subject (all four grades). Fifteen seconds of each grade were recorded for each technique. After mobilisation was completed, students were asked to demonstrate their understanding of the four mobilisation grades by selecting descriptors for each, or providing their own (Appendix 2.2). In addition, characteristics of students and mobilised subjects, such as age, gender, height and weight were recorded. Additional characteristics of students were recorded: year in the physiotherapy program, history and frequency of thumb pain, history of upper limb injury and current upper limb symptoms.

Subjects receiving mobilisation attended one or two sessions where they were mobilised by one to four students. Prior to cervical mobilisation by students, the C2 and C7 central and unilateral spinous processes were pre-marked by an experienced physiotherapist researcher using the same method described in Chapter 6. Spinal stiffness was measured once at the beginning of each session using the protocol described in Chapters 4 and 6, as it was not expected to change after the initial pre-conditioning of the tissues (Shirley et al., 2002; Snodgrass et al., 2008b).

7.2.3 Data analysis

Ten seconds of mobilisation force data for each grade of each technique were analysed, starting two seconds after the student verbally indicated they were performing the requested technique. Data were examined for normality prior to the calculation of descriptive statistics for three force parameters in each direction: mean peak force, the average of the force peaks in Newtons; force amplitude, the average of the differences between force troughs (points of lowest force application) and subsequent force peaks; and oscillation frequency, the rate of oscillation in Hz. Resultant mean peak forces were calculated for each grade of each technique from the mean values for each direction.

Cervical mobilisation technique characteristics associated with forces

The effects of technique characteristics on mobilisation forces were investigated using mixed ANOVAs with technique (C2 central, C2 unilateral, C7 central, C7 unilateral), grade (I through IV) and force direction as fixed factors. A variance components analysis estimated the contribution of random effects (asymptomatic subjects and students) to the variance of each force parameter. Students contributed most to the total variance of all three force parameters, while the asymptomatic subject had little effect. Only 'student' was subsequently included in the final models as a random effect. Differences in force parameters between techniques, spinal levels, grades and mobilisation positions (central or unilateral) were determined using Bonferroni post-hoc tests, with p-values reported using the Bonferroni-adjusted significance level.

Consistency of students' application of forces

Reliability of force application by students was calculated for each force parameter and direction (combining techniques and grades) using intra-class correlations. Inter-student reliability included values for each student applying each technique and grade. Intra-student reliability included all four grades for one technique applied by each student (the first technique that individual students applied was the one they repeated).

Student and mobilised subject characteristics associated with forces

Linear regression determined if student and mobilised subject characteristics, including spinal stiffness, were associated with force parameters. Mobilisation force parameters for individual techniques and grades that were not significantly different, defined as $p > .05$ for the Bonferroni comparison, were grouped for these analyses. The large number of potentially associated characteristics increased the possibility of a statistically significant association with force due to chance alone. Therefore, prior to entering all factors into the regression models, univariate regression was performed for each factor to eliminate those which had minimal association (see complete list of univariate calculations in Appendix 5.2). Characteristics with $p \leq 0.25$ in the univariate regressions were then included in the calculation of final regression models for each unique technique and grade group using the backwards elimination procedure (Neter et al., 1996). Regression analyses were examined for commonalities, and only those factors which consistently reached statistical significance across multiple force parameters, directions, grades and techniques are reported (see data for all final regression analyses in Appendix 5.3, and the complete list of statistically significant factors in Appendix 5.4). All analyses were performed in SPSS 15.0 (SPSS, Inc. Chicago, IL, USA).

7.3. Results

Characteristics of the student participants and mobilised subjects are described in Tables 7.1 and 7.2. The mean spinal stiffness of mobilised subjects was 4.4 N/mm at C2 (95% CI 4.0 to 4.8) and 6.8 N/mm (95% CI 6.0 to 7.5) at C7. Means and 95% confidence intervals for mean peak force in each force direction are reported in Table 7.3, with force amplitude and oscillation frequency in Table 7.4. Mean peak mobilisation force increased from grades I to IV with the majority of forces for each mobilisation grade significantly different (vertical $p < 0.001$, Figure 7.1; caudad-cephalad $p < 0.05$ except caudad-cephalad grades III and IV $p = 0.06$, Figure 7.2; mediolateral $p < 0.05$ except for grades I and II $p = 0.34$, Figure 7.3). Greater vertical and caudad-cephalad forces were applied during central techniques ($p < 0.05$, Figures 7.1 and 7.2), with greater mediolateral forces during unilateral techniques ($p < 0.001$, Figure 7.3). Larger forces were applied at C7 than C2 ($p < 0.001$). Resultant mean peak forces are reported in Table 7.3 and Figure 7.4.

Table 7.1. Description of student participants (n = 120).

	Mean (SD) or % (N)
Age	21.4 years (2.3)
Gender	61.7% (74) female
Height	170.3 cm (8.6)
Weight	68.9 kg (14.1)
Handedness	9.2% (11) left handed
Frequency of thumb pain in the last 3 months	75.8% (91) no history of thumb pain ever 1.7% (2) none 4.2% (5) rarely (only on one occasion while mobilising) 13.3% (16) sometimes (on 1-3 occasions while mobilising) 4.2% (5) regularly/often (most of the time when mobilising) 0.8% (1) very often (daily even if not mobilising, with night pain)
History of injury to the upper limbs	29.2% (35)
Symptoms in upper limbs due to previous injuries	14.2% (17)
Interpretation of the mobilisation grades*	Selecting the same definition, by grade: Grade I: 90.0% (108) selection provided, 'near start of range' Grade II: 78.3% (94) resistance descriptor, Maitland et al. (2005) Grade III: 85.8% (103) resistance descriptor, Maitland et al. (2005) Grade IV: 65.0% (78) range descriptor, Grieve (1991)

*Students were asked to indicate how they defined each mobilisation grade by either selecting a provided description (from Maitland et al., 2005 or Grieve, 1991) or providing their own description.

Table 7.2. Description of asymptomatic mobilised subjects (n = 32).

	Mean (SD) or % (N)
Age	28.4 years (9.0)
Gender	65.6% (21) female
Height	171.1 cm (9.0)
Weight	75.4 kg (14.0)
Stiffness at C2	4.4 N/mm (1.1)
Stiffness at C7	6.8 N/mm (2.1)

Table 7.3. Average mean peak cervical mobilisation forces (N) applied by physiotherapy students (n = 120).

		Vertical		Caudad-cephalad		Mediolateral		Resultant*	
Technique	Grade	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
C2 central	I	24.93	21.51 to 28.35	3.12	2.57 to 3.67	.80	.65 to .96	25.42	21.89 to 28.96
	II	32.40	28.48 to 36.31	3.51	2.88 to 4.14	.88	.71 to 1.04	32.84	28.86 to 36.83
	III	47.51	42.60 to 52.42	4.44	3.79 to 5.08	1.12	.89 to 1.34	47.82	42.83 to 52.82
	IV	52.47	47.63 to 57.31	4.60	3.87 to 5.32	1.17	.92 to 1.43	52.93	47.98 to 57.89
C2 unilateral	I	22.25	19.05 to 25.45	3.53	3.04 to 4.02	2.06	1.60 to 2.52	22.97	19.75 to 26.20
	II	30.09	26.95 to 33.23	4.00	3.48 to 4.52	2.84	2.25 to 3.43	30.71	27.54 to 33.88
	III	42.87	38.64 to 47.10	4.98	4.36 to 5.60	4.28	3.46 to 5.10	43.62	39.33 to 47.91
	IV	49.09	44.30 to 53.89	5.69	4.89 to 6.49	5.24	4.30 to 6.19	50.01	45.14 to 54.88
C7 central	I	28.84	25.54 to 32.14	16.39	14.53 to 18.25	1.24	1.09 to 1.40	33.55	29.86 to 37.24
	II	38.71	34.73 to 42.69	21.15	18.94 to 23.35	1.43	1.24 to 1.62	44.50	40.06 to 48.93
	III	55.55	50.15 to 60.95	29.17	26.23 to 32.11	2.08	1.73 to 2.43	63.17	57.15 to 69.19
	IV	63.65	58.52 to 68.78	33.67	30.75 to 36.60	2.31	1.88 to 2.75	72.55	66.83 to 78.26
C7 unilateral	I	24.78	22.13 to 27.42	13.21	11.79 to 14.64	2.87	2.26 to 3.49	28.62	25.68 to 31.56
	II	34.17	30.66 to 37.69	17.69	15.81 to 19.57	3.79	3.00 to 4.57	39.12	35.20 to 43.04
	III	48.85	44.19 to 53.51	25.34	22.64 to 28.04	6.11	4.94 to 7.28	56.03	50.74 to 61.32
	IV	55.54	50.81 to 60.27	29.19	26.30 to 32.08	7.83	6.55 to 9.11	64.02	58.63 to 69.41

*Resultant mean peak force calculated for each technique from the mean peak forces in each direction using the formula $\sqrt{(vertical)^2 + (caudad - cephalad)^2 + (mediolateral)^2}$.

Table 7.4. Average force amplitudes (N) and oscillation frequencies (Hz) applied by physiotherapy students (n=120).

		Force amplitude (N)						Oscillation frequency (Hz)	
		Vertical		Caudad-cephalad		Mediolateral			
Technique	**Grade**	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**	**Mean**	**95% CI**
C2 central	I	17.65	14.89 to 20.40	3.64	3.32 to 3.96	1.28	1.14 to 1.43	1.17	1.10 to 1.24
	II	25.40	22.24 to 28.56	4.26	3.86 to 4.67	1.42	1.26 to 1.58	1.04	0.98 to 1.10
	III	37.79	33.61 to 41.98	5.09	4.55 to 5.63	1.69	1.47 to 1.92	0.98	0.92 to 1.04
	IV	28.37	25.55 to 31.20	4.22	3.84 to 4.61	1.62	1.40 to 1.84	1.25	1.17 to 1.33
C2 unilateral	I	15.29	12.90 to 17.67	3.52	3.27 to 3.78	2.29	1.92 to 2.66	1.17	1.10 to 1.24
	II	22.72	20.35 to 25.09	4.10	3.80 to 4.40	3.09	2.57 to 3.61	1.05	0.99 to 1.12
	III	33.42	29.93 to 36.91	4.90	4.51 to 5.30	4.50	3.75 to 5.25	0.99	0.93 to 1.05
	IV	26.80	23.95 to 29.65	4.17	3.80 to 4.54	4.33	3.70 to 4.96	1.22	1.15 to 1.29
C7 central	I	19.32	17.13 to 21.51	9.77	8.72 to 10.83	1.45	1.34 to 1.57	1.18	1.10 to 1.25
	II	28.79	25.43 to 32.14	14.19	12.62 to 15.76	1.69	1.55 to 1.83	1.07	1.00 to 1.13
	III	42.08	37.27 to 46.89	20.26	17.85 to 22.68	2.33	2.00 to 2.65	1.00	0.94 to 1.07
	IV	32.50	29.42 to 35.59	16.15	14.46 to 17.83	2.12	1.76 to 2.48	1.24	1.16 to 1.32
C7 unilateral	I	16.16	14.32 to 18.00	7.98	7.15 to 8.81	2.97	2.39 to 3.56	1.16	1.09 to 1.23
	II	25.57	22.76 to 28.37	12.23	10.81 to 13.64	3.98	3.27 to 4.69	1.04	0.92 to 1.04
	III	37.49	33.48 to 41.50	18.17	16.01 to 20.32	6.10	5.00 to 7.19	0.98	0.92 to 1.04
	IV	29.27	26.25 to 32.30	14.28	12.68 to 15.88	5.90	5.01 to 6.78	1.21	1.14 to 1.28

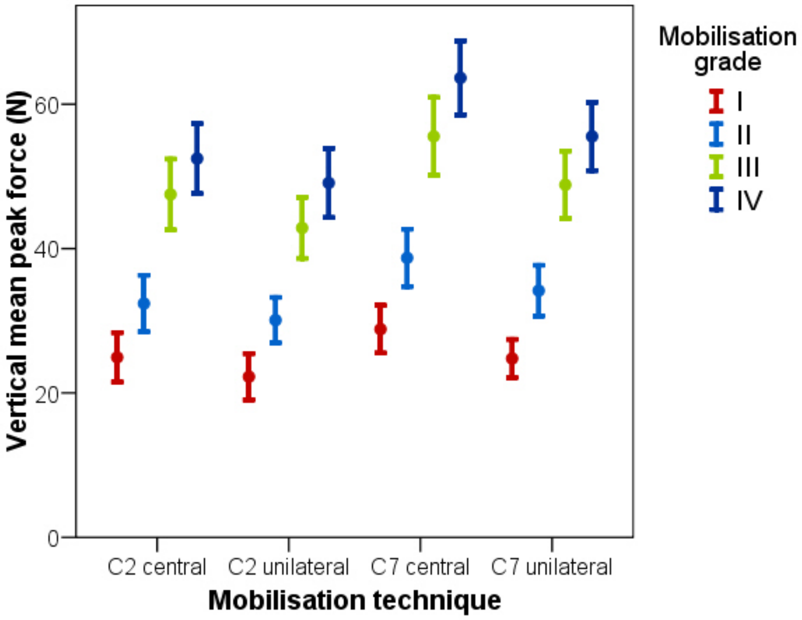

Figure 7.1. Vertical mean peak cervical mobilisation forces (95% CI) applied by students (n = 120) for each technique and grade.

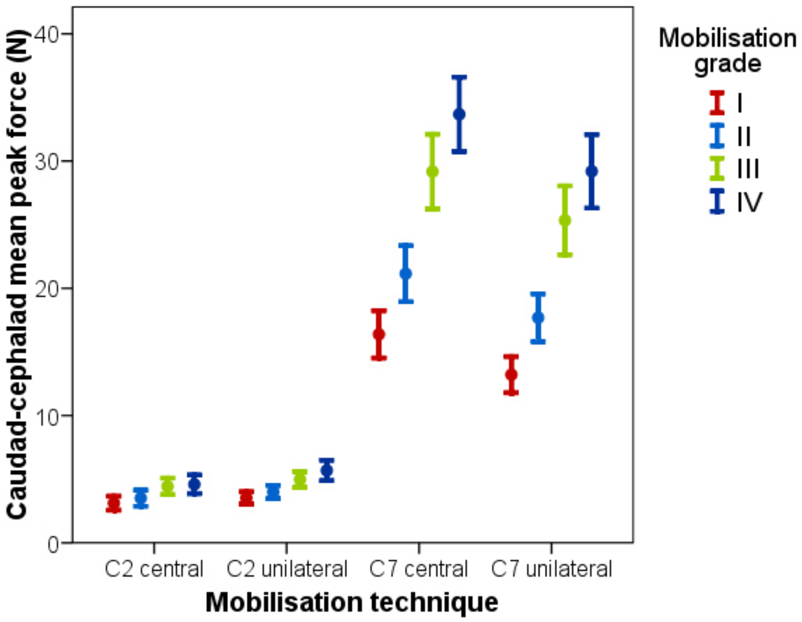

Figure 7.2. Caudad-cephalad mean peak cervical mobilisation forces (95% CI) applied by students (n = 120) for each technique and grade.

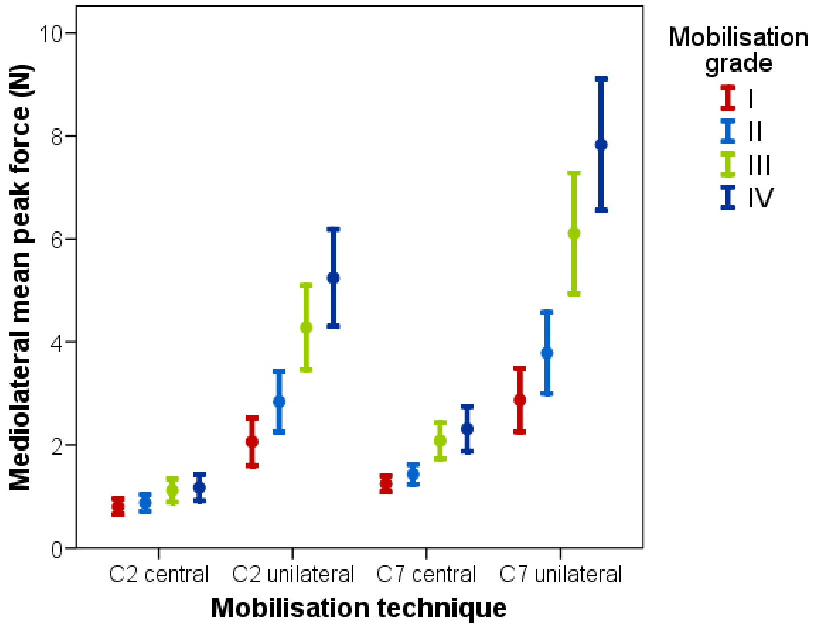

Figure 7.3. Mediolateral mean peak cervical mobilisation forces (95% CI) applied by students (n = 120) for each technique and grade.

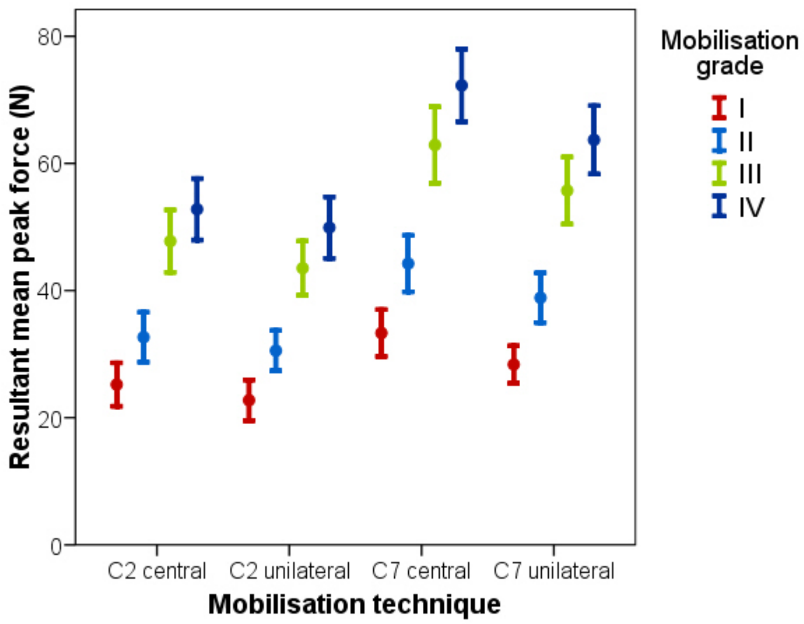

Figure 7.4. Resultant mean peak cervical mobilisation forces (95% CI) applied by students (n = 120) for each technique and grade.

The relationship of force amplitude to mobilisation grade was the same for all techniques. Force amplitude was greatest for grade III mobilisations, followed by grades IV, II, then I ($p < 0.01$, Table 7.4 and Figure 7.5). Grades I and IV were applied with a higher oscillation frequency than II and III ($p < 0.001$, Table 7.4 and Figure 7.6).

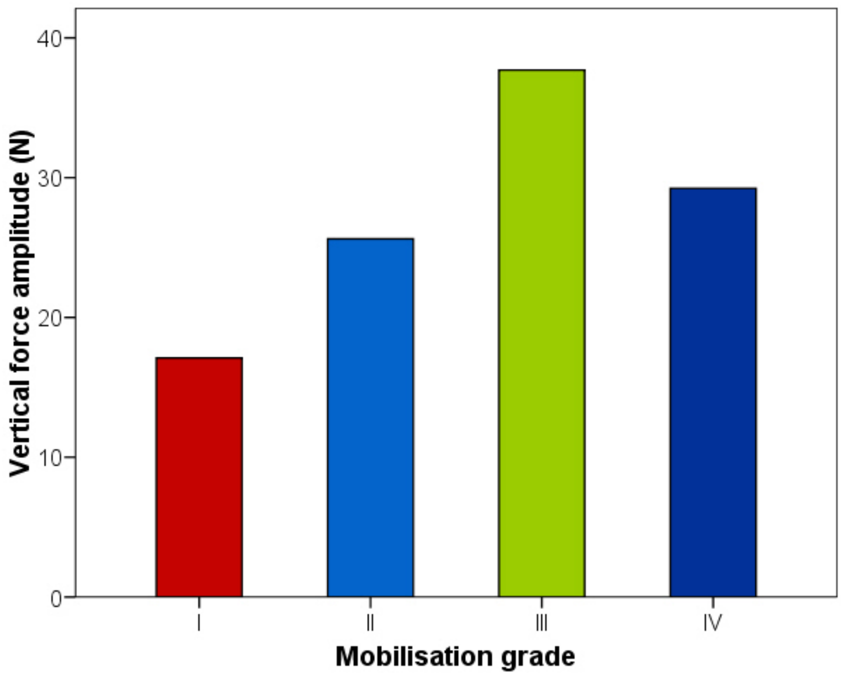

Figure 7.5. Vertical mean force amplitudes applied by students (n = 120) for each grade (all techniques combined).

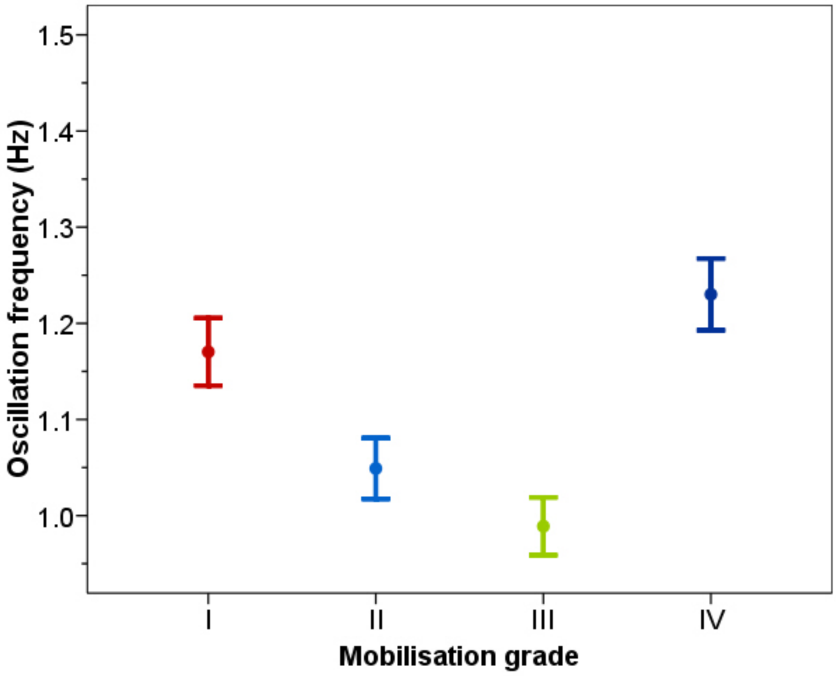

Figure 7.6. Mean oscillation frequency (95% CI) applied by students (n = 120) for each mobilisation grade (all techniques combined).

There were large inter-student variations in forces between students performing the same technique, although intra-student reliability was somewhat better (Table 7.5).

A separate linear regression analysis was performed for each technique and grade category: 24 for mean peak force, 18 for force amplitude, and two for oscillation frequency (listed in Table 7.6; Appendix 5.1 reports the complete results of calculations determining differences between techniques and grades).

Table 7.5. Inter- and intra-student reliability of cervical mobilisation force applications by students (n = 120).

	Inter-student		Intra-student	
	ICC (2,1)	**95% CI**	**ICC (2,1)**	**95% CI**
Mean peak force				
Vertical	0.23	0.14 to 0.43	0.83	0.81 to 0.86
Caudad-cephalad	0.56	0.41 to 0.75	0.94	0.93 to 0.95
Mediolateral	0.25	0.15 to 0.45	0.69	0.64 to 0.73
Force amplitude				
Vertical	0.17	0.10 to 0.33	0.86	0.84 to 0.89
Caudad-cephalad	0.43	0.29 to 0.65	0.89	0.87 to 0.91
Mediolateral	0.22	0.13 to 0.41	0.68	0.63 to 0.72
Oscillation frequency	0.06	0.03 to 0.14	0.73	0.61 to 0.81

†Inter-student analysis includes all four techniques (C2 central, C2 unilateral, C7 central, or C7 unilateral) and grades (I-IV) performed by each student for each force parameter and direction.
‡Intra-therapist includes all four grades performed by each student for the initial technique applied and subsequently repeated by the student.

Characteristics of students and mobilised subjects associated with manual forces varied with parameter, technique, grade, and force direction (Table 7.7). Some characteristics were significantly associated with force parameters across multiple techniques and grades. For example, students in year two of the program, those who experienced thumb pain more frequently or who were male applied higher forces and oscillation frequencies. Additionally, greater forces were used when the mobilised subject was male or when C7 stiffness was greater, although less force was applied if C2 stiffness was greater.

Table 7.6. Categories of unique mobilisation techniques and grades used for linear regression analysis.

Force parameters for each category were significantly different to the others (Bonferroni $p < 0.05$).

Techniques	**Direction Grade***	**Techniques**	**Direction Grade**	**Techniques**	**Direction Grade**
<u>Mean peak force</u>					
	Vertical		Caudad-cephalad		Mediolateral
C2 central & unilateral	I II III IV	C2 central & unilateral	I II III & IV	C2 & C7 central	I & II III IV
C7 central	I II III IV	C7 central & unilateral	I II III & IV	C2 & C7 unilateral	I & II III IV
C7 unilateral	I II III IV				
<u>Force amplitude</u>					
C2 central & unilateral	I II III IV	C2 central & unilateral	I II & IV III	C2 & C7 central	I & II III & IV
C7 central & unilateral	I II III IV	C7 central & unilateral	I II & IV III	C2 & C7 unilateral	I & II III & IV
<u>Oscillation frequency**</u>					
All techniques	I & IV II & III				

*Each grade or grade pair listed on a separate line represents a category of mobilisation technique used to create a linear regression model with student and mobilised subject characteristics.
**Force direction not applicable for oscillation frequency

Table 7.7. Selected* student and asymptomatic mobilised subject characteristics associated with manual force parameters.

Characteristic	Direction/ Technique**	Grades†	p‡	B (range)‡
Mean peak force (N)				
Student in year 2	V-all	I-IV	< 0.05	7.1 to 18.3
	CC-C7	I-IV	< 0.001	5.8 to 10.1
Male gender (student)	V-C2, C7(uni)	I	≤ 0.01	5.6 to 6.7
	CC-C7	II-IV	< 0.05	3.4 to 3.7
Frequency of thumb pain regular or often	V-all	III(C2), IV	< 0.05	15.5 to 34.3
	CC-all	I(C2), III & IV	≤ 0.01	2.2 to14.8
No current UL symptoms due to past injury¥	V-C7(uni)	III-IV	≤ 0.05	-11.2 to -12.1
	ML-all	I-II(cen), IV(uni)	< 0.05	-0.3 to -3.0
Defining grades III & IV using resistance descriptor (selecting description from Maitland et al., 2005)	V-all	III(C7cen)	< 0.05	15.4
		IV(C2 & C7uni)	< 0.05	-9.8 to -11.2
	CC-C7	III	< 0.05	4.1
		IV	< 0.001	-13.5
	ML-uni	IV	< 0.001	-3.8
Male gender (mobilised subject)	V-C2	IV	< 0.005	12.7
Mobilised subject weight (kg)	V-C2	III-IV	< 0.05	0.3 to 0.4
	ML-cen	III	< 0.01	0.02
C2 stiffness (N/mm)	V-C2	I-IV	< 0.001	-4.3 to -6.3
C7 stiffness (N/mm)	V-C7	I-IV	< 0.05	1.9 to 4.5
Force amplitude (N)				
Student in year 2	V-all	I-IV	≤ 0.01	5.9 to 15.6
	CC-all	III, I-IV(C7)	< 0.05	0.9 to 8.7
History of thumb pain	V-C2	IV	< 0.05	5.1
Frequency of thumb pain regular or often	V-all	II-III, IV(C7)	≤ 0.01	12.1 to 25.5
	CC-C7	II-IV	< 0.005	8.7 to 10.8
Frequency of thumb pain sometimes	V-C7	III	< 0.05	9.5
History of upper limb injury	V-all	IV	< 0.05	-4.4 to -5.9
Male gender (mobilised subject)	V-C2	IV	= 0.001	8.6
C2 stiffness (N/mm)	V-C2	I-III	≤ 0.05	-1.9 to -3.0
C7 stiffness (N/mm)	V-C7	II-IV	< 0.05	1.4 to 2.1
Oscillation frequency (Hz)				
Student in year 2	all¥	I-IV	< 0.005	0.09 to 0.10
History of thumb pain	all¥	I & IV	< 0.001	-0.15
Male gender (student)	all¥	II-III	< 0.001	0.08
Frequency of thumb pain sometimes	all¥	II-III	< 0.01	-0.09
No current UL symptoms due to past injury¥	all¥	I-IV	< 0.05	0.08
C2 stiffness (N/mm)	all¥	I & IV	< 0.001	-0.05

*Associations that were clinically insignificant (< 2 N) were omitted, even when statistically significant.
**V = vertical, CC = caudad-cephalad, ML = mediolateral, all = all techniques for that direction, C2 = techniques applied to C2, C7 = techniques applied to C7, cen = central techniques, uni = unilateral techniques; B (range) = range of regression coefficients from the final regression models for each grade, direction and technique; positive values indicate increased force was associated with the characteristic, negative values indicate decreased force.
†Statistical significance applies for all techniques for each grade listed, except when techniques are specified for a particular grade, which indicates the significance only applies for those techniques for those particular grades.
‡Statistics for individual characteristics in the final backwards regression models for each unique technique and grade category.
¥UL = upper limb; category includes only those who have had a previous UL injury.
¥Force direction not applicable for oscillation frequency.

7.4. Discussion

This study describes the cervical mobilisation forces applied by physiotherapy students in terms of specific force parameters. Force magnitude increased from grades I to IV and the majority of techniques and grades were applied with distinct levels of force that were significantly different. Manual forces varied considerably between students performing the same technique, although intra-student reliability was reasonably high. Larger forces were associated with the student or mobilised subject being male, increased frequency of thumb pain and greater C7 stiffness, while lower forces were associated with greater C2 stiffness. These results provide a basis for future research aimed at improving how students learn to apply manual techniques.

7.4.1 Levels of manual force

The mean peak forces applied by this group of students are less than those that have been reported in one previous study measuring students' mobilisation forces applied at C4 using a similar measurement method (Langshaw, 2001). For example, grade IV vertical mean peak force applied centrally to C7 in the current study was 63.7 N, compared to 81.1 N applied to C4 reported previously. Additionally, forces recorded in the present study for grade II central mobilisations (vertical mean peak force 32.4 N at C2 and 38.7 at C7) are lower than those applied centrally at L3 (approximately 42 to 62 N) by students in another study (Lee et al., 1990). Conversely, grade I forces recorded in the present study (means 22.3 to 28.8 N) are much higher than those reported by Smit et al. (approximately 1.5 to 2.0 N), where students mobilised C6 and a different measuring instrument was used (Smit et al., 2003).

Differences between studies are likely due to variations in the methods of measurement used. However, it is also possible that applied forces vary with vertebral level or that differences in teaching methods affect the manual forces students apply.

7.4.2 Variability in applied forces

Cervical mobilisation forces applied by students in the current study varied considerably (Table 7.5), despite this sample of students having undergone very similar training in how to apply mobilisation. All student participants attended the same university where they had been instructed in mobilisation techniques as described by Maitland et al. (2005) by tutors who had Australian post-graduate training in manipulative physiotherapy. Variability in the application of mobilisation forces by physiotherapists and students has been reported in several previous studies (Harms & Bader, 1997; Smit et al., 2003; Snodgrass et al., 2007). Although direct comparisons of reported values from these studies are not possible because each used different calculation methods, it appears the variability between students in the current study was slightly higher than that previously reported for physiotherapists applying lumbar mobilisation (Harms & Bader, 1997) or cervical mobilisation (Snodgrass et al., 2007). However, the variability of grade I forces appears similar to a previous study reporting the consistency between students applying a grade I PA mobilisation to C6 (Smit et al., 2003). Intra-student reliability in the current study was better than inter-student, but was still slightly lower than for practising physiotherapists (Tables 6.5 and 7.5).

The slightly increased variability in applied forces between students compared to therapists was expected, because mastering specialised motor skills requires practice (Guadagnoli & Lee, 2004). Previous research has shown that experts are more accurate and consistent at discriminating stiffness (Maher & Adams, 1995), and have better palpatory sensitivity (Foster & Bagust, 2004). Indeed, forces applied by second year students in the current study were slightly more variable than those applied by students in years three or four, but this difference was minimal (inter-student ICC[2,1] 0.20 for second year students compared to 0.31 for fourth year).

7.4.3 Factors associated with cervical mobilisation forces

Factors associated with students' applied force parameters included gender, spinal stiffness and frequency of thumb pain (Table 7.7). Higher forces were applied by male students or to male subjects, but this association was statistically significant mainly for techniques applied to C2 rather than all techniques, possibly suggesting the association was weak. Students also used higher oscillation frequencies when subjects were male for grades II and III of all techniques. For thumb pain, higher forces were applied by students with an increased frequency of thumb pain. This suggests greater mechanical stresses to their thumb joints might be contributing to their thumb pain.

The relationship between stiffness and applied mobilisation force is uncertain. Higher forces were associated with greater stiffness at C7, but for C2, lower forces were used when it was stiffer. There was no association between gender and C7 stiffness for the subjects mobilised in this study, so gender cannot account for the higher forces applied to male subjects. At C2, males were slightly stiffer than females (mean difference 0.43 N/mm, 95% CI 0.04 to 0.83, $p = 0.03$). However, this difference was very small, and thus may be an incidental finding, as lower forces were applied when C2 was stiffer.

Another factor potentially affecting the level of force applied by students in the current study was their year in the physiotherapy program. Students in year two of the program consistently applied forces that were statistically higher and had larger amplitudes (Table 7.7). Previous studies have reported similar findings: novice students apply greater forces than therapists (Langshaw, 2001; Lee et al., 1990; Smit et al., 2003) or students who are more senior (Langshaw, 2001; Lee et al., 1990; Smit et al., 2003). Year two students in the current study participated within five weeks of their initial instruction of cervical mobilisation techniques, and some, as soon as 24 hours after. This is similar to the time between initial training and the measurement of forces in one of the previous studies measuring student forces (Lee et al., 1990). Additionally, year two students had no clinical experience performing these techniques, which was the same for students in two previous studies (Langshaw, 2001; Lee et al., 1990). The year two students would have had less time to independently practice techniques than those further progressed in the program. Students who are more novice would also not have had as much time to develop their palpation skills as more senior students, which may have affected their levels of applied force. Further learning or supervised clinical experience in years three and four of the program might have contributed to the way those students applied cervical mobilisations.

Alternatively, another factor that may have caused year two students to apply different forces was that they had a different instructor when learning cervical mobilisation techniques from the other students. The potential influence of a tutor’s verbal and tactile instructions during a practical class on the forces applied during manual therapy is unknown. One study has reported that the verbal feedback on force magnitude that students give to their peers while being mobilised does not reliably compare with the true lumbar mobilisation forces measured with a force-plate (Petty et al., 2001). Most physiotherapy graduates have not received objective measured feedback on their manual forces during training. This combines with limitations in instructors' ability to provide objective feedback on levels of force using traditional manual teaching methods and visual observations only. Further, different instructors may use different paradigms to describe the levels of manual force appropriate for each mobilisation grade which may also affect students' resulting force application.

7.4.4 Limitations

These results are limited to manual force data from 120 students completing different stages of an entry-level physiotherapy program at a single university, so they may not apply to students completing different programs. Other limitations in the data collection methods are the same as those reported in Chapter 6 for the study of mobilisation forces applied by physiotherapists. These include the limitations in using an instrumented table which records global forces rather than those specifically transferred to a particular joint, and the data being limited to two spinal levels only. The instrumented table provides a realistic environment for students, enabling them to perform techniques as they would clinically without additional instrumentation directly under their hands. Furthermore, analysis of mobilisation forces applied to different cervical levels may result in different conclusions.

7.5. Conclusion

This study describes the mechanical properties of cervical mobilisation techniques applied by students, and identifies student characteristics associated with forces. This information can be used in developing strategies for providing more objective feedback to students learning to apply cervical mobilisation, laying a foundation for improving the teaching of manual therapy skills.

CHAPTER 8. Comparisons of manual forces between physiotherapists and students

8.1. Introduction

This chapter compares the manual forces applied by practising physiotherapists and students during the performance of cervical mobilisation. It investigates the similarities and differences between physiotherapists and students in their application of manual force parameters, presaged in Chapters 6 and 7, and reports further detail about specific differences in forces applied by therapists and students. This chapter explores whether the differences in applied forces between individuals vary with the addition of clinical experience. Identifying similarities and differences between forces applied by therapists and students is expected to contribute to the development of improved teaching strategies for students learning to apply cervical mobilisation.

8.2. Methods

The methods used to collect the cervical mobilisation force data for physiotherapists and students are described in Chapters 6 and 7. This chapter describes the analysis used to identify similarities and differences in the manual forces applied by physiotherapists and students.

8.2.1 Data analysis

Anthropometric data from physiotherapists and students were compared using independent t-tests to determine if there were any significant differences that might affect manual forces (e.g., height, weight). In addition, the two groups of asymptomatic subjects that were mobilised by either physiotherapists or students were compared to determine if there were any differences between them.

To identify statistical and clinical differences between cervical mobilisation forces applied by physiotherapists and students, independent t-tests were performed for each technique, grade and force direction. An overall comparison of the force magnitude applied by therapists and students was made by calculating differences in resultant forces applied for each technique. To determine if the factors associated with manual forces differed between groups, the linear regression analyses for each group were examined and compared.

8.3. Results

There were no significant differences between the characteristics of physiotherapists and students except for age, weight and history of thumb pain (Table 8.1). Physiotherapists were older, heavier and more of them had a history of thumb pain. For the mobilised subject samples, there were no significant differences (Table 8.2).

Forces applied by physiotherapists and students demonstrated a similar relationship between mobilisation grades (Figure 8.1). However, students' forces were generally lower, particularly for grades III and IV (resultant force mean difference 15.7 N, 95% CI 12.6 to 18.9, $p < 0.001$). When considering individual techniques, therapists applied significantly greater force than students for most grade III and IV mobilisations (Table 8.3). There were no significant differences between physiotherapists' and students' forces for grade I and II

Table 8.1. Comparison of physiotherapist (n = 116) and student (n = 120) participant samples (A, continuous variables; B, categorical variables).

A	**Group**	**Mean**	**P-value**	**Mean difference**	**95% CI of the difference**
Age (years)	Physios* Students	38.49 21.44	< 0.001	17.05	15.20 to 18.90
Height (cm)	Physios Students	171.57 170.32	0.264	1.25	-0.95 to 3.46
Weight (kg)	Physios Students	73.65 68.91	0.011	4.73	1.11 to 8.35

B	**Group**	**Counts**	**χ^2****	**P-value**	**Odds ratio (OR)**	**95% CI for the OR**
Gender	Physios Students	59 female/57 male 74 female/46 male	2.80	0.094	0.64	0.38 to 1.08
Handedness	Physios	1 both 9 left 106 right	0.15	0.990† 0.698†	0.98 1.20	0.06 to 15.90 0.48 to 3.01
	Students	1 both 11 left 108 right				
History of thumb pain	Physios Students	75 yes/41 no 29 yes/91 no	39.23	< 0.001	0.17	0.10 to 0.31
History of upper limb injury (UL)	Physios Students	45 yes/71 no 35 yes/84 no/1 no response	2.30	0.129	0.66	0.38 to 1.13
Current symptoms in UL due to previous injury	Physios Students	30 yes/15 no/71 na 17 yes/18 no/85 na	4.92	0.085	1.15	0.81 to 1.63

*Physiotherapists
**Pearson's Chi-square
†Statistical values are for indicator variables for categories 'both' and 'left-handed'

mobilisations (Appendix 6.1). Physiotherapists applied greater force than students for all techniques where the difference was significant. A similar pattern was observed for force amplitude (Table 8.4).

Students tended to use slower oscillation frequencies than physiotherapists for all techniques and grades (mean difference all grades combined 0.12 Hz, 95% CI 0.09 to 0.14, p < 0.001, Table 8.5). Additionally, students applied more variable force when asked to repeat a technique (intra-student ICC[2,1] for vertical mean peak force 0.83, 95% CI 0.81 to 0.86, compared to intra-therapist 0.93, 95% CI 0.92 to 0.94; Tables 6.5 and 7.5).

Table 8.2. Comparison of asymptomatic subjects mobilised by either physiotherapists or students (A, continuous variables; B, categorical variables).

A	**Study**	**Mean**	**P-value**	**Mean difference**	**95% CI of the difference**
Age (years)	Physio* Student	31.54 28.38	0.175	3.17	-1.45 to 7.78
Height (cm)	Physio Student	170.07 171.06	0.655	-0.99	-5.40 to 3.42
Weight (kg)	Physio Student	71.85 75.44	0.355	-3.60	-11.31 to 4.11
Stiffness at C2 (N/mm)	Physio Student	4.70 4.44	0.348	0.26	-0.29 to 0.82
Stiffness at C7 (N/mm)	Physio Student	7.27 6.78	0.366	0.49	-0.59 to 1.57

B	**Study**	**Counts**	**χ^2****	**P-value**	**Odds ratio (OR)**	**95% CI for the OR**
Gender	Physio Student	20 female/15 male 21 female/11 male	0.51	0.477	0.70	0.26 to 1.88

*Physio = Physiotherapist study
**Pearson's Chi-square

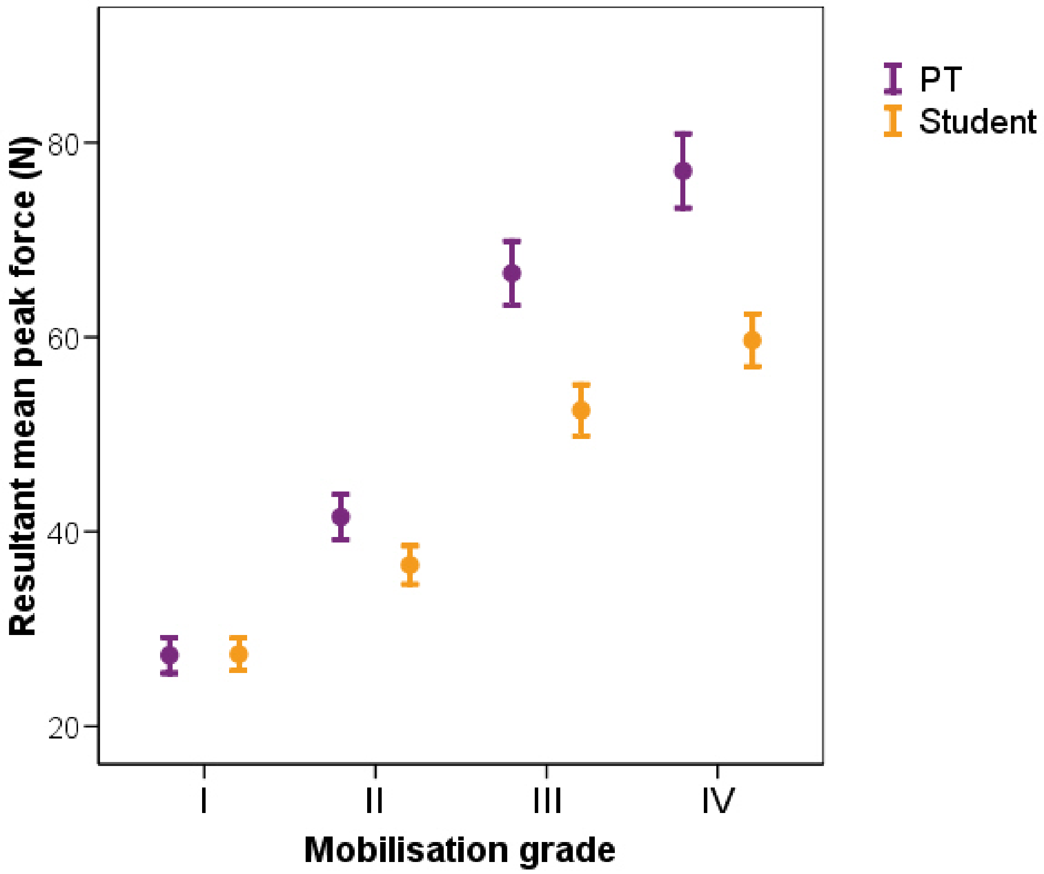

Figure 8.1. Comparison of student and physiotherapist cervical mobilisation forces.

Resultant mean peak cervical mobilisation forces for all techniques (C2 central, C2 unilateral, C7 central, C7 unilateral) applied by students (n = 120) and practising physiotherapists (PT, n = 116), by mobilisation grade.

Table 8.3. Significant differences in mean peak force (N) between physiotherapists and students.

Technique	Grade	P-value	Mean difference*	95% CI of the difference
Vertical				
C2 central	III	0.034	8.17	0.63 to 15.68
	IV	0.003	12.44	4.22 to 20.67
C2 unilateral	III	0.001	11.37	4.70 to 18.04
	IV	< 0.001	14.25	6.54 to 21.96
C7 central	III	0.002	13.20	4.78 to 21.63
	IV	< 0.001	16.71	7.62 to 25.80
C7 unilateral	II	0.017	6.72	1.23 to 12.21
	III	< 0.001	15.99	8.52 to 23.45
	IV	< 0.001	17.49	9.36 to 25.61
Caudad-cephalad				
C7 central	IV	0.031	6.09	0.57 to 11.61
C7 unilateral	III	0.003	6.84	2.28 to 11.41
	IV	0.002	8.38	3.23 to 13.53
Mediolateral				
C2 unilateral	II	< 0.001	2.87	1.62 to 4.12
	III	< 0.001	7.14	4.79 to 9.48
	IV	< 0.001	7.98	5.50 to 10.46
C7 unilateral	II	< 0.001	3.07	1.71 to 4.43
	III	< 0.001	6.60	4.30 to 8.90
	IV	< 0.001	7.25	4.68 to 9.82

*Statistically significant differences that were less than 2 N in magnitude were excluded from the table. Physiotherapists applied greater force than students in all cases where the difference was significant.

Refer to Appendix 6 for the complete list of mean differences for each force parameter, technique, grade and force direction, including those that were not significantly different.

Table 8.4. Significant differences in force amplitude (N) between physiotherapists and students).

Technique	Grade	P-value	Mean difference*	95% CI of the difference
<u>Vertical</u>				
C2 central	IV	0.024	3.06	0.10 to 13.03
C2 unilateral	III	0.010	7.13	1.72 to 12.53
	IV	0.006	7.34	2.09 to 12.59
C7 unilateral	III	0.009	8.33	2.13 to 14.53
	IV	0.022	6.29	0.91 to 11.68
<u>Mediolateral</u>				
C2 unilateral	II	< 0.001	2.77	1.49 to 4.05
	III	< 0.001	6.12	3.63 to 8.62
	IV	< 0.001	5.00	3.15 to 6.84
C7 unilateral	II	0.001	2.21	0.96 to 3.45
	III	< 0.001	4.91	2.81 to 7.02
	IV	< 0.001	3.16	1.49 to 4.83

*Statistically significant differences that were less than 2 N in magnitude were excluded from the table. Physiotherapists' force amplitude was higher than students in all cases where the difference was statistically significant and greater than 2 N.

Table 8.5. Significant differences in oscillation frequency (Hz) between physiotherapists and students.

Technique	Grade	P-value	Mean difference*	95% CI of the difference
C2 central	I	0.025	0.13	0.02 to 0.25
	II	0.010	0.14	0.03 to 0.24
	III	0.013	0.13	0.03 to 0.23
C2 unilateral	I	0.037	0.13	0.01 to 0.25
	II	0.017	0.13	0.02 to 0.24
	III	0.016	0.13	0.02 to 0.23
C7 central	I	0.015	0.14	0.03 to 0.26
	II	0.021	0.13	0.02 to 0.23
C7 unilateral	I	0.034	0.12	0.01 to 0.24
	II	0.005	0.15	0.05 to 0.25
	III	0.011	0.13	0.03 to 0.22

*Physiotherapists' oscillation frequency was greater than students' for all techniques and grades.

When examining the factors associated with manual forces applied by physiotherapists compared to students, there are a number of similarities and one noteworthy difference (Table 8.6). For both physiotherapists and students, higher mean peak forces were applied when the therapist, student or mobilised subject were male. In addition, less mean peak force was applied by both physiotherapists and students as C2 stiffness increased. Another similarity was that increased body weight of the mobilised subject was associated with increased applied force for both physiotherapists and students.

The effect of thumb pain on manually applied force was different for the physiotherapists compared to the students. Physiotherapists with a history of thumb pain, or increased frequency of thumb pain applied lower mean peak forces and smaller force amplitudes, whereas students with thumb pain applied higher mean peak forces and force amplitudes. Physiotherapists who rarely had thumb pain used lower oscillation frequencies, whereas students who reported thumb pain used lower frequencies.

Table 8.6. Summary of factors associated with manual force applied by physiotherapists and students.

Arrows [↑↓] indicate an increase or decrease in the corresponding force parameter was significantly associated with the particular factor for physiotherapists and/or students.

	Mean peak force		**Force amplitude**		**Oscillation frequency**	
	Physio*	**Student**	**Physio**	**Student**	**Physio**	**Student**
Male clinician	↑ V-all, I-IV CC-C7, I-IV†	↑ V-C2 & C7uni, I CC-C7, II-IV	↑ V-all, II-III CC-C7, I-IV	–	–	–
Male mobilised subject	↑ V-all, I-IV CC-C7, I-IV ML-all, I-IV	↑ V-C2, IV	↑ V-all, I-IV CC-all, I-IV ML-all, I-IV	↑ V-C2, IV	–	–
↑ C2 stiffness	↓ V-C2, II-IV ML-uni, III-IV	↓ V-C2, I-IV CC-C2, I ML-all, I-III	↓ V-C2, I-IV CC-C2, I & IV	↓ V-C2, I-III ML-all, I-II	–	–
↑ weight mobilised subject	↑ V-all, II-IV CC-C7, I-IV ML-uni, I-II	↑ V-C2, III-IV ML-cen, III	↑ CC-C7, I-IV ML-uni, III-IV	↑ CC-C7, II & IV	–	–
History of thumb pain	↓ V-C2, I	–	↓ V-all, I ML-uni, III-IV	↑ V-C2, IV	–	↓ all, I & IV
Frequency thumb pain, regular/often	–	↑ V-all, III-IV CC-all, I & II-IV	↓ V-all, IV	↑ V-all, II-IV CC-C7, II-IV	–	–
Frequency thumb pain, sometimes	–	–	–	↑ V-C7, III CC-C2, II & IV ML-cen, III-IV	–	↓ all, II & III
Frequency thumb pain, rarely	–	–	–	–	↓ all, I-IV	–

*Physiotherapist
– = not significant
†For each factor associated with each force parameter, the force directions, techniques, and mobilisation grades with statistical significance in the final regression models are listed: V = vertical, CC = caudad-cephalad, ML = mediolateral; all = all techniques for a force direction; C2 = C2 central and unilateral techniques; C7 = C7 central and unilateral techniques; cen = central techniques to C2 and C7; uni = unilateral techniques to C2 and C7; I, II, III & IV = mobilisation grades I-IV.

8.4. Discussion

The main findings of the comparisons of cervical mobilisation forces between physiotherapists and students were that students generally applied lower mean peak forces, smaller force amplitudes and used lower oscillation frequencies than physiotherapists when performing the same techniques. The factors associated with manual force parameters were similar for both therapists and students, with the exception of thumb pain, which had opposite effects on manual force for therapists and students. This section explores possible reasons for similarities and differences between the forces applied by physiotherapists and students in the context of the published literature.

8.4.1 Participant samples

Anthropometric data for physiotherapists and students were similar (Table 8.1). There were no significant differences between physiotherapists and students in height, handedness, history of upper limb injury, symptoms due to past upper limb injuries and the proportion of male and female participants. There were however, significant differences between therapists and students in age, body weight, and history of thumb pain. Physiotherapists were older and weighed slightly more, and a greater number of them had experienced thumb pain while mobilising. These observations were expected, as practising physiotherapists are more likely to be older than individuals attending an undergraduate program, and in the majority of individuals excess body weight does not accumulate until sometime after the end of the growth years, around 18 for women and 20 for men (Willett, Dietz, & Colditz, 1999).

Previous surveys of practising physiotherapists suggest that thumb pain symptoms are more likely to develop after commencing clinical practice, rather than as a student. Although physiotherapists usually report the onset of work-related musculoskeletal symptoms early in their careers, only 16% of therapists in two surveys developed work-related musculoskeletal symptoms as a student (Cromie, Robertson, & Best, 2000; West & Gardner, 2001). Specific to thumb pain, there were no identified studies reporting its onset while physiotherapists were students (although it is possible that some thumb pain cases were included in the 16% of therapists who developed their work-related symptoms as students in the studies above). Nevertheless, therapists probably develop thumb pain early in their careers, with one survey reporting that 88% of physiotherapists with thumb pain developed symptoms within six years of using manual therapy techniques (Neville & Rivett, 1985).

The groups of asymptomatic subjects mobilised by physiotherapists and students were not significantly different in age, height, weight, spinal stiffness or proportions of males and females (Table 8.2). Therefore, the mean of each manual force parameter applied by physiotherapists and students could be compared, as there were no confounding differences between the groups of mobilised subjects.

8.4.2 Mean peak force

For mean peak force, students' forces were lower than physiotherapists in all force directions for grade III and IV mobilisations (Figure 8.1 and Table 8.3). Differences in physiotherapists' and students' forces for grade I and II mobilisations were very small, and there was no trend for either group to apply greater force for these grades (Appendix 6.1.1). Reasons for the greater force applied by therapists during grade III and IV mobilisation grades are unknown, and only one previous study has reported similar results when comparing the forces applied by two students and five physiotherapists applying mobilisation forces to an artificial device (Hardy & Napier, 1991). The two students applied considerably lower force for all four mobilisation grades (Hardy & Napier, 1991). In contrast, other studies of cervical mobilisation forces applied to asymptomatic persons report that students applied significantly higher forces for grade I and II mobilisations than physiotherapists (Langshaw, 2001) or more experienced students (Smit et al., 2003). In addition, students also applied greater force for a grade II lumbar mobilisation prior to formal feedback on their forces (Lee et al., 1990). A possible reason for the differences between physiotherapists' and students' forces may be the way each group was taught to apply mobilisation.

Another possible explanation for the lower forces applied by students for grade III and IV cervical mobilisations is that students may be apprehensive about applying larger forces due to a lack of experience. Perhaps they may have been taught to be more cautious in their application of manual therapy than therapists who trained in previous years. Alternatively, practising therapists may have found through experience that that they need to use more force to be clinically effective. If excessive force can be considered as potentially associated with a risk of damage to cervical structures, then students possibly pose less risk to patients because they apply lower forces. Additionally, if a certain level of force is needed for clinical effectiveness, students may be less effective, because their forces are lower and more variable than those of experienced therapists.

8.4.3 Force amplitude

In the present study, the differences in force amplitude between therapists and students were similar to the differences in mean peak force: students used smaller force amplitudes than therapists when applying higher grades of mobilisation (Table 8.4). However, there was no difference in the force amplitudes in the caudad-cephalad direction. This suggests that the angle of applied force in the sagittal plane might be similar for students and physiotherapists. However, the true angle of applied force is represented by the relative contributions of measured force in each direction (Snodgrass et al., 2006, 2008a).

No previously identified study has reported multiple directions of mobilisation forces or amplitudes, but one study reporting vertical force amplitude during cervical mobilisation indicated students' amplitude was significantly greater than therapists for grade I and II mobilisations (Langshaw, 2001). This corresponded with greater mean peak forces applied by students for these grades in that study. In the current study, students applied smaller force amplitudes and mean peak forces than physiotherapists for grade III and IV mobilisations, but for grades I and II values were similar (Tables 8.3 and 8.4). The contrasting results between the current study and the study reported by Langshaw (2001) are likely due to different measurement and data collection methods, or because a different spinal level (C4) was mobilised in the earlier study. Alternatively, participants in the previous study may not have been representative of practising therapists and students, as the sample was small (nine in each group).

8.4.4 Oscillation frequency

In the present study, students used lower oscillation frequencies than therapists, particularly for grade I and II mobilisations (Table 8.5). This may imply that students had more difficulty interpreting the stiffness or movement of the underlying tissues, and thus slowed down their application of force in order to allow more time for the cognitive processing of the manual sensations felt during mobilisation. Consistent with this, it has been shown that palpatory sensibility (ability to detect a nylon filament under sheets of paper of varying thickness) is greater in practising chiropractors than students (Foster & Bagust, 2004). This suggests that palpation skills develop with practice, and therefore students are possibly less able to interpret the sensations felt during mobilisation.

Only one previous study was identified that reported oscillation frequency during mobilisations applied by students (Langshaw, 2001). In comparing nine students to an equal number of therapists, Langshaw found students used significantly higher oscillation frequencies when mobilising C4: 1.07 to 1.43 Hz for students compared to 0.93 to 1.20 for therapists (Langshaw, 2001). Conversely, students in the current study used lower oscillation frequencies than practising therapists (0.98 to 1.25 Hz for students compared to 1.11 to 1.33 for therapists).

Although students used lower oscillations frequencies than therapists for all grades and techniques, the differences were statistically significant for grade I-III techniques only (Table 8.5, Appendix 6.1.3). This might suggest that students' oscillating speed decreases when applying lower forces where they must discriminate between smaller magnitudes of force. However, in the current studies there were no correlations between oscillation frequency and the magnitude of mobilisation force applied for either therapists or students (Pearson's $r < 0.2$ for comparisons between oscillation frequency and mean peak force for all techniques, grades and force directions).

8.4.5 Factors associated with manual force parameters

Factors common to therapists and students

Factors which had a similar association with force parameters applied by physiotherapists and students included gender, mobilised subject weight and C2 stiffness (Table 8.6). For both therapists and students, mean peak forces and force amplitudes were significantly higher when the practitioner or mobilised subject was male, increased as mobilised subject weight increased, and decreased as C2 stiffness increased, with one exception. The association between force amplitude and male gender of the practitioner did not reach statistical significance for students, although the trend was in agreement with the physiotherapist data: higher force amplitude was applied by males.

Strength of associations between force, gender and stiffness

A comparison of the linear regression models for therapist and student data indicate that the gender of mobilised subjects was a stronger predictor of force magnitude for therapists than students, and spinal stiffness a stronger predictor for students. When mobilised subjects were male, therapists applied 8.3 to 28.6 N more vertical force (depending on technique and grade) while accounting for other factors (Table 6.7). For students, mobilised subject gender was only significantly associated with one grade and spinal level (12.7 N more force applied to males for grade IV techniques to C2, Table 7.7). Spinal stiffness at both C2 and C7 was significantly associated with the magnitude of force applied by students for all techniques and grades (4.3 to 6.3 N less force applied at C2 and 1.9 to 4.5 N more force applied at C7 for every 1 N/mm increase in stiffness, Table 7.7). For therapists, there was only a significant association for C2 stiffness and mobilisation grades II through to IV (1.3 to 5.6 N less force applied for every 1 N/mm increase in C2 stiffness, Table 6.7). Different levels of variability in either forces or stiffness may have contributed to these differences between the two studies. Alternatively, there may be differences between therapists and students which affect their application of forces.

Perhaps because of a lack of clinical experience, students have fewer preconceptions about how much force they should apply, so they possibly rely more on what they palpate, attempting to adhere closely to the textbook description of the mobilisation grades. This might make students more reliant on subject stiffness when determining how much force to apply. Conversely, clinical reasoning research shows that experienced clinicians learn to recognise patterns in patient symptom behaviour in order to plan and select treatment quickly and effectively (Jones & Rivett, 2004). It may be possible that prior experience and the use of clinical pattern recognition by therapists influenced their application of manual techniques, even though in the experimental environment they did not conduct a complete assessment of the mobilised subject. Therapists might consider the size and gender of the patient as they decide how much force to apply. Students have not as fully developed their ability to recognise clinical patterns and thus may have less of these types of influences. Further research would be needed to determine the reasons that gender and stiffness have somewhat varied effects on applied forces by therapists and students.

Thumb pain: contrasting factor for therapists and students

The effect of thumb pain on manual force was different for practising therapists and students. Students who had increased frequency of thumb pain applied greater forces and amplitudes, whereas practising therapists who had more thumb pain applied lower ones (Tables 6.7 and 7.7). In addition, lower oscillation frequencies for students were associated with having thumb pain whereas in therapists these were associated with rarely having thumb pain. This seems to suggest that therapists early in their career may develop thumb pain due to applying large forces, but with experience therapists with thumb pain tend to reduce the forces they apply, either to protect their thumbs or because their thumb pain limits the amount of force they are able to apply. Indeed, 55% of therapists with thumb pain reported they had altered their mobilisation technique due to thumb pain (Table 6.1).

Comparisons with previous studies

In the cervical spine, only one previous study has reported any associations between manual force and either practitioner or mobilised subject factors. Langshaw (2001) reported that both therapists and students applied higher mean peak forces and force amplitudes to male subjects compared to females, in agreement with the current results. In the lumbar spine, two previous studies have explored different sets of factors potentially associated with manual force. Harms et al. (1999) found that increased body weight in patients (attending an outpatient clinic but pain-free at L3 where force was applied) was associated with higher applied forces. Additionally, Chiradejnant et al. (2002) reported higher force amplitudes were applied to low back patients who were male and had higher body mass index. The current research agrees with these findings, as increased body weight and male gender were also associated with higher forces. The previous studies did not include thumb pain or spinal stiffness in their investigations.

8.5. Conclusion

Students applied lower force magnitudes and amplitudes than physiotherapists when performing the same grade III and IV cervical mobilisation techniques. In addition, students used lower oscillation frequencies than therapists for all techniques. The factors associated with manual force parameters were mostly similar for both groups: increased force applied by or to males, and to subjects with higher body weight, and decreased force applied when C2 was stiffer. The exception to this was thumb pain which differed between the groups: it was associated with higher applied forces in students and lower ones in therapists.

The differences between the forces applied by therapists and students suggest that students may be more cautious when performing cervical mobilisation. Also, therapists with thumb pain may decrease their applied forces in order to manage their thumb symptoms so they can continue to use manual therapy. The similarities in the factors associated with cervical mobilisation forces for both groups suggest that some factors, such as gender, affect applied forces regardless of clinical experience.

CHAPTER 9. Analysis of comments made by mobilised subjects

9.1. Introduction

When performing manual techniques such as cervical mobilisation, therapists are usually concerned with the way the techniques are perceived by patients. Therapists typically aim to apply mobilisation in a manner that is reasonably comfortable for the patient and often ask the patient about their pain levels throughout a treatment session. However, there were no studies identified in the literature investigating the patient's perception about the manual techniques applied.

Studies that report the perceptions of individuals being mobilised all used subjects who were asymptomatic. Most often the subjects were physiotherapists (Petty et al., 2001), physiotherapy students (Waddington, Lau, & Adams, 2007) or chiropractic students (Triano, Scaringe, Bougie, & Rogers, 2006) who might be expected to have a greater awareness about manual techniques. Only one study reported on the perceptions of asymptomatic lay people, and this study investigated only their perceptions of comfort with different oscillation frequencies and contact area while oscillatory forces were applied with a mechanical device (Squires et al., 2000).

Therefore, this is the first study to report perceptions about applied forces from lay people being mobilised in a manner similar to that used in the clinical setting. These comments from subjects about mobilisation forces may contribute to determining how mobilisation techniques should be applied.

The aim of this chapter is to describe the analysis of the comments made by subjects being mobilised by physiotherapists and students. The data includes the subjects' perception of comfort during mobilisation applied by each therapist or student, and additional written comments that were volunteered by subjects in an open-ended question.

9.2. Methods

The perceptions of subjects being mobilised by physiotherapists or students were recorded on a form (Appendix 2.3). Subjects wrote down their comments confidentially, and therapists and students participating in the studies were not given this information. This was done to encourage honest and untempered responses. The subjects' responses were not expected to affect the way therapists or students applied forces, as they were not allowed to view the responses. Therefore, these data have been analysed separately to the other factors potentially associated with the application of mobilisation forces.

9.2.1 Comfort rating scale

All mobilised subjects rated their overall comfort level during mobilisation by each therapist or student. Subjects rated comfort using a 10 cm visual analogue scale (VAS) anchored with 'very comfortable' at the left end and 'very uncomfortable' at the other end. The VAS is commonly used to evaluate comfort and discomfort (de Looze et al., 2003). Subjects rated each therapist or student immediately after they completed their set of mobilisations, prior to being mobilised by a different therapist or student. VAS ratings were not viewed by the therapists or students because it may have influenced them when they were asked to repeat one of their techniques to assess intra-therapist reliability.

Descriptive statistics for VAS comfort ratings were calculated, and linear regression was used to determine if the VAS comfort rating was associated with levels of applied vertical force, vertical force amplitude and oscillation frequency for each grade of each technique. In examining the associations between VAS comfort rating and mobilisation force, only data from the vertical force direction were used. The majority of force was applied in the vertical direction, and it was very unlikely that different associations would be observed in the other force directions, where the values were much smaller.

9.2.2 Written comments

When mobilised subjects completed the VAS, they were also invited to provide written comments about the mobilisations applied by the therapist or student. Although not all subjects provided comments, the majority (83%) did so.

The mobilised subjects' written comments were coded for analysis. To ensure the reliability of this coding, the following methods were used. Three independent raters identified themes within the subjects' comments using a method of content analysis where the written comments were systematically examined for common words and phrases (Mays & Pope, 1996). The raters then discussed them and agreed upon four main themes, with three sub-categories each, for grouping and coding the comments. The themes used for grouping comments, and the categories used to code comments within each theme, are described in Table 9.1.

Following consensus on the themes and categories, the three raters independently coded a random sample of 20 written comments from subjects who were mobilised by physiotherapist participants (Chapter 6). Kappa for multiple raters was calculated from this sample to determine the reliability of coding, using a custom computer program (King, 2004, February) with calculations based on the equations from Fleiss (1981).

Table 9.1. Themes and categories used to group mobilised subject comments for analysis.

Theme	Description	Categories
Consistency	Mobilisation felt consistent (force magnitude or oscillation frequency)	• consistent • not consistent • no comment about consistency
Differentiation of grades	Mobilisation grades felt distinctly different	• grades felt different • grades felt the same • no comment made about difference between grades
Perception of force	Perception of the magnitude of force applied	• heavy • light • no comment about force
Comment on comfort	Written comment included on whether mobilisation was comfortable	• comfortable • not comfortable • no comment about comfort

After the investigation of reliability of the coding method, a single rater coded all of the subjects' comments. Then for each theme, the number and percent of comments in each category were calculated. Linear regressions were used to determine if the vertical mean peak force, amplitude, or oscillation frequency were associated with any comment category for each grade of each technique. Regressions were performed using the backwards elimination procedure with indicator variables for each comment theme entered into the models. All calculations were performed in SPSS 15.0, except for the kappa statistic which was calculated using the program described above.

9.3. Results

9.3.1 Comfort rating scale

The mean VAS comfort ratings from subjects mobilised by physiotherapists and students were similar. Subjects mobilised by physiotherapists responded with a mean VAS of 28.7 mm on the 0 to 100 mm scale, and for subjects mobilised by students this was 23.2 mm. The data suggest subjects were reasonably comfortable with the mobilisation, as a lower number on the scale represents increased comfort. Descriptive statistics for the VAS comfort scale are reported in Table 9.2.

Table 9.2. Descriptive statistics for VAS comfort scale for subjects mobilised by physiotherapists (n = 116) and students (n = 120).

Study	Mean	SD	Median	95% CI	Minimum	Maximum
Physiotherapists	28.7	25.6	20.5	24.0 to 33.4	0.0	100.0
Students	23.2	21.0	18.3	19.4 to 27.0	0.0	92.0

Linear regressions indicated that a higher VAS rating (meaning less comfortable) was associated with higher applied forces and force amplitudes. There was a statistical association between VAS rating and mean peak force and force amplitude for each grade of each technique, but most regression coefficients were small, suggesting the associations were weak (Tables 9.3 and 9.4). The technique and grade with the largest regression coefficient, C7 unilateral grade IV, indicates that for every 1 N of increased applied force, the VAS rating increases by 0.78 mm. This means that for grade IV C7 unilateral techniques, an increase in applied force of approximately 25 N is associated with an increase in discomfort of 20 mm on the VAS scale. There was no significant association between VAS rating and oscillation frequency.

Table 9.3. Significant associations between VAS comfort rating and vertical mean peak force and force amplitude for subjects mobilised by physiotherapists.

Technique	Grade	p-value	B*	95% CI for B
Mean peak force				
C2 central	I	< 0.001	0.21	0.10 to 0.33
	II	< 0.001	0.30	0.14 to 0.45
	III	< 0.001	0.50	0.29 to 0.70
	IV	< 0.001	0.68	0.44 to 0.91
C2 unilateral	I	< 0.001	0.21	0.10 to 0.31
	II	< 0.001	0.25	0.11 to 0.38
	III	< 0.001	0.48	0.29 to 0.67
	IV	< 0.001	0.59	0.37 to 0.80
C7 central	I	< 0.001	0.33	0.18 to 0.48
	II	< 0.001	0.41	0.23 to 0.58
	III	< 0.001	0.61	0.38 to 0.84
	IV	< 0.001	0.67	0.40 to 0.94
C7 unilateral	I	< 0.001	0.30	0.18 to 0.42
	II	< 0.001	0.38	0.23 to 0.53
	III	< 0.001	0.60	0.40 to 0.81
	IV	< 0.001	0.78	0.56 to 1.00
Force amplitude				
C2 central	I	< 0.001	0.18	0.10 to 0.27
	II	< 0.001	0.26	0.12 to 0.40
	III	< 0.001	0.46	0.28 to 0.64
	IV	< 0.001	0.50	0.31 to 0.69
C2 unilateral	I	< 0.001	0.14	0.07 to 0.21
	II	< 0.001	0.18	0.08 to 0.28
	III	< 0.001	0.37	0.22 to 0.52
	IV	< 0.001	0.39	0.23 to 0.55
C7 central	I	< 0.001	0.24	0.14 to 0.34
	II	< 0.001	0.31	0.18 to 0.44
	III	< 0.001	0.54	0.35 to 0.72
	IV	< 0.001	0.52	0.34 to 0.69
C7 unilateral	I	< 0.001	0.20	0.11 to 0.28
	II	< 0.001	0.24	0.13 to 0.36
	III	< 0.001	0.49	0.33 to 0.66
	IV	< 0.001	0.46	0.31 to 0.62

*Regression coefficient

Table 9.4. Significant associations between VAS comfort rating and vertical mean peak force and force amplitude for subjects mobilised by students.

Technique	Grade	p-value	B*	95% CI for B
Mean peak force				
C2 central	I	0.004	0.24	0.08 to 0.40
	II	0.001	0.31	0.13 to 0.49
	III	< 0.001	0.46	0.24 to 0.68
	IV	0.001	0.39	0.16 to 0.61
C2 unilateral	I	0.012	0.19	0.04 to 0.34
	II	< 0.001	0.26	0.12 to 0.41
	III	< 0.001	0.36	0.17 to 0.55
	IV	0.001	0.37	0.15 to 0.59
C7 central	I	< 0.001	0.31	0.17 to 0.46
	II	< 0.001	0.40	0.22 to 0.58
	III	< 0.001	0.53	0.29 to 0.77
	IV	< 0.001	0.48	0.25 to 0.71
C7 unilateral	I	0.001	0.21	0.09 to 0.33
	II	< 0.001	0.35	0.19 to 0.51
	III	< 0.001	0.41	0.20 to 0.62
	IV	< 0.001	0.39	0.18 to 0.61
Force amplitude				
C2 central	I	0.010	0.17	0.04 to 0.30
	II	0.001	0.25	0.11 to 0.40
	III	< 0.001	0.39	0.20 to 0.58
	IV	0.002	0.21	0.08 to 0.34
C2 unilateral	I	0.017	0.14	0.03 to 0.25
	II	< 0.001	0.22	0.11 to 0.33
	III	< 0.001	0.33	0.18 to 0.49
	IV	0.002	0.21	0.08 to 0.34
C7 central	I	< 0.001	0.18	0.08 to 0.28
	II	< 0.001	0.31	0.16 to 0.46
	III	< 0.001	0.45	0.23 to 0.66
	IV	0.001	0.25	0.11 to 0.40
C7 unilateral	I	0.001	0.14	0.06 to 0.23
	II	< 0.001	0.28	0.15 to 0.40
	III	< 0.001	0.35	0.17 to 0.53
	IV	0.001	0.23	0.09 to 0.37

*Regression coefficient

9.3.2 Written comments

The kappa values for agreement between raters on the categorisation of mobilised subject comments ranged from 0.55 to 0.70 (Table 9.5). This level of agreement is accepted as fair to good (Landis & Koch, 1977; Streiner & Norman, 1994).

Table 9.5. Reliability of categorisation of mobilised subject comments by three independent raters (n = 20).

Category	**Kappa***	**95% CI**
Consistency	0.68	0.46 to 0.89
Differentiation of grades	0.55	0.36 to 0.74
Perception of force	0.70	0.48 to 0.92
Comment on comfort	0.64	0.45 to 0.83

*Multiple rater kappa as described by Fleiss (1981).

The majority of comments from mobilised subjects were about their level of comfort or the perceived magnitude of force. The numbers and percentages of mobilised subjects reporting in each category are listed in Tables 9.6 and 9.7.

Linear regressions investigating relationships between mobilised subject comments and vertical forces suggest that there were significant relationships between comments and forces for some mobilisation grades. For subjects mobilised by physiotherapists, comments that they were not comfortable were associated with higher applied forces for grade III and IV techniques. Commenting that the therapist's mobilisation grades felt the same was associated with lower applied forces for some grades of each technique.

Table 9.6. Comments from subjects mobilised by physiotherapists.

Number and percent of subjects commenting on each category of each theme.

Theme	Categories	N	%	χ^{2*}	p-value
Consistency	consistent	8	6.9		
	not consistent	5	4.3	160.7	< 0.001
	no comment about consistency	103	88.8		
Differentiation of grades	grades felt different	10	8.6		
	grades felt the same	14	12.1	110.6	< 0.001
	no comment made about difference between grades	92	79.3		
Perception of force	heavy	19	16.4		
	light	19	16.4	60.0	< 0.001
	no comment about force	78	67.2		
Comment on comfort	comfortable	20	17.2		
	not comfortable	21	18.1	51.2	< 0.001
	no comment about comfort	75	64.7		

*Pearson's chi-square

Table 9.7. Comments from subjects mobilised by students.

Number and percent of subjects commenting on each category of each theme.

Theme	Categories	N	%	χ^{2*}	p-value
Consistency	consistent	5	4.2		
	not consistent	10	8.3	158.8	< 0.001
	no comment about consistency	105	87.5		
Differentiation of grades	grades felt different	14	11.7		
	grades felt the same	15	12.5	97.6	< 0.001
	no comment made about difference between grades	91	75.8		
Perception of force	heavy	29	24.2		
	light	17	14.2	45.2	< 0.001
	no comment about force	74	61.7		
Comment on comfort	comfortable	21	17.5		
	not comfortable	17	14.2	66.4	< 0.001
	no comment about comfort	82	68.3		

*Pearson's chi-square

Lastly, comments about the applied force being heavy or light were significantly associated with greater or less force, respectively, for all grades of each technique (except C7 unilateral techniques). Significant associations between comments from subjects mobilised by physiotherapists and applied forces are listed in Table 9.8.

Table 9.8. Significant associations between vertical mean peak force and comments from subjects mobilised by physiotherapists.

Comment	Technique	Grade	p-value	B*	95% CI for B
Grades felt the same					
	C2 central	I	0.043	-9.5	-18.6 to -0.3
	C2 unilateral	I	0.044	-8.5	-16.7 to -0.2
	C7 central	I	0.026	-13.8	-26.0 to -1.7
		II	0.045	-14.8	-29.3 to -0.3
	C7 unilateral	II	0.049	-12.4	-24.8 to -0.04
		IV	0.030	-21.3	-40.6 to -2.1
Force perceived as light					
	C2 central	I	0.013	-10.3	-18.3 to -2.2
		II	0.005	-15.5	-26.2 to -4.7
		III	0.019	-17.9	-32.9 to -3.0
	C2 unilateral	I	0.047	-7.5	-15.0 to -0.1
		II	0.003	-13.8	-23.0 to -4.7
		III	0.023	-15.6	-28.9 to -2.2
		IV	0.012	-20.3	-36.1 to -4.5
	C7 central	I	0.045	-10.9	-21.6 to -0.2
		II	0.016	-15.6	-28.4 to -2.9
		IV	0.011	-26.2	-46.1 to -6.2
Force perceived as heavy					
	C7 central	III	0.038	18.2	1.0 to 35.4
Not comfortable					
	C2 central	III	0.003	21.9	7.5 to 36.3
		IV	0.001	29.8	13.0 to 46.5
	C2 unilateral	III	0.001	22.6	9.7 to 35.4
		IV	0.004	22.4	7.2 to 37.6
	C7 central	III	0.033	18.0	1.5 to 34.6
	C7 unilateral	I	0.034	9.4	0.7 to 18.1
		II	0.001	18.9	8.4 to 29.5
		III	< 0.001	28.2	13.8 to 42.6
		IV	0.002	26.0	9.4 to 42.5

*Regression coefficient for the mobilised subject comment indicator variable from the final regression model for individual grades of each technique.

For subjects mobilised by students, comments significantly associated with forces were similar to the results for subjects mobilised by physiotherapists (Table 9.9). The main difference was that a subject commenting that the grades felt different was associated with lower applied forces, whereas for subjects mobilised by physiotherapists lower forces were associated with subjects reporting the grades felt the same. Similar to subjects mobilised by physiotherapists, comments that moblisations were uncomfortable were

Table 9.9. Significant associations between vertical mean peak force and comments from subjects mobilised by students.

Comment	Technique	Grade	p-value	B*	95% CI for B
Grades felt different					
	C7 central	I	0.034	-10.6	-20.3 to -0.8
	C7 unilateral	I	0.047	-7.9	-15.6 to -0.1
Force perceived as light					
	C2 central	I	0.006	-13.3	-22.7 to -3.8
		II	0.001	-18.7	-29.4 to -7.9
		III	< 0.001	-26.4	-39.7 to -13.1
		IV	0.004	-19.6	-32.9 to -6.3
	C2 unilateral	I	0.034	-9.8	-18.8 to -0.7
		II	0.003	-13.2	-21.9 to -4.5
		III	< 0.001	-21.3	-32.9 to -9.7
		IV	0.005	-19.3	-32.6 to -5.9
	C7 central	I	0.009	-12.3	-21.4 to -3.1
		II	0.006	-15.5	-26.5 to -4.5
		III	0.002	-24.0	-38.9 to -9.1
		IV	< 0.001	-26.1	-40.0 to -12.2
	C7 unilateral	I	0.003	-11.2	-18.5 to -3.9
		II	0.001	-16.7	-26.3 to -7.1
		III	< 0.001	-23.8	-36.5 to -11.2
		IV	0.002	-21.0	-33.8 to -8.1
Force perceived as heavy					
	C2 unilateral	II	0.026	8.0	1.0 to 15.1
		III	0.031	10.3	1.0 to 19.7
	C7 central	II	0.029	10.1	1.1 to 19.1
	C7 unilateral	I	0.043	6.1	0.2 to 12.1
		II	0.029	8.7	0.9 to 16.6
Not comfortable					
	C2 central	IV	0.031	14.4	1.3 to 27.5
	C7 unilateral	IV	0.018	15.2	2.6 to 27.9

*Regression coefficient for the mobilised subject comment indicator variable from the final regression model for individual grades of each technique.

associated with higher forces applied by students. In addition, comments about the magnitude of force (heavy/light) were associated with either higher or lower forces applied by students.

Significant associations between vertical force amplitude and comments made by subjects followed a similar pattern to the associations with mean peak force. However, there were fewer statistically significant associations. For both subjects mobilised by physiotherapists and those mobilised by students, comments about the magnitude of force were positively associated with the amount of force amplitude used, and subjects were less comfortable when greater force amplitudes were used for grade III and IV mobilisations.

There were few meaningful associations between subject comments and oscillation frequency. There were no associations between oscillation frequency and comments on comfort or perception of mobilisation force (heavy/light). For subjects mobilised by physiotherapists, reporting the mobilisation grades felt different was associated with higher oscillation frequency for some techniques (C2 central grades II and III, C2 unilateral grade III, and C7 central grades I, II and IV). Alternatively for subjects mobilised by students, reporting the mobilisation grades felt the same was associated with higher oscillation frequencies for some techniques (C2 central grade III, C7 central grades II and III, and C7 unilateral grades II and III). Additionally for the subjects mobilised by students, reporting the mobilisations did not feel consistent was associated with higher oscillation frequencies for some techniques (C2 central grades I and II, C7 central grade IV and C7 unilateral grade IV).

9.4. Discussion

The main findings from this analysis of the comfort ratings and comments provided by mobilised subjects are that increased applied force was associated with the subject being more uncomfortable with the mobilisation technique, and that their level of comfort was not associated with oscillation frequency. This suggests that when therapists perform mobilisation techniques on patients, the lowest amount of force that is clinically effective should be used, if it is desired that the patient be comfortable while being treated with mobilisation. It also appears that the oscillating speed is not as important for patient comfort.

9.4.1 Comfort and manual forces

There were few studies identified in the published literature investigating subject comfort in relation to manually applied techniques. One study reporting the development of a hand-held mobilising device investigated subject comfort related to forces applied with the device and with the therapists' hands (Waddington et al., 2007). Mobilisation techniques were applied to the lumbar and thoracic spines and a VAS comfort scale was used. The authors concluded that comfort decreases with increased applied force, and that their device was more uncomfortable than the therapists' hands. Another study investigated subject comfort related to changes in oscillation frequency and mobilising contact area applied using a mechanical device (Squires et al., 2000). There was no association between comfort and oscillation frequency, but increased contact area during mobilisation was more comfortable. The current results agree with these findings, in that increased applied force was associated with decreased subject comfort, and comfort was not affected by changes in oscillation frequency.

A third study identified in the literature investigated changes in subject perceptions about lumbar manipulation techniques following feedback given to students performing the manipulations (Triano et al., 2006). Subjects' perceptions about how the manipulations were performed changed after feedback, but their comfort was not affected. After feedback, the subjects reported that the manipulations were performed with increased speed, force and precision. The current research did not examine changes in subjects' perceptions over time, so results cannot be readily compared with this previous study.

9.4.2 Subject perceptions about force magnitude

An additional finding from the mobilised subjects' comments was that their perception of the force being either heavy or light on their neck was accurate. In each instance when the subjects' perceptions of the magnitude of force were significantly associated with mean peak force, the sign of the regression coefficient indicated the subjects' perceptions were correct: a negative coefficient when the subject perceived the force as light, meaning less applied force was associated with this comment, and a positive coefficient when the subject perceived the force as heavy, meaning more applied force was associated with this comment.

One previous study investigated the ability of subjects to perceive an applied force parameter as 'less than', 'equal to', or 'greater than' a criterion force parameter previously applied to them by another therapist (Petty et al., 2001). The subjects were unable to accurately perceive these differences in peak force, amplitude or oscillation frequency. The subjects were trained physiotherapists completing their post-graduate qualifications in manipulative physiotherapy, so might be expected to have a better ability to perceive differences in mobilisation force, yet the percentage of correct responses ranged from approximately 30 to 60% of trials (Petty et al., 2001).

The fact that the mobilised subjects in the current study did predict force accurately is probably due to the method of analysis. Only comments volunteered from subjects were analysed; subjects were not asked to rate the level of force applied by each therapist. Thus it is likely that subjects made comments about force only when the force was perceived as extreme (either high or low), which might increase the accuracy of these comments. In addition, comments related to force magnitude were grouped into only two categories, rather than three as in the previous study, increasing the likelihood of accuracy. The current results agree with a previous study that reported chiropractic students were able to perceive higher lumbar manipulation forces being applied to them after feedback was given to the students applying the techniques (Triano et al., 2006). The subjects, chiropractic students, perceived this change in force accurately; as the force applied by their student peers following feedback was indeed greater.

9.4.3 Subject perceptions about mobilisation skills

The subjects who received mobilisation from participating physiotherapists and students were asymptomatic individuals who had not sought treatment for neck pain or headaches in the previous 12 months. Most of them had never had their neck mobilised before so would not be expected to have any enhanced ability to identify and rate mobilisation forces. However, it was interesting that many subjects commented about the therapists' or students' mobilisation skills in terms of the consistency of mobilisation and whether the mobilisation grades felt distinctly different. These comments were not statistically associated with any force parameter across both the physiotherapist and student data sets in any consistent manner. This may indicate that a subject's perception of force consistency and grade distinction does not truly reflect the mobilisation force parameters being applied to them. Alternatively, these associations may not have reached statistical significance because there were fewer of these comments (on consistency and differentiations between grades) than for comfort or perceived force magnitude.

Furthermore, several subjects also commented on the confidence of the therapist or student. These comments were not included in the quantitative analysis because the number of comments was small. Nevertheless, it appears that subjects being mobilised may be able to perceive subtle differences between therapists related to mobilisation ability, suggesting therapists should endeavour to improve and maintain high levels of manual skills.

9.4.4 Limitations

This analysis of responses by subjects being mobilised should be regarded with some caution. Although all subjects were requested to complete the VAS comfort rating, providing additional comments about the mobilisations was optional. It is possible that those subjects who provided comments were in some way biased, or had a different experience to other subjects. Nonetheless, the majority of mobilised subjects did make some comment.

9.5. Conclusions

Cervical mobilisation applied with higher forces was associated with decreased levels of comfort for asymptomatic subjects mobilised by physiotherapists or students. Additionally, mobilised subject comments volunteered about the magnitude of applied force (either heavy or light) were accurate. Furthermore, some subjects being mobilised were able to identify subtle differences between mobilisation techniques, such as differences between grades and the consistency of mobilisation. These results provide an understanding about how cervical mobilisation is perceived by subjects being mobilised, offering some insight into how patients might feel when being treated with cervical mobilisation.

CHAPTER 10. Equipment development: Software for real-time feedback on manual forces

10.1. Introduction

The research discussed in this thesis has established that individual physiotherapists apply different levels of manual force when performing the same cervical mobilisation technique. They are, however, reasonably consistent when asked to repeat a technique. Also, some factors affecting the applied forces are not patient-dependent, such as the gender of the therapist and their level of experience. Furthermore, differences between students and therapists suggest that therapists change how they apply cervical mobilisation as they gain experience, possibly leading to even further variability between therapists.

Associations between clinical outcomes and the application of distinct cervical mobilisation techniques cannot be reliably established if therapists are performing techniques differently. However, physiotherapists have been shown to demonstrate high intra-therapist repeatability in their application of cervical mobilisation forces. This suggests that if therapists were given similar training using objective feedback for mean peak force, force amplitude and oscillation frequency during cervical mobilisation, then they might be able to demonstrate greater inter-therapist repeatability. If they could reliably apply cervical mobilisation for individual treatments of specific disorders, evaluating the clinical effectiveness of those treatment applications becomes possible. The research reported in Chapter 11 focuses on investigating the first part of this; i.e., whether therapists can be trained to apply forces consistently.

This chapter reports the development of new and innovative software that uses the mobilisation force data from the instrumented table to provide effective real-time feedback during mobilisation (Appendix 3.3, CD-ROM). It was pilot tested for its usability prior to a formal investigation of whether it might improve cervical mobilisation skills (described in Chapter 11).

10.1.1 Motor learning

Spinal mobilisation is a complex motor task with many components. These include the parameters of the manual force applied, the hand and body position of the therapist, and the therapist's perceptions of the changing resistance of the mobilised subject's tissues. Research into motor learning in humans shows practice is one of the most important factors for learning a motor skill (Guadagnoli & Lee, 2004). Specifically, physical practice is better than observation for retaining new motor skills, although a combination of observation and physical practice appears to be best (Shea, Wright, Wulf, & Whitacre, 2000). Providing students with physical practice using feedback via a computer software program, in addition to their traditional classroom teaching which includes observation, may potentially enhance the learning of spinal mobilisation skills.

Frequency of feedback

Increased frequency of feedback appears more beneficial for learning complex tasks than reducing feedback (Swinnen, Lee, Verschueren, Serrien, & Bogaerds, 1997; Wulf, Shea, & Matschiner, 1998). For simple motor tasks subjects perform better in retention tests when feedback is reduced to a proportion of practice trials so subjects do not become dependent on feedback

(Lai & Shea, 1998; Schmidt & Wulf, 1997). This does not appear to be the case for more complex tasks that require increased attention, memory or motor demands (Wulf & Shea, 2002). Thus, for novices learning cervical mobilisation, more frequent feedback is desirable and the software needs to be able to provide this.

Whole versus part practice of a task

Providing feedback about a single aspect of a complex task appears more effective than providing feedback about multiple components in either a random or sequenced order. During a complex ski-simulation task, participants were given information about the forces exerted by either one or both feet (Wulf & Shea, 2002). Those given information about only one foot performed better in retention tests. It was hypothesised that providing too much information about a complex task may increase attention demands such that learning becomes ineffective. These results suggest that students learning to apply mobilisation may benefit most from the provision of feedback on a single parameter of force.

Practising parts of a complex task in repeated blocks is more effective for learning than practising them in random order, especially for novices (Albaret & Thon, 1999; Hebert, Landin, & Solmon, 1996; Wulf & Shea, 2002). Thus the new software needs to be able to provide feedback on one aspect of mobilisation at a time, focussing the learner's attention on that particular part of the task.

External feedback cues

Learning is enhanced when subjects focus on an external cue rather than their own body movements. For example, in the ski-simulation task, learners improved their performance when they were asked to focus on the wheels under their feet rather than their foot movement (Wulf, Prinz, & Höß, 1998). This phenomenon has been demonstrated for both simple and complex tasks (Riley, Stoffregen, Grocki, & Turvey, 1999; Wulf, Shea, & Park, 2001). These results suggest that providing manual force feedback on the computer screen, an external focus, is likely to be effective.

10.1.2 Feedback software for cervical mobilisation

The new software described in this chapter is designed to provide real-time feedback on applied forces during cervical mobilisation. The software represents an external focus for the learner, and includes a display of multiple force parameters to account for the complexity of cervical mobilisation. It can also provide feedback on a single aspect of cervical mobilisation or a single force parameter, whichever is needed to optimise effective learning of this complex task.

10.2. Methods

10.2.1 Development

The Powerlab® data acquisition system (ADInstruments, Castle Hill, Australia) used for the collection of manual force data from the instrumented table (described in Chapter 3) could not provide enough options to create a user-friendly interface for real-time feedback. Although it was able to collect data in real time, the display was not clearly visible from a distance equivalent to where a therapist might be standing while mobilising, and there was no way to set visible force targets. In addition, the method used for zeroing the body weight of the person lying on the table (described in Chapter 3) could not be performed quickly enough to be able to provide accurate feedback and complete training sessions in a reasonable amount of time for participants. Also, additional features such as audio feedback were not available within the Powerlab® Chart software.

Therefore, the first issue in the development of the software was to select a programming system which would enable effective real-time feedback, and could interact with the existing hardware. This consisted of the X-tran load cells (Model S1W, Applied Measurement Australia, Sydney) and amplifiers (Strain Gauge Signal Conditioners, Model RM-044, Applied Measurement Australia, Sydney) described previously, and a data acquisition card (DT301, Data Translation, Marlboro, MA, USA) which was not previously used when collecting data using the Powerlab® system.

The next issue was the selection of force parameters and how to display them. In order to accurately describe a manual force, all of the investigated force parameters are needed: mean peak force and force amplitude in the three force directions, and oscillation frequency. However, a therapist's ability to observe and process information about all of these force parameters simultaneously while mobilising would likely be limited, so the system needed to be able to selectively display the individual parameters.

Another objective was to be able to display a force target representing the ideal force during a mobilisation technique. Force targets for different cervical mobilisation techniques and mobilised subjects would not be the same, so the system needed a mechanism for an operator to set specific force targets for different applications. Lastly, the type of feedback that would be provided by the system was considered. The options included the sensory input to the user (visual or audio), and the temporal character of the feedback (concurrent, terminal or delayed). Concurrent feedback is provided during the application of a task, terminal feedback is provided at the time of completion of a task, and delayed feedback is given at a later time point following completion of the task (Shumway-Cook & Woollacott, 2007).

A suitable Labview programmer was sourced and given a detailed brief describing the aims of the software.

10.2.2 Description and capability

Labview 8.0 was used to develop the interactive real-time feedback program. It was selected because of its versatility and capability, and because it is a system commonly used in science and engineering and thus licensing and expertise using the system was available. Another useful feature of Labview is that it uses windows and diagrams in programming, rather than a text-based programming language. This is likely to make it easier for non-programmers (e.g., physiotherapist researchers) to alter or create programs.

Manual force is displayed as an oscillating force curve over time for each force direction (conceptual example illustrated in Chapter 2, Figure 2.2). This configuration provides the most visual information about the manual force in the simplest format. By viewing the manual force as an oscillating curve, a therapist can simultaneously view their peak force, trough force, and force amplitude. They can also see the width of the force curves which gives some information about the oscillation frequency.

Each force direction is displayed separately. The option of using a single resultant force was not appropriate, as it would not enable the mobilising therapist to identify which components of their applied force did not match the target force. In addition, ensuring accuracy in real-time required the three directions of force to be visible.

As an option in the current software program, an operator running the program can choose a single force direction for a therapist to view. When a single direction is selected, the other two force directions are minimised, so that the operator can continue to observe the other force directions while the therapist concentrates on the single force direction selected (Figure 10.1). The operator can observe the other directions of force to help ensure the safety of the mobilised subject. For example, a therapist might apply excessive force in a horizontal force direction while trying to achieve a particular peak force in the vertical direction. The feedback on vertical force might indicate they needed to apply greater force. However, the operator viewing the three directions would be able to see that the total force was adequate (or excessive), but it was just being applied at an inappropriate angle to achieve the vertical force peak target. In this case, intervention by the operator could prevent excessive forces being applied to a subject as a result of the feedback.

A vertical bar to the right side of the force curve was used to display the oscillation frequency. The set target frequency is a green area in the middle of the bar, while the current oscillation frequency is represented by a yellow bar which moves in response to changes in frequency. The movement of the yellow bar in this screen is in response to a calculation of oscillation frequency based on the number of peaks detected in the previous 10 seconds, updated at 100 Hz. The oscillation frequency feedback was set up this way because a person mobilising would not be able to effectively respond to a change in frequency occurring over a single repetition of force. By detecting the frequency or rhythm over periods of 10 seconds, a better overall representation of what the frequency actually is over time is provided, without the yellow bar moving with every repetition of force. However, because of this method of calculation, it takes several seconds of mobilising at a changed frequency for the yellow bar to move to the new frequency level.

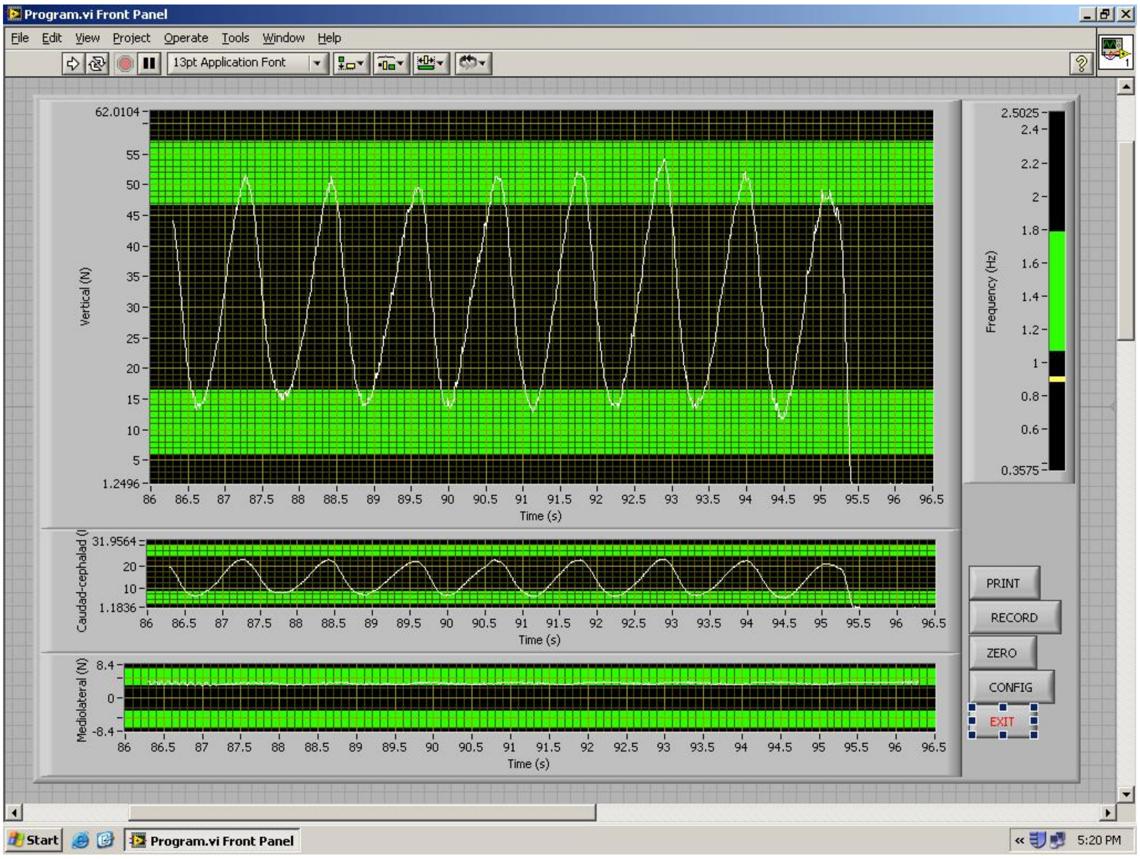

Figure 10.1. Display panel for real-time feedback.

Top window displays vertical force, with caudad-cephalad and mediolateral force windows minimised below. Oscillation frequency is displayed in the vertical bar to the right of the panel. Coloured zones within each window represent the targets for peak force, trough force and frequency.

Targets for peak force, trough force and oscillation frequency are set by the operator. The target range for force amplitude is calculated from the targets set for peak and trough force. A configuration panel is used to set all force targets (Figure 10.2). This panel opens automatically each time the program is started, and can be accessed from a button to the right of the manual force curves at any time during the operation of the program. In the configuration panel, the operator sets an exact numerical target for peak force, trough force and frequency. The operator also selects the direction of the applied force for caudad-cephalad (either caudad or cephalad) and mediolateral forces (either towards the right or left of a prone-lying subject being mobilised). This is done so that the peak applied force displayed for these directions will be viewed towards the top of the screen and the trough towards the bottom. For vertical force, forces are assumed to be applied in a downward direction (towards the bed surface), so selecting a direction for vertical force is not necessary.

Once the exact force targets are set, the operator selects the width of each target in the box labelled 'Tolerance'. The tolerance is set in the units used for each target (N for peak and trough force, Hz for oscillation frequency) and represents the range on either side of the target. For example, a tolerance of two for peak force means that the target bar represents a width of 2 N above the target value and 2 N below the target value. Once set, configurations can be saved for repeated use.

The amount of concurrent feedback can be set by the operator in the configuration panel. Target bars for peak force, trough force and oscillation frequency can change from green to red if the force is out of range. For peak and trough force, the colour changes for each single oscillation of force, only while it is out of range. For oscillation frequency, the target bar changes colour after a 10 second period where the oscillation frequency is out of range, updated at 100 Hz. To select visual feedback, the ‘Visual’ box is ticked on the configuration panel, indicating visual feedback is being provided for that force parameter and the relevant target bar will change colour when the force is out of range. To include audio feedback for a force parameter, ‘Audio’ is ticked in the configuration panel. Thus for forces, the operator can select whether or not each type of feedback (visual and audio) will be given for either peak or trough separately, and whether it is given for exceeding or not reaching the peak or trough, or both. For oscillation frequency, the operator can select whether each type of feedback is given for either exceeding or not reaching the target frequency.

Immediate terminal feedback is provided if practice is recorded. After recording a number of seconds of mobilisation and then finishing recording, a pop-up window displays the percentage of time the therapist was within the target for particular force parameters (Figure 10.3). These percentages can be used to view improvement between subsequent trials during training.

Finally, delayed terminal feedback can be provided to a therapist after mobilising. The program creates a report for each therapist by adding detailed information from each recorded trial to an html file within a folder labelled for that particular therapist (Figure 10.4). The operator labels this folder and each recorded trial in a ‘save’ window which pops up at the end of each recorded trial. The report indicates what the targets were for mean peak force, force amplitude and oscillation frequency, the actual mean values applied by the therapist while mobilising during the trial, and the percentage of time they were within, above and below the targets for each force parameter. This html report provides information on whether a therapist was applying too much or too little force, or mobilising too fast or too slowly during the recorded trial.

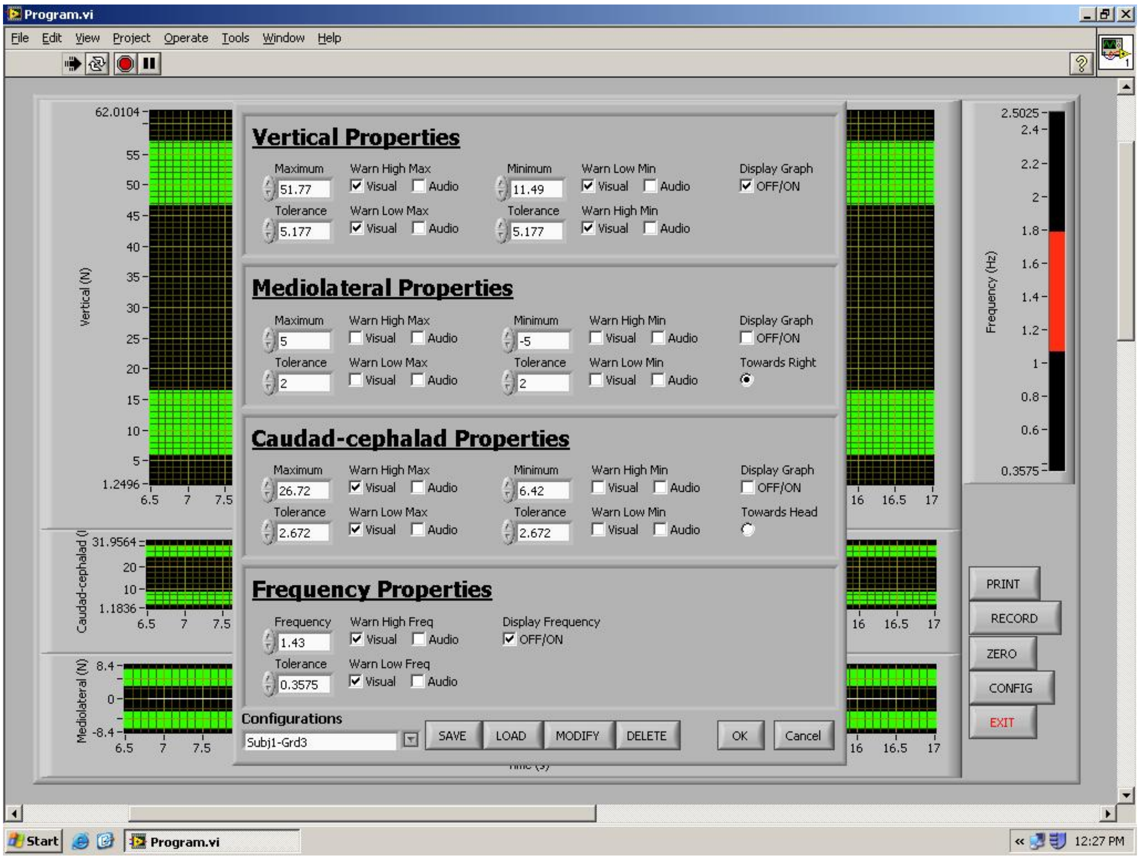

Figure 10.2. Configuration panel for setting force and oscillation frequency targets.

'Maximum' and 'minimum' indicate the target peak and trough forces. Visual or audio feedback can be selected for exceeding ('Warn High') or not reaching ('Warn Low') each force parameter. The direction of force is selected for caudad-cephalad ('Towards Head' on or off) and mediolateral forces ('Towards Right' on or off representing a prone mobilised subject's right). 'Display' indicates whether a particular parameter is displayed in full, or minimised.

In addition to the report, the program creates jpeg files illustrating the force curves for each force direction for each trial. These are automatically saved within the therapist's folder and labelled with the trial number. This might be used when an instructor who was teaching students to mobilise wanted to provide more specific feedback. The student could see where in the recorded trial they made mistakes. For example, peak forces might be initially too high and then reach the target after some seconds, or forces could be initially on target, and then subsequently increase after several oscillations. This could be viewed in the jpeg files, which provide an additional means of interpreting the html report.

As well as the information created to provide feedback to the therapist mobilising, the program records and saves information for use in research. Within each therapist's folder, an Excel file is created which lists each recorded trial as a row of data. All values from the html file (Figure 10.4) are in a single row for each trial. Values will continue to be recorded in the same Excel file (in additional rows for each recorded trial) until the operator changes the name of the folder in the 'save' pop-up window. The program also saves raw data from each trial in a text file which holds the values for each data point, collected at 100 Hz. These raw data files serve as a back-up of collected data. These might be used if a researcher wanted to recreate what was happening while force was recorded in order to make additional observations about the data other than those recorded in the Excel file.

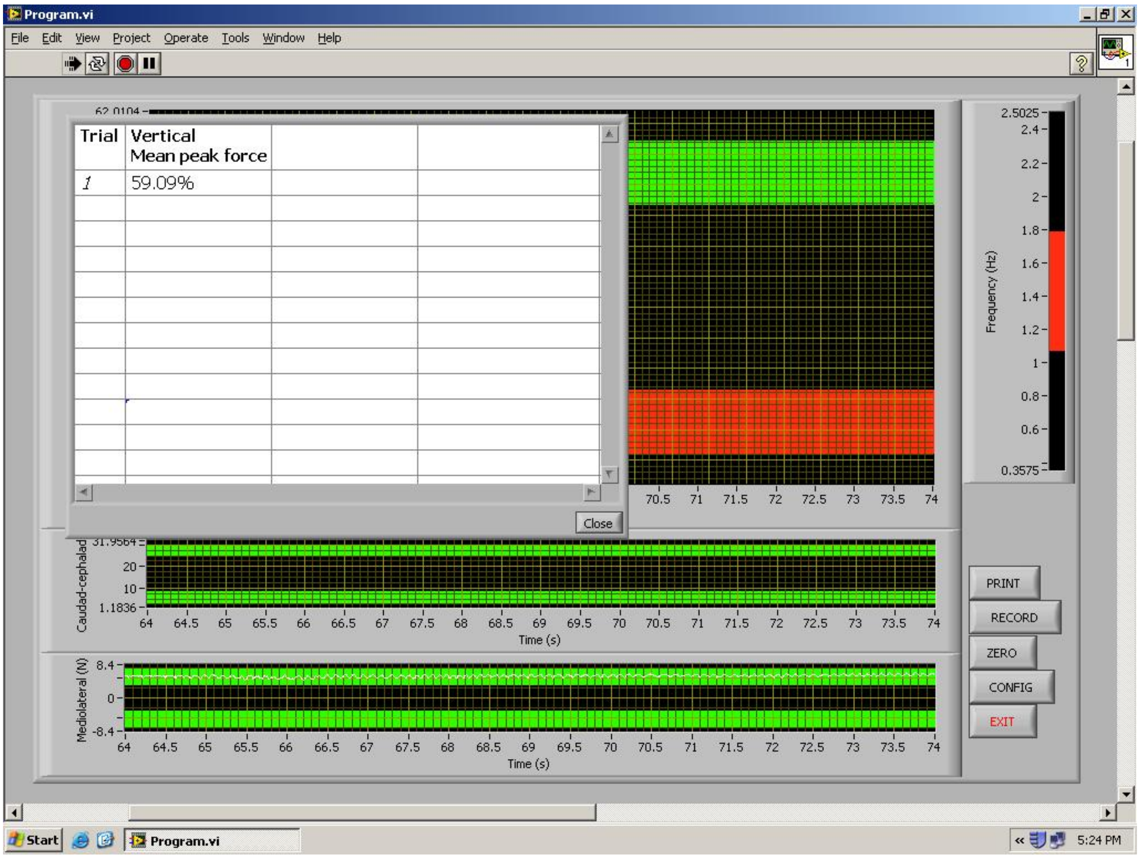

Figure 10.3. Terminal feedback pop-up window.

Pop-up window showing percentage of recorded mobilisation time that peak force was within the programmed target zone.

Operator Name: Pilot student 1

Technique Name: C7 cen grd II (before)   Date: 4/07/2007   Time:12:33 PM

	Vertical	Caudad-cephalad	Mediolateral
Mean peak force (N)			
Target	14.21	8.29	0.00
Target Zone	1.42	0.83	0.00
Actual	41.77	21.91	NaN
% time within Target Zone	0.00	0.00	NaN
% time above Target Zone	100.00	100.00	NaN
% time below Target Zone	0.00	0.00	NaN
Mean force amplitude (N)			
Target	11.67	6.66	0.00
Target Zone	14.51 - 8.83	8.32 - 5.00	0.00 - 0.00
Actual	22.44	11.38	0.00
% time within Target Zone	0.00	0.00	0.00
Oscillation frequency (Hz)			
Target	0.93		
Target Zone	0.28		
Actual	1.01		
%time within Target Zone	100.00		
%time above Target Zone	0.00		
%time below Target Zone	0.00		

Technique Name: C7 cen grd II (after) Date: 4/07/2007   Time:12:39 PM

	Vertical	Caudad-cephalad	Mediolateral
Mean peak force (N)			
Target	14.21	8.29	0.00
Target Zone	1.42	0.83	0.00
Actual	21.04	12.71	NaN
% time within Target Zone	0.00	0.00	NaN
% time above Target Zone	100.00	100.00	NaN
% time below Target Zone	0.00	0.00	NaN
Mean force amplitude (N)			
Target	11.67	6.66	0.00
Target Zone	14.51 - 8.83	8.32 - 5.00	0.00 - 0.00
Actual	16.67	8.92	0.00
% time within Target Zone	0.00	12.50	0.00
Oscillation frequency (Hz)			
Target	0.93		
Target Zone	0.28		
Actual	0.90		
%time within Target Zone	100.00		
%time above Target Zone	0.00		
%time below Target Zone	0.00		

Figure 10.4. Sample html file displaying terminal feedback.

(No mediolateral force was recorded for this technique.)

10.2.3 Testing

Accuracy

To ensure the accuracy of force readings, known weights were applied in the vertical, caudad-cephalad and mediolateral directions using similar procedures to those described in Chapter 3. A 5 kg weight was applied in each force direction. The force reading from the Labview software was compared to the reading from the Powerlab® Chart software by taking a simultaneous reading from the two outputs using two observers.

Application

Usability of the software was pilot tested with two physiotherapists who were experienced instructors in musculoskeletal physiotherapy, and a fourth year undergraduate student who had completed a musculoskeletal clinical placement of four weeks duration. Mobilisations to the spinous process of C7 were used for all trials of the software, as this was the spinal level intended for investigation of the efficacy of the software in student learning (described in Chapter 11). Target force levels were set by recording the forces applied by a qualified physiotherapist to the C7 vertebra of the asymptomatic subject who was to be mobilised by the physiotherapists or student participating in the testing. Thus for the purpose of this testing, the physiotherapists and student attempted to match the forces applied to their mobilised subject by another physiotherapist.

During initial trials with the two physiotherapists, concurrent feedback was provided for vertical forces and for oscillation frequency. For force, therapists viewed their own force curves while mobilising, received visual feedback for peak and trough force (red target bar when out of range), and audio feedback for peak force (beep when out of range). For oscillation frequency, feedback included the moving yellow bar representing current frequency and the target area turning red when the frequency was out of range. Physiotherapists were asked to try to remember what the ‘ideal’ force felt like when they were within the target range, and to reproduce this without looking at the screen after three sets of thirty second practice.

The two physiotherapists were cued by the operator to focus on the vertical force curve. Once they could consistently keep their force within the target zones, they were also asked to observe oscillation frequency. In addition, they were given terminal feedback from the information in the pop-up window after each recording of force. This included the percentage of time within the target ranges for peak force, force amplitude and oscillation frequency.

Following testing with the two physiotherapist instructors, the fourth year student participated in a trial of the software. All conditions were the same for the student, except changes were made to the amount and type of feedback provided. The student was cued to focus solely on the vertical force curve, and was given terminal feedback (in the pop-up window) only about the percentage of time his peak force and force amplitude were within the target zones.

10.3. Results

10.3.1 Development challenges

CPU overload

One initial problem with running the program was that it was collecting and interpreting such a large amount of data in real time that it was overloading the computer’s central processing unit (CPU). The program was usually using

80 to 100% of the CPU while it was running. When this usage exceeded 100%, it would delay the display of the oscillating force. After the delay, the computer would ‘catch up’ a few seconds later and several oscillations of force would appear on the screen simultaneously. This was quite disconcerting for the person mobilising and trying to interpret the feedback displayed. This problem was solved by placing timers within particular loops of the software program, so that different functions repeated their tasks with fewer cycles per second where this was appropriate. The functions in each loop of the program are designed to run as fast as possible. The timers slowed the loops so that they were not running any faster than the data was being collected (100 Hz), thus redundancy within the program was minimised. This reduced the total load per second on the CPU so usage ranged between 30 and 60% when the program was running, and when there was an occasional surge in CPU usage, it stayed under 100%.

Calculating terminal feedback for oscillation frequency

Some problems were also encountered with the calculations that determined one component of the terminal feedback for oscillation frequency. This component was the percentage of time during a recorded trial that a therapist was oscillating within the target frequency. The frequency calculation method for concurrent feedback (the yellow bar on the display panel) used the number of peaks over the previous ten seconds, updating in real-time at 100 Hz. It was not appropriate for calculating a percentage of time during a recorded trial. To determine this, the frequency at each time point during the trial needs to be known. Therefore to calculate this, the time between each individual peak during a trial was recorded. When this value was the correct length of time for the target oscillation frequency, this particular time period was considered within the target zone for frequency. The total amount of time within the target zone during a trial determined the percentage of time.

Using this calculation method, a problem also occurred if there was an erroneous peak detected due to a therapist not applying their oscillating peaks smoothly, or electrical noise in the system. An extra ‘peak’ between two consecutive peaks would cause the frequency calculation for that time period to double. To account for this, the programmer developed a method where both peaks and troughs would be identified in the program. Then, if more than one peak was detected between two troughs, one of these would be discarded so only a single peak would be used in the calculation of frequency. When two peaks were detected between consecutive troughs, the first peak in this time cycle was discarded. This was because in the pilot testing the majority of erroneous peaks that were detected occurred in the time between the trough and true peak (as the therapist presses posterior to anterior) rather than between the true peak and the next trough.

10.3.2 Testing

Accuracy

Tests with a 5 kg known weight indicated the force readings from the Labview program matched the force readings from the Powerlab Chart software in each force direction, to 0.1 N when read simultaneously by two observers.

Application of the software

During the mobilisation with feedback, the physiotherapists found it difficult to focus on both force and frequency at the same time, and forces became more inconsistent as they tried to adjust their frequency. Due to focussing so much on the computer screen rather than on their hands, it was difficult for therapists to recall what they had felt during mobilisation with concurrent feedback and to reproduce this force without feedback. Through these initial trials, it was decided that students in the proposed study (Chapter 11) should only focus on one component of the mobilisation, and this was to be the vertical peak force. By ignoring the feedback on frequency, a student would be able to better focus on the force applied.

Following testing with the student, the terminal feedback was further simplified. It was reduced to include only the percentage of time within the peak force target range. Terminal feedback on the percentage of time the force amplitude was within the target range distracted the student from focussing on being within the peak force target range. For example for a grade IV technique, his peak force was initially within the target zone 80% of the time, but his force amplitude was within the target zone 0% of the time because he was pulling his thumbs back away from the subject too much with each oscillation (i.e., his trough force value was too low, thus the force amplitude was too large). When trying to improve his percentage of time within the force amplitude target in the post-practice test, he applied his peak force too strongly and thus was within the peak force target 0% of the time. Having the terminal feedback about force amplitude seemed to place too much emphasis on it, distracting the student from the main aim of applying the correct peak force. The student also reported that the incorrect force amplitude was easily visible during the concurrent feedback and he was aware of it without needing the terminal feedback.

Therefore, information on force amplitude was omitted from the terminal feedback for the first formal investigation of the software's efficacy (Chapter 11).

10.4. Discussion

This chapter describes the development of a software program used to provide real-time feedback on mobilisation forces. It can provide feedback on the three mobilisation force parameters: peak force, amplitude and oscillation frequency, while displaying force in the vertical, caudad-cephalad and mediolateral force directions. Flexibility in the software program allows the operator to regulate the amount and timing of feedback provided, and to adjust these parameters as relevant to the learning task. This is because feedback about a single aspect or component of a complex task is considered more effective for improving performance than providing simultaneous information about multiple aspects of the task (Guadagnoli & Lee, 2004).

Previous investigations of feedback on manual forces applied to the lumbar or thoracic spines, or to devices designed to simulate them, indicate that practice with feedback is better than no formal practice (Lee et al., 1990; Triano, Rogers, Combs, Potts, & Sorrels, 2003) or practice without feedback (Descarreaux, Dugas, Lalanne, Vincelette, & Normand, 2006; Enebo & Sherwood, 2005; Triano et al., 2006) for improving force application. This supports the development of a system to provide students with feedback on manual forces during training. The literature is unclear, however, on the type, amount and frequency of feedback that is most effective for improving the application of manual forces.

10.4.1 Types of feedback for learning manual therapy

It appears that viewing a dial read-out of the manual force applied increases therapist consistency in lumbar PA force application when compared to applying PA forces without this feedback while using an agreed conceptual definition of force (Waddington & Adams, 2007). In addition, visual feedback (viewing the actual force curve) appears more effective than receiving feedback in the form of verbal knowledge of results (e.g. “too much force”, “pre-load was lost”) for improving accuracy in immediate retention tests of simulated thoracic manipulation thrusts applied to a device (Enebo & Sherwood, 2005). However, when visual feedback for simulated thoracic thrusts consisted of viewing a numerical output of force there was no difference in the accuracy of force application between visual feedback and verbal knowledge of results (“over”, “under”) in retention tests performed one, five or eight days after feedback sessions (Scaringe, Chen, & Ross, 2002). Furthermore, feedback consisting of the numerical spinal stiffness value in N/mm provided during stiffness assessment training did not improve students’ ability to judge stiffness when asked to do this by assigning a numerical value in N/mm to stiffness (Latimer, Lee, & Adams, 1996). These results suggest that viewing the force curve as provided in the current software, rather than a numerical output, may be the more effective form of feedback.

10.4.2 Software design

Because previous research on manual therapy skills has been inconclusive about the most effective type, amount and frequency of feedback for learning, the new software program is designed so these variables can be easily manipulated. The program is able to provide both concurrent and terminal feedback. Concurrent feedback includes the visual representation of the force curve and target bars for peak and trough force that change colour, along with an audio signal, when force is not accurate. Immediate terminal feedback includes the percentage of time within the target zone for vertical peak force. Additional terminal feedback can be provided, such as the mean peak force or the percentage of time force was above or below the target zones, by printing out the html file. Furthermore, a visual representation of the force curve recorded during the performance of a manual technique (jpeg snapshot of the recorded time period) can also be used for providing additional terminal feedback. The software is designed so that the operator, or manual therapy instructor, can select which of the forms of feedback and how much of each to provide.

In using the software for manual therapy training, an instructor can direct a student to focus on a particular aspect of the task, and can then set the software to provide feedback on only that portion of the task. This method of practice is supported by research in motor learning that indicates that focussing on part of a complex task during practice rather than all parts of the task improves performance, particularly for novices (Whitacre & Shea, 2000; Wulf & Shea, 2002). The new software has been designed to be an effective tool for teaching the complex task of spinal mobilisation, and incorporates flexibility so that parameters of feedback can be manipulated by the user. For the purposes of the present research, its effectiveness will be evaluated in the investigation of the effects of feedback on the performance of cervical mobilisation (Chapter 11).

10.5. Conclusion

The newly developed software program described in this chapter provides real-time feedback during mobilisation (Appendix 3.3, CD-ROM). It is designed so that the type, amount and timing of feedback can be adjusted by the user. Because of this flexibility, future studies can investigate which particular parameters of feedback are most effective for improving skills in mobilisation, including but not limited to cervical mobilisation.

CHAPTER 11. Improving skills in cervical mobilisation using feedback

11.1. Introduction

The research discussed in this thesis thus far has established that the cervical mobilisation forces applied by both physiotherapists and students vary widely. However, when individuals are asked to repeat a mobilisation technique, their forces are relatively consistent. This suggests that if therapists or students were trained to apply specific mobilisation forces using the same objective feedback, then consistency of application between practitioners might improve.

11.1.1 Objective feedback for learning manual therapy skills

The effectiveness of providing feedback about applied forces during manual therapy training has been previously investigated in various different contexts (Table 11.1). The majority of these studies involved chiropractic students practising a manipulation thrust task on an artificial device (Descarreaux et al., 2006; Enebo & Sherwood, 2005; Scaringe et al., 2002; Triano, Rogers, Combs, Potts, & Sorrels, 2002). The devices were designed to simulate techniques applied to either the lumbar (Triano et al., 2002) or thoracic spines (Descarreaux et al., 2006; Enebo & Sherwood, 2005; Scaringe et al., 2002). Improvements in thrusting force were evaluated either by applying force to the device (Descarreaux et al., 2006; Enebo & Sherwood, 2005; Scaringe et al., 2002), or by applying the practised technique to an asymptomatic subject (Triano et al., 2002).

Only two studies of chiropractic technique have provided feedback while students applied techniques to asymptomatic subjects (Pringle, 2004; Triano et al., 2006). One of these investigated manipulation of the lumbar spine (Triano et al., 2006) and the other evaluated 'prone spring testing' of the thoracic spine (Pringle, 2004). Prone spring testing involves applying a single oscillation of force using the hypothenar eminence of the hand. It appears similar to the oscillations of force applied by physiotherapists when they assess lumbar or thoracic spinal stiffness, except that only a single oscillation is applied.

For manual skills commonly used by physiotherapists, the effectiveness of feedback has been investigated for PA mobilisations applied to asymptomatic subjects (Lee et al., 1990; Waddington & Adams, 2007) and to devices (Chang, Chang, Chang Chien, Chung, & Hsu, 2007; Keating, Matyas, & Bach, 1993). Feedback for improving the accuracy of stiffness assessment in asymptomatic subjects has also been explored (Latimer, Lee, & Adams, 1996). These investigations into feedback aimed to improve manual treatment or assessment of the lumbar spine (Keating et al., 1993; Latimer, Lee, & Adams, 1996; Lee et al., 1990) or the glenohumeral joint (Chang et al., 2007). No studies examining the effects of feedback on manual forces applied to the cervical spine were identified in either the physiotherapy or chiropractic literature.

Table 11.1. Summary of studies investigating the effects of feedback on manual therapy skills.

Study	Subjects	Technique	Area	Measurement method	Investigations	Time to retention test	Findings
Lee et al. (1990)	53 physiotherapy students	Grade II PA mobilisation	Lumbar spine (L3)	Table on force platform	Compared 30 seconds of practice with feedback to no practice	1 week	Feedback group better than controls, and results retained over 1 week
Keating et al. (1993)	12 physiotherapists	PA mobilisation	Lumbar spine (therapist selected level)	Therapist standing on force platform	Compared daily training of applied forces on a bathroom scale over one month to no practice	One month after cessation of practice	Therapists who practiced on scales were able to apply specific forces on the lumbar spine; skills were retained over one month
Latimer at al. (1996)	4 physiotherapy students	PA stiffness assessment	Lumbar spine (L3)	Stiffness assessment device	Investigated whether feedback on the measured stiffness value would improve students ability to rate posteroanterior stiffness	2 days after 2.5 weeks of training (5 sessions)	Student stiffness rating did not improve with training
Scaringe et al. (2002)	71 chiropractic students	Thoracic manipulation (unilateral hypothenar transverse procedure)	Device	Piezoelectric film providing voltage readout	Compared quantitative (number readout) and qualitative (verbal 'over' or 'under') feedback	1, 5 or 8 days	No difference between types of feedback; retention was less when the time since practice greater
Triano et al. (2002)	39 chiropractic students	Manipulation (mammillary push)	Lumbar spine (L5)	Instrumented table	Compared daily practice of controlled forces on a Dynadjust device during a trimester with normal student practice without feedback	Tested at beginning, middle, and end of the trimester	Students who practised with Dynadjust feedback improved lumbar manipulation force parameters compared to controls

Table 11.1 (continued)

Study	Subjects	Technique	Area	Measurement method	Investigations	Time to retention test	Findings
Pringle (2004)	35 chiropractic students	Prone spring testing	Thoracic spine (spinal level not specified)	Instrumented table	Investigated effects of amount and frequency of feedback on ability to retain skills	1-2 weeks	Intermittent feedback results in better retention of skills compared with constant feedback
Enebo & Sherwood (2005)	33 chiropractic students	PA thoracic manipulation	Device	Load cell measurement on device	Compared visual feedback of force on computer screen with verbal feedback about force; also compared practice of different force parameters in blocks to practice with parameters randomised	10 retention trials over a semester	No difference between types of feedback, both increased accuracy; blocked practice better for immediate learning, but randomised practice better for retention of skills
Triano et al. (2006)	40 chiropractic students	Manipulation (mammillary push)	Lumbar spine (L4)	Instrumented table	Compared visual feedback of force curves to no feedback	10 minutes	Students who had feedback performed better than controls
Chang et al. (2007)	36 physiotherapy students	AP glenohumeral mobilisation	Device	Load cell within device	Compared concurrent and terminal feedback groups with a control group	10 minutes and 5 days	Both feedback groups performed better than controls; no difference between types of feedback
Waddington et al. (2007)	30 physiotherapists	Grade III PA mobilisation	Applied onto a plinth, no area specified	Digital scales	Compared the variance of forces applied with and without feedback from a hand-held dynamometer used during mobilisation	None	Less variance of applied force using the hand-held dynamometer

The previous research on the effectiveness of feedback for learning manual therapy skills suggests that practice with feedback is better than no practice when skills are evaluated either concurrently during feedback (Waddington & Adams, 2007) or immediately after feedback is given (Keating et al., 1993; Lee et al., 1990; Scaringe et al., 2002; Triano et al., 2006). Only a small number of studies have evaluated the retention of skills over time. These studies investigated physiotherapy students applying shoulder (Chang et al., 2007) or lumbar mobilisations (Lee et al., 1990), chiropractic students performing thoracic spine manipulation (Scaringe et al., 2002) or prone spring testing (Pringle, 2004), and physiotherapists applying lumbar mobilisations (Keating et al., 1993). All of these studies reported there was some retention of skills over one to two weeks following feedback, with Keating et al. (1993) reporting therapists were able to retain skills over one month. However, retention decreases over time. Scaringe et al. (2002) reported there was less retention of skills when students were tested at eight days after practice with feedback compared to one or five days.

11.1.2 Amount and timing of feedback

It is unclear whether there is a particular amount or timing of feedback that is most effective for improving manual therapy skills. A study that investigated chiropractic students' ability to apply accurate forces to the thoracic spine during prone spring testing provided verbal knowledge of results using standard phrases for specific force ranges that were within 0.5, 1.5 or > 1.5 SD of the mean applied force by an experienced chiropractor (Pringle, 2004). Students were divided into groups that received feedback for different numbers of trials during training. Providing feedback for 4 out of 12 trials was slightly more effective in retention tests than when feedback was given for either one or two trials, or after every trial. However, the differences between groups were not statistically significant. Another study that investigated students' ability to apply manual forces to a device simulating glenohumeral joint motion was also inconclusive about the timing of feedback (Chang et al., 2007). The accuracy of force application was greater for students who received either concurrent or terminal feedback compared with controls, but neither type of feedback was superior. As the previous literature was inconclusive about the most effective amount and timing of feedback for learning manual therapy skills, the present study design included both concurrent and terminal feedback.

11.1.3 Amount and sequence of practice

The amount of practice or training with feedback may affect therapists' or students' ability to reproduce manual forces during retention tests, although this has not been formally investigated. In one study where physiotherapists practised applying specific manual forces to bathroom scales daily for one month, their improved accuracy in applying these forces was retained at one month after cessation of training compared to controls (Keating et al., 1993). The authors reported the data indicated that therapists in the training group had achieved skill improvement within three to five days of training. In other studies, retention was tested immediately after training (Enebo & Sherwood, 2005) or daily practice (Triano et al., 2002), within 10 minutes of training (Triano et al., 2006), or about one week later (Chang et al., 2007; Lee et al., 1990; Pringle, 2004; Scaringe et al., 2002). All of these studies reported improvements in force application during retention tests by those who were trained using feedback, although the amount of training time varied between studies. In addition, two of these studies reported improvements in applying manual forces to an asymptomatic subject after training using a simulation device (Keating et al., 1993; Triano et al., 2002), so there is some evidence for the carry over of learning effects from simulated practice to the application of techniques on asymptomatic persons. Thus, it appears that the training effects of feedback on manual forces occur within a short time and can be potentially retained for at least one month and carried over to clinical skills, but no conclusion can be made about how much practice with feedback is necessary to achieve these outcomes.

In addition, the order of tasks during practice may affect the retention of skills. A study of practice with feedback compared applying a series of different levels of manual force for the same technique either one at a time (blocked practice) or in a randomised order (random practice) (Enebo & Sherwood, 2005). Students who participated in blocked practice applied manual forces more accurately during the learning phase, but those who participated in random practice performed better during retention tests. This is in agreement with motor learning research that has investigated simple tasks (Sekiya, Magill, & Anderson, 1996), but is in contrast to studies investigating more complex tasks (Jarus & Gutman, 2001; Wulf & Shea, 2002). As cervical spine mobilisation is a complex motor task, blocked practice may possibly be the most effective. Blocked practice of cervical mobilisation means practising one component (e.g., peak force) of the technique at a time, or practising one specific technique in a single session, such as a grade II central mobilisation to C7, without practising others.

11.1.4 Study objectives

The primary aim of this study was to investigate if students provided with real-time objective feedback on applied forces while learning cervical mobilisation could apply standardised forces when tested without feedback. Secondary aims were to determine if feedback improved the consistency of applied forces between students, and if learned skills could be retained over time.

11.2. Methods

The study design was a randomised controlled trial comparing the cervical mobilisation forces applied by one group of students who had received real-time objective feedback on their forces to those applied by another group who practised without feedback. Students' mobilisation forces were also recorded one week after receiving feedback to evaluate retention of mobilisation skills.

11.2.1 Feedback software

To measure manually applied forces, the instrumented treatment table described in Chapter 3 was used. Software was developed to provide a visual representation of cervical mobilisation forces in real-time, along with visual and audio feedback directing students to apply specific targeted forces. This software is described in detail in Chapter 10.

The software is able to provide visual or audio feedback about the three parameters of mobilisation force: mean peak force, force amplitude and oscillation frequency. In addition, it can simultaneously show information about force in each of the three planes: vertical, caudad-cephalad and mediolateral.

For this first study of the effectiveness of the software, students were instructed to focus on one component of force: the vertical mean peak force. This was done to simplify the task for the students, who had never performed cervical mobilisations in the clinical setting with some having only recently learned to apply cervical mobilisations. In addition, the forces recorded from therapists (reported in Chapter 6) indicated that forces are only applied in the vertical and caudad-cephalad directions when they perform the selected technique used for testing the software, the C7 central PA mobilisation. Furthermore, the vertical force component for C7 central mobilisations represents the majority of force applied for that technique.

11.2.2 Data collection

The study protocol was approved by the University's Human Research Ethics Committee. Physiotherapy students mobilised asymptomatic subjects who had been previously mobilised by a single physiotherapist expert. Students from years two and three of a four-year undergraduate physiotherapy program were recruited. Students had learned cervical mobilisation in the traditional manner which consisted of a lecture and a practical session including student practice of techniques on each other with instructor feedback. Students were taught to apply mobilisation techniques using the approach described by Maitland et al. (2005). To ensure consistency in their level of prior mobilisation training, students were eligible to participate only if they had not performed any cervical mobilisations in the clinical setting.

The physiotherapist expert had post-graduate qualifications in manipulative physiotherapy, 27 years clinical experience and used cervical mobilisation regularly in clinical practice. Because there is no available evidence at present to indicate the ideal forces to apply for particular spinal conditions, the forces applied by a single expert were used to determine the force targets. Asymptomatic subjects were recruited using notices posted around the university, and email announcements. They were eligible if they had not sought treatment for neck pain or headaches within the previous twelve months and had no contraindications to mobilisation, which included cancer, inflammatory diseases such as rheumatoid arthritis, infectious diseases affecting the neck, osteoporosis, symptoms of nerve root compromise, instability in the cervical spine, or potential vertebrobasilar insufficiency symptoms such as dizziness or double vision (Corrigan & Maitland, 1998). Asymptomatic subjects were used to avoid any potential confounding factors due to pain.

Prior to all mobilisation, the spinous process of C7 was marked by a single experienced physiotherapist researcher using standardised methods (Gross, Fetto et al., 2002; Palmer & Epler, 1998). The physiotherapist expert applied all four grades of mobilisation as described by Maitland et al. (2005) to the spinous process of C7 of each asymptomatic subject, while forces were recorded. From 10 seconds of the expert's recorded mobilisation, the following parameters were calculated: mean peak force, or the average of the force peaks, mean trough force, or the average of the points of lowest oscillation force, and oscillation frequency, or the rate of oscillation. Mean peak and trough forces were calculated for each direction. These data were used to program force targets for each grade of mobilisation for each individual asymptomatic subject.

All students who volunteered for the study attended two sessions of data collection approximately one week apart. In each session, students first performed ten seconds of mobilisation for one mobilisation grade as a pre-test without feedback, followed by three sets of 30 seconds of practice of that mobilisation grade either with or without feedback, followed by a ten second post-test without feedback. This was repeated for each mobilisation grade in randomised order.

Participating students were randomly allocated into an experimental group or a control group. Students in the experimental group were given feedback during the 30 second practice sets during the first data collection session, while controls performed the same practice without feedback. These roles were reversed for the second session of data collection, with the experimental group practising without feedback, and controls receiving feedback. Controls were given the opportunity to receive feedback due to ethical considerations in recruiting students. The experimental design is illustrated in Figure 11.1.

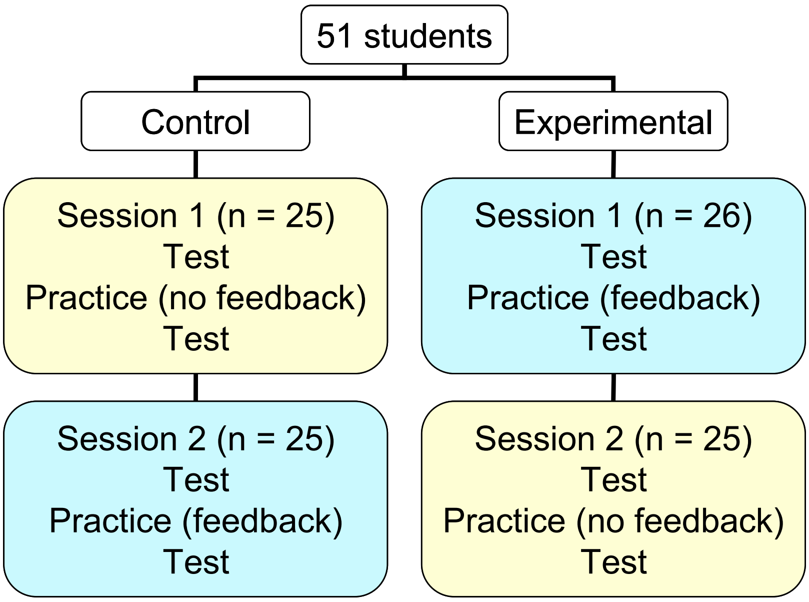

Figure 11.1. Experimental design.

When receiving feedback, the software provided both concurrent feedback (real-time while mobilising) and terminal feedback (after each 30 seconds of practice). Students were instructed to focus on only one component of force, the vertical peak force. Pilot testing suggested that it might be too difficult for novices to focus on multiple mobilisation force parameters, and previous research indicated that practising one component of a task was more effective for learning when the task was complex (Albaret & Thon, 1999; Hebert et al., 1996; Wulf et al., 2001). Students were given visual feedback in the form of a force curve with target bars for vertical peak and trough force which turned red when the force was not within the bars. They were also given auditory feedback (a beep) if the vertical peak force was not within its target bar. Each set of 30 seconds of practice was recorded so that students could receive terminal feedback about their performance in a pop-up window at the completion of each set. The force parameter used for terminal feedback was the percentage of time the peak force was within the target bar during the 30 seconds.

At the end of a session where a student was receiving feedback, they were shown a report containing data from the pre- and post-tests. The numerical data were explained to them, and their improvement after feedback was emphasised. Students were also asked to complete a survey to determine if they thought the activity was beneficial, and whether they found it either too challenging or too easy to achieve the target force ranges with the feedback provided (Appendix 2.4).

11.2.3 Data Analysis

To compare whether real-time feedback enables students to apply mobilisation forces more similar to an expert physiotherapist, the post-test data from the experimental (feedback) and control groups (no feedback) from the first session of data collection were compared. To determine whether students who received real-time feedback would continue to apply forces more similar to an expert after one week, data from the pre-test of the second session of data collection were used to compare the groups. The value used in each of these calculations was the absolute value of the difference in N between the student's vertical mean peak force and the expert's. All analyses of force used the vertical mean peak force, because that is the component of force that students were instructed to focus on while receiving feedback. Because the data was non-normal, median and inter-quartile ranges are reported and non-parametric statistics (Kruskall-Wallis or Wilcoxon signed ranks) were used. Outlier data was examined. Changes in inter-student repeatability of mobilisation grades as a result of feedback were determined using intra-class correlation coefficients (ICCs), using experimental group data from the pre- and post-tests of the first session of data collection and the pre-test from the second session. All calculations were performed in SPSS 15.0 (Chicago, IL, USA).

11.3. Results

Fifty-one students were recruited, 26 from year two and 25 from year three of the physiotherapy program, with 50 completing both sessions of data collection. They mobilised one of 21 asymptomatic subjects over a total of 101 30-minute minute mobilisation sessions. Asymptomatic subjects attended two to six sessions of data collection, and were mobilised by one student only at each session they attended.

Immediately after receiving feedback, students applied mobilisation forces that were more similar to the expert's target force (median difference between student and expert vertical mean peak force 4.0 N, IQR 1.9 to 7.7) than students who practised without feedback (14.3 N, IQR 6.2 to 26.2, $p < 0.001$, Table 11.2 and Figure 11.2).

When these results were stratified by grade, the feedback group applied forces more similar to the expert's forces for all grades except grade III (Table 11.2 and Figure 11.3). Increased variability in the forces applied for grade III techniques is the likely reason it did not reach statistical significance.

Table 11.2. Differences between student and expert forces after Session 1 practice.

Difference (N) between the expert's target force and the vertical mean peak force applied by the student immediately after practice for the experimental (feedback, n = 26) and control (no feedback, n = 25) groups.

Grade	**Median (IQR*)**		**p-value of the difference****
	No feedback	**Feedback**	
All grades	14.3 (6.2, 26.2)	4.0 (1.9, 7.7)	< 0.001
Grade I	10.0 (6.7, 15.7)	2.9 (1.4, 4.5)	< 0.001
Grade II	11.4 (6.6, 22.9)	2.9 (1.7, 6.0)	< 0.001
Grade III	14.3 (3.9, 37.0)	7.9 (4.1, 35.3)	0.060
Grade IV	20.8 (6.0, 37.8)	5.5 (3.1, 8.2)	0.003

*Inter-quartile range
**Kruskall-Wallis p-value for 'All grades' and Mann-Whitney U p-value for individual grades.

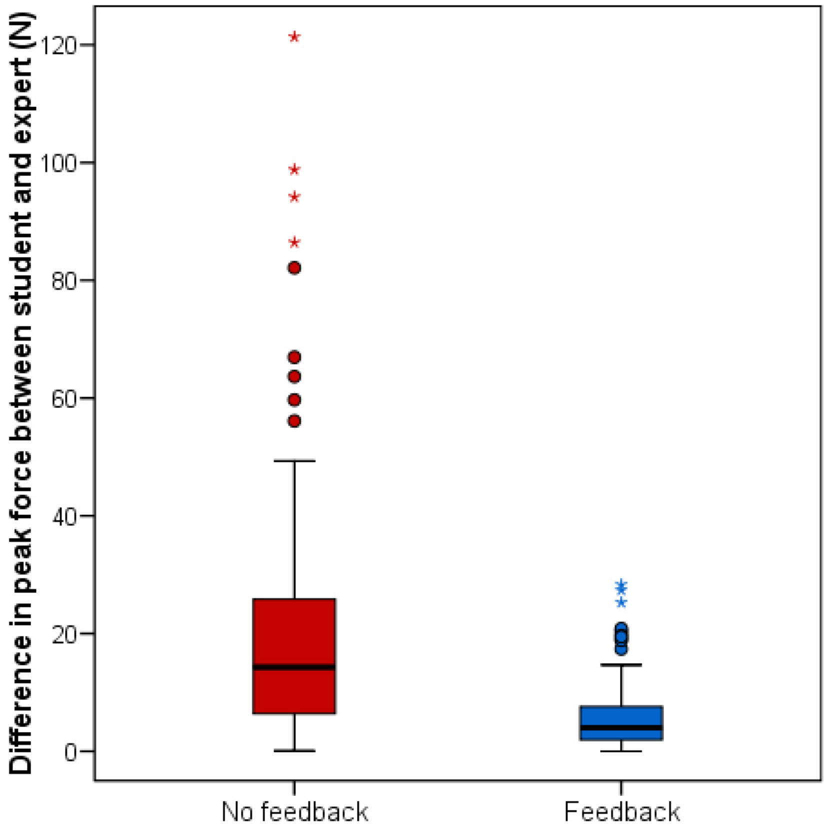

Figure 11.2. Feedback and control groups after Session 1 practice (all grades). Comparison of feedback and control groups for difference between student and expert applied vertical mean peak force immediately after feedback.

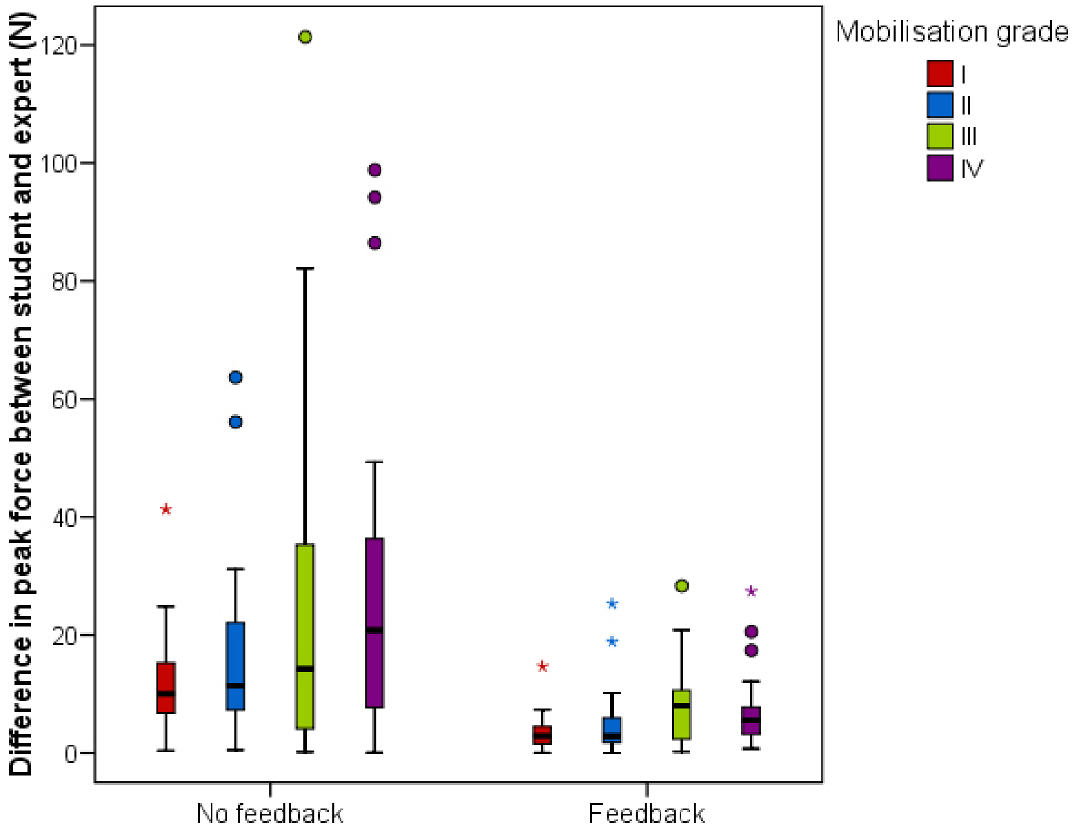

Figure 11.3. Feedback and control groups after Session 1 practice (by grade). Comparison of feedback and control groups for difference between student and expert applied vertical mean peak force immediately after feedback, stratified by grade.

One week later, students who had received feedback continued to apply forces more similar to the expert when compared to controls ($p < 0.01$, Table 11.3 and Figure 11.4).

However, they were not as accurate as they were immediately after feedback. When these results were stratified by grade, students receiving feedback were only significantly better than controls for grade I techniques ($p = 0.01$, Table 11.3 and Figure 11.5).

Table 11.3. Differences between student and expert forces one week after practice.

Difference (N) between the expert's target force and the vertical mean peak force applied by the student one week after their first practice session for the experimental (feedback, n = 25) and control (no feedback, n = 25) groups.

Grade	**Median (IQR*)**		**p-value of the difference****
	No feedback	**Feedback**	
All grades	11.2 (4.9, 18.5)	6.4 (5.0, 18.5)	0.008
Grade I	7.5 (3.3, 13.8)	3.9 (2.3, 6.5)	0.013
Grade II	7.4 (4.3, 12.6)	5.4 (2.7, 13.0)	0.204
Grade III	18.0 (8.0, 22.9)	10.7 (4.3, 21.1)	0.165
Grade IV	15.0 (7.7, 19.8)	13.7 (5.8, 18.9)	0.528

*Inter-quartile range
**Kruskall-Wallis p-value for 'All grades' and Mann-Whitney U p-value for individual grades.

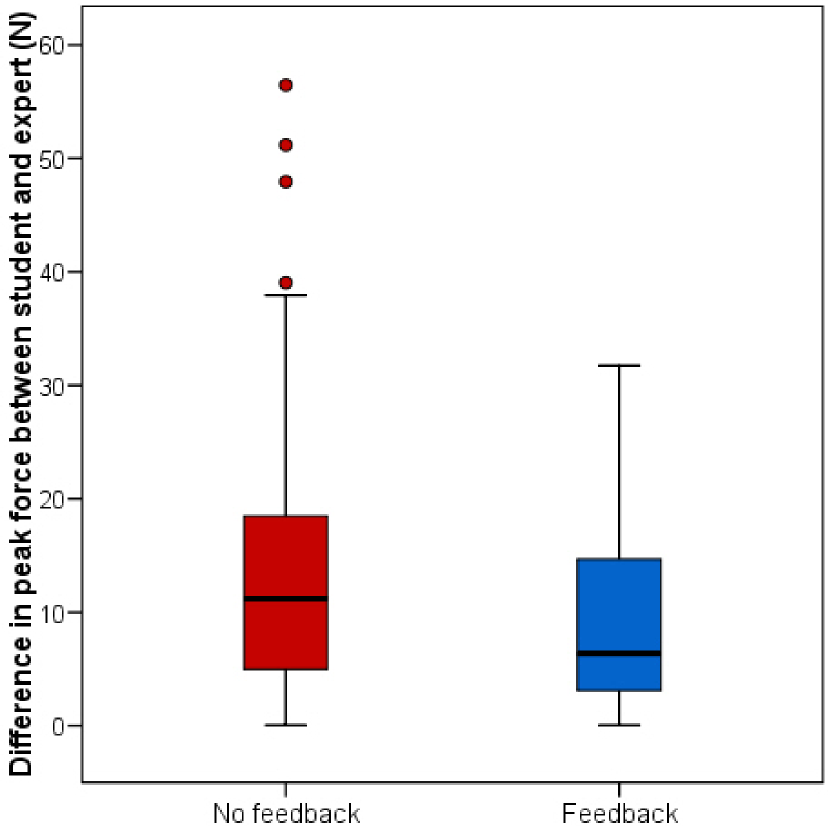

Figure 11.4. Feedback and controls groups one week after practice (all grades).

Comparison of feedback and control groups for difference between student and expert applied vertical mean peak force one week after practice.

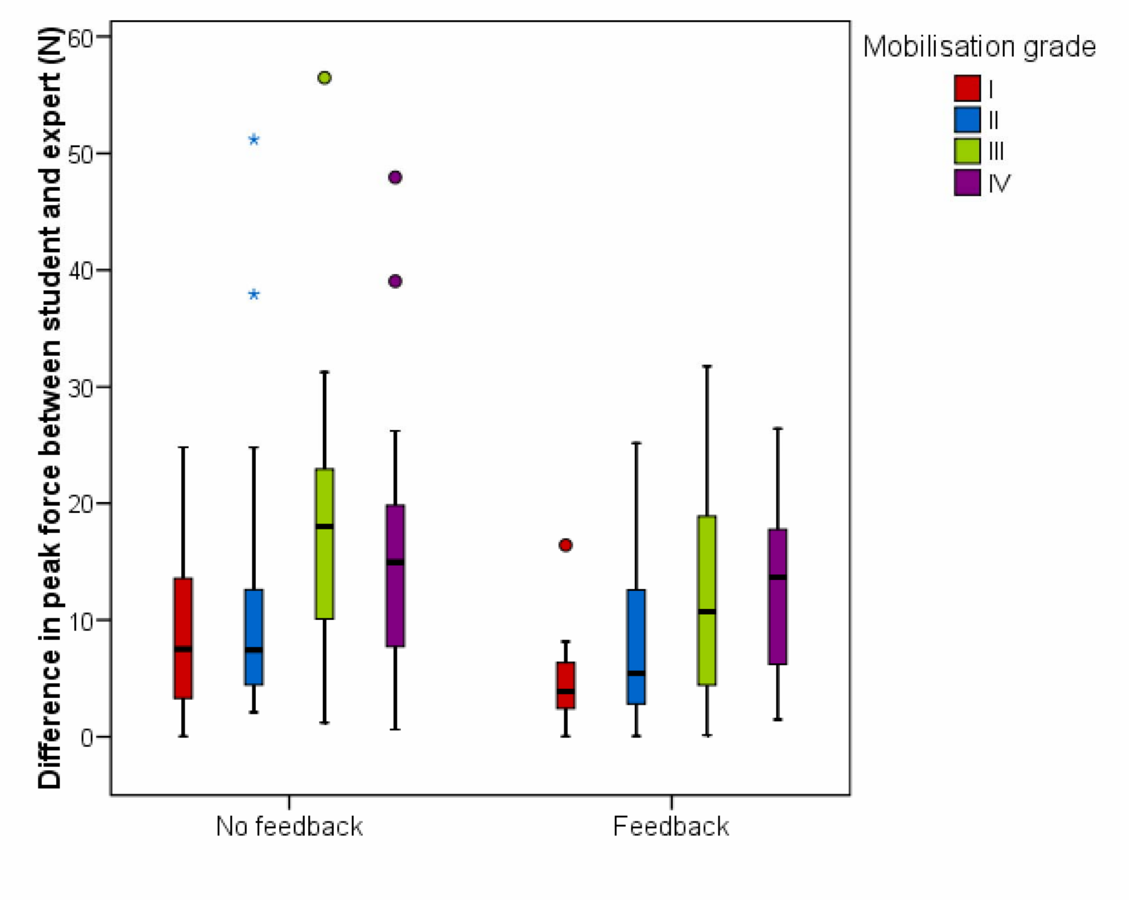

Figure 11.5. Feedback and controls groups one week after practice (by grade). Comparison of feedback and control groups for difference between student and expert applied vertical mean peak force one week after practice, stratified by grade.

Furthermore, there was a significant difference between the forces that the experimental group applied immediately after feedback and one week later (median difference between student and expert vertical mean peak force one week after feedback 6.4 N, IQR 3.1 to 14.7; compared to values reported for experimental group immediately after feedback, $p < 0.001$).

Inter-student repeatability of mobilisation grades improved after receiving feedback, as evaluated by ICCs calculated from experimental group data (Table 11.4).

Table 11.4. Inter-student repeatability of vertical mean peak force (feedback group).

Time point	**ICC (2,1)**	**95% CI**
Before feedback (n = 26)	0.45	0.19 to 0.92
Immediately after feedback (n = 26)	0.82	0.57 to 0.98
One week later (n = 25)	0.62	0.32 to 0.96

Prior to any feedback, there were seven occasions where the difference between the student's and the expert's force was greater than three inter-quartile ranges above the 75^{th} percentile, two from the feedback group and five from the control group. These outliers represented five students applying grade II, III and IV techniques. After feedback, all of these students were able to significantly reduce the difference between their applied force and that of the expert (Figure 11.6).

Forty-eight of the participating students (94% response rate) completed the survey. All respondents agreed or strongly agreed that participating in the feedback activity gave them a better understanding of the levels of manual force they should apply for each grade of mobilisation. The majority of students (93.7%) also agreed or strongly agreed that the activity helped them learn how to apply cervical mobilisation and that they felt more confident in their mobilisation abilities. The difficulty level of the activity appeared to be appropriate, with 60.4% of students reporting they found the challenge of staying within the target force range “just right: challenging, but I felt I could do this,” and 39.6% of students reporting the challenge was “difficult, but with practice I could probably do this.” The responses for difficulty level not selected by students were “too difficult” and “too easy”.

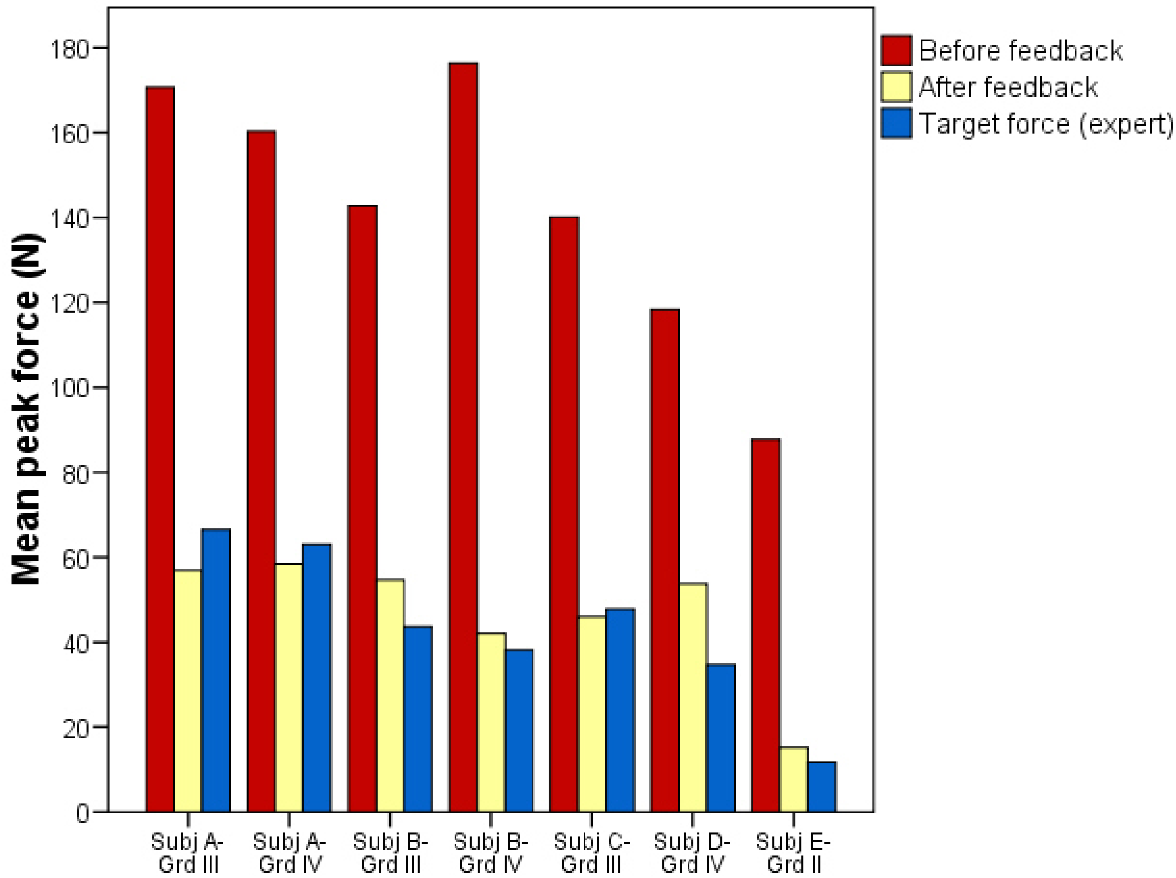

Figure 11.6. Improvement in applied force for outliers.

Improvements in vertical mean peak force (N) after feedback for mobilisation grades applied by five students on seven occasions that represented outliers on the first measurement of mobilisation.

11.4. Discussion

This study demonstrated that physiotherapy students can learn to apply cervical mobilisation with specific and consistent forces if provided with objective feedback about their forces. Students who received feedback applied mobilisation forces that were more similar to a physiotherapist expert than did controls. Furthermore, a difference between groups remained after one week, suggesting students who received feedback retained some of their improved skills. Variability in force between students applying the same mobilisation grade decreased after receiving feedback, even though force targets for individual mobilised subjects were slightly different. Students applying extremely high forces were able to modify their technique, and all those participating in the feedback activity reported it was beneficial for their learning. These results strongly support the inclusion of objective feedback in manual therapy skills training.

11.4.1 Practice and feedback

Practice is considered essential for learning new motor tasks, and when all other factors are constant, increased practice generally relates to improved skill acquisition (Guadagnoli & Lee, 2004). For more complex tasks, increased frequency of feedback appears more beneficial for motor performance than feedback given at intervals (Swinnen et al., 1997; Wulf, Shea et al., 1998). In the current study, students received feedback during and after each practice trial. Some studies on the retention of motor skills after practice have suggested that the retention of skills is less when feedback is given after every trial (Lai & Shea, 1998; Schmidt & Wulf, 1997). Learners become dependent on the feedback, and perform poorly during retention tasks when feedback is withdrawn. Other studies of more complex tasks, such as performing slalom-type movements on a ski simulator, indicate that giving feedback on 100% of trials is better than a reduced frequency of feedback when the motor skill is complex (Wulf, Shea et al., 1998). The current study showed that constant feedback was effective in changing how students applied cervical mobilisation forces and they were able to retain their skills. It is unknown whether student learning would have occurred or perhaps been more effective with reduced feedback. This will require further research.

In the current study, students focussed on the computer screen as an external cue used to adjust their applied force, and they practised one mobilisation grade at a time. This is consistent with previous research that indicates that using an external focus rather than concentrating on one's own limb movement increases accuracy during retention tasks (Riley et al., 1999; Wulf, Shea et al., 1998; Wulf et al., 2001), and practising one component of a complex task in repeated blocks is more effective for learning (Albaret & Thon, 1999; Hebert et al., 1996; Wulf & Shea, 2002). The current results suggest the computer-generated feedback was effective for learning cervical mobilisation, because students' forces improved with the feedback, and there was some retention of skills after one week.

11.4.2 Perceptions about feedback from participating students

Students participating in the feedback activity felt strongly that it helped them learn to apply cervical mobilisations. However, they found the activity challenging. Mobilising and adjusting manual forces in response to real-time feedback is a very complex task. Students must view the feedback, interpret it, and then adjust their manual force using tactile cues. Students reported it was especially difficult to perform mobilisations using the same forces after the feedback was withdrawn. They reported relying on the feedback while it was given rather than tactile cues. One student commented, “When applying forces with feedback, sometimes I concentrated on the feedback rather than what I was doing. You lose the ‘feel’ in your hands and just concentrate on the computer screen.” Nevertheless, students who had received the computer-generated feedback were able to apply mobilisation forces with reasonable accuracy when feedback was removed.

A number of students in the current study were initially applying extremely high mean peak cervical mobilisation forces compared to the physiotherapist expert. The highest of these was 176.4 N applied for a grade IV technique (Figure 11.6). This force was 138.2 N greater than the expert had applied to the same subject for the same technique. Although a relationship between the levels of manual force applied in vivo and potential harm to sensitive structures in the neck has not been established, some adverse effects following mobilisation have been reported (Magarey et al., 2004). Furthermore, the mean peak force applied during cervical manipulation (thrust technique) has been reported to be approximately 100 to 120 N, depending on the technique applied (Herzog et al., 1993; Kawchuk & Herzog, 1993). If manipulation can be considered as having some risk of injury to the vertebral artery (Haldeman et al., 2002; Terret, 2005), very high mobilisation forces may have risks as well. Therefore, it would appear that making students aware that their mobilisation forces differed greatly from the norm and enabling them to modify their forces is important.

11.4.3 Limitations

There are some limitations to the methods used in the current study. The instrumented table calculates the total forces applied to the table rather than the force applied at a particular joint. This means that students must consistently mobilise the same vertebral level with the mobilised subject’s cervical spine identically positioned each session to standardise their practice and for retention tasks to be meaningful. This was controlled by having a single physiotherapist researcher pre-mark the cervical vertebra and position the subject prior to mobilisation by the students. Also, students mobilised the same subject at each session. Using the instrumented table to calculate forces does, however, allow students to practice mobilisations as they would apply them to patients in a clinic, without any additional instrumentation between their hands and the mobilised subject.

Another limitation was the use of asymptomatic subjects for mobilisation practice, rather than patients with neck pain. This eliminated any confounding factors that might occur if a patient’s symptoms changed over time, but it may differ from mobilisation in the clinical setting. It is unknown whether the participating students would be able to apply forces as consistently when they begin to treat patients. There is some evidence for the carry over of mobilisation (Keating et al., 1993) and manipulation skills (Triano et al., 2002) learned during practice on simulation devices to performing those same skills on asymptomatic subjects. However, there were no studies identified that addressed whether manual therapy skills learned using feedback while practising on asymptomatic subjects could transfer to skill performance in the clinical setting.

This study demonstrated that physiotherapy students were able to apply cervical mobilisations consistently with a specific target peak force in the vertical force direction after one session of practice with objective feedback. However, when performing mobilisations, there are additional force parameters that also need to be consistent if mobilisations are to be identical between practitioners. These include the peak force in the caudad-cephalad and mediolateral force directions, the force amplitude in each direction and the oscillation frequency. The amount of practice with feedback needed to achieve accuracy for all force parameters is unknown.

11.5. Conclusion

Students learning cervical mobilisation are able to apply consistent standardised forces after practising with real-time objective feedback, and skills are largely retained over one week. This supports the inclusion of objective feedback in manual therapy training programs. Standardisation of cervical mobilisation forces between therapists will support future investigations to facilitate the consistency of mobilisation dosage, as well as the optimal forces to apply when treating the cervical spine in the clinical setting.

CHAPTER 12. Conclusions

This chapter summarises the major findings of the present thesis. These include the development of equipment for measuring mobilisation forces and cervical spine stiffness, and for providing real-time objective feedback of applied forces, the quantification of cervical mobilisation forces, and the assessment of the effectiveness of real-time feedback during cervical mobilisation training.

12.1. Outcomes of this research

12.1.1 Equipment development

This project has developed and rigorously tested objective methods of measuring cervical mobilisation forces applied by physiotherapists performing their usual clinical techniques. These methods consist of using an instrumented treatment table fitted with load cells measuring forces in three directions, with data collected, displayed and stored electronically. The instrumented table is a reliable tool for objectively quantifying cervical mobilisation forces.

In addition, the present thesis reports the development of a method for measuring cervical spine stiffness which has proven reliable and safe for in vivo use. This consists of instrumentation which applies a standardised force while simultaneously recording resistance to that force and the amount of movement of the spinal tissues. Further, this instrument enabled the quantification of cervical stiffness in normal individuals.

Another outcome of this research is the development of a tool to provide real-time objective feedback on mobilisation forces during the performance of usual clinical techniques. This proved to be a very useful device for students learning manual therapy, enabling them to apply predetermined mobilisation forces.

12.1.2 Quantification of cervical mobilisation forces

The results presented in this thesis describe the objective quantification of the manual forces applied to the cervical spine during mobilisation. Accounting for the wide range of forces therapists apply and the variability between therapists, forces were recorded from a large group of physiotherapists. This provides a clear representation of the forces applied by therapists working in musculoskeletal physiotherapy. In addition, this thesis includes a detailed analysis of the factors potentially affecting cervical mobilisation forces. This analysis indicates that multiple factors are associated with differences in applied forces between therapists, including some that are unrelated to the person being mobilised, such as a therapists' gender or training.

Furthermore, this thesis reports the quantification of cervical mobilisation forces applied by physiotherapy students. Comparison of the forces applied by physiotherapists and students provides insight into the ways that the application of techniques may change with clinical experience. For example, therapists use higher forces for grade III and IV mobilisations, but similar factors are associated with the magnitude of force for both groups. Knowledge about how students apply cervical mobilisation techniques may enable manual therapy instructors to develop strategies to improve the way students learn mobilisation techniques.

12.1.3 Real-time feedback in mobilisation training

This thesis also reports the effectiveness of using real-time objective feedback to teach students to apply cervical mobilisation forces in a specific manner as exemplified by a physiotherapist expert. Students were able to apply consistent forces that closely matched a target force applied by the expert, and students largely retained these skills over at least one week. This suggests that therapists may be able to apply more consistent cervical mobilisation forces if they were provided with the same objective feedback during training.

12.1.4 Experimental data outcomes

Cervical mobilisation forces applied by physiotherapists (Chapter 6)

Findings:

1. Physiotherapists apply cervical mobilisation forces that are essentially consistent with the description of the grades of mobilisation, as described by Maitland et al. (2005) and Grieve (1991).
2. The cervical mobilisation forces applied by physiotherapists vary widely between therapists with inter-therapist repeatability of forces low, but intra-therapist repeatability is high.
3. The following factors are associated with higher cervical mobilisation forces applied by physiotherapists: male gender of the therapist or mobilised subject, greater mobilised subject weight, and for grade II techniques, therapist interpretation of the mobilisation grade. The following factors are associated with lower applied forces: post-graduate training, greater C2 spinal stiffness, a history of thumb pain,

greater mobilised subject height, and the therapist having no upper limb symptoms from previous injuries.

Cervical mobilisation forces applied by physiotherapy students (Chapter 7)

Findings:

1. Physiotherapy students apply cervical mobilisation forces that are reasonably consistent with the description of the grades of mobilisation, as described by Maitland et al. (2005) and Grieve (1991).
2. The cervical mobilisation forces applied by physiotherapy students vary widely between students, similar to those applied by therapists. Intra-student repeatability of forces is considerably higher than inter-student, but is slightly less than intra-therapist repeatability for most force parameters.
3. The following factors are associated with higher cervical mobilisation forces applied by students: male gender of the student or mobilised subject, greater mobilised subject weight, greater C7 spinal stiffness, student in year two of the physiotherapy program, and increased frequency of thumb pain. The following factors are associated with lower applied forces: greater C2 spinal stiffness and the student having no upper limb symptoms from previous injuries.

Comparison of forces applied by therapists and students (Chapter 8)

Findings:

1. Students' forces are lower for grade III and IV techniques, and they use lower oscillation frequencies.

2. Most factors associated with cervical mobilisation forces are similar for students and physiotherapists. These include increased force applied by or to males, and to subjects with higher body weight, and decreased force applied when C2 stiffness is greater.
3. Factors associated with cervical mobilisation forces that are different for therapists and students include:
    a) Thumb pain factors: associated with less force applied by therapists and more for students
    b) Increased C7 spinal stiffness: associated with greater force applied by students, but no statistical relationship with forces applied by therapists.

Analysis of comments by mobilised subjects (Chapter 9)

Findings:

1. Higher cervical mobilisation forces are associated with decreased comfort for asymptomatic subjects.
2. Mobilised subject comments about the magnitude of applied force appear to be accurate.
3. At least some subjects being mobilised are able to identify subtle differences between mobilisation techniques, such as differences between grades and the consistency of mobilisation.

Effects of real-time objective feedback on cervical mobilisation forces applied by students (Chapter 11):

Findings:

1. Students who practice cervical mobilisation while receiving objective real-time feedback apply mobilisation forces that are more similar to

those of a physiotherapist expert than those applied by students who practice without feedback.

2. Students who receive objective real-time feedback on their cervical mobilisation forces continue, one week later, to apply forces more similar to those of an expert than students not receiving feedback.
3. For students receiving real-time feedback on cervical mobilisation forces, inter-student repeatability improves after receiving feedback.
4. Students who receive objective real-time feedback on their cervical mobilisation forces report increased understanding of the levels of forces to apply and increased confidence in performing cervical mobilisation.

12.2. Contributions to knowledge

12.2.1 Quantification of cervical mobilisation techniques

To clearly describe cervical mobilisation techniques, the most common form of manual therapy physiotherapists use when treating neck pain, the mechanical properties of the techniques must be quantified. Manual forces vary considerably when different therapists perform the same technique. This indicates that technique definition alone is not enough to accurately quantify a technique or ensure that it is being applied in a specific manner. Quantifying the mechanical properties of cervical mobilisation techniques in terms of force parameters enables therapists to authenticate the specific manual techniques they choose to use for cervical spine treatment.

The dissemination of findings about cervical mobilisation forces applied by physiotherapists equips them with knowledge about the levels of forces used. Awareness about the factors associated with cervical mobilisation forces provides some insight into possible biases that therapists may have when treating patients. For instance, greater force is usually applied to males regardless of spinal level mobilised, despite the association between gender and stiffness being weak or non-existent at some spinal levels. Increased awareness of the levels of forces usually applied and of the factors associated with forces will influence the way that therapists think about mobilisation techniques, guiding their manual treatment.

12.2.2 Use of real-time feedback for cervical mobilisation training

This research is the only work in the cervical spine that has investigated the ability of students to apply specific mobilisation forces when provided with real-time feedback. Previous studies of feedback during manual therapy training have focussed on lumbar mobilisation or thrust techniques, but none have investigated cervical spine mobilisation techniques. The results of the current research show that students, when provided with real-time feedback, can consistently apply specific forces and largely retain this ability after one week. This has major implications for teaching a range of manual therapy skills.

12.3. Future research

12.3.1 Strengthening the evidence for manual therapy with targeted treatments

Now that a reliable method for quantifying cervical mobilisation forces has been developed and the baseline quantification of mechanical force parameters completed, the next step is to quantify the most effective forces to use when treating patients with specific cervical spine disorders. The optimal levels of mobilisation force may be higher or lower than that applied to asymptomatic persons, but determining the forces applied to normal individuals provides a starting point for further investigating both students and therapists performing cervical mobilisation.

Establishing the optimal mobilisation forces for treating individual subgroups of patients will contribute to the evidence base for manual therapy. Treating patients with specific clinical presentations using targeted interventions is the aim of effective patient care. Being able to quantify specific mobilisation techniques is important and necessary for strengthening the evidence base to justify manual therapy treatment strategies. Quantification of techniques will enable more targeted treatment interventions, potentially resulting in improved patient outcomes.

12.3.2 Feedback and practice

The current research demonstrated that students improved their ability to apply cervical mobilisation forces after receiving real-time feedback. The focus was on the vertical mean peak force component, so it is not known how much feedback or practice would be necessary to improve the force amplitude and oscillation frequency components as well. In addition, different mobilisation techniques are applied at various angles to the spine, so force data from the three cardinal planes should also be utilised for providing feedback if physiotherapists are to learn to apply cervical mobilisation techniques consistently. This will require further studies investigating the amounts of feedback and practice that are necessary for therapists to achieve a uniform technique application for all force parameters. Achieving this would further strengthen future studies investigating cervical mobilisation.

12.4. Summary

Quantifying the forces applied during cervical mobilisation is a first step in systematically investigating the clinical outcomes of manual techniques. Identifying the factors affecting cervical mobilisation forces supports this approach and is expected to facilitate improved consistency between therapists. The ability to apply specific targeted mobilisation forces to the cervical spine following real-time feedback of applied forces means that, in future, therapists may be able to demonstrate they apply consistent mobilisation techniques with mechanical properties that are accurately defined. These results provide a basis for future investigations into which manual techniques are optimal for treating a range of cervical spine disorders.

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APPENDICES

Suzanne Snodgrass
PERFORMANCE OF CERVICAL SPINE MOBILISATION

APPENDIX 1. Copies of published work

1.1. Literature review

This published manuscript corresponds with the information in Chapter 2, Literature review.

The citation for this work is:

Snodgrass, S. J., Rivett, D. A., & Robertson, V. J. (2006). Manual forces applied during posterior to anterior spinal mobilisation: a review of the evidence. *Journal of Manipulative and Physiological Therapeutics, 29*(4), 316-329.
doi: 10.1016/j.jmpt.2006.03.006

1.2. Equipment development: Instrumented treatment table

This published manuscript corresponds with the information in Chapter 3, Equipment development: Instrumented treatment table.

The citation for this work is:

Snodgrass SJ, Rivett DA, Robertson VJ (2007). Calibration of an instrumented treatment table for measuring manual therapy forces applied to the cervical spine. *Manual Therapy*; in press, doi:10.1016/j.math.2007.04.002.

1.3. Equipment development: Stiffness assessment machine

This published manuscript corresponds with the information in Chapter 4, Equipment development: Stiffness assessment machine.

The citation for this work is:

Snodgrass SJ, Rivett DA, Robertson VJ. (2007). Measuring the posteroanterior stiffness of the cervical spine. *Manual Therapy*; in press, doi:10.1016/j.math.2007.07.007.

1.4. Pilot study

This published manuscript corresponds with the information in Chapter 5, Pilot study.

The citation for this work is:

Snodgrass, S. J., Rivett, D. A., & Robertson, V. J. (2007). Manual forces applied during cervical mobilization. *Journal of Manipulative and Physiological Therapeutics, 30*(1), 17-25. doi: 10.1016/j.jmpt.2006.11.008

1.5. Forces applied to the cervical spine during posteroanterior mobilization

This manuscript corresponds with the information in Chapter 6, Cervical mobilisation forces applied by physiotherapists. It has been submitted and is currently under review.

APPENDIX 2. Questionnaires

2.1. Questionnaire for physiotherapists (Chapter 6)

Please tick the appropriate box or fill in the blank as requested.

	Researcher use only Code________ Height________ Weight________
1. Age	___________
2. Gender	M ☐ F ☐
3. Are you right-handed or left-handed?	Right-handed ☐ Left-handed ☐
4. How often do you perform cervical passive accessory mobilisation techniques? (number of treatment sessions per week on average)	___________
5. Years of experience as a physiotherapist	___________
6. Years of experience performing manual therapy in clinical practice	___________
7. Area where you work:	Public hospital ☐ Private hospital ☐ Private clinic ☐ Other ☐

Please turn over →

8. Physiotherapy training (please list all formal qualifications including your initial qualification; do not list weekend professional development courses). Indicate if the training involved the learning of manual therapy skills by placing a tick in the box next to the title of the course:

Full title of course (tick box if course involved learning manual therapy)	Institution	Year completed
______________________ ☐	______________________	________
______________________ ☐	______________________	________
______________________ ☐	______________________	________
______________________ ☐	______________________	________

9. Have you ever had any work-related thumb pain?	Yes ☐ No ☐ (If no, please go to question 12)
10. How often have you experienced work-related thumb pain over the last 3 months?	☐ none ☐ rarely (between 1x/wk and 1x/month) ☐ sometimes (at least 1x/wk, not more than 3x/wk) ☐ regularly (more than 3x/wk, but not every working day) ☐ often (at least daily when working) ☐ very often (daily even if not working, with night pain) ☐ constant pain
11. Have you changed the way you perform cervical passive accessory mobilisations (as described by Maitland et al.) because of work-related thumb pain?	Yes ☐ No ☐
12. Have you had any upper limb injuries? If so, what injury? ______________________ When did it occur? ______________________ Do you still experience symptoms related to this injury? Please describe: ______________________________	Yes ☐ No ☐ (If no, please disregard the rest of this question)

Thank you for completing this section of the questionnaire.

13. Please tick the statement that describes how you would define the grades of mobilisation:	
Grade I	☐ Small amplitude movement near the start of the range. ☐ Other______________________________
Grade II	☐ Large amplitude movement that carries well into the range. It can occupy any part of the range that is resistance-free. ☐ Large amplitude movement which carries well into the range. It can occupy any part of the range, but does not reach the limit of range. ☐ Other______________________________
Grade III	☐ Large amplitude movement that moves into resistance or stiffness. ☐ Large amplitude movement that reaches the limit of range. ☐ Other______________________________
Grade IV	☐ Small amplitude movement stretching into resistance or stiffness. ☐ Small amplitude movement at the limit of range. ☐ Other______________________________

Thank you for completing this questionnaire.

2.2. Questionnaire for students (Chapter 7)

Please tick the appropriate box or fill in the blank as requested.

	Researcher use only Code________ Height________ Weight________
14. Age	__________
15. Gender	M ☐ F ☐
16. Year in the Physiotherapy program	__________
17. Are you right-handed or left-handed?	Right-handed ☐ Left-handed ☐
18. Have you ever had any thumb pain related to performing mobilisation techniques?	Yes ☐ No ☐ (If no, please go to question 7)
19. How often have you experienced thumb pain over the last 3 months?	☐ none ☐ rarely (only on 1 occasion while mobilising) ☐ sometimes (on 1 to 3 occasions when mobilising) ☐ regularly (most of the time when mobilising) ☐ often (every time you perform mobilisation) ☐ very often (daily even if not performing mobilisation, with night pain) ☐ constant pain
20. Have you had any upper limb injuries? If so, what injury? ____________________ When did it occur? ____________________ Do you still experience symptoms related to this injury? Please describe: __________________________________	Yes ☐ No ☐ (If no, please disregard the rest of this question)

Thank you for completing this section of the questionnaire.

21. Please tick the statement that describes how you would define the grades of mobilisation. ***There is no right or wrong answer for this question, make your choice based on what you were thinking while mobilising.*	
Grade I	☐ Small amplitude movement near the start of the range. ☐ Other____ ____
Grade II	☐ Large amplitude movement that carries well into the range. It can occupy any part of the range that is resistance-free. ☐ Large amplitude movement which carries well into the range. It can occupy any part of the range, but does not reach the limit of range. ☐ Other____ ____
Grade III	☐ Large amplitude movement that moves into resistance or stiffness. ☐ Large amplitude movement that reaches the limit of range. ☐ Other____ ____
Grade IV	☐ Small amplitude movement stretching into resistance or stiffness. ☐ Small amplitude movement at the limit of range. ☐ Other____ ____

Thank you for completing this questionnaire.

2.3. Questionnaire for mobilised subjects (Chapters 6 and 7)

Please tick the appropriate box or fill in the blank as requested.

		Researcher use only Code________ Height________ Weight________
Age		__________
Gender		M ☐ F ☐
How comfortable did you feel while receiving mobilisation from each physiotherapist? (*please place one mark on each line to indicate the level of comfort experienced during mobilisation from each individual physiotherapist*)		
Physio 1	Very comfortable ______________________________ Very uncomfortable	
Physio 2	Very comfortable ______________________________ Very uncomfortable	
Physio 3	Very comfortable ______________________________ Very uncomfortable	
Physio 4	Very comfortable ______________________________ Very uncomfortable	

Physio 6	Very comfortable Very uncomfortable ________________________________
Please add any comments you would like to make about the mobilisation you received from each *individual* physiotherapist:	
Physio 1	
Physio 2	
Physio 3	
Physio 4	
Physio 5	
Physio 6	

Thank you for completing this questionnaire.

2.4. Questionnaire for students receiving real-time objective feedback (Chapter 11)

Improving skills in cervical mobilisation

Student Survey on Mobilisation Feedback

1. This activity helped me to learn how to apply cervical mobilisation.
   - ☐ Strongly agree
   - ☐ Agree
   - ☐ Neutral
   - ☐ Disagree
   - ☐ Strongly disagree

2. By participating in this activity, I have a better understanding of the levels of manual force I should apply for each grade of cervical mobilisation.
   - ☐ Strongly agree
   - ☐ Agree
   - ☐ Neutral
   - ☐ Disagree
   - ☐ Strongly disagree

3. I feel more confident in my ability to apply cervical mobilisation to patients because of participating in this activity.
   - ☐ Strongly agree
   - ☐ Agree
   - ☐ Neutral
   - ☐ Disagree
   - ☐ Strongly disagree

4. While applying cervical mobilisation and viewing the real-time feedback, I found the challenge of staying within the target force range generally:
   - ☐ Too difficult: impossible to stay within the target range
   - ☐ Difficult: but with practice I could probably do this
   - ☐ Just right: challenging, but I felt I could do this
   - ☐ Too easy: always within the target range so I needed a more specific target

   Comments:

   ____

   ____

   ____

   ____

   ____

   ____

5. While applying cervical mobilisation and viewing the real-time feedback, I found the challenge of looking at one of the force components (eg. peak force), and adjusting my manual force in response to what I saw:
   ☐ Too difficult: impossible to stay within the target range
   ☐ Difficult: but with practice I could probably do this
   ☐ Just right: challenging, but I felt I could do this
   ☐ Too easy: always within the target range so I needed a more specific target

   Comments:
   ____
   ____
   ____
   ____
   ____

6. While applying cervical mobilisation and viewing the real-time feedback, I found the challenge of looking at multiple force components at the same time (eg. peak force and trough force) and adjusting my manual forces in response to what I saw:
   ☐ Too difficult: unable to process this information simultaneously
   ☐ Difficult: but with practice I could probably do this
   ☐ Just right: challenging, but I felt I could do this
   ☐ Easy: I could possibly process more information about force parameters

   Comments:
   ____
   ____
   ____
   ____
   ____

Please add any other comments you would like to make about this activity and its effect on your ability and confidence to apply cervical mobilisation.

____
____
____
____
____
____
____
____
____

APPENDIX 3. Software programs

3.1. IDL program for determining the linear region of the spinal stiffness curve

```
Pro corr_neck_dst
; First file is the force data with no body
 std_Pth='d:\modified volunteer text files\C7 files\'
 InF1=std_Pth+'\test with no force-C7 friction only.txt'          ; File of just friction
;
; F_Pth='d:\mod student vol text files\C2 stud files\'
; InF2=Dialog_Pickfile(filter='*.txt',path=F_pth)
 InF2=Dialog_Pickfile(filter='*.txt',path=std_pth)
; InF2='d:\wpdocs\research\suzanne_s\volunteer text files\vol2-session1-C2_mod.txt'
;
; *****************************************************
 cut_off=0.3       ; Linear part of the curve, based on sigma value.
; *****************************************************
 OpenR,u,InF1,/get_lun

 NPnts=0
 Num_pks=5                   ; Number of pulses on the stiffness machine
 a_pk_pnt=indgen(Num_pks)*100

 dst=0. & force=0.
 NPnts=file_lines(InF1)       ; Number of points in just friction file
 dNPnts=file_lines(InF2)
 NP=NPnts
 If (dNPnts lt NP) then NP=dNPnts

 f_arr=fltarr(NP)
 d_arr=fltarr(NP)

; Read distance and force data from Friction force only file
 OpenR,u,InF1,/get_lun
 For j=0,NP-1 do $
 Begin
  Readf,u,dst,force
  f_arr(j)=force
  d_arr(j)=dst
 end
 Close,u
 Free_Lun,u

; dNPnts=file_lines(InF2)
 df_arr=fltarr(NP)
 dd_arr=fltarr(NP)

; Read distance and force data from volunteer file
 OpenR,u,InF2,/get_lun
 For j=0,NP-1 do $
 Begin
  Readf,u,dst,force
  df_arr(j)=force
  dd_arr(j)=-dst
 end
```

```
 Close,u
 Free_Lun,u

 Device,decomposed=0
 Set_Plot,'win'
 !p.multi=[0,1,2,0]

; Window,0,title='no_body'
; Plot,-d_arr
; Plot,f_arr
; Window,1,title='with_body'
; Plot,dd_arr
; Plot,df_arr

 lag=indgen(n_elements(d_arr))-n_elements(d_arr)/2.0

 res_x=c_correlate(d_arr,dd_arr,lag)                ; C_Correlate with distance

; Window,4,title='Cross Correlation'
; Plot,lag,res_x

 pos=max(res_x,idx)
 Print,'Max Correlation at lag ',lag(idx)

 md_a=shift(d_arr,lag(idx))                     ; Shift to align the 2 series
; Test bit
; res=c_correlate(md_a,dd_arr,lag)                ; C_Correlate with distance
; pos=max(res,idx)
; Print,'Max Correlation at lag ',lag(idx)

 md_a=shift(f_arr,lag(idx)-1)                   ; Aligned friction force array

 np_a=intarr(num_pks)
 force_a=fltarr(num_pks,100)
 dist_a=fltarr(num_pks,100)

; crv=-1
; np=0
; thrsh=0.0001                           ; False trigger threshold for determining slope of
distance/time graph
; srch_w=5
;stop
; For i=0,n_elements(dd_arr)-2 do $
; Begin
;  diff=dd_arr(i+1)-dd_arr(i)
;  If diff gt thrsh Then $
;  Begin
;;   If crv eq -1 then pk_rng=abs(i-a_pk_pnt(crv+1)) else pk_rng=abs(i-a_pk_pnt(crv))
;   crv=fix(i/100)
;;   If (np eq 0) and (pk_rng lt srch_w) Then crv++
;   If (crv lt num_pks) Then $
;   Begin
;    force_a(crv,np)=df_arr(i)
;    dist_a(crv,np)=dd_arr(i)
;    np++
;    np_a(crv)=np
;   end
;  end else np=0
; end
```

```
For kk=0,Num_pks-1 do $
Begin
 force_a(kk,0:49)=df_arr(kk*100:kk*100+49)
 dist_a(kk,0:49)=dd_arr(kk*100:kk*100+49)
 np_a(0:4)=50
end

Window,5,xsize=420,ysize=700,title='Force vs Distance'
!p.charsize=2
!p.multi=[0,1,5,0]
For k=0,num_pks-1 do $
Begin
 Plot,dist_a(k,0:np_a(k)-1),force_a(k,0:np_a(k)-1),xtitle='Distance',ytitle='Force'
end
w_dist=fltarr(num_pks,50)
w_force=fltarr(num_pks,50)
w_np=intarr(5)

Lngth=10                    ; Min number of points to take for linear fit

npoint_reduction=10         ; Num points in from the end to anchor the linear fit

;stop
Window,6,xsize=450,ysize=700,title='Sigma'
For k=0,num_pks-1 do $
Begin
 err_fit=fltarr(np_a(k)-lngth)
 m=0
 For i=0,np_a(k)-lngth-1 do $
 Begin
  x=dist_a(k,i:np_a(k)-npoint_reduction)
  y=force_a(k,i:np_a(k)-npoint_reduction)
  x=reform(x)         ; Make these 1D arrays so I can search them later
  y=reform(y)
  N=np_a(k)-2-i
  res=linfit(x,y,sigma=gfit)
  mod_y=res(0)+res(1)*x
  err=sqrt(total((mod_y-y)^2)/float(N))
  err_fit(i)=err
 end                       ; End of one curve search for linear part
 idx=where(err_fit lt cut_off)
 pos=idx(0)
 If idx(0) lt 0 Then print,'WARNING: Linear Fit is greater than Threshold'
 w_np(k)=np_a(k)-pos
 w_dist(k,0:w_np(k)-1)=dist_a(k,pos:np_a(k)-1)
 w_force(k,0:w_np(k)-1)=force_a(k,pos:np_a(k)-1)
 plot,dist_a(k,0:np_a(k)-lngth-1),err_fit(0:np_a(k)-lngth-1)
end


!P.CharSize=1.2
Window,7,xsize=450,ysize=700,title='Linear Bits'
For m=0,num_pks-1 do $
Begin
 x=w_dist(m,0:w_np(m)-1)
 y=w_force(m,0:w_np(m)-1)
 res=linfit(x,y,sigma=gfit)
 mn=min(w_dist(m,0:w_np(m)-1))
 mx=max(w_force(m,0:w_np(m)-1))
```

```
  Plot,w_dist(m,0:w_np(m)-npoint_reduction),w_force(m,0:w_np(m)-
npoint_reduction),linestyle=1
  xyouts,mn,mx-5,'slope='+strtrim(string(res(1)/1000.),2)
  xyouts,mn,mx-
10,'x,y='+strtrim(string(w_dist(m,0)*1000.),2)+','+strtrim(string(w_force(m,0)),2)
 end

 Print,'Finished'
End
```

3.2. IDL program for calculating the spinal stiffness of a specified portion of the force-displacement curve

```
Pro corr_neck_segment
; First file is the force data with no body
 std_Pth='d:\mod student vol text files\C7 stud files\'
; std_Pth='d:\mod student vol text files\C2 stud files\'
 InF1=std_Pth+'C7-friction-new-mod.txt'   ; File of just friction

; These number are for C7 files
 St_Force=20
 En_Force=70

; These number are for C2 files
; St_Force=7
; En_Force=40
;
 F_Pth=std_Pth
 InF2=Dialog_Pickfile(filter='*.txt',path=F_pth)
; InF2='d:\wpdocs\research\suzanne_s\volunteer text files\vol2-session1-C2_mod.txt'
;
 OpenR,u,InF1,/get_lun

 NPnts=0
 Num_pks=5                    ; Number of pulses on the stiffness machine

 dst=0. & force=0.
 NPnts=file_lines(InF1)
 f_arr=fltarr(NPnts)
 d_arr=fltarr(NPnts)

; Read distance and force data from Friction force only file
 OpenR,u,InF1,/get_lun
 For j=0,NPnts-1 do $
 Begin
  Readf,u,dst,force
  f_arr(j)=force
  d_arr(j)=dst
 end
 Free_Lun,u

 dNPnts=file_lines(InF2)
 df_arr=fltarr(NPnts)
 dd_arr=fltarr(NPnts)
 If dNPnts gt NPnts then dNPnts=NPnts

; Read distance and force data from volunteer file
```

```
 OpenR,u,InF2,/get_lun
 For j=0,dNPnts-1 do $
 Begin
  Readf,u,dst,force
  df_arr(j)=force
  dd_arr(j)=-dst
 end
 Free_Lun,u

  Device,decomposed=0
 Set_Plot,'win'
 !p.multi=[0,1,2,0]

; Window,0,title='no_body'
; Plot,-d_arr
; Plot,f_arr
; Window,1,title='with_body'
; Plot,dd_arr
; Plot,df_arr

;stop
 lag=indgen(n_elements(d_arr))-n_elements(d_arr)/2.0

 res_x=c_correlate(d_arr,dd_arr,lag)                ; C_Correlate with distance

; Window,4,title='Cross Correlation'
; Plot,lag,res_x

 pos=max(res_x,idx)
 Print,'Max Correlation at lag ',lag(idx)

 md_a=shift(d_arr,lag(idx))                       ; Shift to align the 2 series
; Test bit
; res=c_correlate(md_a,dd_arr,lag)                ; C_Correlate with distance
; pos=max(res,idx)
; Print,'Max Correlation at lag ',lag(idx)

 md_a=shift(f_arr,lag(idx)-1)                     ; Aligned friction force array

 np_a=intarr(num_pks)
 force_a=fltarr(num_pks,100)
 dist_a=fltarr(num_pks,100)

 crv=-1
 np=0
 thrsh=0.00015                               ; False trigger threshold for determining slope of
distance/time graph
 For i=0,n_elements(dd_arr)-2 do $
 Begin
  diff=dd_arr(i+1)-dd_arr(i)
  If diff gt thrsh Then $
  Begin
   If np eq 0 Then crv++
   If (crv lt num_pks) Then $
   Begin
    force_a(crv,np)=df_arr(i)
    dist_a(crv,np)=dd_arr(i)
    np++
    np_a(crv)=np
   end
```

```
 end else np=0
end


Window,5,xsize=420,ysize=700,title='Force vs Distance'
!p.charsize=2
!p.multi=[0,1,5,0]
For k=0,num_pks-1 do $
Begin
 Plot,dist_a(k,0:np_a(k)-1),force_a(k,0:np_a(k)-1),xtitle='Distance',ytitle='Force'
 oPlot,[dist_a(k,0),dist_a(k,np_a(k)-1)],[St_Force,St_Force],linestyle=1
 oPlot,[dist_a(k,0),dist_a(k,np_a(k)-1)],[En_Force,En_Force],linestyle=1
end


err_fit=fltarr(num_pks)
slp_fit=fltarr(num_pks)
Print,'Posn(mm)    Start_Force   Posn(mm)   End_Force    Slope      Sigma         Posn(0)
Force(0)       Posn(End)    Force(End)'

For k=0,num_pks-1 do $
Begin
 tmp_f=reform(force_a(k,0:np_a(k)-1))
 tmp_x=reform(dist_a(k,0:np_a(k)-1))
 idx=where((tmp_f(0:np_a(k)-1) ge St_Force) and (tmp_f(0:np_a(k)-1) le En_force))
 x=tmp_x(idx)
 y=tmp_f(idx)
 N=n_elements(x)-1
 res=linfit(x,y,sigma=gfit)
 mod_y=res(0)+res(1)*x
 err=sqrt(total((mod_y-y)^2)/float(N))
 err_fit(k)=err
 slp_fit(k)=res(1)

Print,x(0)*1000.0,y(0),x(n)*1000.0,y(n),slp_fit(k)/1000.,err_fit(k),tmp_x(0)*1000.0,tmp_f(0),tmp
_x(np_a(k)-1)*1000.0,tmp_f(np_a(k)-1)
end                          ; End of one curve search for linear part


Print,'Finished'
End
```

3.3. Labview program for providing real-time feedback during cervical mobilisation

View visual panels of feedback screens and program documentation on attached CD-ROM.

APPENDIX 4. Additional statistical calculations for forces applied by physiotherapists

4.1. Specific comparisons of mobilisation techniques and grades (Physiotherapists, Chapter 6)

These calculations were used to determine differences and similarities between forces applied for different techniques and grades. The results of these analyses allowed for some techniques and grades to be grouped (Table 6.6) for the analysis of factors associated with manual forces.

4.1.1 Mean peak force

Comparison of mobilisation grades

Vertical force direction

Descriptives

Grade	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
I	464	24.78	18.56	23.09	26.48	-8.43	126.00
II	463	38.02	23.08	35.91	40.12	1.70	135.60
III	463	60.86	32.44	57.90	63.82	5.47	192.70
IV	463	70.42	37.48	67.00	73.84	5.46	219.80
Total	1853	48.51	34.04	46.96	50.06	-8.43	219.80

*missing values due to electrical noise obscuring some of the smaller values

Anova: $F[3,1849] = 242.03$, $p < 0.001$

Bonferroni post-hoc

Grade (I)	Grade (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
I	II	-13.31	1.89	.000	-18.31	-8.30
	III	-36.09	1.89	.000	-41.09	-31.09
	IV	-45.63	1.89	.000	-50.63	-40.63
II	I	13.31	1.89	.000	8.30	18.31
	III	-22.78	1.89	.000	-27.79	-17.78
	IV	-32.32	1.89	.000	-37.33	-27.32
III	I	36.09	1.89	.000	31.09	41.09
	II	22.78	1.89	.000	17.78	27.79
	IV	-9.54	1.89	.000	-14.54	-4.54
IV	I	45.63	1.89	.000	40.63	50.63
	II	32.32	1.89	.000	27.32	37.33
	III	9.54	1.89	.000	4.54	14.54

Caudad-cephalad force direction

Descriptives

Grade	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
I	464	8.52	9.46	7.66	9.38	-11.63	58.30
II	463	12.14	12.99	10.95	13.33	-9.74	74.19
III	463	19.44	20.63	17.55	21.32	-11.04	130.50
IV	463	22.44	24.31	20.22	24.66	-24.83	128.50
Total	1853	15.63	18.68	14.78	16.48	-24.83	130.50

*missing values due to electrical noise obscuring some of the smaller values

Anova: $F[3,1849] = 59.94$, $p < 0.001$

Bonferroni post-hoc

Grade (I)	Grade (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
I	II	-3.62	1.17	.012	-6.72	-.52
	III	-10.92	1.17	.000	-14.01	-7.82
	IV	-13.92	1.17	.000	-17.02	-10.83
II	I	3.62	1.17	.012	.52	6.72
	III	-7.30	1.17	.000	-10.40	-4.20
	IV	-10.30	1.17	.000	-13.40	-7.21
III	I	10.92	1.17	.000	7.82	14.01
	II	7.30	1.17	.000	4.20	10.40
	IV	-3.01	1.17	.063	-6.11	.09
IV	I	13.92	1.17	.000	10.83	17.02
	II	10.30	1.17	.000	7.21	13.40
	III	3.01	1.17	.063	-.09	6.11

Mediolateral force direction

Descriptives

Grade	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
I	463	2.57	3.84	2.22	2.92	-1.60	27.54
II	462	3.97	5.10	3.50	4.43	-2.52	27.57
III	461	7.10	8.91	6.29	7.92	-2.73	50.85
IV	462	8.47	10.49	7.51	9.43	-5.41	27.54
Total	1848	5.53	7.94	5.16	5.89	-5.41	66.09

*missing values due to electrical noise obscuring some of the smaller values

Anova: $F[3,1844] = 59.87$, $p < 0.001$

Bonferroni post-hoc

Grade (I)	Grade (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
I	II	-1.40	.50	.031	-2.72	-.08
	III	-4.53	.50	.000	-5.85	-3.22
	IV	-5.90	.50	.000	-7.22	-4.59
II	I	1.40	.50	.031	.08	2.72
	III	-3.14	.50	.000	-4.45	-1.82
	IV	-4.51	.50	.000	-5.82	-3.19
III	I	4.53	.50	.000	3.22	5.85
	II	3.14	.50	.000	1.82	4.45
	IV	-1.37	.50	.037	-2.69	-.05
IV	I	5.90	.50	.000	4.59	7.22
	II	4.51	.50	.000	3.19	5.82
	III	1.37	.50	.037	.05	2.69

Comparison of techniques (C2 central, C2 unilateral, C7 central and C7 unilateral)

Vertical force direction

Descriptives

Technique	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
C2 central	464	44.17	32.66	41.19	47.15	-8.43	219.80
C2 unilateral	461	43.06	29.96	40.32	45.81	.90	209.20
C7 central	464	55.33	37.91	51.87	58.79	-1.37	195.10
C7 unilateral	464	51.43	33.70	48.35	54.50	1.58	195.90
Total	1853	48.51	34.04	46.96	50.06	-8.43	219.80

*missing values due to electrical noise obscuring some of the smaller values

Anova: $F[3,1849] = 14.08$, $p < 0.001$

Bonferroni post-hoc tests

Technique (I)	Technique (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
C2 central	C2 unilateral	1.11	2.22	1.000	-4.74	6.96
	C7 central	-11.15	2.22	.000	-16.99	-5.31
	C7 unilateral	-7.25	2.22	.006	-13.09	-1.41
C2 unilateral	C2 central	-1.11	2.22	1.000	-6.96	4.74
	C7 central	-12.26	2.22	.000	-18.11	-6.41
	C7 unilateral	-8.36	2.22	.001	-14.22	-2.51
C7 central	C2 central	11.15	2.22	.000	5.31	16.99
	C2 unilateral	12.26	2.22	.000	6.41	18.11
	C7 unilateral	3.90	2.22	.468	-1.94	9.74
C7 unilateral	C2 central	7.25	2.22	.006	1.41	13.09
	C2 unilateral	8.36	2.22	.001	2.51	14.22
	C7 central	-3.90	2.22	.468	-9.74	1.94

Caudad-cephalad force direction

Descriptives

Technique	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
C2 central	464	4.38	5.35	3.89	4.87	-11.68	41.97
C2 unilateral	461	5.36	5.65	4.85	5.88	-7.09	57.24
C7 central	464	26.95	21.82	24.96	28.94	-24.83	128.50
C7 unilateral	464	25.76	19.92	23.95	27.58	-9.74	130.50
Total	1853	15.63	18.68	14.78	16.48	-24.83	130.50

*missing values due to electrical noise obscuring some of the smaller values

Anova: $F[3,1849] = 305.81$, $p < 0.001$

Bonferroni post-hoc tests

Technique (I)	Technique (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
C2 central	C2 unilateral	-.98	1.01	1.000	-3.64	1.67
	C7 central	-22.57	1.01	.000	-25.22	-19.92
	C7 unilateral	-21.38	1.01	.000	-24.03	-18.73
C2 unilateral	C2 central	.98	1.01	1.000	-1.67	3.64
	C7 central	-21.58	1.01	.000	-24.24	-18.93
	C7 unilateral	-20.40	1.01	.000	-23.05	-17.74
C7 central	C2 central	22.57	1.01	.000	19.92	25.22
	C2 unilateral	21.58	1.01	.000	18.93	24.24
	C7 unilateral	1.18	1.01	1.000	-1.47	3.84
C7 unilateral	C2 central	21.38	1.01	.000	18.73	24.03
	C2 unilateral	20.40	1.01	.000	17.74	23.05
	C7 central	-1.18	1.01	1.000	-3.84	1.47

Mediolateral force direction

Descriptives

Technique	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
C2 central	464	1.47	2.82	1.22	1.73	-2.52	27.57
C2 unilateral	457	8.18	9.32	7.32	9.03	-5.41	66.09
C7 central	464	2.91	3.61	2.58	3.24	-.96	27.28
C7 unilateral	463	9.59	9.91	8.68	10.50	-4.77	63.96
Total	1848	5.53	7.94	5.16	5.89	-5.41	66.09

*missing values due to electrical noise obscuring some of the smaller values

Anova: $F[3,1844] = 140.50$, $p < 0.001$

Bonferroni post-hoc tests

Technique (I)	Technique (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
C2 central	C2 unilateral	-6.70	.47	.000	-7.95	-5.46
	C7 central	-1.44	.47	.014	-2.68	-.20
	C7 unilateral	-8.12	.47	.000	-9.36	-6.87
C2 unilateral	C2 central	6.70	.47	.000	5.46	7.95
	C7 central	5.27	.47	.000	4.02	6.51
	C7 unilateral	-1.41	.47	.017	-2.66	-.16
C7 central	C2 central	1.44	.47	.014	.20	2.68
	C2 unilateral	-5.27	.47	.000	-6.51	-4.02
	C7 unilateral	-6.68	.47	.000	-7.92	-5.43
C7 unilateral	C2 central	8.12	.47	.000	6.87	9.36
	C2 unilateral	1.41	.47	.017	.16	2.66
	C7 central	6.68	.47	.000	5.43	7.92

Comparison of central versus unilateral techniques

Vertical force direction

Descriptives

Position	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
central	928	49.75	35.80	47.44	52.06	-8.43	219.80
unilateral	925	47.26	32.15	45.18	49.33	0.90	209.20
Total	1853	48.51	34.04	46.96	50.06	-8.43	219.80

*missing values due to electrical noise obscuring some of the smaller values

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
1.58	18.51	.115	2.49	-0.61	5.59

Caudad-cephalad force direction

Descriptives

Position	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
central	928	15.66	19.48	14.41	16.92	-24.83	128.50
unilateral	925	15.60	17.86	14.44	16.75	-9.74	130.50
Total	1853	15.63	18.68	14.78	16.48	-24.83	130.50

*missing values due to electrical noise obscuring some of the smaller values

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
2.30	1851	.937	0.07	-1.63	1.77

Mediolateral force direction

Descriptives

Position	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
central	928	2.19	3.32	1.98	2.41	2.52	27.57
unilateral	920	8.89	9.64	8.26	9.51	5.41	66.09
Total	1853	5.53	7.94	5.16	5.89	5.41	66.09

*missing values due to electrical noise obscuring some of the smaller values

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
19.92	1846	.000	6.70	6.04	7.35

Comparison of forces applied to the upper versus lower cervical spine

Vertical force direction

Descriptives

Position	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
Upper (C2)	925	43.62	31.33	41.60	45.64	-8.43	219.80
Lower (C7)	928	53.38	35.90	51.06	55.69	-1.37	195.90
Total	1853	48.51	34.04	46.96	50.06	-8.43	219.80

*missing values due to electrical noise obscuring some of the smaller values

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
6.23	1851	.000	9.76	6.69	12.83

Caudad-cephalad force direction

Descriptives

Position	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
Upper (C2)	925	4.87	5.52	4.51	5.23	-11.68	57.24
Lower (C7)	928	26.36	20.89	25.01	27.70	-24.83	130.50
Total	1853	15.63	18.68	14.78	16.48	-24.83	130.50

*missing values due to electrical noise obscuring some of the smaller values

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
30.25	1851	.000	21.48	20.09	22.88

Mediolateral force direction

Descriptives

Position	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
Upper (C2)	921	4.80	7.63	4.31	5.29	5.41	66.09
Lower (C7)	927	6.25	8.17	5.72	6.77	4.77	63.96
Total	1848	5.53	7.94	5.16	5.89	5.41	66.09

*missing values due to electrical noise obscuring some of the smaller values

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
3.94	1846	.000	1.45	0.73	2.17

4.1.2 Force amplitude

Comparison of mobilisation grades

Vertical force direction

Descriptives

Grade	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
I	464	16.22	12.88	15.04	17.39	1.39	89.56
II	463	27.69	17.92	26.05	29.32	1.87	132.50
III	463	44.56	26.52	42.14	46.98	3.35	169.60
IV	463	35.80	26.32	33.39	38.20	2.24	211.30
Total	1853	31.06	24.06	29.96	32.15	1.39	211.30

*missing values due to electrical noise obscuring some of the smaller values

Anova: $F[3, 1849] = 143.29$, $p < 0.001$

Bonferroni post-hoc

Grade (I)	Grade (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
I	II	-11.47	1.43	.000	-15.23	-7.71
	III	-28.34	1.43	.000	-32.11	-24.58
	IV	-19.58	1.43	.000	-23.34	-15.82
II	I	11.47	1.43	.000	7.71	15.23
	III	-16.88	1.43	.000	-20.64	-13.11
	IV	-8.11	1.43	.000	-11.88	-4.35
III	I	28.34	1.43	.000	24.58	32.11
	II	16.88	1.43	.000	13.11	20.64
	IV	8.76	1.43	.000	5.00	12.53
IV	I	19.58	1.43	.000	15.82	23.34
	II	8.11	1.43	.000	4.35	11.88
	III	-8.76	1.43	.000	-12.53	-5.00

Caudad-cephalad force direction

Descriptives

Grade	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
I	464	5.26	5.50	4.76	5.76	.63	43.87
II	463	8.17	8.58	7.38	8.95	-2.63	72.11
III	463	13.24	14.60	11.90	14.57	.75	96.43
IV	463	10.51	12.06	9.41	11.61	.75	81.68
Total	1853	9.29	11.14	8.78	9.80	-2.63	96.43

*missing values due to electrical noise obscuring some of the smaller values

Anova: $F[3, 1849] = 46.25$, $p < 0.001$

Bonferroni post-hoc

Grade (I)	Grade (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
I	II	-2.907	.71	.000	-4.77	-1.04
	III	-7.98	.71	.000	-9.84	-6.11
	IV	-5.25	.71	.000	-7.12	-3.39
II	I	2.91	.71	.000	1.04	4.77
	III	-5.07	.71	.000	-6.94	-3.21
	IV	-2.35	.71	.006	-4.21	-.48
III	I	7.98	.71	.000	6.11	9.84
	II	5.07	.71	.000	3.21	6.94
	IV	2.73	.71	.001	.86	4.59
IV	I	5.25	.71	.000	3.39	7.12
	II	2.35	.71	.006	.48	4.21
	III	-2.73	.71	.001	-4.59	-.86

Mediolateral force direction

Descriptives

Grade	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
I	463	2.33	2.59	2.10	2.57	.45	18.93
II	462	3.83	4.38	3.43	4.23	.54	33.57
III	461	6.35	7.51	5.66	7.03	.44	48.76
IV	462	5.60	6.47	5.00	6.19	.46	42.32
Total	1848	4.52	5.78	4.26	4.79	.44	48.76

*missing values due to electrical noise obscuring some of the smaller values

Anova: $F[3, 1844] = 48.49$, $p < 0.001$

Bonferroni post-hoc

Grade (I)	Grade (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
I	II	-1.49	.37	.000	-2.46	-.53
	III	-4.01	.37	.000	-4.98	-3.05
	IV	-3.26	.37	.000	-4.23	-2.30
II	I	1.49	.37	.000	.53	2.46
	III	-2.52	.37	.000	-3.49	-1.55
	IV	-1.77	.37	.000	-2.74	-.80
III	I	4.01	.37	.000	3.05	4.98
	II	2.52	.37	.000	1.55	3.49
	IV	.75	.37	.247	-.22	1.72
IV	I	3.26	.37	.000	2.30	4.23
	II	1.77	.37	.000	.80	2.74
	III	-.75	.37	.247	-1.72	.22

Comparison of techniques (C2 central, C2 unilateral, C7 central and C7 unilateral)

Vertical force direction

Descriptives

Technique	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
C2 central	464	30.44	25.41	28.12	32.75	1.39	211.30
C2 unilateral	461	28.29	21.00	26.37	30.21	1.79	116.00
C7 central	464	33.99	25.91	31.62	36.35	1.66	178.90
C7 unilateral	464	31.50	23.33	29.37	33.62	1.70	163.40
Total	1853	31.06	24.06	29.96	32.15	1.39	211.30

*missing values due to electrical noise obscuring some of the smaller values

Anova: $F[3, 1849] = 4.51$, $p = 0.004$

Bonferroni post-hoc tests

Technique (I)	Technique (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
C2 central	C2 unilateral	2.14	1.58	1.000	-2.02	6.31
	C7 central	-3.55	1.58	.145	-7.71	.61
	C7 unilateral	-1.06	1.58	1.000	-5.22	3.10
C2 unilateral	C2 central	-2.14	1.58	1.000	-6.31	2.02
	C7 central	-5.70	1.58	.002	-9.87	-1.53
	C7 unilateral	-3.21	1.58	.254	-7.37	.96
C7 central	C2 central	3.55	1.58	.145	-.61	7.71
	C2 unilateral	5.70	1.58	.002	1.53	9.87
	C7 unilateral	2.49	1.58	.682	-1.67	6.65
C7 unilateral	C2 central	1.06	1.58	1.000	-3.10	5.22
	C2 unilateral	3.21	1.58	.254	-.96	7.37
	C7 central	-2.49	1.58	.682	-6.65	1.67

Caudad-cephalad force direction

Descriptives

Technique	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
C2 central	464	3.90	2.95	3.63	4.17	.64	26.01
C2 unilateral	461	4.15	3.40	3.84	4.47	-2.63	25.89
C7 central	464	14.70	13.60	13.46	15.94	.76	96.43
C7 unilateral	464	14.38	13.43	13.15	15.60	.77	84.36
Total	1853	9.29	11.14	8.78	9.80	-2.63	96.43

*missing values due to electrical noise obscuring some of the smaller values

Anova: $F[3, 1849] = 176.89$, $p < 0.001$

Bonferroni post-hoc tests

Technique (I)	Technique (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
C2 central	C2 unilateral	-.26	.65	1.000	-1.96	1.45
	C7 central	-10.80	.65	.000	-12.50	-9.10
	C7 unilateral	-10.48	.65	.000	-12.18	-8.78
C2 unilateral	C2 central	.26	.65	1.000	-1.45	1.96
	C7 central	-10.54	.65	.000	-12.25	-8.84
	C7 unilateral	-10.22	.65	.000	-11.93	-8.52
C7 central	C2 central	10.80	.65	.000	9.10	12.50
	C2 unilateral	10.54	.65	.000	8.84	12.25
	C7 unilateral	.32	.65	1.000	-1.38	2.02
C7 unilateral	C2 central	10.48	.65	.000	8.78	12.18
	C2 unilateral	10.22	.65	.000	8.52	11.93
	C7 central	-.32	.65	1.000	-2.02	1.38

Mediolateral force direction

Descriptives

Technique	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
C2 central	464	1.63	1.12	1.53	1.74	.44	9.29
C2 unilateral	457	6.80	6.84	6.17	7.43	.48	47.35
C7 central	464	2.37	2.29	2.16	2.58	.50	16.68
C7 unilateral	463	7.33	7.40	6.65	8.00	.60	48.76
Total	1848	4.52	5.78	4.26	4.79	.44	48.76

*missing values due to electrical noise obscuring some of the smaller values

Anova: $F[3, 1844] = 148.87$, $p < 0.001$

Bonferroni post-hoc tests

Technique (I)	Technique (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
C2 central	C2 unilateral	-5.17	.34	.000	-6.07	-4.26
	C7 central	-.74	.34	.187	-1.64	.16
	C7 unilateral	-5.69	.34	.000	-6.59	-4.79
C2 unilateral	C2 central	5.17	.34	.000	4.26	6.07
	C7 central	4.43	.34	.000	3.53	5.33
	C7 unilateral	-.52	.34	.753	-1.43	.38
C7 central	C2 central	.74	.34	.187	-.16	1.64
	C2 unilateral	-4.43	.34	.000	-5.33	-3.53
	C7 unilateral	-4.96	.34	.000	-5.86	-4.06
C7 unilateral	C2 central	5.69	.34	.000	4.79	6.59
	C2 unilateral	.52	.34	.753	-.38	1.43
	C7 central	4.96	.34	.000	4.06	5.86

Comparison of central versus unilateral techniques

Vertical force direction

Descriptives

Position	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
central	928	32.21	25.71	30.56	33.87	1.39	211.30
unilateral	925	29.90	22.24	28.46	31.33	1.70	163.40
Total	1853	31.06	24.06	29.96	32.15	1.39	211.30

*missing values due to electrical noise obscuring some of the smaller values

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
2.07	1851	.038	2.31	0.12	4.50

Caudad-cephalad force direction

Descriptives

Position	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
central	928	9.30	11.22	8.58	10.02	.64	96.43
unilateral	925	9.28	11.06	8.57	10.00	-2.63	84.36
Total	1853	9.29	11.14	8.78	9.80	-2.63	96.43

*missing values due to electrical noise obscuring some of the smaller values

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
0.03	1851	.976	0.02	-1.00	1.03

Mediolateral force direction

Descriptives

Position	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
central	928	2.00	1.84	1.88	2.12	.44	16.68
unilateral	920	7.06	7.13	6.60	7.53	.48	48.76
Total	1848	4.52	5.78	4.26	4.79	.44	48.76

*missing values due to electrical noise obscuring some of the smaller values

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
20.86	1846	.000	5.06	4.59	5.54

Comparison of forces applied to the upper versus lower cervical spine

Vertical force direction

Descriptives

Position	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
Upper (C2)	925	29.37	23.33	27.86	30.87	1.39	211.30
Lower (C7)	928	32.74	24.67	31.15	34.33	1.66	178.90
Total	1853	31.06	24.06	29.96	32.15	1.39	211.30

*missing values due to electrical noise obscuring some of the smaller values

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
3.03	1851	.003	3.38	1.19	5.56

Caudad-cephalad force direction

Descriptives

Position	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
Upper (C2)	925	4.03	3.18	3.82	4.23	-2.63	26.01
Lower (C7)	928	14.54	13.51	13.67	15.41	.76	96.43
Total	1853	9.29	11.14	8.78	9.80	-2.63	96.43

*missing values due to electrical noise obscuring some of the smaller values

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
23.07	1851	.000	10.51	9.62	11.41

Mediolateral force direction

Descriptives

Position	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
Upper (C2)	921	4.20	5.52	3.84	4.56	.44	47.35
Lower (C7)	927	4.84	6.01	4.46	5.23	.50	48.76
Total	1848	4.52	5.78	4.26	4.79	.44	48.76

*missing values due to electrical noise obscuring some of the smaller values

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
2.41	1846	.016	0.65	0.12	1.17

4.1.3 Oscillation frequency

Comparison of mobilisation grades

Descriptives

Grade	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
I	463	1.30	.50	1.26	1.35	.26	2.88
II	463	1.19	.45	1.15	1.23	.31	2.65
III	463	1.11	.459	1.07	1.15	-.90	2.40
IV	463	1.30	.51	1.25	1.35	-1.22	2.72
Total	1852	1.23	.49	1.20	1.25	-1.22	2.88

*missing values due to electrical noise obscuring some of the smaller values

Anova: $F[3, 1848] = 16.93$, $p < 0.001$

Bonferroni post-hoc

Grade (I)	Grade (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
I	II	.11	.03	.002	.03	.20
	III	.19	.03	.000	.11	.27
	IV	.002	.03	1.000	-.08	.09
II	I	-.11	.03	.002	-.20	-.03
	III	.07	.03	.116	-.01	.16
	IV	-.11	.03	.002	-.20	-.03
III	I	-.19	.03	.000	-.27	-.11
	II	-.07	.03	.116	-.16	.01
	IV	-.19	.03	.000	-.27	-.10
IV	I	-.002	.03	1.000	-.09	.08
	II	.11	.03	.002	.03	.20
	III	.19	.03	.000	.10	.27

Comparison of techniques (C2 central, C2 unilateral, C7 central and C7 unilateral)

Descriptives

Technique	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
C2 central	464	1.22	.48	1.17	1.26	.22	2.78
C2 unilateral	461	1.24	.50	1.19	1.28	.26	2.88
C7 central	464	1.23	.49	1.19	1.28	-.90	2.67
C7 unilateral	463	1.21	.48	1.17	1.26	-1.22	2.70
Total	1852	1.23	.49	1.20	1.25	-1.22	2.88

*missing values due to electrical noise obscuring some of the smaller values

Anova: $F[3,1848] = 0.25$, $p = 0.863$

Bonferroni post-hoc tests

Technique (I)	Technique (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
C2 central	C2 unilateral	-.02	.03	1.000	-.10	.07
	C7 central	-.02	.03	1.000	-.10	.07
	C7 unilateral	.002	.03	1.000	-.08	.09
C2 unilateral	C2 central	.02	.03	1.000	-.07	.10
	C7 central	.003	.03	1.000	-.08	.09
	C7 unilateral	.02	.03	1.000	-.06	.11
C7 central	C2 central	.02	.03	1.000	-.07	.10
	C2 unilateral	-.003	.03	1.000	-.09	.08
	C7 unilateral	.02	.03	1.000	-.07	.10
C7 unilateral	C2 central	-.003	.03	1.000	-.09	.08
	C2 unilateral	-.02	.03	1.000	-.11	.06
	C7 central	-.02	.03	1.000	-.10	.07

Comparison of central versus unilateral techniques

Descriptives

Position	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
central	928	1.23	.48	1.19	1.26	.90	2.78
unilateral	924	1.23	.49	1.19	1.26	1.22	2.88
Total	1852	1.23	.49	1.20	1.25	1.22	2.88

*missing values due to electrical noise obscuring some of the smaller values

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
.01	1850	.992	.0002	-.04	.04

Comparison of forces applied to the upper versus lower cervical spine

Descriptives

Position	N*	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
Upper (C2)	925	1.23	.49	1.19	1.26	.22	2.88
Lower (C7)	927	1.22	.48	1.19	1.25	-1.22	2.70
Total	1852	1.23	.49	1.20	1.25	-1.22	2.88

*missing values due to electrical noise obscuring some of the smaller values

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
.13	1850	.894	.003	-.04	.05

4.2. Univariate regressions (Physiotherapists, Chapter 6)

The following tables list p-values for univariate regressions for each factor potentially associated with manual force. Univariate regressions were performed for each unique technique and grade combination. Factors with p ≤ 0.25 (highlighted) were entered in the final regression models using the backwards elimination procedure.

Key of labels for predictor variables (factor potentially associated with manual force) entered into the univariate regressions:

Predictor variable label	Description
Physio age	Physiotherapist age
Physio height	Physiotherapist height
Physio weight	Physiotherapist weight
Physio gender	Physiotherapist gender
Mob sessions/wk	Mobilisation sessions performed per week
Yrs MS exp	Years experience in musculoskeletal physiotherapy
Worksett dumvar (pub hosp)	'Public hospital' indicator for categorical variable 'work setting'
Worksett dumvar (priv clin)	'Private clinic' indicator for categorical variable 'work setting'
Training	Post-graduate training that included a manual therapy component
Hx thumb pain	Any history of thumb pain
Freqtp dumvar (rarely)	'Rarely' indicator for categorical variable 'frequency of thumb pain'
Freqtp dumvar (sometimes)	'Sometimes' indicator for categorical variable 'frequency of thumb pain'
Freqtp dumbvar (reg/often)	'Regular or often' indicator for categorical variable 'frequency of thumb pain'
Chgtech dumvar (no)	'No' indicator for categorical variable 'changed cervical mobilisation technique due to thumb pain' (third category was those who had never experienced thumb pain)
Chgtech dumvar (yes)	'Yes' indicator for categorical variable 'changed cervical mobilisation technique due to thumb pain' (third category included those who had never experienced thumb pain)
Curr symp UL dumvar (no)	'No' indicator for categorical variable 'experiencing current symptoms due to past upper limb injury (third category included those who had no past upper limb injuries)

Curr symp UL dumvar (yes)	'Yes' indicator for categorical variable 'experiencing current symptoms due to past upper limb injury (third category included those who had no past upper limb injuries)
Definition (I)	Definition of a grade I mobilisation ('small amplitude movement near the start of the range' or 'other')
Definition dumvar (resistance)	'Defining a mobilisation grade using resistance' indicator for categorical variable 'definition of a mobilisation grade' (see Questionnaire for physiotherapists, Appendix 2.1 for category selections)
Definition dumvar (range)	'Defining a mobilisation grade using range' indicator for categorical variable 'definition of a mobilisation grade' (see Questionnaire for physiotherapists, Appendix 2.1 for category selections)
Patient age	Mobilised subject age
Patient gender	Mobilised subject gender
Patient height	Mobilised subject height
Patient weight	Mobilised subject weight
Stiffness C2	Mobilised subject stiffness at C2
Stiffness C7	Mobilised subject stiffness at C7

4.2.1 Mean peak force

Vertical force direction		Physio age	Physio height	Physio weight	Physio gender	Mob session/wk	Yrs MS exp	Worksett dumvar (pub hosp)	Worksett dumvar (priv clin)	Training	Hx thumb pain	Freqtp dumvar (rarely)	Freqtp dumvar (sometimes)	Freqtp dumvar (reg/often)	Chgtech dumvar (no)	Chgtech dumvar (yes)	Curr symp UL dumvar (no)	Curr symp UL dumvar (yes)	Definition (I)	Definition dumvar (resistance)	Definition dumvar (range)	Patient age	Patient gender	Patient height	Patient weight	Stiffness C2	Stiffness C7
C2 central & C2 unilateral	I	.185	.425	.156	.020	.442	.365	.525	.679	.000	.021	.112	.360	.323	.207	.021	.501	.750	.587			.806	.000	.278	.006	.073	
	II	.210	.759	.681	.028	.429	.414	.473	.279	.002	.198	.566	.285	.558	.708	.128	.981	.341		.366	.015	.563	.000	.109	.002	.049	
	III	.750	.241	.585	.003	.052	.804	.901	.492	.007	.861	.629	.953	.932	.226	.932	.973	.667		.842	.937	.884	.000	.016	.004	.013	
	IV	.522	.726	.723	.012	.021	.147	.719	.135	.007	.723	.712	.771	.696	.285	.563	.768	.939		.900	.924	.575	.000	.025	.001	.035	
C7 central & C7 unilateral	I	.296	.100	.021	.001	.173	.374	.891	.308	.006	.066	.318	.563	.198	.270	.064	.561	.596	.348			.066	.000	.260	.061	.003	.259
	II	.233	.200	.112	.001	.148	.394	.481	.623	.008	.443	.923	.520	.469	.876	.393	.589	.997		.554	.167	.038	.000	.068	.050	.002	.006
	III	.570	.072	.230	.000	.091	.851	.671	.284	.053	.837	.676	.782	.298	.305	.702	.745	.758		.048	.089	.072	.000	.019	.067	.001	.002
	IV	.864	.097	.130	.000	.050	.874	.261	.636	.070	.939	.731	.978	.367	.381	.945	.123	.813		.298	.104	.045	.000	.009	.191	.000	.001

Caudad-cephalad force direction		Physio age	Physio height	Physio weight	Physio gender	Mob session/wk	Yrs MS exp	Worksett dumvar (pub hosp)	Worksett dumvar (priv clin)	Training	Hx thumb pain	Freqtp dumvar (rarely)	Freqtp dumvar (sometimes)	Freqtp dumvar (reg/often)	Chgtech dumvar (no)	Chgtech dumvar (yes)	Curr symp UL dumvar (no)	Curr symp UL dumvar (yes)	Definition (I)	Definition dumvar (resistance)*	Definition dumvar (range)*	Patient age	Patient gender	Patient height	Patient weight	Stiffness C2	Stiffness C7
C2 central & C2 unilateral	I	.013	.005	.325	.006	.082	.047	.221	.334	.034	.419	.813	.275	.932	.487	.116	.472	.167	.124			.887	.310	.215	.733	.378	
	II	.012	.007	.666	.020	.127	.041	.259	.338	.188	.621	.536	.434	.175	.634	.794	.330	.376		.540	.046	.861	.801	.652	.952	.523	
	III & IV	.005	.000	.486	.000	.001	.015	.237	.130	.005	.349	.440	.931	.146	.139	.816	.237	.008		.485 .017	.409 .032	.620	.230	.197	.801	.127	
C7 central & C7 unilateral	I	.279	.021	.015	.007	.349	.441	.051	.119	.017	.069	.277	.098	.557	.098	.071	.302	.973	.080			.054	.003	.881	.000		.573
	II	.563	.105	.037	.021	.345	.843	.449	.536	.079	.486	.718	.438	.790	.644	.334	.206	.284		.945	.130	.039	.000	.209	.000		.036
	III & IV	.878	.006	.005	.000	.023	.358	.341	.335	.188	.925	.566	.706	.942	.461	.760	.190	.102		.283 .766	.594 .712	.000	.000	.022	.000		.001

*P values listed for the indicator variable for each grade.

Mediolateral force direction		Physio age	Physio height	Physio weight	Physio gender	Mob session/wk	Yrs MS exp	Worksett dumvar (pub hosp)	Worksett dumvar (priv clin)	Training	Hx thumb pain	Freqtp dumvar (rarely)	Freqtp dumvar (sometimes)	Freqtp dumvar (reg/often)	Chgtech dumvar (no)	Chgtech dumvar (yes)	Curr symp UL dumvar (no)	Curr symp UL dumvar (yes)	Definition (I)	Definition dumvar (resistance)	Definition dumvar (range)	Patient age	Patient gender	Patient height	Patient weight	Stiffness C2	Stiffness C7
C2 central & C7 central	I	.025	.068	.564	.046	.579	.094	.096	.534	.271	.308	.450	.809	.222	.363	.287	.897	.432	.000			.778	.023	.055	.080	.966	.605
	II	.047	.079	.578	.192	.894	.189	.090	.468	.217	.555	.794	.855	.282	.432	.560	.222	.811		.103	.589	.821	.002	.012	.017	.969	.827
	III	.094	.036	.352	.082	.901	.495	.052	.226	.714	.946	.915	.933	.846	.613	.788	.248	.902		.391	.649	.823	.005	.007	.034	.680	.582
	IV	.163	.020	.221	.064	.705	.535	.228	.520	.613	.779	.678	.659	.440	.994	.886	.716	.802		.913	.706	.932	.001	.012	.070	.697	.436
C2 unilateral & C7 unilateral	I	.001	.141	.953	.109	.519	.002	.233	.294	.001	.931	.446	.550	.864	.695	.821	.744	.208	.469			.028	.001	.140	.134	.074	.150
	II	.002	.062	.846	.073	.497	.005	.460	.447	.027	.281	.229	.368	.308	.127	.488	.557	.121		.706	.933	.034	.001	.069	.051	.021	.253
	III	.034	.020	.356	.047	.248	.099	.542	.208	.091	.304	.204	.461	.718	.065	.553	.390	.624		.857	.872	.022	.000	.022	.155	.025	.032
	IV	.039	.064	.908	.030	.336	.121	.777	.245	.150	.335	.108	.322	.713	.041	.748	.839	.735		.968	.403	.006	.000	.001	.133	.022	.012

4.2.2 Force amplitude

Vertical force direction		Physio age	Physio height	Physio weight	Physio gender	Mob session/wk	Yrs MS exp	Worksett dumvar (pub hosp)	Worksett dumvar (priv clin)	Training	Hx thumb pain	Freqtp dumvar (rarely)	Freqtp dumvar (sometimes)	Freqtp dumvar (reg/often)	Chgtech dumvar (no)	Chgtech dumvar (yes)	Curr symp UL dumvar (no)	Curr symp UL dumvar (yes)	Definition (I)	Definition dumvar (resistance)	Definition dumvar (range)	Patient age	Patient gender	Patient height	Patient weight	Stiffness C2	Stiffness C7
C2 central & C2 unilateral	I	.748	.636	.173	.045	.271	.611	.816	.598	.070	.039	.341	.641	.110	.472	.040	.652	.657	.575			.423	.003	.449	.634	.013	.655
	II	.577	.876	.952	.227	.446	.783	.855	.321	.180	.469	.863	.669	.522	.818	.447	.846	.736		.184	.003	.895	.001	.325	.328	.034	
	III	.669	.322	.559	.068	.067	.197	.995	.226	.137	.586	.360	.374	.889	.178	.442	.679	.802		.978	.939	.827	.000	.132	.161	.023	
	IV	.015	.776	.630	.260	.047	.003	.827	.109	.061	.427	.467	.779	.147	.422	.400	.520	.373		.901	.897	.728	.001	.251	.175	.057	
C7 central & C7 unilateral	I	.511	.297	.158	.062	.254	.974	.843	.216	.072	.035	.289	.704	.089	.229	.034	.482	.872	.235			.045	.008	.798	.994		.774
	II	.403	.266	.347	.059	.241	.952	.626	.364	.107	.514	.781	.718	.308	.989	.466	.812	.728		.854	.018	.079	.000	.354	.760		.044
	III	.991	.134	.333	.022	.073	.347	.982	.119	.295	.852	.722	.524	.285	.307	.836	.566	.507		.093	.184	.164	.002	.216	.668		.057
	IV	.109	.575	.177	.113	.050	.057	.624	.352	.055	.259	.384	.626	.093	.968	.299	.141	.323		.745	.577	.094	.001	.135	.896		.096

Caudad-cephalad force direction		Physio age	Physio height	Physio weight	Physio gender	Mob session/wk	Yrs MS exp	Worksett dumvar (pub hosp)	Worksett dumvar (priv clin)	Training	Hx thumb pain	Freqtp dumvar (rarely)	Freqtp dumvar (sometimes)	Freqtp dumvar (reg/often)	Chgtech dumvar (no)	Chgtech dumvar (yes)	Curr symp UL dumvar (no)	Curr symp UL dumvar (yes)	Definition (I)	Definition dumvar (resistance)	Definition dumvar (range)	Patient age	Patient gender	Patient height	Patient weight	Stiffness C2	Stiffness C7
C2 central & C2 unilateral	I	.317	.600	.742	.669	.681	.488	.596	.858	.346	.858	.433	.724	.697	.917	.964	.555	.619	.102			.122	.000	.001	.203	.014	
	II	.988	.746	.288	.792	.848	.712	.567	.942	.287	.463	.255	.664	.762	.564	.236	.541	.996		.082	.016	.737	.000	.015	.148	.126	
	III	.821	.206	.504	.611	.289	.954	.948	.361	.580	.334	.418	.417	.260	.400	.149	.296	.227		.283	.249	.696	.008	.056	.257	.192	
	IV	.725	.258	.941	.154	.121	.938	.660	.418	.069	.907	.767	.241	.549	.269	.969	.879	.146		.270	.207	.407	.002	.040	.352	.021	
C7 central & C7 unilateral	I	.279	.021	.015	.007	.349	.441	.051	.119	.017	.069	.277	.098	.557	.098	.071	.302	.973	.080			.054	.003	.881	.000		.573
	II	.563	.105	.037	.021	.345	.843	.449	.536	.079	.486	.718	.438	.790	.644	.334	.206	.284		.945	.130	.039	.000	.209	.000		.036
	III	.828	.028	.042	.003	.153	.445	.293	.281	.520	.591	.572	.587	.655	.832	.577	.069	.155		.427	.707	.018	.001	.066	.000		.018
	IV	.986	.074	.048	.002	.074	.574	.720	.726	.234	.737	.784	.974	.775	.427	.940	.856	.344		.969	.778	.006	.002	.147	.000		.014

Mediolateral force direction		Physio age	Physio height	Physio weight	Physio gender	Mob session/wk	Yrs MS exp	Worksett dumvar (pub hosp)	Worksett dumvar (priv clin)	Training	Hx thumb pain	Freqtp dumvar (rarely)	Freqtp dumvar (sometimes)	Freqtp dumvar (reg/often)	Chgtech dumvar (no)	Chgtech dumvar (yes)	Curr symp UL dumvar (no)	Curr symp UL dumvar (yes)	Definition (I)	Definition dumvar (resistance)*	Definition dumvar (range)*	Patient age	Patient gender	Patient height	Patient weight	Stiffness C2*	Stiffness C7*
C2 central & C7 central	I	.074	.355	.558	.173	.617	.235	.237	.274	.090	.810	.581	.125	.577	.617	.857	.185	.763	.413			.252	.002	.018	.105	.008 (.015)	.126 (.291)
	II	.148	.146	.272	.333	.812	.515	.119	.165	.191	.788	.603	.392	.834	.940	.844	.017	.682		.580	.482	.346	.001	.034	.171	.081 (.126)	.202 (.334)
	III & IV	.398	.088	.187	.204	.527	.873	.037	.087	.394	.155	.272	.080	.541	.464	.165	.034	.887		.407 .826	.706 .929	.086	.000	.001	.145	.016	.832
C2 unilateral & C7 unilateral	I	.001	.150	.908	.238	.216	.004	.709	.367	.005	.641	.285	.281	.946	.383	.812	.691	.195	.211			.003	.025	.702	.764	.037 (.019)	.270 (.123)
	II	.004	.153	.810	.579	.298	.016	.917	.495	.134	.080	.073	.139	.239	.027	.164	.426	.139		.857	.253	.010	.002	.256	.237	.005	.078
	III & IV	.026	.022	.434	.152	.076	.197	.791	.051	.029	.056	.065	.005	.989	.003	.062	.142	.982		.412 .591	.223 .031	.000	.000	.009	.188	.003	.004

*P values listed for the indicator variable for each grade.

4.2.3 Oscillation frequency

	Grade	Physio age	Physio height	Physio weight	Physio gender	Mob session/wk	Yrs MS exp	Worksett dumvar (pub hosp)	Worksett dumvar (priv clin)	Training	Hx thumb pain	Freqtp dumvar (rarely)	Freqtp dumvar (sometimes)	Freqtp dumvar (reg/often)	Chgtech dumvar (no)	Chgtech dumvar (yes)	Curr symp UL dumvar (no)	Curr symp UL dumvar (yes)	Definition (I)*	Definition dumvar (resistance)*	Definition dumvar (range)*	Patient age	Patient gender	Patient height	Patient weight	Stiffness C2	Stiffness C7
All techniques	I & IV	.760	.002	.000	.105	.004	.708	.416	.063	.008	.297	.015	.969	.000	.355	.003	.106	.158	.001 .026	.033 .316	.001 .033	.001	.162	.249	.607	.004	.337
	II & III	.123	.295	.022	.554	.004	.248	.477	.071	.019	.542	.000	.155	.000	.131	.035	.943	.494		.041 .006	.002 .032	.000	.301	.336	.906	.001	.273

*P values listed for the indicator variable for each grade.

4.3. Statistics for final regression models (Physiotherapists, Chapter 6)

These tables list the statistics for factors included in the final regression models for each unique technique and grade category.

4.3.1 Mean peak force

Vertical force direction

		Adjusted R-square value Factor and p-value	B (regression coefficient)	95% CI for B
C2 central & C2 unilateral	I	Adj R-square .155		
		Physio gender .028	4.2	.04 to 8.1
		Training .001	-8.5	-13.2 to -3.8
		Hx thumb pain .032	-4.4	-8.4 to -0.3
		Pt gender .000	8.3	4.4 to 12.1
		C2 stiffness .070	-1.7	-3.4 to 0.1
	II	Adj R-square .212		
		Physio gender .013	6.0	1.3 to 11.0
		Training .030	-6.6	-12.4 to -0.6
		Pt gender .000	17.8	10.7 to 24.6
		Pt weight .001	.4	0.2 to 0.6
		C2 stiffness .002	-3.7	-6.0 to -1.4
		Definition dumvar (range) .002	7.8	2.7 to 12.6
		Pt height .000	-.8	-1.3 to -0.4
	III	Adj R-square .185		
		Physio gender .002	10.9	4.0 to 18.3
		Training .027	-10.0	-18.5 to -1.2
		Pt gender .000	24.0	13.6 to 34.2
		Pt height .011	-.8	-1.4 to -0.2
		Pt weight .018	.4	0.1 to 0.7
		C2 stiffness .003	-5.3	-8.7 to -1.8
	IV	Adj R-square .197		
		Physio gender .007	11.5	3.2 to 19.7
		Yrs MS exp .005	.75	0.2 to 1.3
		Training .003	-16.1	-26.6 to -5.6
		Pt gender .000	28.6	16.6 to 40.6
		Pt height .004	-1.1	-1.8 to -0.4
		Pt weight .007	.5	0.1 to 0.9
		C2 stiffness .006	-5.6	-9.6 to -1.6
C7 central & C7 unilateral	I	Adj R-square .131		
		Physio gender .000	9.1	4.2 to 14.1
		Training .005	-8.7	-14.8 to -2.7
		Pt gender .000	12.2	6.5 to 17.9
		C7 stiffness .094	-1.3	-2.7 to 0.2
	II	Adj R-square .246		
		Physio height .011	-.6	-1.0 to -0.1
		Physio gender .000	17.8	10.0 to 25.5
		Training .014	-8.7	-15.7 to -1.8
		Definition dumvar (range) .002	9.5	3.6 to 15.3
		Pt age .000	-.8	-1.2 to -0.4
		Pt gender .000	24.1	15.9 to 32.3
		Pt height .000	-1.4	-2.0 to -0.9
		Pt weight .001	.5	0.2 to 0.8
	III	Adj R-square .161		
		Physio gender .000	17.5	9.4 to 25.7
		Training .055	-9.6	-19.3 to 0.2
		Definition dumvar (resist) .023	23.6	3.3 to 43.9
		Definition dumvar (range) .067	19.2	-1.4 to 39.7
		Pt gender .000	19.1	10.9 to 27.3
	IV	Adj R-square .174		
		Physio gender .000	19.9	10.7 to 29.1

		Training .071 Curr symp in UL dumvar (no) .014 Definition dumvar (range) .047 Pt gender .000	-10.3 -17.5 10.3 23.5	-21.4 to 0.9 -31.3 to -3.6 0.1 to 20.6 14.2 to 32.9

Caudad-cephalad force direction

		Adjusted R-square value Factor and p-value	B (regression coefficient)	95% CI for B
C2 central & C2 unilateral	I	Adj R-square .070 Physio age .003 Physio height .079 Mob sessions/wk .049 Curr symp in UL dumvar (yes) .084 Pt height .083	 -0.1 0.04 0.04 0.9 0.04	 -0.1 to -0.02 -0.01 to 0.1 0 to 0.1 -0.1 to 1.9 -0.01 to 0.1
	II	Adj R-square .066 Physio age .023 Physio height .011 Freqtp dumvar (reg/often) .053 Definition dumvar (range) .067	 -0.1 0.1 1.4 1.0	 -0.1 to -0.01 0.02 to 0.1 -0.02 to 2.7 -0.1 to 2.0
	III & IV	Adj R-square .094 Physio age .000 Physio height .007 Mob sessions/wk .001 Freqtp dumvar (reg/often) .059 Curr symp in UL dumvar (yes) .001 Pt height .028	 -0.1 0.1 0.1 1.7 2.3 0.1	 -0.2 to -0.1 0.03 to 0.2 0.04 to 0.2 -0.1 to 3.2 0.9 to 3.7 0.01 to 0.1
C7 central & C7 unilateral	I	Adj R-square .156 Physio gender .002 Worksett dumvar (pub hosp) .050 Worksett dumvar (priv clin) .077 Definition grd I .004 Pt age .076 Pt gender .033 Pt weight .014	 4.2 5.8 4.8 12.0 0.1 3.2 0.1	 1.6 to 6.8 -.001 to 11.7 -0.5 to 10.1 3.9 to 20.0 -0.02 to 0.3 0.3 to 6.2 0.03 to 0.3
	II	Adj R-square .254 Physio gender .015 Definition dumvar (range) .001 Pt age .079 Pt gender .000 Pt height .000 Pt weight .000	 3.9 5.4 -0.2 10.4 -0.8 0.5	 0.8 to 7.1 2.2 to 8.6 -0.4 to 0.02 5.9 to 14.9 -1.1 to -0.5 0.4 to 0.7
	III & IV	Adj R-square .209 Physio gender .000 Curr symp in UL dumvar (yes) .041 Pt gender .000 Pt height .000 Pt weight .000	 7.6 4.6 14.3 -0.8 0.7	 3.8 to 11.5 0.2 to 8.9 8.8 to 19.9 -1.2 to -0.5 0.5 to 0.8

Mediolateral force direction

		Adjusted R-square value Factor and p-value	B (regression coefficient)	95%CI for B
C2 central & C7 central	I	Adj R-square .275		
		Physio age .022	-0.04	-0.1 to -0.01
		Physio gender .043	0.7	0.02 to 1.3
		Worksett dumvar (pub hosp).046	0.8	0.01 to 1.5
		Definition grd I .000	-8.2	-10.2 to -6.2
		Pt gender .023	0.7	0.1 to 1.4
	II	Adj R-square .080		
		Physio age .027	-0.1	-0.1 to -0.01
		Physio height .058	0.04	-0.01 to 0.1
		Pt gender .000	1.2	0.5 to 1.9
		Definition dumvar (resistance) .016	0.9	0.2 to 1.5
	III	Adj R-square .059		
		Physio height .025	0.1	0.01 to 0.1
		Worksett dumvar (pub hosp) .049	1.0	0.01 to 2.0
		Pt gender .002	1.4	0.5 to 2.2
	IV	Adj R-square .063		
		Physio height .012	0.1	0.02 to 0.1
		Pt gender .001	1.7	0.7 to 2.8
C2 unilateral & C7 unilateral	I	Adj R-square .135		
		Physio age .029	-0.1	-0.1 to -0.01
		Training .005	-1.9	-3.3 to -0.6
		Pt age .005	-0.1	-0.2 to -0.03
		Pt gender .002	2.4	0.9 to 3.9
		Pt height .022	-0.1	-0.2 to -0.02
		Pt weight .045	0.1	0.001 to 0.1
	II	**Col		
		Adj R-square .124		
		Physio age .040	-0.1	-0.2 to -0.004
		Physio height .034	0.1	0.01 to 0.2
		Traning .052	-1.9	-3.7 to 0.02
		Curr symp in UL dumvar (yes) .039	-1.9	-3.7 to -0.1
		Pt gender .001	2.4	0.9 to 3.9
		C2 stiffness .013	-0.8	-1.5 to -0.2
	III	Adj R-square .098		
		Physio height .007	-0.2	0.1 to 0.4
		Pt gender .000	4.7	2.1 to 7.3
		C2 stiffness .023	-1.4	-2.5 to -0.2
		Chg tech dumvar (no) .076	2.5	-0.3 to 5.3
	IV	Adj R-square .122		
		Physio age .069	-0.1	-0.3 to 0.01
		Physio height .042	0.2	0.01 to 0.4
		Chg tech dumvar (no) .046	3.3	0.1 to 6.5
		Pt gender .000	6.3	3.3 to 9.3
		C2 stiffness .024	-1.6	-2.9 to -0.2

**Col – indicates there was some collinearity in the model

4.3.2 Force amplitude

Vertical force direction

	Grade	Adjusted R-square value Factor and p-value	B (regression coefficient)	95%CI for B
C2 central & C2 unilateral	I	Adj R-square .075 Hx thumb pain .018 Pt gender .002 C2 stiffness .011	 -3.7 4.6 -1.7	 -6.7 to -0.6 1.7 to 7.6 -3.1 to -0.4
	II	Adj R-square .082 Definition dumvar (range) .008 Pt gender .002 C2 stiffness .034	 6.0 7.0 -2.2	 1.6 to 10.4 2.7 to 11.4 -4.1 to -0.2
	III	Adj R-square .102 Physio gender .044 Yrs MS exp .032 Training .056 Pt gender .000 Pt height .054 C2 stiffness .031	 6.5 0.4 -7.8 18.0 -0.5 -3.2	 0.2 to 12.8 0.04 to 0.8 -15.7 to 0.2 8.9 to 27.1 -1.0 to 0.01 -6.1 to -0.3
	IV	Adj R-square .140 Yrs MS exp .000 Training .004 Freqtp dumvar (reg/often) .040 Pt gender .000 Pt height .025 C2 stiffness .041	 0.9 -12.2 -9.3 17.9 -0.6 -3.1	 0.5 to 1.3 -20.4 to -4.0 -18.1 to -0.4 8.5 to 27.2 -1.1 to -0.1 -6.1 to -0.1
C7 central & C7 unilateral	I	Adj R-square .071 Worksett dumvar (priv clin) .012 Training .097 Hx thumb pain .018 Pt gender .008	 4.9 -3.7 -4.5 4.8	 1.1 to 8.8 -8.0 to 0.7 -8.3 to -0.8 1.3 to 8.4
	II	Adj R-square .096 Physio gender .025 Definition dumvar (range) .003 Pt gender .000	 5.2 7.0 8.3	 0.7 to 9.7 2.4 to 11.6 3.7 to 12.9
	III	Adj R-square .101 Physio gender .025 Worksett dumvar (priv clin) .002 Definition dumvar (resist) .026 Definition dumvar (range) .088 Pt gender .003	 7.9 12.0 19.8 15.2 10.7	 1.0 to 14.8 4.7 to 19.4 2.4 to 37.1 -2.3 to 32.7 3.7 to 17.6
	IV	Adj R-square .137 Mob sessions/wk .082 Yrs MS exp .004 Training .005 Freqtp dumvar (reg/often) .017 Curr symp in UL dumvar (no) .034 Pt age .050 Pt gender .000 Pt height .040	 0.3 0.6 -11.7 -10.6 -10.3 -0.4 18.1 -0.5	 -.04 to 0.6 0.2 to 1.0 -19.9 to -3.6 -19.2 to -1.9 -19.9 to -0.8 -0.7 to 0.001 8.9 to 27.3 -1.1 to -0.02

Caudad-cephalad force direction

	Grade	Adjusted R-square value Factor and p-value	B (regression coefficient)	95%CI for B
C2 central & C2 unilateral	I	Adj R-square .086		
		Pt gender .000	0.8	0.4 to 1.2
		C2 stiffness .019	-0.2	-0.4 to -0.03
	II	Adj R-square .071		
		Definition dumvar (resist) .051	0.8	-0.003 to 1.5
		Definition dumvar (range) .014	0.9	0.2 to 1.7
		Pt gender .000	1.1	0.5 to 1.6
	III	Adj R-square .028		
		Pt gender .007	1.5	0.4 to 2.5
	IV	Adj R-square .063		
		Training .069	-1.0	-2.2 to 0.1
		Pt gender .003	1.4	0.5 to 2.3
		C2 stiffness .022	-0.5	-0.9 to -0.1
C7 central & C7 unilateral	I	Adj R-square .149		
		Physio gender .004	3.7	1.2 to 6.2
		Definition grd I .005	11.6	3.5 to 19.6
		Pt age .091	0.1	-0.02 to 0.3
		Pt gender .053	2.9	-0.04 to 5.9
		Pt weight .003	0.2	0.1 to 0.3
	II	Adj R-square .254		
		Physio gender .015	3.9	0.8 to 7.1
		Definition dumvar (range) .001	5.4	2.2 to 8.6
		Pt age .079	-0.2	-0.4 to 0.02
		Pt gender .000	10.4	5.9 to 14.9
		Pt height .000	-0.8	-1.1 to -0.5
		Pt weight .000	0.5	0.4 to 0.7
	III	Adj R-square .215		
		Physio gender .004	7.259	2.3 to 12.2
		Pt gender .000	12.777	5.7 to 19.9
		Pt height .001	-.746	-1.2 to -0.3
		Pt weight .000	.638	0.4 to 0.8
	IV	Adj R-square .190		
		Physio gender .002	9.1	3.2 to 14.9
		Pt gender .001	15.0	6.6 to 23.4
		Pt height .000	-0.9	-1.4 to -0.4
		Pt weight .000	0.7	0.4 to 0.9

Mediolateral force direction

	Grade	Adjusted R-square value Factor and p-value	B (regression coefficient)	95%CI for B
C2 central & C7 central	I	Adj R-square .124		
		Physio gender .072	0.2	-0.02 to 0.5
		Training .024	-0.3	-0.6 to -0.04
		Freqtp dumvar (sometimes) .021	0.4	0.1 to 0.8
		Pt gender .000	0.7	0.4 to 1.0
		C7 stiffness .000	-0.1	-0.2 to -0.1
	II	Adj R-square .097		
		Training .096	-0.4	-0.8 to 0.1
		Curr symp in UL dumvar (no) .092	0.5	-0.1 to 1.0
		Pt gender .000	0.9	0.5 to 1.3
		C7 stiffness .000	-0.2	-0.3 to -0.1
	III & IV	Adj R-square .081		
		Physio weight .014	0.02	0.004 to 0.03
		Worksett dumvar (pub hosp) .001	1.5	0.6 to 2.4
		Worksett dumvar (priv clin) .025	1.0	0.1 to 1.8
		Freqtp dumvar (sometimes) .006	0.9	0.3 to 1.5
		Pt gender .000	1.1	0.7 to 1.5
		C2 stiffness .037	-0.2	-0.4 to -0.01
C2 unilateral & C7 unilateral	I	Adj R-square .115		
		Physio age .003	-0.1	-0.1 to -0.02
		Mob sessions/wk .048	0.04	0 to 0.1
		Training .010	-1.3	-2.3 to -0.3
		Pt age .016	-0.1	-0.1 to -0.01
		Pt gender .061	0.8	-0.04 to 1.6
	II	Adj R-square .112		
		Physio age .001	-0.1	-0.2 to -0.05
		Chg tech dumvar (no) .025	1.9	0.2 to 3.5
		Chg tech dumvar (yes) .051	1.6	-0.01 to 3.3
		Pt gender .004	2.0	0.6 to 3.3
		C2 stiffness .008	-0.8	-1.4 to -0.2
	III & IV	**Col		
		Adj R-square .154		
		Physio age .015	-0.2	-0.4 to -0.1
		Physio height .031	0.1	0.01 to 0.2
		Yrs MS exp .062	0.2	-0.01 to 0.4
		Worksett dumvar (priv clin) .005	2.4	0.7 to 4.1
		Training .010	-2.5	-4.3 to -0.6
		Hx thumb pain .001	-9.5	-15.1 to -3.9
		Freqtp dumvar (sometimes) .013	2.8	0.6 to 5.0
		Chg tech dumvar (no) .000	11.3	5.5 to 17.1
		Chg tech dumvar (yes) .000	10.4	4.7 to 16.2
		Definition dumvar (IV-range) .009	2.2	0.6 to 3.9
		Pt age .002	-0.2	-0.3 to -0.1
		Pt gender .003	3.2	1.1 to 5.3
		Pt height .054	-0.1	-0.3 to 0.002
		Pt weight .030	0.1	0.01 to 0.2

**Col – indicates there was some collinearity in the model

4.3.3 Oscillation frequency

	Grade	Adjusted R-square value Factor and p-value	B (regression coefficient)	95%CI for B
All techniques	I & IV	Adj R-square .119		
		Physio height .000	.001	0.004 to 0.01
		Worksett dumvar (priv clin) .050	0.07	0 to 0.14
		Training .003	0.12	0.04 to 0.219
		Freqtp dumvar (rarely) .000	-0.17	-0.25 to -0.10
		Freqtp dumvar (reg/often) .002	.016	0.06 to 0.26
		Chg tech dumvar (yes) .005	0.10	0.03 to 0.18
		Definition grd I .000	0.43	0.23 to 0.64
		Definition dumvar (range) .006	0.10	0.03 to 0.17
		Pt age .092	-0.003	-0.01 to 0.001
		Pt gender .000	0.23	0.14 to 0.33
		Pt height .000	-0.01	-0.02 to -0.01
	II & III	Adj R-square .125		
		Physio weight .002	0.003	0.001 to 0.01
		Yrs MS exp .003	-0.01	-0.01 to -0.002
		Worksett dumvar (priv clin) .001	0.12	0.05 to 0.18
		Training .022	0.09	0.01 to 0.16
		Freqtp dumvar (rarely) .000	-0.17	-0.23 to -0.10
		Freqtp dumvar (reg/often) .004	0.13	0.04 to 0.22
		Chg tech dumvar (yes) .024	0.08	0.01 to 0.14
		Definition dumvar (resist-grd II) .002	0.13	0.05 to 0.21
		Definition dumvar (range-grd II) .010	-0.11	-0.19 to -0.03
		Definition dumvar (resist-grd III) .074	0.14	-0.01 to 0.29
		Definition dumvar (range-grd III) .006	0.21	0.06 to 0.37
		Pt age .011	-0.004	-0.01 to -0.001

4.4. Detailed summary of statistics for all factors significantly associated with manual force (final models, Physiotherapists, Chapter 6)

Table of all factors significantly associated with force parameters. Included if association was clinically meaningful, if it was statistically significantly associated for multiple techniques, grades and directions, and if regression coefficient (B) > 1 N. However, table also includes some techniques with B < 1 N if other techniques statistically associated with the same factor have B > 1 N.

Force parameter / Characteristic	Direction*	Techniques*	Grades	$P^{\dagger}$	B**
Mean peak force (N)					
Gender (clinician)	V	C2 cen/C2 uni	I	.028	4.2
			II	.013	6.0
			III	.002	10.9
			IV	.007	11.5
	V	C7 cen/C7 uni	I	.000	9.1
			II	.000	17.8
			III	.000	17.5
			IV	.000	19.9
	CC	C7 cen/C7 uni	I	.004	3.7
			II	.015	3.9
			III & IV	.000	7.7
Gender (volunteer)	V	C2 cen/C2 uni	I	.000	8.3
			II	.000	17.8
			III	.000	24.0
			IV	.000	28.6
	V	C7 cen/C7 uni	I	.000	12.2
			II	.000	24.1
			III	.000	19.1
			IV	.000	23.5
	CC	C7 cen/C7 uni	I	.053	2.9
			II	.000	10.4
			III & IV	.000	14.3
	ML	C2 cen/C7 cen	I	.043	.7
			II	.000	1.2
			III	.002	1.4
			IV	.001	1.7
	ML	C2 uni/C7 uni	I	.002	2.4
			II	.003	3.2
			III	.000	4.9
			IV	.000	6.3
C2 spinal stiffness	V	C2 cen/C2 uni	II	.002	-3.7
			III	.003	-5.3
			IV	.006	-5.6
	ML	C2 uni/C7 uni	III	.027	-1.3
			IV	.024	-1.6
Post-grad training	V	C2 cen/C2 uni	I	.001	-8.5

			II	.030	-6.6
			III	.027	-10.0
			IV	.003	-16.1
	V	C7 cen/C7 uni	I	.005	-8.7
			II	.014	-8.7
	ML	C2 uni/C7 uni	I	.005	-1.9
Mobilized volunteer height (cm)	V	C2 cen/C2 uni	II	.000	-.8
			III	.011	-.8
			IV	.004	-1.1
	V	C7 cen/ C7 uni	II	.000	-1.4
	CC	C2 cen/C2 uni	III & IV	.028	.1
	CC	C7 cen/ C7 uni	II	.000	-.8
			III & IV	.000	-.9
	ML	C2 uni/C7 uni	I	.022	-.1
Mobilized volunteer weight (kg)	V	C2 cen/C2 uni	III	.018	.4
			IV	.007	.5
	V	C7 cen/C7 uni	II	.001	.5
	CC	C7 cen/C7 uni	I	.003	.2
			II	.000	.5
			III & IV	.000	.7
	ML	C2 uni/C7 uni	I	.045	.1
			II	.013	.1
Have current UL‡ symptoms due to past UL injury	CC	C2 cen/C2 uni	III & IV	.001	2.3
	CC	C7 cen/C7 uni	III & IV	.041	4.6
Do not have current UL symptoms due to past UL injury	V	C7 cen/C7 uni	IV	.014	-17.5
Have not changed technique due to hx of thumb pain	ML	C2 uni/C7 uni	IV	.046	3.3
Defining a grade II mobilisation using range rather than stiffness	V	C2 cen/C2 uni	II	.002	7.8
	V	C7 cen/C7 uni	II	.002	9.5
	CC	C7 cen/C7 uni	II	.001	5.4
Hx thumb pain	V	C2 cen/C2 uni	I	.032	-4.4
<u>Force amplitude (N)</u>					
Gender (clinician)	V	C2 cen/C2 uni	III	.044	6.5
	V	C7 cen/C7 uni	II	.025	5.2
			III	.025	7.9
	CC	C7 cen/C7 uni	I	.004	3.7
			II	.015	3.9
			III	.004	7.3
			IV	.002	9.1
Gender (volunteer)	V	C2 cen/C2 uni	I	.002	4.6
			II	.002	7.0

			III	.000	18.0
			IV	.000	17.9
	CC	C2 cen/C2 uni	I	.000	.8
			II	.000	1.1
			III	.007	1.5
			IV	.002	1.5
	V	C7 cen/C7 uni	I	.008	4.8
			II	.000	8.3
			III	.003	10.7
			IV	.000	19.6
	CC	C7 cen/C7 uni	I	.053	2.9
			II	.000	10.4
			III	.000	12.8
			IV	.001	15.0
	ML	C2 cen/C7 cen	I	.000	.7
			II	.000	.9
			III & IV	.000	1.1
	ML	C2 uni/C7 uni	II	.004	2.0
			III & IV	.032	2.5
C2 spinal stiffness	V	C2 cen/C2 uni	I	.011	-1.7
			II	.034	-2.2
			III	.031	-3.2
			IV	.041	-3.1
	CC	C2 cen/C2 uni	I	.019	-.2
			IV	.015	-.5
Post-grad training	V	C2 cen/C2 uni	IV	.004	-12.2
	V	C7 cen/C7 uni	IV	.008	-11.0
	ML	C2 cen/C7 cen	I	.024	-.3
	ML	C2 uni/C7 uni	I	.010	-1.3
Mobilized volunteer height (cm)	V	C2 cen/C2 uni	III	.054	-.5
			IV	.025	-.6
	CC	C7 cen/C7 uni	II	.000	-.8
			III	.001	-.7
			IV	.000	-.9
	ML	C2 uni/C7 uni	III & IV	.042	-.2
Mobilized volunteer weight (kg)	CC	C7 cen/C7 uni	I	.003	.2
			II	.000	.5
			III	.000	.6
			IV	.000	.7
	ML	C2 uni/C7 uni	III & IV	.041	.1
Defining a grade II mobilisation using range rather than stiffness	V	C2 cen/C2 uni	II	.008	6.0
	CC	C2 cen/C2 uni	II	.014	.9
	V	C7 cen/C7 uni	II	.003	7.0
	CC	C7 cen/C7 uni	II	.001	5.4
Frequency of thumb pain regular or often	V	C2 cen/C2 uni	IV	.040	-9.3
	V	C7 cen/C7 uni	IV	.006	-12.6

	Working in a private clinic	V	C7 cen/C7 uni	I III	.012 .002	4.9 12.0
	Hx thumb pain	V	C2 cen/C2 uni	I	.018	-3.7
		V	C7 cen/C7 uni	I	.018	-4.5
		ML	C2 uni/C7 uni	III & IV	.000	-11.0
	Do not have current UL symptoms due to past UL injury	V	C7 cen/C7 uni	IV	.044	-9.8
Oscillation frequency (Hz)						
	Working in a private clinic	n/a	All techniques	I & IV II & III	.014 .002	.17 .11
	Post-grad training	n/a	All techniques	I & IV II & III	.001 .009	.13 .10
	Rarely having thumb pain	n/a	All techniques	I & IV II & III	.000 .000	-.30 -.30

*V = vertical, CC = caudad-cephalad, ML = mediolateral, all = all techniques for that direction, C2 = techniques applied to C2, C7 = techniques applied to C7, cen = central techniques, uni = unilateral techniques.
**B = regression coefficient from the final regression models for each grade, direction and technique; positive values indicate increased force was associated with the characteristic, negative values indicate decreased force.
†Statistics for individual characteristics in the final backwards regression models for each unique technique and grade category.
‡UL = Upper limb; category includes only those who have had a previous UL injury.

APPENDIX 5. Additional statistical calculations for forces applied by students

5.1. Specific comparisons of mobilisation techniques and grades (Students, Chapter 7)

These calculations were used to determine differences and similarities between forces applied for different techniques and grades. The results of these analyses allowed for some techniques and grades to be grouped (Table 7.6) for the analysis of factors associated with manual forces.

5.1.1 Mean peak force

Comparison of mobilisation grades

Vertical force direction

Descriptives

Grade	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
I	480	25.20	17.56	23.62	26.77	-.10	161.90
II	480	33.84	20.40	32.01	35.67	3.69	178.20
III	480	48.69	26.96	46.27	51.11	6.53	262.80
IV	480	55.19	27.43	52.73	57.65	8.04	204.80
Total	1920	40.73	26.28	39.56	41.91	-.10	262.80

Anova: $F[3,1916] = 162.99$, $p < 0.001$

Bonferroni post-hoc

Grade (I)	Grade (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
I	II	-8.65	1.52	.000	-12.65	-4.64
	III	-23.50	1.52	.000	-27.50	-19.49
	IV	-29.99	1.52	.000	-33.99	-25.99
II	I	8.65	1.52	.000	4.64	12.65
	III	-14.85	1.52	.000	-18.85	-10.85
	IV	-21.35	1.52	.000	-25.35	-17.34
III	I	23.450	1.52	.000	19.49	27.50
	II	14.85	1.52	.000	10.85	18.85
	IV	-6.50	1.52	.000	-10.50	-2.49
IV	I	29.99	1.52	.000	25.99	33.99
	II	21.35	1.52	.000	17.34	25.35
	III	6.50	1.52	.000	2.49	10.50

Caudad-cephalad force direction

Descriptives

Grade	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
I	480	9.06	8.95	8.26	9.86	-4.26	63.60
II	480	11.58	11.48	10.55	12.61	-3.80	76.08
III	480	15.98	16.01	14.55	17.42	-2.56	124.30
IV	480	18.29	17.70	16.70	19.88	-4.32	101.90
Total	1920	13.73	14.43	13.08	14.37	-4.32	124.30

Anova: F[3,1916] = 42.78, p < 0.001

Bonferroni post-hoc

Grade (I)	Grade (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
I	II	-2.52	.90	.031	-4.91	-.14
	III	-6.92	.90	.000	-9.30	-4.54
	IV	-9.23	.90	.000	-11.61	-6.84
II	I	2.52	.90	.031	.14	4.91
	III	-4.40	.90	.000	-6.78	-2.02
	IV	-6.70	.90	.000	-9.09	-4.32
III	I	6.92	.90	.000	4.54	9.30
	II	4.40	.90	.000	2.02	6.78
	IV	-2.31	.90	.064	-4.69	.08
IV	I	9.23	.90	.000	6.84	11.61
	II	6.70	.90	.000	4.32	9.09
	III	2.31	.90	.064	-.08	4.69

Mediolateral force direction

Descriptives

Grade	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
I	480	1.74	2.35	1.53	1.96	-2.22	22.64
II	480	2.23	3.024	1.96	2.50	-.88	31.08
III	480	3.40	4.53	2.99	3.80	-.71	32.31
IV	480	4.14	5.28	3.67	4.61	-1.24	36.99
Total	1920	2.8786	4.07903	13.08	14.37	-4.32	124.30

Anova: $F[3,1916] = 36.13$, $p < 0.001$

Bonferroni post-hoc

Grade (I)	Grade (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
I	II	-.49	.26	.344	-1.16	.19
	III	-1.65	.26	.000	-2.33	-.98
	IV	-2.39	.26	.000	-3.08	-1.72
II	I	.49	.26	.344	-.19	1.16
	III	-1.16	.26	.000	-1.84	-.49
	IV	-1.91	.26	.000	-2.58	-1.23
III	I	1.65	.26	.000	.98	2.33
	II	1.16	.26	.000	.49	1.84
	IV	-.74	.26	.023	-1.42	-.06
IV	I	2.39	.26	.000	1.72	3.07
	II	1.91	.26	.000	1.23	2.58
	III	.74	.26	.023	.07	1.42

Comparison of techniques (C2 central, C2 unilateral, C7 central and C7 unilateral)

Vertical force direction

Descriptives

Technique	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
C2 central	480	39.33	26.28	36.97	41.68	.92	204.80
C2 unilateral	480	36.08	23.98	33.93	38.23	2.34	182.10
C7 central	480	46.69	28.50	44.13	49.25	-.10	262.80
C7 unilateral	480	40.83	25.07	38.59	43.08	2.31	190.80
Total	1920	40.73	26.26	39.56	41.91	-.10	262.80

Anova: F[3,1916] = 13.99, p < 0.001

Bonferroni post-hoc tests

Technique (I)	Technique (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
C2 central	C2 unilateral	3.25	1.68	.319	-1.18	7.68
	C7 central	-7.36	1.68	.000	-11.80	-2.93
	C7 unilateral	-1.51	1.68	1.000	-5.94	2.93
C2 unilateral	C2 central	-3.25	1.68	.319	-7.68	1.18
	C7 central	-10.61	1.68	.000	-15.05	-6.18
	C7 unilateral	-4.76	1.68	.028	-9.19	-.32
C7 central	C2 central	7.36	1.68	.000	2.93	11.80
	C2 unilateral	10.61	1.68	.000	6.18	15.05
	C7 unilateral	5.86	1.68	.003	1.42	10.29
C7 unilateral	C2 central	1.51	1.68	1.000	-2.93	5.94
	C2 unilateral	4.76	1.68	.028	.32	9.19
	C7 central	-5.86	1.68	.003	-10.29	-1.42

Caudad-cephalad force direction

Descriptives

Technique	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
C2 central	480	3.91	3.59	3.59	4.24	-4.32	17.22
C2 unilateral	480	4.55	3.52	4.23	4.86	-2.56	30.75
C7 central	480	25.09	15.47	23.71	26.48	2.07	124.30
C7 unilateral	480	21.36	14.16	20.09	22.63	2.06	98.97
Total	1920	13.73	14.43	13.08	14.37	-4.32	124.30

Anova: $F[3,1916] = 506.41$, $p < 0.001$

Bonferroni post-hoc tests

Technique (I)	Technique (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
C2 central	C2 unilateral	-.63	.70	1.000	-2.47	1.20
	C7 central	-21.18	.70	.000	-23.02	-19.34
	C7 unilateral	-17.44	.70	.000	-19.28	-15.61
C2 unilateral	C2 central	.63	.70	1.000	-1.20	2.47
	C7 central	-20.55	.70	.000	-22.38	-18.71
	C7 unilateral	-16.81	.70	.000	-18.65	-14.97
C7 central	C2 central	21.18	.70	.000	19.34	23.02
	C2 unilateral	20.55	.70	.000	18.71	22.38
	C7 unilateral	3.74	.70	.000	1.90	5.57
C7 unilateral	C2 central	17.44	.70	.000	15.61	19.28
	C2 unilateral	16.81	.70	.000	14.97	18.65
	C7 central	-3.74	.70	.000	-5.57	-1.90

Mediolateral force direction

Descriptives

Technique	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
C2 central	480	.99	1.14	.89	1.09	-2.22	10.18
C2 unilateral	480	3.61	4.19	3.23	3.98	-.63	27.73
C7 central	480	1.77	1.74	1.61	1.92	-1.24	16.49
C7 unilateral	480	5.15	5.85	4.63	5.68	-1.95	36.99
Total	1920	2.88	4.08	2.70	3.06	-2.22	36.99

Anova: F[3,1916] = 119.51, p < 0.001

Bonferroni post-hoc tests

Technique (I)	Technique (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
C2 central	C2 unilateral	-2.61	.24	.000	-3.25	-1.98
	C7 central	-.78	.24	.008	-1.41	-.14
	C7 unilateral	-4.16	.24	.000	-4.80	-3.52
C2 unilateral	C2 central	2.61	.24	.000	1.98	3.25
	C7 central	1.84	.24	.000	1.20	2.48
	C7 unilateral	-1.54	.24	.000	-2.18	-.91
C7 central	C2 central	.78	.24	.008	.14	1.41
	C2 unilateral	-1.84	.24	.000	-2.48	-1.20
	C7 unilateral	-3.38	.24	.000	-4.02	-2.74
C7 unilateral	C2 central	4.16	.24	.000	3.52	4.80
	C2 unilateral	1.54	.24	.000	.91	2.18
	C7 central	3.38	.24	.000	2.74	4.02

Comparison of central versus unilateral techniques

Vertical force direction

Descriptives

Position	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
central	960	43.01	27.65	41.26	44.76	-.10	262.80
unilateral	960	38.46	24.63	36.89	40.02	2.31	190.80
Total	1920	40.73	26.28	39.56	41.91	-.10	262.80

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
3.81	1918	.000	4.55	2.21	6.90

Caudad-cephalad force direction

Descriptives

Position	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
central	960	14.50	15.43	13.53	15.48	-4.32	124.30
unilateral	960	12.95	13.31	12.11	13.80	-2.56	98.97
Total	1920	13.73	14.43	13.08	14.37	-4.32	124.30

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
2.36	1918	.018	1.55	.26	2.84

Mediolateral force direction

Descriptives

Position	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
central	960	1.38	1.52	1.28	1.48	-2.22	16.49
unilateral	960	4.38	5.15	4.05	4.70	-1.95	36.99
Total	1920	2.88	4.08	2.70	3.06	-2.22	36.99

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
-17.32	1918	.000	-3.00	-3.34	-2.66

Comparison of forces applied to the upper versus lower cervical spine

Vertical force direction

Descriptives

Position	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
Upper (C2)	960	37.70	25.19	36.11	39.30	.92	204.80
Lower (C7)	960	43.76	26.99	42.05	45.47	-.10	262.80
Total	1920	40.73	26.28	39.56	41.91	-.10	262.80

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
-5.09	1918	.000	-6.06	-8.40	-3.72

Caudad-cephalad force direction

Descriptives

Position	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
Upper (C2)	960	4.23	3.57	4.01	4.46	-4.32	30.75
Lower (C7)	960	23.23	14.94	22.28	24.17	2.06	124.30
Total	1920	13.73	14.43	13.08	14.37	-4.32	124.30

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
-38.32	1918	.000	-19.00	-19.97	-18.02

Mediolateral force direction

Descriptives

Position	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
Upper (C2)	960	2.30	3.34	2.09	2.51	-2.22	27.73
Lower (C7)	960	3.46	4.63	3.17	3.75	-1.95	36.99
Total	1920	2.88	4.08	2.70	3.06	-2.22	36.99

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
-6.29	1918	.000	-1.16	-1.52	-.80

5.1.2 Force amplitude

Comparison of mobilisation grades

Vertical force direction

Descriptives

Grade	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
I	480	17.1039	12.86165	15.9504	18.2574	2.25	139.70
II	480	25.6177	16.40601	24.1463	27.0891	2.02	149.80
III	480	37.6971	23.09399	35.6259	39.7684	4.34	235.30
IV	480	29.2370	16.39301	27.7667	30.7072	4.58	123.00
Total	1920	27.4139	19.06183	26.5607	28.2671	2.02	235.30

Anova: $F[3,1916] = 113.13$, $p < 0.001$

Bonferroni post-hoc

Grade (I)	Grade (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
I	II	-8.51	1.13	.000	-11.51	-5.52
	III	-20.59	1.13	.000	-23.59	-17.60
	IV	-12.13	1.13	.000	-15.13	-9.14
II	I	8.51	1.13	.000	5.52	11.51
	III	-12.08	1.13	.000	-15.08	-9.08
	IV	-3.62	1.13	.009	-6.62	-.62
III	I	20.59	1.13	.000	17.60	23.59
	II	12.08	1.13	.000	9.08	15.08
	IV	8.46	1.13	.000	5.46	11.46
IV	I	29.99	1.52	.000	25.99	33.99
	II	21.35	1.52	.000	17.34	25.35
	III	6.50	1.52	.000	2.49	10.50

Caudad-cephalad force direction

Descriptives

Grade	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
I	480	6.23	4.73	5.80	6.65	1.37	31.33
II	480	8.69	7.54	8.02	9.37	1.26	62.18
III	480	12.11	11.59	11.07	13.14	1.41	111.40
IV	480	9.71	8.61	8.93	10.48	1.15	60.50
Total	1920	9.18	8.73	8.79	9.57	1.15	111.40

Anova: $F[3,1916] = 39.55$, $p < 0.001$

Bonferroni post-hoc

Grade (I)	Grade (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
I	II	-2.47	.55	.000	-3.91	-1.02
	III	-5.88	.55	.000	-7.32	-4.43
	IV	-3.48	.55	.000	-4.92	-2.03
II	I	2.47	.55	.000	1.02	3.91
	III	-3.41	.55	.000	-4.86	-1.96
	IV	-1.01	.55	.389	-2.46	.43
III	I	5.88	.55	.000	4.43	7.32
	II	3.41	.55	.000	1.96	4.86
	IV	2.40	.55	.000	.95	3.85
IV	I	3.48	.55	.000	2.03	4.92
	II	1.01	.55	.389	-.43	2.46
	III	-2.40	.55	.000	-3.85	-.95

Mediolateral force direction

Descriptives

Grade	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
I	480	2.00	2.09	1.81	2.19	.33	22.51
II	480	2.55	2.71	2.30	2.79	.48	21.61
III	480	3.65	4.20	3.28	4.03	.48	28.85
IV	480	3.49	3.65	3.16	3.82	.58	24.29
Total	1920	2.92	3.33	2.77	3.07	.33	28.85

Anova: F[3,1916] = 27.74, p <0.001

Bonferroni post-hoc

Grade (I)	Grade (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
I	II	-.55	.21	.059	-1.10	.01
	III	-1.65	.21	.000	-2.21	-1.10
	IV	-1.49	.21	.000	-2.05	-.93
II	I	.55	.21	.059	-.01	1.10
	III	-1.11	.21	.000	-1.66	-.55
	IV	-.95	.21	.000	-1.50	-.39
III	I	1.65	.21	.000	1.10	2.21
	II	1.11	.21	.000	.55	1.66
	IV	.16	.21	1.000	-.40	.72
IV	I	1.49	.21	.000	.93	2.05
	II	.95	.21	.000	.39	1.50
	III	-.16	.21	1.000	-.72	.40

Comparison of techniques (C2 central, C2 unilateral, C7 central and C7 unilateral)

Vertical force direction

Descriptives

Technique	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
C2 central	480	27.30	19.49	25.56	29.05	3.06	156.80
C2 unilateral	480	24.56	16.85	23.05	26.07	2.61	120.80
C7 central	480	30.67	20.91	28.80	32.55	2.70	235.30
C7 unilateral	480	27.12	18.33	25.48	28.77	2.02	175.10
Total	1920	27.41	19.06	26.56	28.27	2.02	235.30

Anova: $F[3,1916] = 8.41$, $p < 0.001$

Bonferroni post-hoc tests

Technique (I)	Technique (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
C2 central	C2 unilateral	2.75	1.22	.149	-.48	5.98
	C7 central	-3.37	1.22	.036	-6.60	-.14
	C7 unilateral	.18	1.22	1.000	-3.05	3.41
C2 unilateral	C2 central	-2.75	1.22	.149	-5.98	.48
	C7 central	-6.12	1.22	.000	-9.35	-2.88
	C7 unilateral	-2.57	1.22	.216	-5.80	.66
C7 central	C2 central	3.37	1.22	.036	.14	6.60
	C2 unilateral	6.12	1.22	.000	2.88	9.35
	C7 unilateral	3.55	1.22	.023	.32	6.78
C7 unilateral	C2 central	-.18	1.22	1.000	-3.41	3.05
	C2 unilateral	2.57	1.22	.216	-.66	5.80
	C7 central	-3.55	1.22	.023	-6.78	-.32

Caudad-cephalad force direction

Descriptives

Technique	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
C2 central	480	4.30	2.38	4.09	4.52	1.37	20.79
C2 unilateral	480	4.17	1.91	4.00	4.35	1.15	13.08
C7 central	480	15.09	10.37	14.16	16.02	1.78	111.40
C7 unilateral	480	13.16	9.43	12.32	14.01	1.32	90.13
Total	1920	9.18	8.73	8.79	9.57	1.15	111.40

Anova: $F[3,1916] = 310.08$, $p < 0.001$

Bonferroni post-hoc tests

Technique (I)	Technique (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
C2 central	C2 unilateral	.13	.46	1.000	-1.09	1.35
	C7 central	-10.79	.46	.000	-12.01	-9.57
	C7 unilateral	-8.86	.46	.000	-10.08	-7.64
C2 unilateral	C2 central	-.13	.46	1.000	-1.35	1.09
	C7 central	-10.92	.46	.000	-12.14	-9.70
	C7 unilateral	-8.99	.46	.000	-10.21	-7.77
C7 central	C2 central	10.79	.46	.000	9.57	12.01
	C2 unilateral	10.92	.46	.000	9.70	12.14
	C7 unilateral	1.93	.46	.000	.71	3.15
C7 unilateral	C2 central	8.86	.46	.000	7.64	10.08
	C2 unilateral	8.99	.46	.000	7.77	10.21
	C7 central	-1.93	.46	.000	-3.15	-.71

Mediolateral force direction

Descriptives

Technique	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
C2 central	480	1.51	1.07	1.41	1.60	.33	9.77
C2 unilateral	480	3.55	3.36	3.25	3.85	.48	19.59
C7 central	480	1.90	1.46	1.77	2.03	.48	15.92
C7 unilateral	480	4.74	4.82	4.30	5.17	.48	28.85
Total	1920	2.92	3.33	2.77	3.07	.33	28.85

Anova: $F[3,1916] = 114.17$, $p < 0.001$

Bonferroni post-hoc tests

Technique (I)	Technique (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
C2 central	C2 unilateral	-2.05	.20	.000	-2.57	-1.52
	C7 central	-.39	.20	.287	-.92	.13
	C7 unilateral	-3.23	.20	.000	-3.75	-2.71
C2 unilateral	C2 central	2.05	.20	.000	1.52	2.57
	C7 central	1.65	.20	.000	1.13	2.18
	C7 unilateral	-1.18	.20	.000	-1.71	-.66
C7 central	C2 central	.39	.20	.287	-.13	.92
	C2 unilateral	-1.65	.20	.000	-2.18	-1.13
	C7 unilateral	-2.84	.20	.000	-3.36	-2.31
C7 unilateral	C2 central	3.23	.20	.000	2.71	3.75
	C2 unilateral	1.18	.20	.000	.66	1.71
	C7 central	2.84	.20	.000	2.31	3.36

Comparison of central versus unilateral techniques

Vertical force direction

Descriptives

Position	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
central	960	28.99	20.27	27.70	30.27	2.70	235.30
unilateral	960	25.84	17.64	24.72	26.96	2.02	175.10
Total	1920	27.41	19.06	26.56	28.27	2.02	235.30

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
3.63	1918	.000	3.15	1.45	4.85

Caudad-cephalad force direction

Descriptives

Position	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
central	960	9.70	9.25	9.11	10.28	1.37	111.40
unilateral	960	8.67	8.15	8.15	9.19	1.15	90.13
Total	1920	9.18	8.73	8.79	9.57	1.15	111.40

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
2.59	1918	.010	1.030	.25	1.81

Mediolateral force direction

Descriptives

Position	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
central	960	1.70	1.29	1.62	1.78	.33	15.92
unilateral	960	4.14	4.19	3.88	4.41	.48	28.85
Total	1920	2.92	3.33	2.77	3.07	.33	28.85

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
-17.24	1918	.000	2.44	2.72	2.16

Comparison of forces applied to the upper versus lower cervical spine

Vertical force direction

Descriptives

Position	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
Upper (C2)	960	25.93	18.26	24.77	27.09	2.61	156.80
Lower (C7)	960	28.90	19.73	27.65	30.15	2.02	235.30
Total	1920	27.41	19.06	26.56	28.27	2.02	235.30

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
-3.42	1918	.001	2.97	-4.67	-1.27

Caudad-cephalad force direction

Descriptives

Position	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
Upper (C2)	960	4.24	2.16	4.10	4.38	1.15	20.79
Lower (C7)	960	14.13	9.95	13.50	14.76	1.32	111.40
Total	1920	9.18	8.73	8.79	9.57	1.15	111.40

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
-30.09	1918	.000	9.89	10.53	-9.24

Mediolateral force direction

Descriptives

Position	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
Upper (C2)	960	2.53	2.69	2.36	2.70	.33	19.59
Lower (C7)	960	3.32	3.83	3.07	3.56	.48	28.85
Total	1920	2.92	3.33	2.77	3.07	.33	28.85

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
-5.21	1918	.000	.79	-1.08	-.49

5.1.3 Oscillation frequency

Comparison of mobilisation grades

Descriptives

Grade	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
I	480	1.17	.39	1.14	1.21	.00	2.48
II	480	1.05	.35	1.02	1.08	.00	2.40
III	480	.99	.33	.96	1.02	.35	2.24
IV	480	1.23	.42	1.19	1.27	.32	3.02
Total	1920	1.11	.39	1.09	1.13	.00	3.02

Anova: $F[3,1916] = 41.46$, $p < 0.001$

Bonferroni post-hoc

Grade (I)	Grade (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
I	II	.12	.02	.000	.06	.19
	III	.18	.02	.000	.12	.25
	IV	-.06	.02	.081	-.12	.004
II	I	-.12	.02	.000	-.19	-.06
	III	.06	.02	.078	-.003	.12
	IV	-.18	.02	.000	-.25	-.12
III	I	-.18	.02	.000	-.25	-.12
	II	-.06	.02	.078	-.12	.003
	IV	-.24	.02	.000	-.31	-.18
IV	I	0.06	.02	.081	-.004	.12
	II	0.18	.02	.000	.12	.25
	III	0.24	.02	.000	.18	.31

Comparison of techniques (C2 central, C2 unilateral, C7 central and C7 unilateral)

Descriptives

Technique	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
C2 central	480	1.11	.39	1.08	1.15	.00	3.02
C2 unilateral	480	1.11	.38	1.07	1.14	.00	2.48
C7 central	480	1.12	.40	1.09	1.16	.00	2.46
C7 unilateral	480	1.10	.37	1.06	1.13	.00	2.34
Total	1920	1.11	.39	1.09	1.13	.00	3.02

Anova: $F[3,1916] = 0.35$, $p = 0.790$

Bonferroni post-hoc tests

Technique (I)	Technique (J)	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
C2 central	C2 unilateral	.002	.02	1.000	-.06	.07
	C7 central	-.01	.02	1.000	-.08	.06
	C7 unilateral	.01	.02	1.000	-.05	.08
C2 unilateral	C2 central	-.002	.02	1.000	-.07	.06
	C7 central	-.01	.02	1.000	-.08	.05
	C7 unilateral	.01	.02	1.000	-.05	.08
C7 central	C2 central	.01	.02	1.000	-.06	.08
	C2 unilateral	.01	.02	1.000	-.05	.08
	C7 unilateral	.03	.02	1.000	-.04	.09
C7 unilateral	C2 central	-.01	.02	1.000	-.08	.05
	C2 unilateral	-.01	.02	1.000	-.08	.05
	C7 central	-.03	.02	1.000	-.09	.04

Comparison of central versus unilateral techniques

Descriptives

Position	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
central	960	1.12	.40	1.09	1.14	.00	3.02
unilateral	960	1.10	.37	1.08	1.13	.00	2.48
Total	1920	1.11	.39	1.09	1.13	.00	3.02

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
.80	1918	.424	.01	.02	.05

Comparison of forces applied to the upper versus lower cervical spine

Descriptives

Position	N	Mean	SD	95% Confidence Interval		Minimum	Maximum
				Lower Bound	Upper Bound		
Upper (C2)	960	1.1099	.38780	1.0853	1.1345	.00	3.02
Lower (C7)	960	1.1092	.38567	1.0848	1.1337	.00	2.46
Total	1920	1.1096	.38664	1.0923	1.1269	.00	3.02

Independent samples t-test

				95% Confidence Interval	
t	Degrees of freedom	P-value	Mean difference	Lower Bound	Upper Bound
.038	1918	.970	.00067	-.03395	.03529

5.2. Univariate regressions (Students, Chapter 7)

The following tables list p-values for univariate regressions for each factor potentially associated with manual force. Univariate regressions were performed for each unique technique and grade combination. Factors with p ≤ 0.25 (highlighted) were entered in the final regression models using the backwards elimination procedure.

Key of labels for predictor variables (factor potentially associated with manual force) entered into the univariate regressions:

Predictor variable label	Description
Physio age	Physiotherapy student age
Physio height	Physiotherapy student height
Physio weight	Physiotherapy student weight
Physio gender	Physiotherapy student gender
Yrinpgm_2	'Student in year 2' indicator variable for categorical variable 'year in the physiotherapy program'
Yrinpgm_3	'Student in year 3' indicator variable for categorical variable 'year in the physiotherapy program'
Hx thumb pain	Any history of thumb pain
Freqtp dumvar (rarely)	'Rarely' indicator for categorical variable 'frequency of thumb pain'
Freqtp dumvar (sometimes)	'Sometimes' indicator for categorical variable 'frequency of thumb pain'
Freqtp dumvar (reg/often)	'Regular or often' indicator for categorical variable 'frequency of thumb pain'
Hx UL injury	Any history of past upper limb injury
Curr symp UL dumvar (no)	'No' indicator for categorical variable 'experiencing current symptoms due to past upper limb injury (third category included those who had no past upper limb injuries)
Curr symp UL dumvar (yes)	'Yes' indicator for categorical variable 'experiencing current symptoms due to past upper limb injury (third category included those who had no past upper limb injuries)
Definition (I)	Definition of a grade I mobilisation ('small amplitude movement near the start of the range' or 'other')

Definition dumvar (resistance)	'Defining a mobilisation grade using resistance' indicator for categorical variable 'definition of a mobilisation grade' (see Questionnaire for students, Appendix 2.3 for category selections)
Definition dumvar (range)	'Defining a mobilisation grade using range' indicator for categorical variable 'definition of a mobilisation grade' (see Questionnaire for students, Appendix 2.3 for category selections)
Patient age	Mobilised subject age
Patient gender	Mobilised subject gender
Patient height	Mobilised subject height
Patient weight	Mobilised subject weight
Stiffness C2	Mobilised subject stiffness at C2
Stiffness C7	Mobilised subject stiffness at C7

5.2.1 Mean peak force

Vertical force direction		Physio age	Physio height	Physio weight	Physio gender	Yrinpgm_2	Yrinpgm_3	Hx thumb pain	Freqtp dumvar (rarely)	Freqtp dumvar (sometimes)	Freqtp dumvar (reg/often)	HX UL injury	Curr symp UL dumvar (no)	Curr symp UL dumvar (yes)	Definition (I)	Definition dumvar (resistance)	Definition dumvar (range)	Patient age	Patient gender	Patient height	Patient weight	Stiffness C2	Stiffness C7
C2 central & C2 unilateral	I	.081	.030	.010	.005	.001	.243	.302	.146	.650	.828	.801	.816	.902	.730			.557	.007	.050	.001	.000	
	II	.022	.059	.046	.012	.000	.805	.823	.074	.890	.294	.560	.326	.767		.254	.078	.380	.001	.014	.000	.000	
	III	.021	.101	.222	.019	.000	.446	.260	.276	.517	.010	.513	.124	.443		.072	.047	.168	.000	.004	.000	.000	
	IV	.006	.179	.364	.041	.000	.332	.109	.662	.297	.024	.882	.126	.153		.015	.051	.078	.000	.005	.000	.000	
C7 central	I	.339	.132	.140	.181	.004	.786	.476	.200	.894	.912	.875	.763	.909	.862			.140	.192	.215	.322		.028
	II	.304	.166	.217	.163	.001	.353	.538	.114	.950	.516	.480	.352	.961		.847	.584	.038	.038	.084	.076		.005
	III	.316	.123	.334	.130	.005	.087	.658	.216	.387	.307	.588	.289	.683		.106	.234	.109	.014	.093	.040		.007
	IV	.251	.229	.537	.132	.019	.106	.258	.185	.109	.175	.604	.235	.569		.066	.125	.052	.003	.050	.029		.003
C7 unilateral	I	.362	.022	.053	.012	.014	.769	.455	.202	.445	.430	.612	.422	.844	.712			.253	.034	.071	.073		.009
	II	.231	.028	.095	.028	.002	.398	.983	.301	.942	.215	.696	.181	.372		.625	.345	.131	.008	.015	.017		.002
	III	.589	.031	.186	.017	.005	.187	.398	.365	.316	.239	.471	.061	.313		.329	.497	.128	.003	.007	.026		.001
	IV	.325	.147	.598	.174	.022	.131	.094	.436	.302	.003	.592	.049	.177		.022	.139	.076	.001	.028	.035		.000

Caudad-cephalad force direction		Physio age	Physio height	Physio weight	Physio gender	Yrinpgm_2	Yrinpgm_3	Hx thumb pain	Freqtp dumvar (rarely)	Freqtp dumvar (sometimes)	Freqtp dumvar (reg/often)	HX UL injury	Curr symp UL dumvar (no)	Curr symp UL dumvar (yes)	Definition (I)	Definition dumvar (resistance)*	Definition dumvar (range)*	Patient age	Patient gender	Patient height	Patient weight	Stiffness C2	Stiffness C7
C2 central & C2 unilateral	I	.175	.430	.199	.459	.425	.855	.266	.698	.730	.047	.077	.418	.154	.225			.083	.067	.183	.159	.116	
	II	.226	.104	.962	.521	.592	.399	.872	.503	.827	.437	.388	.899	.343		.351	.937	.408	.222	.443	.187	.161	
	III & IV	.361	.216	.120	.727	.716	.390	.010	.572	.194	.007	.323	.848	.306		.367 .186	.075 .604	.040	.075	.651	.147	.514	
C7 central & C7unilateral	I	.134	.098	.040	.039	.000	.321	.095	.042	.207	.561	.534	.422	.993	.914			.050	.455	.084	.229		.217
	II	.111	.083	.060	.029	.000	.028	.188	.046	.438	.334	.297	.181	.984		.135	.051	.011	.213	.039	.064		.133
	III & IV	.083	.148	.601	.057	.000	.000	.452	.034	.525	.002	.056	.003	.583		.066* .000	.351 .004	.000	.001	.001	.006		.002

*P values listed for the indicator variable for each grade.

Mediolateral force direction		Physio age	Physio height	Physio weight	Physio gender	Yrinpgm_2	Yrinpgm_3	Hx thumb pain	Freqtp dumvar (rarely)	Freqtp dumvar (sometimes)	Freqtp dumvar (reg/often)	HX UL injury	Curr symp UL dumvar (no)	Curr symp UL dumvar (yes)	Definition (I)	Definition dumvar (resistance)	Definition dumvar (range)	Patient age	Patient gender	Patient height	Patient weight	Stiffness C2	Stiffness C7
C2 central & C7 central	I & II	.025	.107	.253	.010	.007	.176	.658	.019	.037	.724	.113	.006	.467	.516	.242	.534	.198	.455	.006	.001	.000	.016
	III	.148	.722	.825	.326	.635	.798	.257	.256	.023	.770	.251	.063	.688		.262	.511	.355	.952	.288	.004	.023	.008
	IV	.224	.738	.975	.271	.559	.892	.368	.512	.152	.598	.111	.053	.920		.955	.864	.702	.501	.106	.103	.058	.137
C2 unilateral & C7 unilateral	I & II	.042	.000	.000	.000	.000	.433	.313	.030	.550	.666	.514	.173	.571	.278	.083	.111	.234	.416	.006	.041	.000	.009
	III	.251	.007	.016	.012	.009	.288	.792	.223	.352	.910	.566	.083	.293		.706	.913	.718	.190	.015	.021	.002	.001
	IV	.179	.016	.027	.037	.018	.288	.665	.181	.304	.678	.623	.014	.056		.000	.002	.291	.068	.004	.039	.014	.003

5.2.2 Force amplitude

Vertical force direction		Physio age	Physio height	Physio weight	Physio gender	Yrinpgm_2	Yrinpgm_3	Hx thumb pain	Freqtp dumvar (rarely)	Freqtp dumvar (sometimes)	Freqtp dumvar (reg/often)	HX UL injury	Curr symp UL dumvar (no)	Curr symp UL dumvar (yes)	Definition (I)	Definition dumvar (resistance)	Definition dumvar (range)	Patient age	Patient gender	Patient height	Patient weight	Stiffness C2	Stiffness C7
C2 central & C2 unilateral	I	.094	.368	.023	.156	.001	.472	.371	.253	.627	.918	.621	.441	.899	.714			.619	.112	.198	.021	.002	
	II	.022	.772	.171	.616	.000	.940	.770	.089	.818	.051	.778	.337	.511		.364	.134	.473	.085	.105	.005	.001	
	III	.020	.773	.606	.545	.000	.334	.085	.295	.319	.002	.403	.053	.356		.217	.201	.225	.001	.050	.001	.001	
	IV	.002	.700	.900	.997	.000	.441	.206	.450	.438	.029	.135	.041	.862		.214	.161	.051	.000	.059	.002	.002	
C7 central & C7 unilateral	I	.147	.572	.063	.504	.000	.913	.152	.173	.209	.310	.516	.693	.666	.532			.049	.269	.111	.156		.132
	II	.121	.319	.140	.614	.000	.280	.997	.159	.847	.072	.666	.100	.256		.256	.708	.031	.016	.014	.014		.016
	III	.313	.182	.258	.313	.000	.035	.135	.244	.105	.037	.462	.038	.233		.207	.479	.072	.009	.032	.016		.004
	IV	.038	.635	.988	.562	.000	.056	.226	.170	.848	.000	.065	.031	.857		.069	.125	.003	.000	.010	.014		.003

Caudad-cephalad force direction		Physio age	Physio height	Physio weight	Physio gender	Yrinpgm_2	Yrinpgm_3	Hx thumb pain	Freqtp dumvar (rarely)	Freqtp dumvar (sometimes)	Freqtp dumvar (reg/often)	HX UL injury	Curr symp UL dumvar (no)	Curr symp UL dumvar (yes)	Definition (I)	Definition dumvar (resistance)*	Definition dumvar (range)*	Patient age	Patient gender	Patient height	Patient weight	Stiffness C2	Stiffness C7
C2 central & C2 unilateral	I	.077	.851	.952	.155	.002	.953	.925	.281	.679	.904	.211	.212	.768	.509			.046	.000	.000	.000	.003	
	II & IV	.004	.809	.291	.186	.002	.879	.342	.265	.125	.951	.143	.095	.903		.449 .028	.656 .082	.346	.000	.003	.000	.015	
	III	.261	.634	.551	.057	.005	.788	.457	.513	.196	.650	.163	.461	.316		.481	.288	.434	.002	.120	.005	.043	
C7 central & C7 unilateral	I	.069	.642	.644	.892	.000	.220	.054	.151	.075	.368	.208	.431	.393	.192			.001	.370	.025	.117		.382
	II & IV	.006	.392	.594	.310	.000	.001	.708	.040	.468	.001	.009	.008	.477		.738 .003	.305* .019	.000	.003	.000	.002		.128
	III	.368	.626	.961	.828	.000	.001	.345	.255	.427	.025	.220	.044	.640		.559	.822	.002	.019	.020	.042		.075

*P values listed for the indicator variable for each grade.

Mediolateral force direction		Physio age	Physio height	Physio weight	Physio gender	Yrinpgm_2	Yrinpgm_3	Hx thumb pain	Freqtp dumvar (rarely)	Freqtp dumvar (sometimes)	Freqtp dumvar (reg/often)	HX UL injury	Curr symp UL dumvar (no)	Curr symp UL dumvar (yes)	Definition (I)	Definition dumvar (resistance)*	Definition dumvar (range)*	Patient age	Patient gender	Patient height	Patient weight	Stiffness C2	Stiffness C7
C2 central & C7 central	I & II	.014	.194	.071	.027	.000	.021	.209	.097	.121	.069	.216	.023	.489	.443	.004	.012	.096	.001	.000	.000	.000	.036
	III & IV	.045	.775	.895	.171	.086	.971	.035	.290	.004	.282	.060	.011	.883		.116 .577	.542 .956	.969	.013	.000	.000	.002	.001
C2 unilateral & C7 unilateral	I & II	.039	.005	.001	.011	.000	.360	.827	.090	.721	.226	.874	.110	.145	.381	.098	.186	.289	.339	.021	.045	.001	.002
	III & IV	.083	.015	.015	.023	.000	.193	.461	.117	.170	.591	.445	.002	.033		.201* .000	.727 .000	.408	.031	.001	.001	.001	.000

*P values listed for the indicator variable for each grade.

5.2.3 Oscillation frequency

		Physio age	Physio height	Physio weight	Physio gender	Yrinpgm_2	Yrinpgm_3	Hx thumb pain	Freqtp dumvar (rarely)	Freqtp dumvar (sometimes)	Freqtp dumvar (reg/often)	HX UL injury	Curr symp UL dumvar (no)	Curr symp UL dumvar (yes)	Definition (I)	Definition dumvar (resistance)*	Definition dumvar (range)*	Patient age	Patient gender	Patient height	Patient weight	Stiffness C2	Stiffness C7
All techniques	I & IV	.075	.000	.000	.000	.000	.202	.000	.026	.002	.172	.805	.139	.276	.000	.206	.201	.039	.006	.057	.000	.000	.442
	II & III	.197	.033	.067	.001	.000	.222	.000	.170	.000	.095	.507	.027	.002		.639 .046	.813 .190	.803	.003	.129	.391	.161	.615

*P values listed for the indicator variable for each grade.

5.3. Statistics for final regression models (Students, Chapter 7)

These tables list the statistics for factors included in the final regression models for each unique technique and grade category.

5.3.1 Mean peak force

Vertical force direction

		Adjusted R-square value Factor and p-value	B (regression coefficient)	95%CI for B
C2 central & C2 unilateral	I	Adj R-square .174		
		Physio student gender .014	5.6	1.1 to 10.0
		Dumvar-in yr 2 .000	11.6	6.4 to 16.9
		Dumvar-in yr 3 .000	10.4	5.2 to 15.6
		C2 stiffness .000	-4.3	-6.3 to -2.2
	II	Adj R-square .145		
		Dumvar-in yr 2 .006	7.1	2.0 to 12.1
		Pt weight .029	0.2	0.0 to 0.4
		C2 stiffness .000	-4.5	-6.8 to -2.2
	III	Adj R-square .215		
		Dumvar-in yr 2 .001	10.9	4.5 to 17.4
		Freq thumb pain (reg/often) .001	22.5	9.1 to 35.9
		Definition (resistance) .065	7.9	-0.5 to 16.2
		Pt weight .013	0.3	0.1 to 0.5
		C2 stiffness .000	-6.3	0 to -9.2
	IV	**Col		
		Adj R-square .268		
		Physio student age .052	-1.4	-2.7 to 0
		Dumvar-in yr 2 .025	8.5	1.1 to 15.9
		Hx thumb pain .096	8.5	0.8 to 16.3
		Freq thumb pain (reg/often) .041	15.5	0.6 to 30.3
		Definition (resistance) .031	-9.8	-16.5 to -3.2
		Pt age .080	-0.4	-0.8 to 0
		Pt gender .003	12.7	4.2 to 21.2
		Pt height .002	-0.9	-1.5 to -0.3
		Pt weight .021	0.4	0.1 to 0.8
		C2 stiffness .000	-5.7	-8.7 to -2.7
C7 central	I	**Col		
		Adj R-square .112		
		Physio student height .095	0.3	-0.1 to 0.7
		Dumvar-in yr 2 .001	11.1	4.4 to 17.7
		C7 stiffness .026	1.9	0.2 to 3.6
	II	Adj R-square .143		
		Dumvar-in yr 2 .001	14.1	6.3 to 21.9
		C7 stiffness .002	3.2	1.2 to 5.1
	III	Adj R-square .142		
		Dumvar-in yr 2 .001	18.3	7.6 to 29.0
		Definition (resistance) .036	15.4	1.0 to 29.9
		C7 stiffness .003	4.1	1.4 to 6.7
	IV	Adj R-square .163		
		Physio student gender .096	8.3	-1.5 to 18.0
		Dumvar-in yr 2 .003	15.5	5.3 to 25.8
		Freq thumb pain (sometimes) .086	12.5	-1.8 to 26.7
		Freq thumb pain (reg/often) .035	24.1	1.7 to 46.4
		Definition (resistance) .092	-9.0	-19.5 to 1.5
		C7 stiffness .011	3.4	0.8 to 5.9
C7 unilateral	I	Adj R-square .141		
		Physio student gender .009	6.7	1.7 to 11.8
		Dumvar-in yr 2 .006	7.4	2.2 to 12.6

		C7 stiffness .005	1.9	0.6 to 3.2
	II	Adj R-square .197 Physio student height .012 Dumvar-in yr 2 .000 Freq thumb pain (reg/often) .079 C7 stiffness .003	 0.5 13.9 13.2 2.6	 0.1 to 0.9 7.0 to 20.7 -1.6 to 28.0 0.9 to 4.4
	III	Adj R-square .201 Physio student gender .014 Dumvar-in yr 2 .002 Dumvar exp curr UL symp-no .043 C7 stiffness .000	 10.9 14.2 -12.1 4.2	 2.3 to 19.5 5.3 to 23.1 -23.8 to 0.4 1.9 to 6.4
	IV	Adj R-square .295 Physio student gender .064 Dumvar-in yr 2 .003 Freq thumb pain (reg/often) .000 Dumvar exp curr UL symp-no .051 Definition (resistance) .014 C7 stiffness .000	 7.8 13.1 34.3 -11.2 -11.2 4.5	 -0.5 to 16.0 4.5 to 21.7 15.4 to 53.2 -22.4 to 0 -20.1 to -2.3 2.4 to 6.7

**Col – indicates there was some collinearity in the model

Caudad-cephalad force direction

		Adjusted R-square value Factor and p-value	B (regression coefficient)	95%CI for B
C2 central & C2 unilateral	I	Adj R-square .038 Freq thumb pain (reg/often) .012 Dumvar exp curr UL symp-yes .025 C2 stiffness .042	 2.2 -1.2 -0.4	 0.5 to 3.9 -2.3 to -0.2 -0.7 to 0
	II	Adj R-square .007 Physio student height .104	 .04	 -.01 to .09
	III & IV	Adj R-square .038 Physio student height .001 Physio student weight .004 Freq thumb pain (reg/often) .006 Pt age .087	 .09 -.05 2.2 -.04	 .04 to .14 -.08 to -.02 0.6 to 3.8 -.08 to .01
C7 central & C7 unilateral	I	Adj R-square .099 Physio student weight .019 Dumvar-in yr 2 .000	 .1 5.8	 .02 to .18 3.5 to 8.2
	II	Adj R-square .130 Physio student gender .019 Dumvar-in yr 2 .000 C7 stiffness .075	 3.4 8.2 0.7	 0.6 to 6.2 5.3 to 11.0 -0.1 to 1.4
	III & IV	Adj R-square .193 Physio student gender.010 Dumvar-in yr 2 .000 Freq thumb pain (reg/often) .000 Dumvar exp curr UL symp-no .073 Definition (resistance grd3) .040 Definition (resistance grd4) .000 Definition (range grd4) .034 Pt age .008 Pt height .014 Pt weight .062 C7 stiffness .051	 3.7 10.1 14.8 -3.5 4.1 -13.5 -6.3 -0.26 -0.3 0.14 0.74	 0.9 to 6.6 6.9 to 13.3 8.6 to 21.1 -7.2 to 0.3 -0.2 to 8.0 -19.8 to -7.2 -12.2 to -0.5 -0.46 to -0.07 -0.54 to -0.06 -0.01 to 0.28 0 to 1.5

Mediolateral force direction

		Adjusted R-square value Factor and p-value	B (regression coefficient)	95%CI for B
C2 central & C7 central	I & II	Adj R-square .066		
		Physio student age .010	-.05	-.09 to -.01
		Physio student gender .019	.21	.04 to .39
		Dumvar exp curr UL symp-no .024	-.28	-.52 to -.04
		C2 stiffness .004	-.12	-.20 to -.04
		C7 stiffness .012	.06	.01 to .10
	III	Adj R-square .073		
		Freq thumb pain (sometimes) .028	.70	.08 to 1.3
		Hx UL injury .054	-.47	.01 to .9
		Pt weight .008	.02	.01 to .04
		C7 stiffness .015	.14	.03 to .26
	IV	Adj R-square .024		
		Hx UL injury .074	-.53	-1.12 to .05
		C2 stiffness .100	-.21	-.45 to .04
		C7 stiffness .078	.13	-.01 to .27
C2 unilateral & C7 unilateral	I & II	Adj R-square .097		
		Physio student age .022	-.16	-.30 to -.02
		Physio student weight .000	-.05	.03 to .07
		Dumvar-in yr 2 .003	1.01	.34 to 1.67
		C2 stiffness .011	-.38	-.67 to -.09
		C7 stiffness .006	.23	.07 to .39
	III	Adj R-square .109		
		Physio student weight.017	.06	.01 to .11
		Dumvar-in yr 2 .041	1.67	.07 to 3.26
		Pt gender .067	-1.79	-3.70 to .13
		Pt height .099	.09	-.02 to .20
		C2 stiffness .012	-.88	-1.56 to -.20
		C7 stiffness .001	.65	.27 to 1.02
	IV	Adj R-square .170		
		Physio student age .070	-.31	-.65 to .03
		Physio student weight .005	.08	.02 to .13
		Dumvar-in yr 2 .098	1.37	-.25 to 2.99
		Dumvar exp curr UL symp-no .005	-2.97	-5.04 to -.99
		Definition (resistance) .000	-3.76	-5.40 to -2.12
		C7 stiffness .003	.61	.21 to 1.01

5.3.2 Force amplitude

Vertical force direction

	Grade	Adjusted R-square value Factor and p-value	B (regression coefficient)	95%CI for B
C2 central & C2 unilateral	I	Adj R-square .079 Physio student weight .028 Dumvar-in yr 2 .002 C2 stiffness .028	 .14 5.89 -1.89	 .02 to .27 2.11 to 9.67 -3.56 to -.20
	II	Adj R-square .116 Physio student age .073 Physio student weight .087 Dumvar-in yr 2 .001 Freq thumb pain (reg/often) .005 C2 stiffness .015	 -.78 .12 7.16 12.30 -2.23	 -1.63 to .07 -.02 to .26 2.99 to 11.32 3.68 to 20.93 -4.02 to .45
	III	Adj R-square .141 Dumvar-in yr 2 .001 Freq thumb pain (reg/often) .000 Pt weight.058 C2 stiffness .051	 9.60 23.15 .20 -2.98	 3.97 to 15.24 11.37 to 34.93 -.01 to .41 -5.51 to -.45
	IV	**Col (patient variables) Adj R-square .175 Physio student age .010 Dumvar-in yr 2 .012 Hx thumb pain .041 Freq thumb pain (reg/often) .065 Hx UL injury .044 Definition (range) .090 Pt age .044 Pt gender .001 Pt height .001 Pt weight .082	 -1.15 6.04 5.12 8.73 -4.39 3.39 -.27 8.64 -.57 .19	 -2.02 to -.28 1.34 to 10.73 .20 to 10.01 -.56 to 18.01 -8.67 to -.12 -.53 to 7.31 -.54 to -.01 3.35 to 13.93 -.92 to -.22 -.02 to .40
C7 central & C7 unilateral	I	Adj R-square .081 Physio student weight .040 Dumvar-in yr 2 .000 C7 stiffness .088	 .10 6.29 .64	 .01 ot .20 3.37 to 9.21 -.10 to 1.38
	II	Adj R-square .123 Physio student weight .074 Dumvar-in yr 2 .000 Freq thumb pain (reg/often) .014 C7 stiffness .015	 .13 11.39 12.10 1.37	 -.01 to .28 6.96 to 15.81 2.50 to 21.70 .26 to 2.47
	III	Adj R-square .126 Dumvar-in yr 2 .000 Freq thumb pain (sometimes) .036 Freq thumb pain (reg/often) .005 C7 stiffness .012	 15.64 9.50 19.95 2.07	 9.27 to 22.01 .65 to 18.36 6.14 to 33.75 .47 to 3.66
	IV	Adj R-square .202 Dumvar-in yr 2 .000 Dumvar-in yr 3 .058 Freq thumb pain (reg/often) .000 Hx UL injury .009 Pt gender .056 C7 stiffness .003	 10.51 4.84 25.45 -5.94 4.35 1.69	 5.34 to 15.68 -.17 to 9.85 16.03 to 34.88 -10.40 to -1.48 -.11 to 8.80 .60 to 2.78

**Col – indicates there was some collinearity in the model

Caudad-cephalad force direction

	Grade	Adjusted R-square value Factor and p-value	B (regression coefficient)	95%CI for B
C2 central & C2 unilateral	I	Adj R-square .111		
		Pt gender .000	1.14	.73 to 1.54
	II & IV	Adj R-square .075		
		Physio student age .007	-.11	-.19 to -.03
		Freq thumb pain (sometimes) .033	.57	.05 to 1.09
		Hx UL injury .013	-.50	-.89 to -.11
		Definition (resistance) .059	-.38	-.77 to .01
		Pt gender .000	.88	.50 to 1.25
	III	**Col (patient variables)		
		Adj R-square .056		
		Dumvar-in yr 2 .021	.88	.14 to 1.63
		Pt gender .083	.81	-.11 to 1.73
		Pt height .097	-.05	-.10 to .01
		Pt weight .064	.03	0 to .06
C7 central & C7 unilateral	I	Adj R-square .102		
		Dumvar-in yr 2 .000	2.94	1.48 to 4.39
		Pt age .045	-.08	-.16 to 0
	II & IV	Adj R-square .177		
		Dumvar-in yr 2 .000	4.47	2.71 to 6.22
		Freq thumb pain (reg/often) .000	8.65	5.27 to 12.03
		Hx UL injury .062	-1.55	-3.18 to .08
		Definition (resistance-grd4) .000	-2.95	-4.59 to -1.32
		Pt age .000	-.22	-.33 to -.12
		Pt height .016	-.16	-.30 to -.03
		Pt weight .001	.13	.06 to .21
	III	Adj R-square .121		
		Dumvar-in yr 2 .000	8.66	5.39 to 11.94
		Freq thumb pain (reg/often) .003	10.78	3.67 to 17.88
		C7 stiffness .075	.74	-.08 to 1.56

**Col – indicates there was some collinearity in the model

Mediolateral force direction

	Grade	Adjusted R-square value Factor and p-value	B (regression coefficient)	95%CI for B
C2 central & C7 central	I & II	*Col		
		Adj R-square .145		
		Dumvar-in yr 2 .011	.21	.05 to .38
		Hx thumb pain .043	.18	.01 to .35
		Freq thumb pain (reg/often) .060	.32	-.01 to .65
		Definition (resistance-grd2) .001	-.29	-.45 to -.12
		Pt gender .015	-.23	-.42 to -.05
		Pt height .006	.02	0 to .03
		Pt weight .001	.01	.01 to .02
		C2 stiffness .007	-.09	-.16 to -.03
	III & IV	Adj R-square .081		
		Freq thumb pain (sometimes) .004	.61	.20 to 1.03
		Hx UL injury .004	-.46	-.78 to -.14
		Pt weight .000	.03	.01 to .04
		C7 stiffness .003	.12	.04 to .20
C2 unilateral & C7 unilateral	I & II	Adj R-square .087		
		Physio student age .038	-.13	-.26 to -.01
		Physio student weight .000	.04	.02 to .06
		Dumvar-in yr 2 .000	1.11	.49 to 1.72
		Freq thumb pain (reg/often) .086	1.11	-.16 to 2.38
		C2 stiffness .054	-.26	-.52 to 0
		C7 stiffness .002	.23	.08 to .38
	III & IV	Adj R-square .166		
		Physio student weight .013	.04	.01 to .07
		Dumvar-in yr 2 .001	1.58	.69 to 2.47
		Dumvar exp curr UL symp-no .003	-1.72	-2.84 to -.60
		Definition (resistance-grd4) .000	-2.76	-3.64 to -1.87
		Pt gender .052	-1.07	-2.15 to .01
		Pt weight .025	.04	.01 to .08
		C7 stiffness .000	.52	.30 to .74

**Col – indicates there was some collinearity in the model

5.3.3 Oscillation frequency

	Grade	Adjusted R-square value Factor and p-value	B (regression coefficient)	95%CI for B
All techniques	I & IV	*Col (pt variables, mobilisation definitions)		
		Adj R-square .094		
		Physio student height .001	.005	.002 to .008
		Dumvar-in yr 2 .002	.100	.038 to .161
		Hx thumb pain .000	-.154	-.221 to -.088
		Freq thumb pain (reg/often) .093	.108	-.018 to .233
		Dumvar exp curr UL symp-no .021	.084	.013 to .155
		Definition grd1 .000	-.156	-.243 to -.069
		Definition (resistance-grd4) .003	.178	.060 to .297
		Definition (range-grd4) .032	.124	.011 to .237
		Pt age .000	.007	.004 to .010
		Pt height .031	.004	0 to .007
		C2 stiffness .000	-.054	-.079 to -.029
	II & III	Adj R-square .047		
		Physio student gender .000	.081	.036 to .125
		Dumvar-in yr 2 .000	.087	.040 to .134
		Freq thumb pain (sometimes) .006	-.093	-.159 to -.027
		Dumvar exp curr UL symp-no .016	.079	.015 to .142
		Dumvar exp curr UL symp-yes .084	-.058	-.123 to .008
		Definition (range-grd3) .011	-.101	-.180 to -.023

**Col – indicates there was some collinearity in the model

5.4. Detailed summary of statistics for all factors significantly associated with manual force (final models, Students, Chapter 7)

Table of all factors significantly associated with force parameters. Included if association was clinically meaningful, if it was statistically significantly associated for multiple techniques, grades and directions, and if regression coefficient (B) > 1 N. However, table also includes some techniques with B < 1 N if other techniques statistically associated with the same factor have B > 1 N.

Force parameter	Characteristic	Direction*	Techniques	Grade	*P*†	B**†
Mean peak force (N)						
	Student in year 2	V	C2cen/C2uni	I	.000	11.6
				II	.006	7.1
				III	.001	1.09
				IV	.025	8.5
			C7cen	I	.001	11.1
				II	.001	14.1
				III	.001	18.3
				IV	.003	15.5
			C7uni	I	.006	7.4
				II	.000	13.9
				III	.002	14.2
				IV	.003	13.1
		CC	C7cen/C7uni	I	.000	5.8
				II	.000	8.2
				III & IV	.000	1.01
		ML	C2uni & C7uni	I & II	.003	1.01
				III	.041	1.67
	C2 stiffness	V	C2cen/C2uni	I	.000	-4.3
				II	.000	-4.5
				III	.000	-6.3
				IV	.000	-5.7
		CC	C2cen/C2uni	I	.042	-0.4
		ML	C2cen/C7cen	I & II	.004	-0.12
			C2uni/C7uni	I & II	.011	-0.38
				III	.012	-0.88
	C7 stiffness	V	C7cen	I	.026	1.9
				II	.002	3.2
				III	.003	4.1
				IV	.011	3.4
			C7uni	I	.005	1.9
				II	.003	2.6
				III	.000	4.2
				IV	.000	4.5
		CC	C7cen/C7uni	III & IV	.051	0.74
		ML	C2cen/C7cen	I & II	.012	0.06
				III	.015	0.14

			C2uni/C7uni	I & II III IV	.006 .001 .003	0.23 0.65 0.61
	Physio student gender	V	C2 cen/C2uni	I	.014	5.6
			C7uni	I	.009	6.7
		CC	C7 cen/C7uni	II III & IV	.019 .010	3.4 3.7
		ML	C2cen/C7cen	I & II	.019	0.21
	Frequency of thumb pain regular/often	V	C2cen/C2uni	III IV	.001 .041	22.5 15.5
			C7cen	IV	.035	24.1
			C7uni	IV	.000	34.3
		CC	C2cen/C2uni	I III & IV	.012 .006	2.2 2.2
			C7cen/C7uni	III & IV	.000	14.8
	No UL‡ symptoms due to past injury (includes those who had a past UL injury)	V	C7uni	III IV	.043 .051	-12.1 -11.2
		ML	C2cen/C7cen	I & II	.024	-0.28
			C2uni/C7uni	IV	.005	-2.97
	Defining mobilisation grades III & IV using resistance	V	C2cen/C2uni	IV	.031	-9.8
			C7cen	III	.036	15.4
			C7uni	IV	.014	-11.2
		CC	C7cen/C7uni	III & IV	.040 .000	4.1 -13.5
		ML	C2uni/C7uni	IV	.000	-3.76
	Defining mobilisation grade IV using range	CC	C7cen/C7uni	III & IV	.034	-6.3
	Patient gender	V	C2cen/C2uni	IV	.003	12.7
	Patient weight	V	C2cen/C2uni	III IV	.013 .021	0.3 0.4
		ML	C2cen/C7cen	III	.008	0.02
<u>Force amplitude</u>						
	Student in year 2	V	C2cen/C2uni	I II III IV	.002 .001 .001 .012	5.89 7.16 9.60 6.04
			C7cen/C7uni	I	.000	6.29

			II III IV	.000 .000 .000	11.39 15.64 10.51
	CC	C2cen/C2uni	III	.021	0.88
		C7cen/C7uni	I II & IV III	.000 .000 .000	2.94 4.47 8.66
	ML	C2cen/C7cen	I & II	.011	0.21
		C2uni/C7uni	I & II III & IV	.000 .001	1.11 1.58
C2 stiffness	V	C2cen/C2uni	I II III	.028 .015 .051	-1.89 -2.23 -2.98
	ML	C2cen/C7cen	I & II	.007	-0.09
		C2uni/C7uni	I & II	.054	-0.26
C7 stiffness	V	C7cen/C7uni	II III IV	.015 .012 .003	1.37 2.07 1.69
	ML	C2cen/C7cen	III & IV	.003	0.12
		C2uni/C7uni	I & II III & IV	.002 .000	0.23 0.52
History of thumb pain	V	C2cen/C2uni	IV	.041	5.12
Frequency of thumb pain regular/often	V	C2cen/C2uni	II III	.005 .000	12.3 23.15
		C7cen/C7uni	II III IV	.014 .005 .000	12.1 19.95 25.45
	CC	C7cen/C7uni	II & IV III	.000 .003	8.65 10.78
Frequency of thumb pain sometimes	V	C7cen/C7uni	III	.036	9.5
	CC	C2cen/C2uni	II & IV	.033	0.57
	ML	C2cen/C7cen	III & IV	.004	0.61
History of UL injury	V	C2cen/C2uni	IV	.044	-4.39
		C7cen/C7uni	IV	.009	-5.94
	CC	C2cen/C2uni	II & IV	.013	-0.5
	ML	C2cen/C7cen	III & IV	.004	-0.46
Defining mobilisation grade IV using resistance	CC	C7cen/C7uni	II & IV	.000	-2.95
	ML	C2uni/C7uni	III & IV	.000	-2.76
Patient gender	V	C2cen/C2uni	IV	.001	8.64

	Patient weight	CC	C7cen/C7uni	II & IV	.001	0.13
<u>Oscillation frequency</u>						
	Student in year 2	na	all	I & IV	.002	.100
		na	all	II & III	.000	.087
	C2 stiffness	na	all	I & IV	.000	-.054
	Physio student gender	na	all	II & III	.000	.081
	History of thumb pain	na	all	I & IV	.000	-.154
	Frequency of thumb pain sometimes	na	all	II & III	.006	-.093
	No UL symptoms due to past injury (includes those who had a past UL injury)	na	all	I & IV II & III	.021 .016	.084 .079
	Defining grade I using 'other' (11 of 12 used resistance, 1 used large amp not to range limit)	na	all	I & IV	.000	-.156
	Defining mobilisation grade IV using resistance	na	all	I & IV	.003	.178
	Defining mobilisation grades III & IV using range	na	all	I & IV II & III	.032 .011	.124 -.101

*V = vertical, CC = caudad-cephalad, ML = mediolateral, all = all techniques for that direction, C2 = techniques applied to C2, C7 = techniques applied to C7, cen = central techniques, uni = unilateral techniques.
**B = regression coefficient from the final regression models for each grade, direction and technique; positive values indicate increased force was associated with the characteristic, negative values indicate decreased force.
†Statistics for individual characteristics in the final backwards regression models for each unique technique and grade category.
‡UL = Upper limb; category includes only those who have had a previous UL injury.

APPENDIX 6. Additional statistical calculations for comparisons of physiotherapists and students (Chapter 8)

6.1. Comparison of manual cervical mobilisation forces between physiotherapists and students

These tables compare manual forces between physiotherapists and students for each technique and grade. Statistical differences are highlighted.

6.1.1 Mean peak force

Vertical force direction

	Grade	Group	Mean	SD	P value	Mean difference	95% CI of the difference
C2 central	I	PTs Students	21.76 24.93	16.69 18.91	0.175	-3.16	-7.74 to 1.42
	II	PTs Students	34.50 32.40	22.25 21.65	0.463	2.86	-3.53 to 7.73
	III	PTs Students	55.66 47.51	31.45 27.15	0.034	8.17	0.63 to 15.68
	IV	PTs Students	64.92 52.47	36.76 26.79	0.003	12.44	4.22 to 20.67
C2 unilateral	I	PTs Students	21.57 22.25	15.23 17.71	0.755	-0.67	-4.91 to 3.57
	II	PTs Students	33.75 30.09	19.03 17.38	0.124	3.66	-1.01 to 8.33
	III	PTs Students	54.24 42.87	28.43 23.41	0.001	11.37	4.70 to 18.04
	IV	PTs Students	63.34 49.09	33.32 26.53	<0.001	14.25	6.54 to 21.96
C7 central	I	PTs Students	28.98 28.84	22.01 18.25	0.959	0.13	-5.04 to 5.31
	II	PTs Students	43.21 38.71	26.30 22.02	0.155	4.50	-1.71 to 10.71
	III	PTs Students	68.75 55.55	35.51 29.86	0.002	13.20	4.78 to 21.63
	IV	PTs Students	80.37 63.65	41.08 28.38	<0.001	16.71	7.62 to 25.80
C7 unilateral	I	PTs Students	26.96 24.78	18.51 14.63	0.317	2.18	-2.11 to 6.47
	II	PTs Students	40.89 34.17	23.14 19.46	0.017	6.72	1.23 to 12.21
	III	PTs Students	64.83 48.85	31.93 25.79	<0.001	15.99	8.52 to 23.45
	IV	PTs Students	73.03 55.54	36.16 26.18	<0.001	17.49	9.36 to 25.61

Caudad-cephalad force direction

	Grade	Group	Mean	SD	P value	Mean difference	95% CI of the difference
C2 central	I	PTs Students	3.15 3.12	3.64 3.03	0.934	0.04	-0.82 to 0.89
	II	PTs Students	4.03 3.51	4.00 3.48	0.285	0.52	-0.44 to 1.48
	III	PTs Students	5.43 4.44	6.08 3.58	0.130	0.99	-0.30 to 2.28
	IV	PTs Students	5.75 4.60	6.25 4.02	0.094	1.15	-0.20 to 2.51
C2 unilateral	I	PTs Students	3.19 3.53	2.83 2.69	0.348	-0.34	-1.05 to 0.37
	II	PTs Students	4.49 4.00	3.99 2.87	0.277	0.49	-0.40 to 1.39
	III	PTs Students	6.76 4.98	5.95 3.46	0.006	1.78	0.53 to 3.04
	IV	PTs Students	7.36 5.69	7.89 4.44	0.047	1.68	0.02 to 3.33
C7 central	I	PTs Students	14.55 16.39	11.22 10.30	0.190	-1.84	-4.60 to 0.92
	II	PTs Students	20.36 21.15	14.31 12.19	0.650	-0.79	-4.19 to 2.62
	III	PTs Students	33.55 29.17	22.32 16.24	0.087	4.38	-0.64 to 9.40
	IV	PTs Students	39.77 33.67	25.61 16.17	0.031	6.09	0.57 to 11.61
C7 unilateral	I	PTs Students	13.40 13.21	9.55 7.87	0.868	0.19	-2.06 to 2.44
	II	PTs Students	19.89 17.69	13.54 10.39	0.163	2.20	-0.90 to 5.31
	III	PTs Students	32.19 25.34	20.18 14.94	0.003	6.84	2.28 to 11.41
	IV	PTs Students	37.57 29.19	23.33 15.99	0.002	8.38	3.23 to 13.53

Mediolateral force direction

	Grade	Group	Mean	SD	P value	Mean difference	95% CI of the difference
C2 central	I	PTs Students	0.99 0.80	2.61 0.85	0.461	0.19	-0.31 to 0.68
	II	PTs Students	1.21 0.88	2.68 0.90	0.202	0.26	0.18 to 0.86
	III	PTs Students	1.78 1.12	2.94 1.26	0.025	0.30	0.08 to 1.25
	IV	PTs Students	1.91 1.17	2.94 1.41	0.016	0.30	0.14 to 1.33
C2 unilateral	I	PTs Students	3.74 2.06	5.29 2.55	0.002	1.68	0.61 to 2.76
	II	PTs Students	5.71 2.84	6.02 3.25	<0.001	2.87	1.62 to 4.12
	III	PTs Students	11.42 4.28	11.97 4.51	<0.001	7.14	4.79 to 9.48
	IV	PTs Students	13.22 5.24	12.50 5.21	<0.001	7.98	5.50 to 10.46
C7 central	I	PTs Students	1.89 1.24	2.95 0.87	0.026	0.64	0.08 to 1.20
	II	PTs Students	2.29 1.43	2.52 1.06	0.001	0.86	0.36 to 1.36
	III	PTs Students	3.38 2.08	3.67 1.93	0.001	1.30	0.54 to 2.05
	IV	PTs Students	4.09 2.31	4.57 2.41	<0.001	1.78	0.84 to 2.73
C7 unilateral	I	PTs Students	3.92 2.87	4.14 3.41	0.035	1.05	0.07 to 2.02
	II	PTs Students	6.85 3.79	6.05 4.36	<0.001	3.07	1.71 to 4.43
	III	PTs Students	12.71 6.11	10.83 6.47	<0.001	6.60	4.30 to 8.90
	IV	PTs Students	15.08 7.83	12.19 7.08	<0.001	7.25	4.68 to 9.82

6.1.2 Force amplitude

Vertical force direction

	Grade	Group	Mean	SD	P value	Mean difference	95% CI of the difference
C2 central	I	PTs Students	15.71 17.65	12.67 15.23	0.290	-1.94	-5.54 to 1.66
C2 central	II	PTs Students	27.25 25.40	20.28 17.51	0.453	1.85	-3.00 to 6.71
C2 central	III	PTs Students	43.42 37.79	27.47 23.16	0.090	5.62	-0.88 to 12.13
C2 central	IV	PTs Students	35.36 28.37	29.16 15.64	0.024	3.06	.095 to 13.03
C2 unilateral	I	PTs Students	14.40 15.29	10.29 13.19	0.565	-0.89	-3.93 to 2.15
C2 unilateral	II	PTs Students	25.01 22.72	14.21 13.12	0.199	2.29	-1.21 to 5.80
C2 unilateral	III	PTs Students	40.55 33.42	22.74 19.32	0.010	7.13	1.72 to 12.53
C2 unilateral	IV	PTs Students	34.14 26.80	24.11 15.78	0.006	7.34	2.09 to 12.59
C7 central	I	PTs Students	18.39 19.32	15.10 12.12	0.601	-0.93	-4.44 to 2.57
C7 central	II	PTs Students	30.59 28.79	19.45 18.59	0.468	1.80	-3.08 to 6.68
C7 central	III	PTs Students	48.64 42.08	29.13 26.61	0.072	6.55	-0.60 to 13.71
C7 central	IV	PTs Students	38.34 32.50	27.47 17.05	0.052	2.99	-0.05 to 11.73
C7 unilateral	I	PTs Students	16.37 16.16	12.83 10.17	0.890	0.21	-2.76 to 3.17
C7 unilateral	II	PTs Students	28.22 25.57	17.19 15.51	0.213	2.66	-1.54 to 6.85
C7 unilateral	III	PTs Students	45.82 37.49	25.94 22.17	0.009	8.33	2.13 to 14.53
C7 unilateral	IV	PTs Students	35.57 29.27	24.35 16.73	0.022	6.29	0.91 to 11.68

Caudad-cephalad force direction

	Grade	Group	Mean	SD	P value	Mean difference	95% CI of the difference
C2 central	I	PTs Students	2.85 3.64	1.56 1.78	<0.001	-0.80	-1.22 to -0.37
	II	PTs Students	3.65 4.26	2.16 2.23	0.033	-0.61	-1.18 to -0.05
	III	PTs Students	4.99 5.09	3.93 3.00	0.818	-0.10	-1.00 to 0.79
	IV	PTs Students	4.12 4.22	3.16 2.14	0.766	-0.10	-0.80 to 0.59
C2 unilateral	I	PTs Students	2.87 3.52	1.52 1.41	0.001	-0.65	-1.02 to -0.27
	II	PTs Students	3.67 4.10	2.43 1.68	0.120	-0.43	-0.96 to 0.11
	III	PTs Students	5.51 4.90	4.28 2.17	0.174	0.61	-0.27 to 1.48
	IV	PTs Students	4.85 4.17	4.38 2.07	0.132	0.68	-0.21 to 1.56
C7 central	I	PTs Students	7.95 9.77	7.02 5.84	0.031	-1.82	-3.47 to -0.17
	II	PTs Students	12.83 14.19	10.43 8.70	0.276	-1.36	-3.82 to 1.10
	III	PTs Students	21.43 20.26	17.22 13.35	0.561	1.17	-2.79 to 5.13
	IV	PTs Students	16.58 16.15	13.81 9.32	0.779	0.43	-2.60 to 3.47
C7 unilateral	I	PTs Students	7.36 7.98	6.68 4.59	0.409	-0.62	-2.09 to 0.86
	II	PTs Students	12.55 12.23	9.71 7.82	0.780	0.32	-1.94 to 2.59
	III	PTs Students	21.03 18.17	16.38 11.94	0.128	2.86	-0.83 to 6.55
	IV	PTs Students	16.58 14.28	14.73 8.86	0.150	2.30	-0.84 to 5.43

Mediolateral force direction

	Grade	Group	Mean	SD	P value	Mean difference	95% CI of the difference
C2 central	I	PTs Students	1.19 1.28	0.59 0.80	0.318	-0.09	-0.27 to 0.09
	II	PTs Students	1.49 1.42	0.88 0.88	0.532	0.07	-0.15 to 0.30
	III	PTs Students	2.02 1.69	1.51 1.25	0.070	0.33	-0.03 to 0.69
	IV	PTs Students	1.83 1.62	1.11 1.23	0.177	0.21	-0.09 to 0.51
C2 unilateral	I	PTs Students	3.68 2.29	6.20 2.06	0.023	1.39	0.19 to 2.59
	II	PTs Students	5.86 3.09	6.36 2.89	<0.001	2.77	1.49 to 4.05
	III	PTs Students	10.62 4.50	12.97 4.16	<0.001	6.12	3.63 to 8.62
	IV	PTs Students	9.33 4.33	9.46 3.50	<0.001	5.00	3.15 to 6.84
C7 central	I	PTs Students	1.58 1.45	1.25 0.63	0.324	0.13	-0.13 to 0.38
	II	PTs Students	2.15 1.69	1.78 0.77	0.012	0.46	0.10 to 0.81
	III	PTs Students	3.00 2.33	2.93 1.78	0.035	0.67	0.05 to 1.30
	IV	PTs Students	2.75 2.12	2.57 2.00	0.039	0.62	0.03 to 1.22
C7 unilateral	I	PTs Students	3.36 2.97	3.18 3.24	0.353	0.39	-0.43 to 1.21
	II	PTs Students	6.19 3.98	5.60 3.93	0.001	2.21	0.96 to 3.45
	III	PTs Students	11.01 6.10	9.81 6.04	<0.001	4.91	2.81 to 7.02
	IV	PTs Students	9.05 5.90	7.73 4.91	<0.001	3.16	1.49 to 4.83

6.1.3 Oscillation frequency

	Grade	Group	Mean	SD	P value	Mean difference	95% CI of the difference
C2 central	I	PTs Students	1.30 1.17	0.50 0.38	0.025	0.13	0.02 to 0.25
	II	PTs Students	1.18 1.04	0.46 0.35	0.010	0.14	0.03 to 0.24
	III	PTs Students	1.11 0.98	0.46 0.32	0.013	0.13	0.03 to 0.23
	IV	PTs Students	1.28 1.25	0.49 0.45	0.707	0.02	-0.10 to 0.14
C2 unilateral	I	PTs Students	1.30 1.17	0.52 0.40	0.037	0.13	0.01 to 0.25
	II	PTs Students	1.19 1.05	0.47 0.36	0.017	0.13	0.02 to 0.24
	III	PTs Students	1.12 0.99	0.46 0.34	0.016	0.13	0.02 to 0.23
	IV	PTs Students	1.33 1.22	0.53 0.39	0.074	0.11	-0.01 to 0.23
C7 central	I	PTs Students	1.32 1.18	0.49 0.41	0.015	0.14	0.03 to 0.26
	II	PTs Students	1.19 1.07	0.45 0.37	0.021	0.13	0.02 to 0.23
	III	PTs Students	1.11 1.00	0.49 0.36	0.054	0.11	-0.00 to 0.22
	IV	PTs Students	1.31 1.24	0.49 0.44	0.268	0.07	-0.05 to 0.19
C7 unilateral	I	PTs Students	1.29 1.16	0.49 0.38	0.034	0.12	0.01 to 0.24
	II	PTs Students	1.18 1.04	0.45 0.33	0.005	0.15	0.05 to 0.25
	III	PTs Students	1.11 0.98	0.43 0.32	0.011	0.13	0.03 to 0.22
	IV	PTs Students	1.28 1.21	0.53 0.39	0.215	0.08	-0.04 to 0.20

APPENDIX 7. Verbal instructions given to participants in the study investigating the effects of feedback on mobilisation forces (Chapter 11)

7.1. Instructions for persons being mobilised

You are going to have your lower neck area mobilised. In order to record accurate data, you should lie as still as possible during the treatment and do not talk. There can sometimes be some discomfort with mobilisation, this is normal. If it becomes too uncomfortable and you need to stop, let me know by raising your right hand out to the side.

Four grades of mobilisation will be applied. Each grade is recorded for 10 seconds, then applied for 30 seconds repeated 3 times, then recorded for 10 seconds. I'll zero the load cells prior to each application of mobilisation. It's especially important to lie still while I am zeroing the load cells and while you are being mobilised. If you need to wiggle around a bit, you can do this when I am talking to the student about their mobilisation after they have finished each set of mobilisation.

I'd like for you not to give any feedback to the student mobilising you. However, if you become too uncomfortable, do let me know this.

7.2. Instructions for students receiving feedback (experimental condition)

7.2.1 Instructions for testing

This table is fitted with load cells which measure your mobilisation force as you apply it. The lean bar on the table is separate to the load cells so you can lean on it without affecting the force you apply. However, the table measures all force applied to the person, so if you lean onto them through your fingers, this is added to the force you apply. Ok to rest your fingers on them if this is comfortable to you, just know that if there's a lot of force through the fingers this does get added to the total force measured

I am going to record your mobilisation force before and after 3 sets of 30 seconds of mobilisation practice. For this first recording, I would like you to apply a grade X mobilisation to C7, as you learned in class. First, you can palpate the level and get a feel for the stiffness of the level, how you'd like to hold your hands, and whether you would like to use a box to stand on.

Then, you will take your hands off the subject while I zero the load cells. I will record 10 seconds of you applying that mobilisation grade. After the zeroing, you can start applying your mobilisation. When you feel you are doing the particular grade, say 'now' or 'yes' and I will then record 10 seconds.

We'll repeat this procedure after the 3 sets of 30 second practice.

7.2.2 Instructions for practising

Now you'll practice this mobilisation for 30 seconds, repeated 3 times.

This screen will provide feedback. I want you to focus on this top window while mobilising. It shows your vertical force applied. Your mobilisation force will appear as an oscillation curve on the screen (show paper example). This is the peak force, where you are pressing hardest on the subject, and this is the trough force, where you are letting off your force (point). These green bars represent the target peak force and target trough force that you should try to apply. The very middle of each bar is the exact force that an expert physiotherapist applied to this subject. You should try to make your peak force in the top bar, near the middle as much as possible, and your trough force in the bottom bar, near the middle as much as possible. When you achieve this, your peak force will be similar to that of the expert, and your force amplitude, which is the height of the curve (point to example), will also be similar to that of the expert. When your peak force or trough force is not within its green bar, the bar will blink red. Also, for each peak that is not within the green bar, there will be a beep. Do you have any questions about what you're looking at on the screen?

I'll tell you when you can start mobilising after I have zeroed the load cells. Keep mobilising until I tell you to stop. I won't say anything while you are mobilising, I want you to concentrate on the feedback you get from the computer screen, and feeling with your hands what the ideal force feels like. I will give you some feedback at the end of each 30 seconds of practice. When you have the force within the green bars, try to remember what this feels like with your hands, because at the end of the 3 sets of 30 seconds practice you will then try to replicate this force without looking at the screen. Do you have any questions about this procedure?

OK. Now I'll just zero the load cells… now start applying a grade X PA mobilisation to CX.

7.2.3 Terminal feedback

Your peak force was within the target force X% of the time. You tended to over/undershoot the target peak force.

Your amplitude was correct X% of the time. This means the height of your oscillating force was close to the same as the expert's for that percentage of time.

*If force in the horizontal direction was excessive (quantified by peak being well outside the visible area), then make a comment about angling force too much whichever direction.

7.3. Instructions for students not receiving feedback (control condition)

7.3.1 Instructions for testing

Control 1 (control condition occurring first for the student)
Instructions for testing are the same as described in 7.2.1.

Control 2 (control condition completed after experimental condition)

I am going to record your mobilisation force before and after 3 sets of 30 seconds of mobilisation practice, as we did in the last session. For this first recording, I would like you to apply a grade X PA mobilisation to C7, trying to apply the mobilisation with the same force that you used last week on this subject when you were able to see your forces on the screen. We're looking at whether you will apply the mobilisation the same way to this subject after one week.

The procedure will be the same as before. First, you will palpate the neck and get a feel for the stiffness of the level, how you'd like to hold your hands, and whether you would like to use a box to stand on.

Then, you will take your hands off the subject while I zero the load cells. I will then record 10 seconds of you applying that mobilisation. After the zeroing, you can start applying your mobilisation. When you feel you are doing the particular grade, say ‘now’ or ‘yes’ and I will then record for 10 seconds.

We’ll repeat this procedure after the 3 sets of 30 seconds practice.

7.3.2 Instructions for practising

Control 1 (control condition occurring first for the student)

Now you’ll practice this mobilisation for 30 seconds, repeated 3 times. I am not going to give you any formal feedback today. However, as you are practicing, you should think about what you learned in class and try to apply the techniques using the principles you were taught.

Control 2 (control condition completed after experimental condition)

Now you’ll practice this mobilisation for 30 seconds, repeated 3 times. I am not going to give you any formal feedback today. However, as you are practicing, you should try to apply the technique using what you learned and remember from the feedback you received last week.