DEVELOPMENT OF A NEW METHOD OF MEASUREMENT OF CRANIO-CERVICAL FLEXOR MUSCLE PERFORMANCE

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STATEMENT OF ORIGINALITY

I declare that the work presented in this thesis is, to the best of my knowledge and belief, original and my own work, except as acknowledged in the text, and that the material has not been submitted, either in whole or in part, for a degree at this or any other university.

Shaun O'Leary
28th January 2005
This thesis is dedicated to my parents Daniel and Yvonne O’Leary, who after 48 happy years of marriage were parted following the passing of my father Danny on the 21st of April 2005.
ABSTRACT

Neck pain is a common and costly problem in the community. In the practice of musculoskeletal rehabilitation, accurate measurements of muscle performance facilitate diagnosis, guide best-practice therapeutic intervention, and monitor rehabilitative progress that ultimately hastens recovery and minimises rehabilitative expense. The cranio-cervical flexor (CCF) muscles have shown evidence of impairment in persons with neck pain, and rehabilitation of their performance is effective in reducing painful neck symptoms. Measures of CCF muscle performance do exist, however, there remains a lack of methodology available that measures their primary biomechanical function, that is, the production of flexion torque to the cranio-cervical junction (C0/I). It was proposed that such a method would have valuable clinical application in the assessment of CCF muscle performance.

An isometric cranio-cervical flexion dynamometry (CCFD) method was developed, inclusive of a dynamometry device, and measurement protocol. The dynamometry device was constructed to directly resist and measure isometric cranio-cervical flexor (ICCF) muscle torque. The dynamometry measurement protocol was designed to challenge ICCF muscle performance in a manner that closely reflected their postural function. Measures included isometric strength (isometric maximal voluntary contraction (IMVC)), and isometric endurance at moderate (50% of IMVC), and low (20% of IMVC) levels of muscle effort. An electromyography (EMG) study established that these CCFD measures were specific to the activity of the CCF muscles compared to the other flexor muscles of the neck, particularly when performed at the low (P < 0.01), and moderate (P < 0.02) intensities of effort.

The clinical application of the CCFD measurements in the assessment of ICCF muscle performance was evaluated by investigating their test-retest reliability, their capacity to quantify ICCF muscle impairment, and their capacity to respond to a change in ICCF muscle performance following rehabilitation. Measurements of ICCF muscle strength and endurance were shown to have good reliability (ICC 0.7-0.9) and
similar measurement error in participants with and without neck disorders. When CCFD measurements of these groups were compared, the neck pain sufferers were significantly weaker (15.9%), and had significantly less endurance both at low (35% deficit) and moderate (27% deficit) ICCF muscle efforts. This is the first method to have demonstrated ICCF muscle impairment over a range of contraction intensities in persons with neck disorders, and is suggestive of its potential clinical application in the diagnosis of neck muscle impairment.

The method has also shown a capacity to monitor changes in ICCF muscle performance pre-post rehabilitation. This clinical measurement attribute was assessed by comparing CCFD measurements in individuals pre-post rehabilitative training of their CCF muscles. Changes in performance were tested for significance (P < 0.05) accounting for measurement error. Twenty-one to 40% of participants demonstrated reliable performance changes pre-post rehabilitation. Although these figures are modest they are encouraging considering most of the characteristics of the rehabilitative exercises were not matched to the characteristics of the CCFD measurements, potentially leaving outcomes vulnerable to issues related to specificity of training.

This thesis provides a foundation for the development of a new method of measurement of ICCF muscle performance. The new method is based on sound biomechanical principles and the studies within the thesis have shown that the measurements have potential clinical application.
ACKNOWLEDGEMENTS

In completing this doctoral study there are many people who should be acknowledged in sincere appreciation of their professional contribution and their support. In particular I have been lucky to have two supervisors who epitomise the fundamental link between research and good clinical physiotherapy practice.

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LIST OF PUBLICATIONS

The following publications by the candidate have emanated from the work presented in this thesis -


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O'Leary, S., Jull, G., Kim, M., Vicenzino, B. Cranio-cervical flexor muscle impairment at maximal, moderate, and low loads is a feature of neck pain. Submitted for publication.

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LIST OF ABBREVIATIONS

AOR: Axis of rotation
AS: Anterior scalenes
CCF: Cranio-cervical flexor
CCFD: Cranio-cervical flexion dynamometry
CCFT: Cranio-cervical flexion test
CFD: Cervical flexion dynamometry
CCFEx: Cranio-cervical flexion exercise
CFEx: Cervical flexion exercise
CSA: Cross-sectional area
DHF: Dorsal head force
EMG: Electromyography
HD: Hyoid
ICC: Intraclass correlational coefficient
ICCF: Isometric cranio-cervical flexor
IMVC: Isometric maximal voluntary contraction
IMVC\textsubscript{20}: Contraction at 20% of IMVC
IMVC\textsubscript{50}: Contraction at 50% of IMVC
kp: Kilopond
LC: Longus capitis
LCo: Longus colli
N: Newtons
Nm: Newton-meters
NDI: Neck disability index
RCA: Rectus capitis anterior
RMS: Root-mean-square
S: Seconds
SC: Splenius capitis
SCM: Sternocleidomastoid

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<table>
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<tr>
<td>SEM</td>
<td>Standard error of the measure</td>
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<td>SOE</td>
<td>Suboccipital extensor</td>
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<td>SSC</td>
<td>Semispinalis capitis</td>
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<tr>
<td>12RM</td>
<td>12-repetition maximum</td>
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Neck related pain disorders are a common and costly problem in the community with approximately 13-20% of the population currently suffering neck pain (Bovim et al. 1992; Cote et al. 1998). It is estimated that 70% of all people will experience neck pain at some point in their life (Makela et al. 1991; Cote et al. 1998), and that approximately 2-3% of the population suffer from cervicogenic headache (Pfaffenrath and Kaube 1990; Rasmussen et al. 1991; Nilsson 1995). Additionally, traumatic neck injury such as whiplash is the most commonly reported injury in compulsory third party claims (MAIC 2002). Therefore, it is of no surprise that neck pain stands, with back pain, as the most common reasons that people visit physiotherapists (42% of visits) (PABC 2001). With much of the treatment costs falling on private health insurers, there is, in turn, mounting pressure on musculoskeletal health care professionals such as physiotherapists to justify their management approach to these neck disorders. An emphasis has been placed on the use of accurate clinical measurements of physical impairment that can be used diagnostically to justify intervention, as well as to provide a responsive outcome measure to monitor recovery. There is also an air of expectation from the rehabilitation industry that physical impairment measures must reflect certain aspects of vocational or self-care function.

In the mobile cervical spine where the muscle system accounts for approximately 80% of mechanical stability (Panjabi et al. 1998), physical measurements of muscle performance are the cornerstone in rehabilitative examination practice. The challenge in the cervical spine is that functionally, motion at the specialised upper cranio-cervical articulations can occur independently of the remainder of the cervical spine (Worth 1994), and accordingly, the morphology of the cranio-cervical muscles differs to that of the other cervical spine muscles. Cranio-cervical muscles have their uppermost attachment to the cranium, and in the case of the deep cranio-cervical muscles, predominantly span only the uppermost cervical motion segments. Consequently these muscles are ideally
positioned to orientate the head on the cervical spine, as well as provide mechanical stability to the cranio-cervical articulations. With regard to the cervical flexor muscles, this division has underpinned a trend in research and in clinical practice to measure cranio-cervical flexor (CCF) muscle performance separately to the other cervical flexors and has resulted in mounting evidence of their impairment in painful neck disorders (Watson and Trott 1993; Jull et al. 1999; Jull 2000; Sterling et al. 2003; Jull et al. 2004b; Falla et al. 2004a; Falla et al. 2004b). Consequently, specific measures of CCF muscle performance are considered to be an integral component in the clinical examination of the cervical spine (Jull et al. 2004a).

Functionally, the CCF muscles exert a flexion torque about the cranio-cervical junction, which contributes to orientation and support of the cranio-cervical spine region (Kamibayashi and Richmond 1998; Vasavada et al. 1998; Moore and Dalley 1999). Findings from electromyographic (EMG) studies indicate that this function may be compromised in the presence of neck pain. For example, EMG studies have shown persons with neck pain to have delayed CCF muscle recruitment when supporting the cervical spine in response to upper limb perturbation (Falla et al. 2004a), as well as reduced amplitude of CCF muscle activity when performing a graded test of cranio-cervical flexion (Falla et al. 2004b). Such findings offer some support to clinical associations that have been reported between poor CCF muscle performance and abnormal postural orientation of the upper cervical region (Janda 1988; Jull 1988; Watson and Trott 1993; Grimmer and Trott 1998). These EMG measures at present do not have practical clinical application, as they require invasive techniques, expert analysis, and sophisticated equipment that are not accessible in contemporary clinical settings. Other methods using force sensitive devices have measured deficits in the capacity of neck pain sufferers, compared to control participants, to generate and sustain isometric cranio-cervical flexor (ICCF) muscle contractions (Watson and Trott 1993; Jull et al. 1999; Jull 2000; Jull et al. 2004b). These methods do have practical clinical application but fail to measure the primary biomechanical function of the CCF muscles; which is the generation of a flexion torque to the head about the C0/I motion segment.
It is proposed that a measure specific to the contractile performance of the CCF muscles should directly resist their biomechanical action of cranio-cervical flexion, and measure their resultant torque generated about their primary articulation of action, the C0/I motion segment. The purpose of this doctoral project was to develop a new method of cranio-cervical flexion dynamometry (CCFD) to satisfy these criteria. This process involved both the development of an appropriate dynamometry device, and the formulation of a testing protocol (Chapter 3).

The CCFD device features a resistance arm application point that is placed at the under-surface of the mandible in order to directly resist the action of cranio-cervical flexion, and an adjustable dynamometer axis for alignment and measurement of static torque about the axis of rotation (AOR) of the C0/I motion segment. It was hypothesised that these mechanical features would enable the method to be specific to the action of the CCF muscle group. The specificity of muscle action of the CCFD method was tested and is reported in Chapter 4.

The CCFD test protocol was developed to measure ICCF muscle performance at maximal, moderate, and low intensities of contraction. These tests were developed to reflect aspects of isometric loads faced by the CCF muscles in ordinary daily function, particularly with regards to the maintenance of cranio-cervical spine posture. It was the intention for the measurements to have clinical application. These isometric measurements were therefore examined for their test-retest reliability (Chapter 5), their capacity to quantify ICCF muscle impairment (Chapter 6), and in their responsiveness to quantify a change in ICCF muscle performance following rehabilitation (Chapter 7).

This thesis describes the iterative process to develop this method of CCFD. The application of the method solely to the CCF muscle group in this thesis does not reflect a priority of importance of these muscles over the cranio-cervical extensor muscles, or any other muscle groups. The decision to apply the method to the CCF muscles only, was firstly to simplify the developmental process of the dynamometry method, and secondly at this initial development stage of the method where potential adverse effects of
dynamometry in this region of the neck are unknown, to avoid complications from excessive multidirectional muscle testing. Furthermore, as stated above, previous research has established impairment in CCF muscle performance in neck pain sufferers, affording the opportunity to test the new method in a muscle group of known impairment.

Similarly, the thesis will concentrate on an isometric mode of muscle contraction performed in a neutral mid-range cranio-cervical flexion position. Again this is not to suggest that isometric performance of the CCF muscles in the mid-range is of priority over other modes of muscle contraction, or other positions in the range of motion. Isometric testing was chosen in this initial stage, as technically it is a simpler method to apply than other modes of muscle testing such as isokinetic dynamometry. Again, with little known of possible adverse effects of dynamometry in this region, isometric testing in the mid-range was thought to be the safest approach. Additionally, investigating ICCF muscle performance in the mid-range may better replicate the postural function of the CCF muscle group, as was an aim of the thesis (Chapter 2).

Similar isometric dynamometry methods to measure the torque produced by muscle groups about primary articulation axes have been utilised for many regions of the body including the neck (Berg et al. 1994; Jordan et al. 1997; Sparto et al. 1997; Jordan et al. 1999; Peolsson et al. 2001; Worrell et al. 2001). The body of research in this thesis is novel in that this method of dynamometry has not previously been used specifically for the CCF muscles. It was anticipated that the results of this thesis would justify consideration of the method as a clinical measure, as well as to advance our understanding of neck muscle impairment. It was also expected that the results of the thesis would guide subsequent improvements in the dynamometry method in the pursuit of the optimal test of CCF muscle performance.
General Aims of the Thesis:

To develop a measure of physical impairment of the cranio-cervical flexor muscles with the following attributes –

• Specificity to the biomechanical action of the CCF muscles.
• Clinical application such that it can be used both diagnostically and as an outcome measure to monitor recovery.
• Is reflective of a daily function of the cranio-cervical flexor muscles.
CHAPTER 2: BACKGROUND – FUNCTIONAL DIVISION, METHODS OF MEASUREMENT, AND EVIDENCE OF IMPAIRMENT OF THE CRANIO-CERVICAL FLEXOR MUSCLES.

2.1 Anatomical Division and Specificity of Action of the Cranio-Cervical Muscles

Motion of the head on the neck can occur relatively independently from the remainder of the cervical spine (Worth 1994). This occurs in the specialised cranio-cervical motion segments serving the visual (Andre-Deshays et al. 1988; Andre-Deshays et al. 1991), vestibular (Peterson et al. 1985), and proprioceptive systems (Keshner 1990; Winters and Peles 1990; Dutia 1991). Flexion/extension of the cranio-cervical region occurs principally about the atlanto-occipital (C0/1) joint, accounting for approximately 14-19 degrees of sagittal plane motion (Worth 1994; Bogduk and Mercer 2000). Only muscles that attach to the cranium and mandible are capable of inducing cranio-cervical motion. Accordingly, there is a distinct anatomical division between muscles capable of flexion/extension of the cranio-cervical region (C0-2), and those confined to flexion/extension of the typical cervical region (C2-T1). For the purposes of this thesis these two muscle groups are referred to as cranio-cervical flexor/extensor muscles and cervico-thoracic flexor/extensor muscles, respectively.

2.1.1 Cranio-Cervical Flexor/Extensor Muscles

Primary cranio-cervical flexor (CCF) muscles include the longus capitis, rectus capitis anterior, and rectus capitis lateralis muscles (Figure 2.1). These muscles directly link the anterior cervical vertebrae to the cranium and consequently flex the cranio-cervical
region (Conley et al. 1995; Kamibayashi and Richmond 1998; Moore and Dalley 1999). Rectus capitis anterior and lateralis act exclusively at the C0/1 motion segment, while longus capitis has inferior attachments from C2-6, spanning and exerting flexor moments to C0-2. The hyoid muscles can also flex 0/C1 (when the mandible is closed),

**Figure 2.1** Deep dissection of the anterior upper cervical spine, the anterior tubercle of the first cervical vertebrae (C1) is visible. The hyoid muscles and larynx have been removed to reveal the longus capitis (LC) and longus colli (LCo) muscles. On the left side of the figure the LC muscle has been removed to reveal the underlying rectus capitis anterior (RCA) muscle. LC and RCA muscles are attached to the cranium and therefore can flex the cranium on the C1 about the atlanto-occipital joint (C0/1). The LCo muscles most cephalad attachment is C1.
however their extensive attachments joining the thorax to the mandible span the entire anterior cervical region (Moore and Dalley 1999) permitting them to grossly flex all cervical motion segments. The sternocleidomastoid muscle also attaches to the cranium and is a strong flexor of the lower cervical spine, however, its insertion onto the mastoid process and lateral superior nuchal line results in a net extensor moment at C0/I (Vasavada et al. 1998).

Directly opposing the action of the CCF muscles are the cranio-cervical extensor (CCE) muscles. These include muscles that extend the cranio-cervical region exclusively (rectus capitis posterior major and minor, obliquus capitis superior muscles) (Vasavada et al. 1998; Moore and Dalley 1999; Oatis 2004), and other muscles (semispinalis capitis, splenius capitis, longissimus capitis, upper trapezius) that due to their extensive attachments to the occiput and large lever arms span and collectively exert strong extensor moments to multiple cervical motion segments, including the C0/I motion segment (Conley et al. 1995; Vasavada et al. 1998; Moore and Dalley 1999).

2.1.2 Cervico-Thoracic Flexor/Extensor Muscles

In contrast to the cranio-cervical flexors and extensor muscles, the cervico-thoracic muscles have caudal attachments to the thorax and cephalad attachments to the cervical vertebrae only, and are therefore not able to act about the C0/I motion segment. The anterior scalene and longus colli muscles flex the cervical spine with superior insertions to C3 and C1 respectively (Kamibayashi and Richmond 1998; Vasavada et al. 1998). Cervico-thoracic extensor muscles include the splenius cervicis, semispinalis cervicis, iliocostalis and longissimus cervicis, and the cervical multifidus muscles (Vasavada et al. 1998; Moore and Dalley 1999; Oatis 2004).
2.1.3 Summary

It is evident that the attachment of the crania-cervical flexor and extensor muscles to the head, and their consequent capacity to exert moments to the C0/l motion segment, permit them functional autonomy as a muscle group of the cervical spine. This functional division provides the justification for separate methods of performance measurement of the cranio-cervical and cervico-thoracic muscles. The remainder of the thesis will concentrate on the CCF muscles. Tests into cranio-cervical flexion only were chosen for this thesis to simplify the initial development stage of this new measurement method, and to avoid multi-directional cranio-cervical muscle tests that may prove aggravating to painful neck disorders.

2.2 Specificity of Muscle Action - Basis for Specific Tests of Functional Cervical Flexor Muscle Groups

Based on the division of the cervical flexor muscle group described above, two basic sagittal plane flexion motions may be described for the cervical spine. One is cranio-cervical flexion (head on neck flexion) that occurs principally at the C0/l motion segment. The other may involve flexion of all cervical motion segments (including C0/l) resulting in flexion of the head and neck together on the thorax and is consequently termed cervico-thoracic flexion. Figure 2.2 compares the actions of cranio-cervical flexion to cervico-thoracic flexion from a neutral resting starting position.

Division of the cervical spine into these two independent units for the purposes of load calculation and motion analysis has been reported previously (Hunting et al. 1980; Harms-Ringdahl et al. 1986). It is common practice in biomechanics to resolve the action of muscle groups to a single axis of rotation (AOR) usually relating to the primary articulation about which muscle groups act. Cranio-cervical flexion can be resolved to
Figure 2.2 Comparison between the actions of cranio-cervical flexion (A), and cervico-thoracic flexion (B) indicated by the arrows. The locations of the axis of rotation (AOR) about which these different motions are resolved are indicated by a crossed circle.
motion about the AOR of the C0/I motion segment (Harms-Ringdahl et al. 1986; White and Panjabi 1990; vanMameran et al. 1992), while cervico-thoracic flexion, although involving movement about multiple cervical motion segment axes, can be primarily resolved to motion about an AOR at the C7/T1 motion segment (Harms-Ringdahl et al. 1986; Berg et al. 1994; Jordan et al. 1997; Jordan et al. 1999). It is evident that these are separate cervical flexor muscle actions, exerting torque about separate AOR landmarks. Consequently kinematic and kinetic analysis of these groups should be undertaken separately (Figure 2.2).

The focus of this thesis is on the contractile performance of the CCF muscles. In summary, the CCF muscles exert torque to the cranio-cervical region principally about the AOR of the C0/I motion segment. Thus these muscles flex the cranio-cervical region when contracting concentrically, control cranio-cervical extension against gravity when contracting eccentrically, and maintain cranio-cervical spine orientation against gravitational and external loads when contracting isometrically. In this thesis it is the isometric function of the CCF muscles that is the function of interest and measurement.

2.3 Isometric Postural Function of the CCF Muscles

In an upright neutral posture of the cervical spine (Figure 2.3), passive resistance to motion is minimal (Oatis 2004) and forces imposed on the cervical spine by gravity are balanced by moments of the cranio-cervical and cervico-thoracic muscle groups. The centre of gravity of the head lies anterior to the AOR of the C0/I and C7/T1 motion segments and as such applies a flexor moment to the head and cervical spine, tending to drop the head and neck forward (Winters and Peles 1990; Yoganandan et al. 2001; Oatis 2004). Gravity imposed flexor moments are counteracted by the cranio-cervical and cervico-thoracic extensor muscles, their contraction imposing extensor moments that accentuate the cervical lordosis (Mayoux Benhamou et al. 1997; Sasai et al. 2000; Oatis 2004). The cervical lordosis in turn is counterbalanced by the flexor muscles of both cervical regions. Anterior shifts in the position of the head, as may be found in patients with forward head postures, further increases the flexion moment to the cervical spine.
and further increases demands on the cervical extensor muscles (Oatis 2004). The cranio-cervical region must extend in forward head postures if the eyes remain on the horizontal plane, such as is needed to look at a computer monitor or when driving a car for example.

Figure 2.3 Free-body diagram demonstrating the position of the centre of gravity of the head (black circle) and the line of gravitational force (black arrow) that lies anterior to the axis of rotation of the C0/I and C7/T1 motion segments inducing flexor moments to the cervical spine that are counteracted by moments from the cervical extensor muscles (Adapted from Oatis (2004) pg. 489).

Ideally, cranio-cervical and cervico-thoracic muscle groups together control cervical spine posture in the sagittal plane. Postural orientation of the typical cervical region (C2-T1) is counterbalanced by moments produced by the cervico-thoracic flexor/extensor muscles, in particular the sleeve (Mayoux-Benhamou et al. 1994) formed by longus colli anteriorly and semispinalis cervicis and cervical multifidus muscles posteriorly. These
deep muscles appear to have both a histological and morphological design that enable the support of the cervical lordosis and cervical spine (Mayoux-Benhamou et al. 1994; Conley et al. 1995; Vasavada et al. 1998; Boyd Clark et al. 2001; Boyd Clark et al. 2002).

Postural orientation of the cranio-cervical spine region (C0-2) in the sagittal plane is achieved by counterbalanced cranio-cervical flexor/extensor muscle moments (Figure 2.4). CCF muscles exert and sustain a static flexor torque to the cranio-cervical region,

Figure 2.4 Postural orientation of the cranio-cervical region is counterbalanced by the cranio-cervical flexor muscles including the longus capitis (LC), rectus capitis anterior (RCA), and the hyoid (HD) muscles and the cranio-cervical extensor muscles including the suboccipital extensor muscles (SOE), semispinalis capitis (SSC), and splenius capitis (SC) muscles. Arrows indicate approximate vectors of force from these muscles resulting in flexor/extensor moments about the axis of rotation of C0/1 indicated by the crossed circle (Adapted from Kapandji (1974) pg. 229).
counterbalancing the extensor moments of the much larger CCE muscle group to resist changes in cranio-vertebral angle. A biomechanical model simulating the action of the longus capitis, splenius capitis, and semispinalis capitis muscles has shown the interaction of these cranio-cervical flexor and extensor muscles to stabilize intact and injured upper cervical spine specimens (C0-2) in all loading directions (Kettler et al. 2002). Theoretically, deficits in the isometric contractile capacity of the CCF muscles would destabilize the cranio-cervical region with a tendency for it to extend. Clinical observations of a relationship between forward head postures and impaired ICCF muscle performance have been reported in the literature (Janda 1988; Jull 1988). Watson and Trott (1993) found a relationship between ICCF muscle endurance and the postural cranio-vertebral angle such that lower endurance scores in these muscles were associated with greater forward head postures. Lower endurance scores of the CCF muscles have been found in persons with large excursion angles of the upper cervical spine associated with an exaggerated cervical lordosis (Grimmer and Trott 1998). Grimmer and Trott (1998) suggested that the CCF muscles in this position are in a lengthened mechanically disadvantaged position.

While it is not the intention of this thesis to investigate the relationship between posture and ICCF muscle performance, the isometric contractile properties of the CCF muscles is the performance attribute to be measured. The following section (Section 2.4) describes methods previously used to measure the isometric performance of the CCF muscles, consequential evidence of their impairment in neck disorders, and the limitations of these methods.
2.4 Methods of Measurement and Evidence of Impairment of the CCF Muscles

2.4.1 Anti-gravity Tests

A clinical test has been described that attempts to quantify ICCF muscle performance utilising head weight and gravity (Trott 1988; Grimmer 1994). In supine, the patient firstly performs cranio-cervical flexion and while maintaining this position lifts the head just off the supporting surface. The time between the assumption of the test position and the loss of the isometric cranio-cervical flexion position (chin pokes forward) is measured in seconds. Although the test relies on the perceptual abilities of the investigators, interpretation of the loss of the cranio-cervical flexion position was found to have sound intra-rater reliability ($ICC = 0.96$) (Blizzard et al. 2000). The same test was also used to compare the endurance of the cervical flexor muscles in a group of headache sufferers compared to control participants (Placzek et al. 1999). The headache group could maintain the cranio-cervical flexion position for significantly less time ($24.1 \pm 17.6$ seconds) compared to a non-headache group ($80.3 \pm 45.6$ seconds). Similar reductions in cervical flexor endurance using this test has been found in persons with post-concussional headache (Treleaven et al. 1994).

2.4.2 Isometric Dynamometry Methods

Watson and Trott (1993) described an isometric dynamometry method in supine to specifically assess ICCF muscle performance. This method measured the force the CCF muscles could exert on a force sensitive metal bar at the under-surface of the mandible. A pressure sensor, placed under the supporting surface of the head, simultaneously monitored changes in the dorsal head force (DHF) on the supporting surface to ensure an isolated cranio-cervical flexion action. Using this method, Watson and Trott reported good intra-examiner reliability (Pearson correlation coefficient $r = 0.93$) and found
significant reductions in the isometric maximal voluntary contraction (IMVC) of the CCF flexor muscles in cervicogenic headache sufferers (5.02 ± 6.8 kilopond (kp)) compared to participants with no history of neck pain (5.8 ± 1 kp). Watson and Trott (1993) also compared the endurance capacity of the CCF muscle group by assessing the time the participant could sustain their IMVC effort until fatigue beyond 50% of the commencing value. The headache group had a much lower endurance mean value (43.6 ± 12.9 sec) compared to the non-headache group (84.9 ± 22.6 sec). This identical method of dynamometry has also been used to demonstrate that no significant effects of age on ICCF muscle strength exist in asymptomatic women over the age range of 20-65 years (Barber 1994). However, the measurement of muscle force can be problematic in that it is dependent on the distance the resistance is applied from AOR about which the muscles act (Mayhew and Rothstein 1985). Force measurements may vary considerably unless the device is applied at the exact anatomical position for each test even if muscle tension is identical. Consequently, it may be difficult to compare measurements of force in different points of range within individuals, or at the same point in range between individuals, and compromises the method’s potential to be used in the future for dynamic through range muscle tests. A similar isometric dynamometry method has also been described (Levoska et al. 1992) during which the participant, in the supine position, was asked to press their jaw against the resistance of the dynamometer without raising the back of the head off the supporting surface. This is an instruction that should encourage cranio-cervical flexion, however this was not stipulated by the authors. Instead it was reported as an isometric measurement of forward flexion of the cervical spine and demonstrated questionable intra-rater and inter-rater reliability (Pearson correlation coefficient r = 0.54-0.72).

Numerous other conventional isometric cervical flexion dynamometry (CFD) methods have been described to assess the isometric performance of the cervical flexor muscles. These have mostly applied resistance to the forehead, resisting muscular effort, that if unrestrained, would result in cervico-thoracic flexion (flexion of the head and neck together on the thorax) (Silverman et al. 1991; Vernon et al. 1992; Berg et al. 1994; Mayer et al. 1994; Ylinen and Ruuska 1994; Barton and Hayes 1996; Jordan et al. 1999; Placzek et al. 1999; Ylinen et al. 1999; Kumar et al. 2001; Peolsson et al. 2001; Chiu and
Lo 2002; Garces et al. 2002; Seng et al. 2002; Gabriel et al. 2004; Ylinen et al. 2004a).

Some investigators have recognised this pattern of muscle effort and have resolved the measurement to torque primarily about the cervico-thoracic junction as depicted in Figure 2.2b (Berg et al. 1994; Jordan et al. 1997; Randlov et al. 1998; Jordan et al. 1999; Peolsson et al. 2001; Seng et al. 2002). Many of these CFD methods have shown deficits in IMVC of the cervical flexor muscles in participants with neck pain compared to control participants (Silverman et al. 1991; Vernon et al. 1992; Barton and Hayes 1996; Jordan et al. 1997; Placzek et al. 1999; Chiu and Lo 2002; Ylinen et al. 2004a), and also in the endurance capabilities of these muscles (Randlov et al. 1998; Bronfort et al. 2001). However, CFD that restrains muscle effort at the forehead in this manner combines flexion moments of both cranio-cervical and cervico-thoracic flexor muscles. The efficiency of a dynamometry test to measure performance or expose impairment of a specific muscle group is dependent on its ability to preferentially challenge the target muscle group of interest. It is for this reason that it was proposed that CFD will not adequately discriminate between the cranio-cervical and cervico-thoracic flexor muscle groups. This hypothesis is tested in Chapter 4.

2.4.3 The Cranio-Cervical Flexion Test (CCFT)

A clinical test that has demonstrated, in individuals with neck pain, a reduced capacity of the CCF muscles to exert and sustain isometric cranio-cervical flexion at low intensity is the cranio-cervical flexion test (CCFT) (Jull et al. 1999; Jull 2000; Jull et al. 2002; Jull et al. 2004b). This method uses the cranio-cervical flexion movement to assess the anatomical action of the CCF muscles in synergy with the longus colli muscle. The intimate relationship of the CCF muscles with the anterior cervical vertebrae optimally positions them to assist the longus colli muscle to flatten the cervical lordosis (Mayoux-Benhamou et al. 1994). A pressure sensitive device, the pressure biofeedback unit (Stabilizer, Chattanooga Group Inc, USA), is used to guide progressive stages of the test by monitoring the combined flattening effect of the longus capitis and colli muscles on the cervical lordosis. A study by Falla et al (2003a) used a bipolar surface electrode inbuilt into a nasopharyngeal suction catheter to measure the activity of the deep cervical
flexor muscles (longus capitis, longus colli) in the CCFT (Falla et al. 2003a). This study confirmed the anatomical predictions of the test. A strong linear relationship was found between the amplitude of these deep cervical flexor muscles and the increasing incremental pressure stages of the test (Falla et al. 2003a). Consequently, in the CCFT the capacity of these muscles to generate and sustain tensile force is measured in the clinical setting by their capacity to flatten the cervical lordosis.

During this graded test in supine, the pressure biofeedback unit is inflated to 20 mmHg to fill the space between the cervical lordotic curvature and the testing surface and the pressure is displayed on a dial. Patients perform cranio-cervical flexion in a graded manner of five increments, simultaneously maintaining contact of the posterior head on the supporting surface. The air filled pressure sensor responds to the change in shape of the lordosis. As the CCF range is increased the pressure progressively elevates in increments of 2 mmHg from the 20 mmHg up to 30 mmHg. The test is, in part, graded according to the pressure level the participant can achieve concentrically and accurately sustain isometrically for a 10 second period. Both neck pain sufferers of insidious onset and of traumatic onset (Jull et al. 1999; Jull 2000; Jull et al. 2004b) demonstrated larger pressure shortfalls at all stages of the CCFT compared to control participants, inferring poorer active contractile capacity of the longus colli/CCF muscle synergy.

A disadvantage of the CCFT is that it does not directly resist the primary biomechanical action of the CCF muscles and therefore does not directly measure their performance. It can therefore not measure the maximal capacity of the CCF muscles to generate maximum isometric tension (IMVC), and as such the capacity of the CCF muscles to sustain tension at contraction intensities/loads relative to the IMVC is not assessable. Additionally, the CCFT requires a competent level of clinical skill to administer accurately and appropriately. For example, patients may perform a retraction manoeuvre (posterior head pushes into the supporting surface) directly increasing the pressure in the biofeedback unit without actually performing the correct cranio-cervical flexion action (Jull et al. 2004a). A false indication of a satisfactory performance of a test may be
judged if the retraction manoeuvre is not identified by the clinician. This is often difficult as it relies on the clinical judgement and perceptual abilities of the therapist.

2.4.4 Combined CCFT and Electromyography

According to Jull et al (2004a), the CCFT may also be graded according to the pressure level a participant can achieve without excessive contribution from the superficial cervical flexors (sternocleidomastoid and anterior scalene muscles) that are not anatomically positioned to be primary cranio-cervical flexors (Section 2.1). Amplitudes of EMG signals have been recorded in the superficial muscles following the hypothesis that increased activity of the superficial muscles might be a measurable compensation of poor segmental stability (Cholewicki et al. 1997), or in the case of the CCFT, poor deep CCF muscle activity. Greater superficial muscle EMG amplitudes have been found during all stages of the CCFT in persons with both insidious onset and traumatic onset neck pain compared to control subjects (Jull et al. 1999; Jull 2000; Sterling et al. 2003) with no significant difference in superficial muscle EMG amplitudes found between either neck pain group (Jull et al. 2004b). Falla et al (2004b), using the nasopharyngeal EMG technique described above to measure the activity of the deep CCF muscles, found the elevated superficial muscle activity to coincide with reduced activity of the deep CCF muscles during the CCFT in symptomatic compared to control participants (Falla et al. 2004b). The relative EMG amplitude of the deep CCF muscles was less in the neck pain group than for the control group particularly at the higher levels of the test providing direct evidence of a link between poor CCFT performance and impaired activity of the deep CCF muscles (Falla et al. 2004b).

In a clinical setting, efforts to monitor superficial muscle activity during the CCFT have been performed using electronic feedback devices (EMG) and palpation of muscle tissue. The short fall of these measures is that they fail to quantify the level of overactivity of these muscles during a test that could be compared on subsequent tests. Measurement of this muscle activity would require expensive EMG equipment and technical skill that is out of reach of most musculoskeletal practitioners in ordinary clinical practice.
2.5 Summary: Limitations of Existing Methods

The evidence suggests that impairment of the CCF muscle group is a significant issue to be addressed in the management of painful neck disorders. Compared to controls, neck pain sufferers have shown deficits in their CCF muscles capacity to exert and sustain maximal (Watson and Trott 1993), and sub-maximal (Jull et al. 1999; Jull et al. 2004b) muscle tension, as well as showing alterations in their coordination within the cervical flexor synergy (Falla et al. 2004b). However, as discussed above, current methods of measurement have limitations such as issues pertaining to the measurement of muscle force (Mayhew and Rothstein 1985), poor specificity to the CCF muscle group such as in conventional CFD, and a limited capacity to measure performance over a range of contraction intensities as may be expected in daily function. No clinical method exists that directly measures the primary biomechanical function of the CCF muscles to exert flexion torque to the C0/I motion segment. The development of such a method and the investigation of its usefulness as a clinical measure of CCF muscle performance is the overall aim of the thesis. The specific aims of the thesis are described below in Section 2.6.

2.6 Specific Aims of the Thesis

The aims of the thesis were three-fold:

1. To develop a dynamometry method appropriate for the measurement of the isometric performance of the cranio-cervical flexor muscles, including the development of a -
   - Dynamometry device that is specific to the biomechanical action of the cranio-cervical flexor muscles (Chapter 3), and
   - Isometric test protocol that reflects the isometric postural function of the cranio-cervical flexor muscles (Chapter 3)
2. To assess the specificity of the new method to the activation of the cranio-cervical flexor muscles (Chapter 4).

3. To assess the clinical application of the method to -
   - Reliably measure isometric cranio-cervical flexor muscle performance (Chapter 5),
   - Quantify isometric cranio-cervical flexor muscle impairment (Chapter 6), and
   - Respond to changes in isometric cranio-cervical flexor muscle performance following rehabilitation (Chapter 7).
CHAPTER 3: DEVELOPMENT OF THE CRANIO-CERVICAL FLEXION DYNAMOMETRY METHOD

As concluded in Chapter 2, no method exists to measure the capacity of the cranio-cervical flexor (CCF) muscles to exert static torque to the C0/I motion segment. It was postulated that such a method may be of value as a clinical measurement of isometric cranio-cervical flexor (ICCF) muscle performance. This chapter describes the development of the Cranio-Cervical Flexion Dynamometry (CCFD) method, which includes the development of the CCFD device and the CCFD testing protocol.

3.1 Concept – Dynamometry Specific to the Cranio-Cervical Flexor Muscles

Isometric dynamometry measures the static torque that muscles impart about a specific articulation. In complex multi-segmental regions such as the spine, the torque-generating capacity of planar muscle groups can be simplified by resolving all moments to a single axis of rotation (AOR) or a single motion segment (Harms-Ringdahl and Schuldt 1988; Moroney et al. 1988) as depicted in Figures 2.2 and 2.4. This model assumes multiple mobile spinal motion segments act as rigid levers about a single motion segment AOR. Such a model has previously been used for cervical flexion dynamometry (CFD) where resistance was applied at the forehead and torque was measured about the C7/T1 junction (Berg et al. 1994; Jordan et al. 1997; Randlov et al. 1998; Jordan et al. 1999; Peolsson et al. 2001; Seng et al. 2002). As discussed in Section 2.4.2, this method combines flexion of both cranio-cervical and cervico-thoracic flexor muscle groups. It is proposed that to specifically challenge and measure the isometric contractile capacity of the CCF muscle group, a method should directly resist the anatomical action of cranio-cervical flexion, and should measure the resultant static torque about the primary motion segment, C0/I. It was hypothesised that CCFD that directly resists cranio-cervical flexion at the under-
surface of the mandible, and measures the resultant static torque about the AOR of the C0/I motion segment will be more specific to the CCF muscle group than CFD, which measures torque about the cervico-thoracic junction. This hypothesis is tested in Chapter 4.

The new CCFD method would also overcome the problems associated with the measurement of muscle force (Mayhew and Rothstein 1985) at an arbitrary point on the mandible as in the method of Watson and Trott (1993). Instead, ICCF torque (Newton-meters) would be measured about a consistent landmark (C0/I AOR) within and between participants. Similar dynamometry methods measuring static torque about specific articulations have been used in many regions of the body including the neck (Berg et al. 1994; Jordan et al. 1997; Sparto et al. 1997; Jordan et al. 1999; Peolsson et al. 2001; Worrell et al. 2001) and have gained acceptance as a method of muscular assessment.

3.2 CCFD Device Specifications and Calibration

The CCFD device is pictured in Figure 3.1 and detailed mechanical specifications are presented in Appendix A.1. The CCFD device records two measurements simultaneously in the supine position. The primary measurement is ICCF muscle torque in Newton-meters (Nm) about the AOR of the C0/I motion segment. The secondary measure is the dorsal head force (DHF) on the supporting surface in Newtons (N). This secondary measure is to monitor compensatory strategies during the performance of the ICCF torque measurements and was also a feature of the device described by Watson and Trott (1993).
3.1 Dynamometry device for the measurement of ICCF muscle torque about the AOR of the atlanto-axial (C0/1) motion segment. Figure A is a line diagram from a caudo-lateral perspective. Figure B depicts a participant performing cranio-cervical flexion against the resistance of the dynamometer. The following components of the device are numbered - 1. Dynamometer axis that was aligned to the participant’s AOR of C0/1. 2. Dynamometer resistance arm consisting of a lever arm and application pad. The lever arm was extended to a distance (D) from the dynamometer axis so that the application pad sat comfortably at the under-surface of the mandible. When the participant performed cranio-cervical flexion the participant exerted a force (F) to the dynamometer application pad at a lever arm distance (D) resulting in torque (T = F x D) at the dynamometer axis. 3. Adjustment housing for the dynamometers axis. 4. Load cell deflection arm and load cell for the measurement of ICCF muscle torque. The load cell deflection arm could be locked to the dynamometer axis for torque measurement, and unlocked for adjustment of axis between participants. 5. Padded head support platform supported on ball bearings to minimise friction at the point of head contact. 6. Load cell for the measurement of dorsal head force. 7. Web camera. 8. Visual display unit.

3.2.1 Isometric Cranio-Cervical Flexor (ICCF) Muscle Torque Measurement

The dynamometer has an adjustable axis that is aligned to the participant’s C0/1 AOR landmark. The AOR for C0/1 sagittal plane flexion/extension occurs about the mastoid process, varying from the centre of the mastoid process (White and Panjabi 1990), anterior mastoid process (Harms-Ringdahl et al. 1986), to an area slightly dorsal and cranial to the mastoid process (vanMameran et al. 1992). For the practical purposes of
dynamometry, the concha of the ear, a depression immediately posterior to the bony external acoustic meatus, was chosen as the landmark adjacent to which the dynamometer axis would be aligned. This landmark approximates the mastoid process that is otherwise difficult to localise to one point and is occluded from direct vision by the ear. The dynamometer axis/participant AOR alignment method is depicted and explained below in Figure 3.2.

Figure 3.2 Download of images generated by web camera/computer interface as viewed by investigator during participant/dynamometer axes alignment procedure. CCFD set up is performed using digitized recordings of dynamometer and participant landmarks. Recordings were first made of 3 dynamometer reference points (C1, C2, C3) so that alignment of the camera/dynamometer could be checked for consistency on subsequent applications. The position of the dynamometer axis (E) in the horizontal plane was then recorded. The participant was then positioned so that their AOR landmark (concha of the ear) was aligned in the horizontal plane with the dynamometer axis (E). The position of the E marker was then adjusted so that it also aligned to the participants AOR in the vertical plane. The position of the dynamometer axis was then adjusted in the vertical plane to align to the E marker and subsequently to the participants AOR landmark in both horizontal and vertical planes. Once the dynamometer resistance arm and application pad were fitted at the undersurface of the mandible in the neutral position of the head, the position of the participants left nostril (N), and the end of the dynamometer resistance arm (D2) were recorded. In this manner the position of the participant (AOR (E), nostril (N)) and the position of the dynamometer (axis (E), lever arm angle (D2)) could be replicated if required.
The dynamometer resistance arm consists of two metal arms at right angles. One arm is the lever arm that is extended from the dynamometer axis to a distance such that the adjoining application pad sat under the inferior border of the participant's mandible (Figure 3.1B). This resultant lever arm length is adjustable to accommodate different sized individuals. A participant's ICCF muscle effort is resisted at the inferior border of the mandible by the application pad of the dynamometer. The force that the mandible exerts on the application pad is transferred via the lever arm, producing torque at the dynamometer axis that is locked to the load cell deflection arm of the dynamometer. This torque is transferred via the load cell deflection arm to deflect one end of a thin beam load cell (TBS Series) causing a change in voltage across the load cell. The voltage change is amplified (PM4-SG-240-5E-A) and transmitted to a personal computer equipped with a custom written Labview (LabView 6i Virtual Instruments) program calibrated to convert the amplified voltage to the corresponding torque measurement in Newton-meters. The data is sampled, recorded, and displayed in real time at a rate of 20 Hertz (Figures 3.3 and 3.5).

The dynamometer axis is adjustable such that it can be freely rotated to the appropriate point in the cranio-cervical flexion range for testing, and then locked to the load cell deflection arm allowing torque to be measured at the chosen point within the available range. To account for the effects of gravity on the lever arm at different positions relative to the horizontal, the Labview software is programmed to negate the effects of gravity on the lever arm prior to any torque measurements. This is achieved by zeroing the measure immediately before the participant commences their muscle effort. The participant is specifically asked not to exert pressure on the dynamometer application pad while the measure is being zeroed. In this manner the torque exerted by a participant to the dynamometer axis can then be accurately measured.

1 Transducer Techniques, 42480 Rio Nedo, Temecula, CA 92590.
2 Davidson Measurement Pty. Ltd., 1-3 Lakewood Boulevard, Braeside, VIC, 3195 Australia.
3 National Instruments Corp, 1 1500 N Mopac Expressway, Austin, TX 78759.
3.2.2 Dorsal Head Force (DHF) Monitor

Another feature of the device is a force sensitive supporting surface for the head (Figure 3.1). Changes in dorsal force on the supporting surface by the head due to flexion (a reduction in force) or extension (an increase in force) of the head and neck together in the sagittal plane is measured by a second load cell (ESP Series) attached under the head platform of the dynamometer. The head platform is secured to one end of the load cell while the other end of the load cell is secured to the bench. The dorsal force that the head exerts on the head platform deflects one end of the load cell causing a change in the voltage across the load cell. This voltage change is amplified and transmitted to the personal computer where the Labview program converts the amplified voltage to the calibrated Newtons (N) measurement. DHF is recorded and displayed in real time simultaneous to the ICCF muscle torque measurements at a rate of 20 Hertz, allowing the changes in DHF to be monitored and measured in real time (Figures 3.3 and 3.5). Additionally, the supporting surface of the head platform is positioned on ball bearings to allow ICCF with minimal frictional effects at the head-platform interface.

3.2.3 Data Acquisition Software and Visual Output Display

Two LabView programs were custom written for the acquisition of the data pertaining to ICCF muscle performance. One program was designed for the measurement of IMVC, and the other for the measurement of sustained voluntary contraction.

3.2.3.1 Isometric Maximal Voluntary Contraction Tests

This program (Labview Block Diagram depicted in Appendix A.2) permitted up to 5 isometric maximal voluntary contraction (IMVC) repetitions to be performed (ten second epoch allowed for performance of each test) with sixty seconds rest between each repetition. ICCF muscle torque and DHF measurements are recorded simultaneously at 20 Hz, displayed on the computer monitor (Figure 3.3), and documented on an Excel spreadsheet so that the dual measurements can be analysed off-line. A visual display unit
positioned in the participants view was linked to the LabView program, to provide live feedback to the participant of their ICCF muscle torque amplitude in the form of a live, single bar graph (Figure 3.4A). The visual feedback graph increases or decreases in accordance with torque production so that participants are asked to maximally elevate the graph.

Figure 3.3 Labview program permits simultaneous recordings of ICCF muscle torque in Newton-meters (Nm) (top graph) about the dynamometer axis, and DHF in kilograms (kg) (converted to Newtons (N)) (bottom graph) on the supporting surface during IMVC trials. The data are stored allowing for the relationship between peak torque and DHF to be analysed off-line. Labview block diagram for this program depicted in Appendix A.2.
3.2.3.2 Sustained Voluntary Contraction Tests

This program (Labview Block Diagram depicted in Appendix A.3) allows the investigator to test a participant’s capacity to sustain ICCF muscle torque at any intensity level based on a percentage of their IMVC score, by imputing both the participant’s IMVC score and the percentage intensity for a particular test (e.g. 20% or 50% of IMVC). Visual feedback is displayed to the participant as two vertical bar graphs, a target graph and a live graph (Figure 3.4B). The LabView program is written so that the target graph automatically elevates to represent the desired contraction intensity (e.g. 20% or 50% of IMVC). The live graph displays ICCF torque amplitude in real time. The participant is asked to perform the required ICCF muscle effort in order to match the live graph to the target graph and to sustain it at that level for the duration of the test. ICCF muscle torque and DHF are recorded continuously at 20 Hz, displayed on the computer monitor (Figure

![Figure 3.4](image)

Figure 3.4 Live visual feedback of ICCF muscle torque output given to the participant during an isometric maximal voluntary contraction (IMVC) test (A) and during a sustained sub-maximal test (B). During the IMVC test the participant is instructed to elevate the blue column as far as possible. During the sub-maximal sustained test the participant is instructed to match the blue live graph (L) to the red target graph (T) and to hold it as level as possible for the duration of the test.
3.5), and documented on an Excel spreadsheet up to a duration of ten minutes at which point the program is defaulted to terminate recordings.

Figure 3.5 Simultaneous measurements of ICCF muscle torque in Newton-meters (Nm) (top graph) about the dynamometer axis, and DHF in kilograms (kg) (converted to Newtons (N)) (bottom graph) on the supporting surface during sustained tests at pre-determined percentages of IMVC. The contraction accuracy (A) and the change in DHF (C) over time could be analysed off-line. The duration of the contraction (B) could be either determined by muscle fatigue or pre-determined by some other measure. Labview block diagram for this program depicted in Appendix A.3.
Amplified voltage outputs of the instrument were recorded for known torque increments at the dynamometer axis, achieved by positioning calibrated weights on the horizontal dynamometer resistance arm at staged distances from the axis. Masses ranging from 0.5 – 15 kilograms were used over lever arm distances of 75 - 135 millimetres. These parameters comfortably covered the range of the lever arm length / force variables observed in pilot trials. The relationship between voltage output recordings and torque increments was modeled by linear regression to determine the least squares regression equation for the voltage data. The Labview programs used this equation to convert the amplified voltage to the appropriate torque measurements.

The accuracy and linearity of the dynamometer / computer software instrument to measure static torque was then tested by reapplying the weights at various lever arm lengths. The relationship between the recorded and expected torque was evaluated by linear regression analysis. The measurement system demonstrated excellent linearity (R > 0.99) with minimum offset (-0.072Nm) (Figure 3.6). This level of instrument accuracy

![Figure 3.6 Linearity of the dynamometer instrument, comparing expected static torque measurements for a given lever arm length and applied mass, to the recorded torque measurements.](image-url)
was considered to be appropriate for the measurement of neck muscle performance. The calibration procedure was repeated at regular intervals weekly throughout the data collection process of the project to ensure the instrument provided consistently accurate measurements of applied loads. Instrument measurements remained accurate throughout the data collection process.

3.2.5 Summary: Development of the CCFD Device

A new dynamometry device has been described to measure the isometric performance of the CCF muscles. The device was constructed with the concept to resist and measure the primary biomechanical action of the CCF muscles, that being, the production of a flexion torque about the AOR of the C0/I motion segment. Two mechanical features of the device addressed this concept. The first was the application of resistance to the undersurface of the mandible such that the cranio-cervical flexion action was directly resisted. The second was the alignment of the dynamometer axis to the participant’s C0/I AOR so that the primary biomechanical action of the CCF muscle group (torque about the C0/I AOR) was measured. The device was shown to be accurate in the measurement of static torque (Section 3.2.4). The concept that these mechanical features of this device would selectivity test the CCF muscle group is examined in Chapter 4. The following section (Section 3.3) describes the development of the CCFD test protocol aimed to quantify ICCF muscle performance. The development and refinement of these test protocols was done in preparation for the clinical measurement studies performed in Chapters 5-7.

3.3 Development of the CCFD Test Protocols

An aim of this thesis was to develop CCFD tests that reflected daily function of the CCF muscles. The following section describes the characteristics of the CCFD test protocol used in this thesis intentionally aimed to replicate the postural function of the CCF muscles as described in Section 2.3.
3.3.1 Mode of Muscle Contraction and Functional Attribute of Isometric Muscle Tests

The dynamometry method described in the thesis has been designed to measure the isometric performance of the CCF muscles. Isometric muscle tests have been questioned previously regarding their functional attributes, much of which has been drawn with regards to sport, with most studies showing maximal isometric force measurements to be a poor discriminator of sports performance abilities (Wilson and Murphy 1996). It is suggested that isometric assessments do not account for the neural and mechanical aspects of the dynamic muscle contractions in most functional and sporting tasks (Wilson and Murphy 1996; Portero and Genries 2003).

The strength of the relationship between an isometric muscle test and muscle function will be largely dependent on how well that isometric test mimics the muscle function in question. While the relationship between isometric muscle tests and dynamic muscle function (e.g. ballistic movements) such as that found in sport may be weak, isometric muscle tests may better mimic static postural muscle function. An isometric function of the CCF muscles is in the maintenance of cranio-cervical spine orientation (Section 2.3) that could be challenged under various functional loads imposed by factors such as gravity, extensor antagonist muscles, and external perturbations. Theoretically, rapid perturbations of the head on the neck in the direction of cranio-cervical extension such as that when an upright person is pushed in the back, or against gravitational force as when the head in supine is held off the supporting surface, may require high intensity ICCF muscle contractions. In contrast, the maintenance of a neutral cranio-cervical spine posture during tasks such as prolonged upright sitting may require low intensity isometric contractions of the CCF muscles over prolonged durations.

As such the protocol of CCFD tests performed in this doctoral project were selected with the intention of measuring the capacity of the CCF muscles to exert and sustain static
torque at C0/I, under a range of loads and durations as may be expected in daily postural function. To best replicate postural function, the tests were designed with respect to several factors such as the position in the cranio-cervical flexion range, the intensity of contraction, and the duration of muscle contraction under which the muscles were challenged.

3.3.2 Test Position in Range

Isometric dynamometry literature suggests that the posture adopted during an isometric test should mimic the function of interest (Secher 1975; Abernethy et al. 1995), in particular with regard to joint angle (Abernethy et al. 1995; Wilson and Murphy 1996). It has been noted that the activation level of synergistic muscle groups varies as a function of joint angle particularly in multi-joint tests (Hasan and Enoka 1985; Howard et al. 1986; Van Zuylen et al. 1988), such as in the cervical spine. Contemporary clinical retraining of posture suggests that the muscle system should maintain the spine in a neutral spine position (Lee 2003; Jull et al. 2004a). The ICCF muscle tests were consequently performed in a neutral cranio-cervical flexion/extension position according to a standard anthropometric neutral position of the head, the Frankfort Plane. In this cranio-cervical position in supine, a vertical line bisects the orbitale and the tragion (Norton and Olds 1996).

3.3.3 Intensity of Contraction Load

As discussed in Section 2.4, deficits in the contractile performance of the CCF muscles in neck pain sufferers has previously been shown at maximal voluntary contraction (Watson and Trott 1993) and at low contraction intensities (Jull et al. 1999; Jull 2000; Jull et al. 2002; Jull et al. 2004b). It was the intention of the CCFD testing protocol to challenge and measure the isometric function of this muscle group over a range of contraction intensities (low to maximal) similar to intensities which could feasibly be faced in ordinary daily function. Based on this ideal as well as the evidence provided previously,
three contraction intensities were chosen; an isometric maximal voluntary contraction test (IMVC), a sustained isometric voluntary contraction test at 50% of IMVC ($\text{IMVC}_{50}$), and a sustained isometric voluntary contraction test at 20% of IMVC ($\text{IMVC}_{20}$). These tests represent muscle tests at maximal, moderate, and low contraction intensities. Isometric cervical muscle tests at low (20-25% of IMVC) loads (Falla et al. 2003b; Gogia and Sabbahi 1994), and at moderate loads (50-60% of IMVC) (Falla et al. 2003b; Gogia and Sabbahi 1994; Randlov et al. 1998; Portero et al. 2001) have been previously reported for cervical muscle fatigue studies. Studies investigating muscle fatigue in other regions of the body have also used similar sub-maximal sustained contraction intensities (Duchateau and Hainaut 1993; Duchateau et al. 2002; Hunter et al. 2002; Hunter et al. 2004).

3.3.4 Duration of Contraction Load

IMVC tests are a measure of isometric muscle strength (Enoka 1994) that is defined as the peak magnitude of torque exerted by a muscle group in a single maximum isometric contraction. This test is therefore only sustained for a short time, approximately 3-5 seconds, as would be required when head on neck orientation is challenged under large forces of a transient nature.

$\text{IMVC}_{50,20}$ tests are at least in part, tests of muscle fatigue. Muscle fatigue is defined as any exercise-induced reduction in force generating capacity that is reversed by rest (Gandevia 2001). One aspect of fatigue is task failure (Gandevia 2001; Hunter et al. 2004). It was decided to sustain these tests for the time to task failure. For the purposes of this thesis, task failure was nominated by the participant as the perceived inability to continue the contraction at the predetermined ICCF torque intensity. Two measures were taken from these tests intended to reflect fatigability of the CCF muscles. The first, 'time to task failure', was the time in seconds until the participant-nominated task failure. The second measure, 'contraction accuracy', reflected the muscle tremor associated with muscle fatigue (Gandevia 2001). Muscle tremor was analysed by computing the accuracy of the contraction (sustained torque sampled at 20Hz) to stay within set margins either side of the nominated contraction intensity (predetermined torque amplitude) over the
duration of the test. The aim of these tests was to challenge the CCF muscles to sustain contractions as may be required in prolonged postures against low and moderate loads.

3.3.5 Control of Other Measurement Variables

3.3.5.1 Mechanical Variables

The isometric torque producing capacity of a muscle group such as the CCF muscles is the product of their isometric tensile force and their moment arm length (Vasavada et al. 1998), which both fluctuate as a function of joint angle (Doss and Karpovich 1965; Harms-Ringdahl and Schuldt 1988; Murphy et al. 1995). Inferences are made regarding the CCF muscles capacity to generate torque between-tests by ensuring all other mechanical test factors are kept constant (AOR landmark, C0/I joint angle, position of the rest of the spine and body). Replicating these mechanical variables between tests ensures that factors such as lever arm length and fascicle length of muscles remain constant. Between-participant comparisons are also made under the same assumptions of constant mechanical variables between participants, although normal anatomical variation between individuals may be a source of some error. Isometric dynamometry measurements should be able to distinguish between normal, impaired, and trained muscles by detecting the difference in the torque these muscles impart and/or sustain on the skeletal system, but only when all other mechanical variables are kept constant.

3.3.5.2 Central Nervous System Variables

Factors other than the properties of the muscle organ itself will significantly affect an isometric dynamometry measurement outcome. As Gandevia (2001) aptly states,

"if a muscle is regarded as a motor, then the way it behaves depends not only on its intrinsic properties but also on the way that it is driven and the way feedback systems maintain its output"4

Studies utilising the technique of twitch interpolation (Bigland and Lippold 1954; Merton 1954) have shown that under most circumstances the central nervous system (CNS) sub-maximally drives muscles, and that the degree of central drive varies between muscle groups and between individuals (Gandevia 2001). Reduced central drive has been shown in the presence of joint injury (Stokes and Young 1984; Newham et al. 1989; Hurley and Newham 1993), and post surgery (Mizner et al. 2003; Stevens et al. 2003), and it is thought to contribute to muscle atrophy by preventing maximal force generation. Improvements in muscle tensile force following training is at least in part attributed to improvements in central drive to muscles (Hurley and Newham 1993; Gandevia 2001) often referred to as the neural training effect (Gandevia 2001). Besides maximal force generation, the onset of muscle fatigue has also been substantially attributed to a reduction in central drive. Muscle fatigue is an exercise-induced reduction in the ability of a muscle group to generate force and has peripheral and central causes. Eventually there is task failure when the exercise can no longer be continued, part of which can be attributed to supraspinal influences (Gandevia 2001).

While the physical properties of muscles may limit their absolute maximal capacity to generate and sustain tensile force, under most circumstances it would appear that spinal and supraspinal factors (neural drive) substantially limit their performance (Gandevia 2001). The important consideration for isometric dynamometry measurement consistency is to ensure that all sources of input to the participants’ central nervous system are kept consistent between measurements (environmental conditions, instructions, visual and verbal encouragement, feedback of performance) (Gandevia 2001). If input to the central nervous system as well as the other mechanical variables (Section 3.3.5.1) are kept constant between tests and measurement sessions, stronger inferences can be made from the CCFD measurements regarding the performance of the CCF muscles to produce static torque about C0/1.
3.3.5.3 Dorsal Head Force Variable

Another variable that may impact on the CCFD measurements when performed in supine, is the DHF exerted onto the supporting surface during a test. It is feasible that participants may increase or decrease the force of the dorsum or back of their head on the supporting surface in an effort to improve the mechanical or physiological advantage of the CCF muscles to exert or sustain torque to the dynamometer. Participants may also attempt a retraction manoeuvre as a substitute for the correct CCF action in order to apply a downward force on to the application pad of the dynamometer resistance arm. These substitution strategies may be particularly prevalent in the presence of CCF muscle impairment to compensate for poor performance. Consequently, measurement may be less sensitive to detect CCF muscle impairment between individuals with and without neck pain. Alterations in DHF during ICCF muscle dynamometry tests had also been a concern in the method of Watson and Trott (1993). Watson and Trott (1993) monitored and controlled their participants DHF to ensure an isolated cranio-cervical flexion action, but they did not stipulate to what degree DHF was controlled.

The unknown factor was whether DHF would change significantly during the CCFD tests, sufficient enough to impact on the ICCF torque measurements. Additionally, if DHF needed to be controlled, it was questioned by what degree could DHF changes be practically controlled. The latter point reflected a concern namely, that the control of DHF during the CCFD tests introduced a dual task that may prove difficult for some participants particularly during the short duration IMVC tests. The following preliminary study (Section 3.3.6) addressed the DHF control issue by investigating the DHF response during CCFD measurements, and analysing its effect on ICCF torque measurements in symptomatic and control participants.
3.3.6 The Impact of Dorsal Head Force on Isometric Cranio-Cervical Flexor Muscle Torque Measurements (Preliminary Study)

3.3.6.1 Abstract

Objective: To determine the dorsal head force (DHF) response when not controlled during tests of isometric cranio-cervical flexor (ICCF) muscle performance in neck pain and control participants.

Participants and Methods: Thirty-two participants with a history of neck pain (symptomatic participants) and 32 participants without a history of neck pain (control participants) were included in the cranio-cervical flexion dynamometry (CCFD) study. DHF recordings were made at the moment of peak torque during IMVC tests, and over the first 5s and final 5s periods during IMVC and IMVC50 tests, sustained for 60 and 30 second time periods, respectively.

Results: Significant increases in DHF were found for both symptomatic and control participants during IMVC tests (58.8 N, 68.6 N, respectively), IMVC20 tests (23.1 N, 22.6 N, respectively), and IMVC50 tests (45.3 N, 48.1 N) (all P < 0.0001). There were no between group differences in DHF or ICCF measurements. IMVC peak torque measurements (11 – 11.5 Nm) were well in excess of those expected based on previous studies (3 - 6 Nm). These IMVC peak torque measurements were substantially reduced (5.8 - 6.1 Nm) when change in DHF limits were applied.

Discussion and Conclusion: It would appear that the DHF response when not controlled during ICCF tests is excessive, and produces peak torque measurements almost double the expected values. DHF may mask differences in ICCF muscle performance between neck pain and control groups.
3.3.6.2 Background and Aims of Study

It was proposed that not controlling dorsal head force (DHF) during cranio-cervical flexion dynamometry (CCFD) tests could potentially enhance an individual's ability to exert isometric cranio-cervical flexor (ICCF) muscle torque. Potentially participants may mask poor ICCF muscle performance. This may be of detriment to the method's capacity to quantify impairment between participants with a history of neck pain (symptomatic participants), and without a history of neck pain (control participants). To investigate this issue a study was conducted to determine the DHF response during CCFD tests of isometric maximal voluntary contraction (IMVC), and sustained tests at 20% of IMVC (IMVC₂₀), and 50% of IMVC (IMVC₅₀), when the participants were not asked to control DHF. Both symptomatic and control participants were included to establish if differences in the DHF response existed between the groups. It was hypothesised that the symptomatic participants would display greater changes in DHF during the CCFD tests as a substitution strategy for poorer ICCF muscle performance.

Of particular interest was determining the impact of uncontrolled DHF on IMVC peak torque amplitudes. This was analysed in three ways. In the first analysis, peak torque amplitudes were compared between symptomatic and control participant groups. Watson and Trott's (1993) dynamometry study had previously measured differences in ICCF muscle strength between symptomatic and control participant groups when DHF was controlled. This study would investigate if these group differences existed when DHF was not controlled.

In the second analysis, peak torque recordings of female control participants were compared to torque amplitude estimates derived from similar studies investigating isometric strength of upper cervical flexor muscles in female control participants (Watson and Trott 1993; Barber 1994; Vasavada et al. 2001). Based on these studies (Table 3.1), IMVC peak torque measurements in female control participants were expected to be in the vicinity of 3-6 Nm. In the study performed by Vasavada et al (2001), the measurement of isometric cervical flexor torque was resolved about the mastoid process.
and a peak torque of 6 Nm was recorded. Similar amplitudes of peak torque were found when the ICCF force measurements recorded by Watson and Trott (1993) and Barber (1994), were converted (conversion computation explained in Table 3.1) into estimated torque measurements. These studies revealed peak torque measurements of 5.4 Nm and 3.2 Nm in female control participants, respectively.

In the third analysis the peak torque data were reviewed such that peak torque was accepted only for samples that coincided with a change in DHF of ± 20% of the resting DHF. A margin of ± 20% was chosen following observations during pilot trials. During pilot trials we experimented with the ability of participants to perform IMVC while controlling DHF at margins of ± 10%, ± 20%, and ± 30% of the resting DHF value. The ± 20% of resting DHF appeared to be the minimum amount of DHF change during which participants appeared to be satisfied that they could exert a maximal effort while also controlling their DHF within this margin. Participants mostly described the ± 10% margin as being too difficult to achieve during the maximal contractions.

Table 3.1 Estimated IMVC peak torque data in studies investigating upper cervical flexor muscle strength of female control participants.

<table>
<thead>
<tr>
<th>Study</th>
<th>n</th>
<th>IMVC (Nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watson and Trott (1993)</td>
<td>30</td>
<td>5.4 ± .9 Nm (estimated) a</td>
</tr>
<tr>
<td>Barber (1994)</td>
<td>54</td>
<td>3.2 ± .8 Nm (estimated) b</td>
</tr>
<tr>
<td>Vasavada et al (2001)</td>
<td>5</td>
<td>6 ± 1 Nm c</td>
</tr>
</tbody>
</table>

*a Estimated torque measurements based on the conversion of the recorded 5.88 ± 1 Kilopond (Kp) (1 Kp = 9.8 N) IMVC measurement, to a corresponding Newtons force value. Torque was then estimated by finding the product of the force value (57.7 ± 9.8 N), and the average dynamometer lever arm length (.0931 m) observed in a preliminary study (Appendix B.1).

b This study used the same dynamometry method as Watson and Trott (1993) therefore conversion to torque follows the same process as in a. 3.5 ± .9 kp was converted to 34.3 ± 8.8 N and then to torque units (Nm).

c This measurement of torque is based on resolving cervical flexor torque to the mastoid process and is not a direct measurement of ICCF muscle torque but is close to the above figures.
The aims of the study were:

- To determine the DHF response during CCFD tests and to establish if the magnitude and direction of any change in DHF was different between persons with and without neck pain. We hypothesised that greater changes in DHF (increased or decreased) would occur in neck pain patients compared to asymptomatic participants during ICCF muscle tests in supine, most likely as a substitution strategy for impaired ICCF muscle performance.
- To determine the impact of not controlling DHF on the magnitude of the IMVC peak torque recordings.
- To establish criteria for control of DHF parameters should it be deemed necessary to control.

3.3.6.3 Methods

Participants

Sixty-four volunteers agreed to participate in this study. There were 32 symptomatic participants and 32 control participants and the groups were similar in their gender (23 females and nine males in both groups), age, height, and weight characteristics (Table 3.2). Sample size was determined with reference to the findings of Watson and Trott (1993) and was based on a power of 0.9 and an alpha of 0.05. Participants were recruited through written and electronic advertising in the University and general community.

Symptomatic participants were included if they reported neck pain of greater than three months duration (Appendix C.1), scored 10 or greater on the neck disability index (NDI) (Vernon and Mior 1991) (Appendix C.2), and demonstrated signs of cervical spine dysfunction on a physical examination of the neck (Jull 1994). Control participants were included if they reported no history of neck pain, scored less than 10 on the NDI, and had no signs of cervical spine dysfunction on a physical examination of the neck.
Neck pain and control participants were excluded if they had specifically trained their neck or shoulder girdle muscles in the preceding six months, suffered neck pain from non-musculoskeletal causes, demonstrated neurological signs, or had any medical disorder contraindicating physical exercise. After receiving verbal and written information each participant signed a consent form. Ethical clearance was gained from the University's Medical Research Ethics Committee and was in accordance with the declaration of Helsinki (Appendix D.1 and D.2).

**Procedure**

CCFD procedures were performed involving participant position and alignment of participant/dynamometer axes as described in Section 3.2.1 (Figure 3.2). To minimize the effects of limb leverage, the participant's legs were positioned on a padded wooden stool on wheels such that the knees and the hips were flexed to forty-five degrees, the arms folded across the chest, and soft straps placed lightly over the shoulders to minimise movement of the trunk on the supporting surface. DHF measurements during the ICCF tests were performed in all 64 participants. All participants were given standardised instructions in a between-participant consistent manner and were familiarised to the testing procedure before data was collected. IMVC trials were performed first.

**Table 3.2 Group Means ± SD (range) for variables of age, height, weight, and NDI score. There was no significant difference between neck pain and control participant groups (P > 0.05).**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Symptomatic</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>28.3 ± 8.5 (19 – 52)</td>
<td>27.6 ± 6.1 (18 – 45)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>167.7 ± 7.8 (150 – 183)</td>
<td>169.3 ± 8.6 (152 – 187)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>66.7 ± 14.3 (40– 105)</td>
<td>62.5 ± 10 (50 – 85)</td>
</tr>
<tr>
<td>NDI (score/100)</td>
<td>18.9 ± 9.1 (10 – 46)</td>
<td>2 ± 2.7 (0 – 8)</td>
</tr>
</tbody>
</table>
Participants were instructed to nod their head such that their mandible pushed downwards on the application pad of the dynamometer so as to elevate the visual display graph maximally (Figure 3.4A). Participants were requested to perform this test ensuring that the head remained in contact with the surface upon which it rested. Participants performed a standard warm-up consisting of four sub-maximal repetitions, with each successive repetition at a greater intensity than the previous one and a fifth repetition to their maximal ability.

Three IMVC trials were then performed with sixty seconds rest between each effort. This duration of rest period between maximal contractions has been used in previous studies of neck muscle performance (Silverman et al. 1991; Levoska et al. 1992; Jordan et al. 1999; Placzek et al. 1999; Strimpakos et al. 2004). Each contraction lasted between three to five seconds. The peak of the three IMVC trials was recorded as the peak ICCF torque score. The participant was asked to rate their level of perceived exertion on a ten point modified Borg Scale (Borg 1982) following each contraction (Appendix E). The sole purpose of this report was to allow the participant to self-reflect if they had performed the test to their maximal ability. The Borg score was not intended for analysis.

Following a three-minute rest period the participant then sustained an IMVC\textsubscript{20} contraction for 65 seconds. Two minutes rest was given before the participant performed an IMVC\textsubscript{50} contraction for 35 seconds. The participant was allowed the initial five seconds of both the IMVC\textsubscript{20} and IMVC\textsubscript{50} tests to reach the requested ICCF torque amplitude. Data for this initial five-second period was discarded, thus IMVC\textsubscript{20} and IMVC\textsubscript{50} data was analysed for a 60 and 30 second period, respectively. The participant's focus was directed towards their ICCF torque production with visual and verbal encouragement given. Participants were blinded to the measurement of DHF, which was recorded simultaneously with the performance of all ICCF tests.

This procedure has previously shown sound reliability in the measurement of DHF during CCFD tests (ICC 0.81-0.9), and in the measurement of IMVC peak torque (ICC 0.92) (Appendix B).
Data Management and Statistical Analysis

Data was excluded for a CCFD measurement if the participant experienced any neck, head, or upper limb pain during the dynamometry procedure. There were no reports of pain during any of the test procedures in this study.

Change in DHF Data: DHF data were transformed to a change value in Newtons by calculating the difference between the DHF measurement at rest immediately before commencing the test and the recorded DHF measurement during the performance of the tests. Change in DHF measurements at peak torque for the IMVC test, and change in DHF over the first and final 5-second period of the sustained IMVC\textsubscript{20} and IMVC\textsubscript{50} tests were computed for all participants. Independent sample t-tests were used to analyse group differences between the neck pain and control groups for all changes in DHF measurements (P-value = 0.05).

IMVC Peak Torque Data:

Peak torque data was analysed in three ways -

- Independent samples t-tests were used to analyse between-group differences in peak torque between symptomatic and control participant groups.
- IMVC data for female control participants (n=23) were separated and the mean and standard deviation calculated.
- Peak torque data were reviewed accepting only peak torque recordings that were achieved with concurrent DHF recordings within a margin of ± 20% of the resting DHF. Each participant's IMVC data was inspected and samples discarded that coincided with DHF recordings outside the accepted ± 20% margin. The highest amplitude torque sample of the remaining data was accepted as the peak torque score.
Results

The primary statistical findings for the change in DHF data and the IMVC peak torque data are reported below. For complete statistical output refer to Appendix F.1.

Change in DHF Data

Both neck pain and control participants demonstrated substantial increases in DHF from resting values during all tests. There were no significant differences in DHF between groups for any of the tests (Table 3.3).

**IMVC tests:** At the moment of peak torque, only three (two symptomatic, one control) of the 64 participants had decreased their DHF compared to their resting DHF. All other participants increased their DHF. Symptomatic participants increased their DHF at peak torque by 136% of their resting DHF, and control participants by 159% of resting DHF.

Table 3.3 Group (symptomatic, control) means and standard deviations (SD) of change in DHF data (net DHF change from rest) during ICCF tasks at IMVC, at IMVC<sub>20</sub>, and at IMVC<sub>50</sub>. No significant group differences (P > 0.05) were found for any of the measures.

<table>
<thead>
<tr>
<th>Test</th>
<th>Epoch&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Symptomatic</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>DHF change (N)</td>
<td>IMVC</td>
<td>58.84 (45.11)</td>
<td>68.65 (43.15)</td>
</tr>
<tr>
<td>IMVC&lt;sub&gt;20&lt;/sub&gt;</td>
<td>Start</td>
<td>16.18 (11.47)</td>
<td>15.1 (10.89)</td>
</tr>
<tr>
<td></td>
<td>End</td>
<td>23.14 (15.4)</td>
<td>22.65 (8.92)</td>
</tr>
<tr>
<td>IMVC&lt;sub&gt;50&lt;/sub&gt;</td>
<td>Start</td>
<td>39.52 (22.36)</td>
<td>39.52 (25.6)</td>
</tr>
<tr>
<td></td>
<td>End</td>
<td>45.31 (24.71)</td>
<td>48.05 (24.62)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Start = first 5 second epoch after participant achieved target IMVC level (20 & 50% IMVC), End = last 5 second epoch.
**IMVC\textsubscript{20,50} tests:** Sixty-three of the 64 participants increased their DHF during both the IMVC\textsubscript{20} and IMVC\textsubscript{50} tests. For the IMVC\textsubscript{20} test both symptomatic and control participants significantly increased their DHF from resting values in the first five seconds ($P < 0.0001$) by 35.6% and 33.6% for the symptomatic and control groups, respectively, and continued to increase their DHF significantly ($P < 0.0001$) as a function of time such that by the final five seconds of the test their DHF had elevated by 51% and 50.3%, respectively.

For the IMVC\textsubscript{50} tests, both groups significantly increased their DHF from resting values in the first five seconds ($P < 0.0001$) by 87.4% and 86.4% for the symptomatic and control groups, respectively. Both groups continued to increase their DHF as a function of time as determined by comparing the first and last five second periods, but this was only statistically significant for the control group (105.2%, $P < 0.0001$) not the symptomatic group (100.2%, $P = 0.054$).

**IMVC Peak Torque Data**

- **Group comparisons** - There were no significant differences between symptomatic (11 ± 3.8 Nm) and control participant (11.5 ± 3.9 Nm) groups for the measurement of peak torque during IMVC tests.
- Peak torque values for female control participants only were on average 10.1 ± 2.5 Nm in magnitude.
- Reviewed peak torque values (peak torque with coinciding DHF within ± 20% of resting DHF) were substantially less than the original values for both neck pain (5.8 ± 3.6 Nm) and control participant (6.1 ± 4.2 Nm) groups.
3.3.6.5 Discussion

Change in DHF Data

Both symptomatic and control groups demonstrated similar substantial increases in DHF for all tests. These findings do not support the hypothesis that neck pain patients would display more pronounced changes in DHF on the supporting surface than matched controls. The results are only valid for the CCFD tests performed in this study. It is possible that if the IMVC\textsubscript{20} and IMVC\textsubscript{50} tests were sustained until task failure instead of the pre-determined 60s and 30s time limits, results may have been different. The fact that both groups demonstrated increases in DHF would indicate that this is most likely a normal response during these CCFD tests, possibly to enhance ICCF muscle torque production to counteract muscle weakness and/or fatigue. Participants may extend their head and cervical spine together on the thorax (retraction manoeuvre of the head and neck) in an effort to apply greater force to the dynamometer application pad. The substantial increases in DHF at peak torque during the IMVC tests would suggest that this could be the case.

IMVC Peak Torque Data

The three different analyses of the impact of not controlling DHF on the amplitude of the peak torque data strongly suggests that uncontrolled DHF results in excessive peak torque recordings and may mask differences in isometric strength between symptomatic and control participant groups.

In contrast to the study of Watson and Trott (1993), no group differences in IMVC peak torque was found in this study ($P = 0.57$). Watson and Trott (1993) reported a small but significant reduction in ICCF muscle strength in cervicogenic headache sufferers when compared to control participants in a similar dynamometry test where DHF was controlled. In this current study in which DHF was not controlled during IMVC tests, any differences in peak torque between the groups may have been masked.
IMVC peak torque amplitudes were much greater than expected. For example, female control participants in this study recorded peak torque amplitudes of 10.1 ± 2.5 Nm. These values are double those expected (3.2 - 6 Nm) based on the results from comparable studies cited in Table 3.1. It would appear that the substantial increases in DHF during the IMVC tests may improve a participant’s capacity to exert maximal ICCF muscle torque. This was further confirmed when the peak torque measurements were reviewed for change in DHF (limits of ± 20% of resting DHF), and as a consequence reduced significantly (symptomatic participants 11 to 5.8 Nm, control participants from 11.5 to 6.1 Nm) in amplitude. The reviewed peak torque amplitudes were much closer to those expected based on estimates from the previous studies (Table 3.1). It would appear that limiting the change in DHF by this margin of ± 20% of resting DHF, is appropriate for the IMVC testing procedure.

3.3.6.6 Conclusion of Preliminary Study

The results of this study have indicated that DHF does need to be controlled during the CCFD test procedure to optimise the capacity of the method to measure ICCF muscle impairment. It would appear that controlling DHF by a margin of ± 20% of resting DHF is practical for the IMVC tests. The following section (Section 3.3.7) describes the changes in the CCFD procedures and equipment to accommodate for the control of DHF in the CCFD method for the clinical measurement studies (Chapter 5-7).

3.3.7 Implications of Preliminary Study on the Cranio-Cervical Flexion Dynamometry Test Protocol for Clinical Measurement Studies (Chapters 5-7)

IMVC Tests

The preliminary study demonstrated that controlling DHF to a limit of ± 20% of the resting DHF resulted in ICCF muscle torque values in the range expected, based on previous studies (Table 3.1). Consequently the LabView program was modified so that
the peak torque measurement, recorded for any single trial, corresponded to the maximal torque sample where the concurrent DHF recording was within ± 20% of the resting DHF. Additionally, an audible alarm was set into the program that alerted both the investigator and participant when these DHF limits were breached. This permitted the investigator to give the participant verbal feedback regarding the direction of the breach (increase or decrease in DHF) in an effort to facilitate a more accurate subsequent IMVC effort. To accommodate for the increased complexity of the dual task of performing an IMVC and controlling DHF, five instead of three IMVC trials were performed in the clinical measurement studies.

**IMVC_{20,50} Tests**

The IMVC data analysis confirmed that not controlling increases in DHF permitted participants to exert greater amplitudes of ICCF muscle torque. The preliminary study also demonstrated substantial increases in DHF during both the IMVC_{20} and IMVC_{50} tests, possibly also being a mechanism of improving the capacity to sustain ICCF torque over time. Potentially this may diminish the ability of the tests to expose differences between impaired and unimpaired ICCF muscle performance, particularly if differences in performance are subtle, as may be the case in the IMVC_{20} test. Consequently it appeared necessary to impose DHF control limits on these tests as well.

It was decided to impose limits on an increase in DHF only. Limits were not placed on a reduction in DHF during these sustained tests as the preliminary study had revealed all participants except one increased their DHF, not reduced it. Additionally, it was not considered advantageous to reduce DHF during these sustained tasks as that required greater muscular effort as the participant had to lift the weight of the head over a sustained period. Practically, if the participant, during the sustained test, had to respond to an alarm that sounded with either an increase or decrease in DHF then the direction of response required may be confusing. During pilot trials, participants appeared to be capable of controlling a DHF margin of +10% of the resting DHF during either the IMVC_{20} or IMVC_{50} tests, possibly due to the fact the tests are sustained allowing
individuals time to react and adjust to an alarm. As we wished for the least DHF change possible during these tests, the +10% of resting DHF margin was chosen.

The Labview program was modified such that an audible alarm would sound during the test if the participant increased their DHF by greater than 10% of their resting DHF, and would continue to sound until the DHF was reduced to within the acceptable limits. In this way the participant had to perform the dual task of sustaining the required ICCF torque amplitude while ensuring their DHF did not increase to the unacceptable limits. As these tests were to be performed until task failure, the Labview program was written so that it could be terminated by the investigator in response to the participant ceasing the test. In the event of the participant failing to cease a test, the program was defaulted to terminate after a ten-minute duration.

Stabilisation of the Trunk

The degree to which the trunk should be stabilised during dynamometry testing is controversial (Keating and Matyas 1996). In the preliminary studies in this thesis the torso of participants was stabilized, as is a common practice in neck dynamometry methods (Levoska et al. 1992; Portero and Genries 2003), with soft straps placed over the shoulders to minimise trunk movement. It was obvious on preliminary trials that varying the firmness of the straps altered the participants' mandibles resting pressure on the dynamometer application pad and appeared to substantially alter peak torque during the IMVC tests. Additionally participants reported that they could enhance their ICCF torque production by shrugging their shoulders into the straps, thus assisting a downward motion of the mandible onto the application pad. The clinical measurement studies (Chapter 5-7) were therefore performed without the soft straps, using bodyweight onto the supporting surface only to restrain trunk motion. To ensure that the participant did not move during the testing session, landmarks as recorded on the web camera (Figure 3.2) were checked for consistency between IMVC, IMVC_{20}, and IMVC_{50} measurements.
3.4 Summary - Development of the Cranio-Cervical Flexion Dynamometry Method

A new method called cranio-cervical flexion dynamometry (CCFD) was developed to measure the ICCF muscle performance to address inadequacies of current methods. CCFD measures the capacity of the CCF muscles to exert and sustain static torque about the C0/I motion segment. It achieves this by directly resisting cranio-cervical flexion (the primary biomechanical action of the CCF muscles), and measuring the resultant torque about their primary articulation of action, the atlanto-occipital joint (C0/1). A CCFD test protocol was also developed. These measurements are thought to reflect the capacity of the CCF muscles to maintain head on neck postural relationships under a range of functional loads.

CCFD was developed under the concept that to selectively challenge the CCF muscles, a dynamometry method must directly resist and measure the primary biomechanical function of the CCF muscles, that being the biological action of cranio-cervical flexion about the C0/I motion segment. The concept was extended to propose that conventional CFD methods that combined flexion at both cranio-cervical and cervico-thoracic regions of the neck by resisting motion at the forehead, would not be specific to the CCF muscles and consequently would not be a specific test of their performance. For these reasons it was hypothesised that CCFD was a more selective test of the CCF muscles than CFD. In the following chapter (Chapter 4), this hypothesis is tested by observing the electromyographic activity of the cranio-cervical and cervico-thoracic flexor muscle groups during the different dynamometry methods.
CHAPTER 4: PROOF OF CONCEPT STUDY – MUSCLE
SPECIFICITY IN CRANIO-CERVICAL FLEXION DYNAMOMETRY

4.1 Abstract

Objective: The purpose of this study was to compare the use of the cranio-cervical flexor (CCF) muscles during different dynamometry testing methods. It was proposed that cranio-cervical flexion dynamometry (CCFD) would challenge the CCF muscles more specifically than would conventional cervical flexion dynamometry (CFD).

Participants and Methods: Ten volunteers with no history of neck pain participated in the study. Electromyographic signals were recorded from the right longus capitis (LC), sternocleidomastoid (SCM), anterior scalene (AS), and hyoid (HD) muscles during CCFD and CFD tests at isometric maximal voluntary contraction (IMVC), at 50% of IMVC (IMVC50), and at 20% of IMVC (IMVC20). Normalised root-mean-square amplitudes for the LC (CCF) muscle were compared to those for the SCM, AS, and HD (cervico-thoracic flexors) muscles.

Results: During CCFD tests, the LC muscle demonstrated greater relative activity than the SCM, AS, and HD muscles at IMVC20 (P = 0.003 - 0.012) and greater relative activity than the SCM and AS muscles at IMVC50 (P = 0.002 – 0.023). CFD tests showed no differences between the LC and the other muscles at IMVC20, and relatively greater use of the SCM and AS muscles at IMVC50, and of the AS muscle at IMVC.

Discussion and Conclusion: CCFD appears to be a more specific test of the CCF muscles than CFD.
4.2 Background and Aims of Study

It was proposed that the new method of cranio-cervical flexion dynamometry (CCFD) is more specific to the cranio-cervical flexor (CCF) muscles than conventional cervical flexion dynamometry (CFD) and consequently may be a more specific test of their performance. This hypothesis was based on the concept that CCFD directly resists the primary biomechanical action of the CCF muscles by resisting cranio-cervical flexion at the under-surface of the mandible, compared to CFD that resists combined cranio-cervical and cervico-thoracic flexion via resistance to the forehead. The purpose of this study was to evaluate if this concept was correct and test whether CCFD activated the CCF muscles more selectively than did CFD.

In order to test this hypothesis, electromyographic (EMG) signals were measured from both the deep CCF muscles (Falla et al. 2003a; Falla et al. 2004b) and the superficial cervico-thoracic flexor muscles during tests of isometric maximal voluntary contraction (IMVC), 50% of IMVC (IMVC$_{50}$), and 20% of IMVC (IMVC$_{20}$) contraction intensities with both methods of dynamometry. Additionally, the same EMG measures were taken when participants performed the cranio-cervical flexion test (CCFT) (Falla et al. 2003a; Jull et al. 2004a). Although the CCFT method does not directly resist cranio-cervical flexion, it utilises the anatomical action of the CCF muscles, is a current clinical test of CCF muscle performance, and has recently been studied in a similar fashion (Falla et al. 2003a). It was hypothesized that the CCFT test and CCFD would display similar patterns of muscle use.

The aims of the study were:

- To compare the patterns of muscle usage of the cranio-cervical and cervico-thoracic flexor muscles during CCFD, CFD, and the CCFT.
- To determine if CCFD preferentially activated the CCF muscles.
- To determine the effect of contraction intensity on the patterns of muscle usage for the dynamometry methods.
4.3 Methods

4.3.1 Participants

Ten volunteers (five females, five males) with no history of neck pain and a mean age of 31.6 years (range 20-55 years) participated in the study. Participants were excluded if they had suffered neck pain over the previous year, had a history of orthopaedic disorders affecting the neck, or neurological disorders. They were also not considered if they had specifically trained their neck or shoulder girdle muscles over the previous six months. Individuals without a history of neck pain were tested in this study in order to evaluate the relative muscle usage of the cervical flexors when performing tests with the different dynamometry methods, in the absence of muscle impairment. Impaired cervical flexor muscle coordination has been previously shown in symptomatic participants (Jull 2000; Jull et al. 2004b; Falla et al. 2004b) and may have posed a confounding variable.

Participants were also screened for contraindications and precautions for the use of Xylocaine spray local anaesthetic\(^5\) (MIMS 2001) and for the use of a nasopharyngeal suctioning technique (Hough 1996) which were a part of the EMG technique for measuring activity of the deep CCF muscles. After receiving verbal and written information, each participant signed a consent form containing information about the nature of the study (Appendix D.3). Ethical approval for the study was granted by the Institutional Medical Research Ethics Committee and was conducted in accordance with the declaration of Helsinki (Appendix D.1).

\(^5\) Astra Pharmaceuticals, 50 Otis St, Westborough, MA 01581.
4.3.2 Instrumentation and Measurements

4.3.2.1 Electromyographic Equipment

EMG recordings of the right longus capitis (LC) muscle were made using custom made bipolar electrodes (Falla et al. 2003a). The apparatus consisted of bipolar silver wire electrode contacts (dimensions: 2mm x 0.6mm, inter-electrode distance: 10mm) inbuilt into a suction catheter (size 10FG), with a heat sealed distal end. The bipolar electrode was inserted via the nose to the posterior oropharyngeal wall at approximately the level of the C2/3 intervertebral disc. The LC muscle is situated posterior to the oropharyngeal wall providing an ideal location to make recordings via the mucosal wall without requiring intramuscular recording techniques (Falla et al. 2003a; Falla et al. 2004b). In this position the catheter directly overlies the belly of the LC muscle that in tum overlies part of the superior portion of the LCo muscle (Moore and Dailey 1999). Each electrode catheter was individually packed and sterilized using standard gas sterilization procedures.

Surface electrodes (Grass Telefactor\textsuperscript{6}) were used to detect EMG signals for the sternocleidomastoid (SCM), anterior scalene (AS), and hyoid (HD) muscles. These surface electrodes were positioned over the lower one third of the SCM (20mm Ag/Ag Cl disc electrodes) and AS (11mm Ag/Ag Cl disc electrodes) muscles (Falla et al. 2002), and over the infrahyoid muscles (11mm Ag/Ag Cl disc electrodes) midway between the attachments at the manubrium and the thyroid cartilage. Electrodes were not placed over the suprathyroid muscles as they would interfere with the positioning of the resistance arm during CCFD. EMG data were amplified (Gain = 1000), band pass filtered between 20 Hz – 1 kHz and sampled at 2kHz (NeuroLog\textsuperscript{7}). Data were sampled with Spike software\textsuperscript{8} and converted into a format suitable for signal processing with Matlab software\textsuperscript{9}.

\textsuperscript{6} Astro-Med Inc, 600 East Greenwich Avenue, West Warwick, Rhode Island, 02893, USA.
\textsuperscript{7} Digitimer Ltd, Welwyn Garden City, Hertfordshire, AL73BE, England.
\textsuperscript{8} Cambridge Electronic Design, Cambridge, UK.
\textsuperscript{9} The MathWorks Inc, 3 Apple Hill Dr, Natick, MA 01760-2098.
4.3.2.2 Dynamometry Equipment

Isometric CCFD tests (Figure 4.1 A) were performed in the supine position with the CCFD device as described in Section 3.2. Isometric CFD tests were performed with a load cell attached to a block padded for contact with the participants' forehead (Figure 4.1B). The load cell was rigidly attached to the supporting couch. The participant's effort to flex the cervical spine was resisted at the forehead and a resultant change in voltage from the load cell (STC Series\(^{10}\)) was amplified (PM4-SG-240-5E-A\(^11\)). The signals were transmitted to a personal computer and custom written program (LabView 6i Virtual Instruments\(^{12}\)) which was calibrated to give an appropriate force measurement in Newtons (N). Both isometric dynamometry methods utilized the same software and visual feedback to the participant for IMVC and IMVC\(_{20,50}\) contractions as described in Section 3.2.3. EMG activity of the neck flexors was recorded with both dynamometry methods at IMVC, as well as at IMVC\(_{50}\) and IMVC\(_{20}\). Thus, EMG measurements were recorded over a range of muscular efforts at maximal, moderate, and low intensities.

The CCFT test was performed as in the clinical setting (Jull et al. 2004a) using the Stabilizer Pressure Biofeedback Unit\(^{13}\) (Figure 4.1C). The air-filled pressure sensor was positioned behind the participant's upper cervical region to guide performance in the test. The test consists of staged increases in cranio-cervical flexion such that the pressure increases from 20mmHg to 30mmHg in five 2mmHg increments. Due to the inability to grade a contraction effort against a maximal voluntary contraction (MVC) with the CCFT, participants in this study sustained contractions at pressure levels of 24mmHg and 28mmHg to represent low and higher grades of muscle effort specific to this test.

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\(^{10}\) Celtron Technologies Inc, Santa Clara, CA, 95054.

\(^{11}\) Davidson Measurement Pty. Ltd., I-3 Lakewood Boulevard, Braeside, VIC, 3195 Australia.

\(^{12}\) National Instruments Corp, 11500 N Mopac Expressway, Austin, TX 78759.

\(^{13}\) Chattanooga Group Inc, 4717 Adams Rd, Hixson, TN 37343.
Figure 4.1 Recording of neck flexor muscle activity during three methods of testing muscle performance. The nasopharyngeal electrode was positioned over the right longus capitis muscle via the nose, surface electrodes were located over the right sternocleidomastoid, anterior scalene, and hyoid muscles. Photo A depicts recordings during CCFD where flexion of the head on the cervical spine is directly resisted at the undersurface of the mandible. Photo B depicts recordings during CFD where flexion of the head and neck together on the thorax is directly resisted at the forehead. Photo C depicts recordings during the CCFT where the pressure sensitive airbag positioned behind the neck measures pressure increases resulting from the flattening of the cervical lordosis.

4.3.3 Experimental Procedure

All tests were performed in a supine position as described in the preliminary study in Chapter 3 (Section 3.3.6). Soft straps were placed lightly over the shoulders during this study to minimise movement of the trunk on the supporting surface between dynamometry methods as time limits made adjusting the position of the participant between methods undesirable. All procedures were performed in a neutral upper cervical spine flexion/extension position according to a standard anthropometric neutral position of the head (a vertical line bisects the orbitale and the tragion) (Norton and Olds 1996).

For CCFD, the participant’s C0/I AOR landmark (concha of the ear) and the dynamometer axis were aligned as described in Chapter 3 (Figure 3.2). The dynamometer
lever arm was then fitted at the under-surface of the mandible at an angle such that the cranio-cervical flexion/extension neutral position was achieved. For CFD, the padded resistance block was positioned in contact with the participant's forehead in the cranio-cervical flexion/extension neutral position. This was also the starting position (20mmHg pressure reading) for the CCFT.

Following skin preparation, the surface electrodes were positioned over the participant's right SCM, AS, and HD muscles. Participants were set up on each apparatus and performed practice trials for familiarization and warm up purposes. Anaesthetic spray (Xylocaine) was then applied to the right nostril (three applications) and back of the mouth (three applications). A one-minute period was allowed for the anaesthetic to take effect before the nasopharyngeal electrode was passed down the right nostril until it became visible through the mouth over the right oropharynx. The suction was then applied so that the electrode had good contact with the oropharynx. Signals from all four EMG channels were checked for clarity.

The normalisation manoeuvre consisting of a combination of cranio-cervical and cervico-thoracic flexion was performed first. The participant was asked to flex their head on their neck followed by a lift of their head to just clear the supporting surface and to sustain the position for ten seconds while the EMG signals were recorded.

The order of testing of the CCFD, CFD, and CCFT methods was randomised between participants to minimise order effects especially that of muscle fatigue. For the CCFD tests, participants were instructed to nod their head into flexion such that their jaw pushed downwards on the padded bar while the back of their head maintained contact with the supporting surface. Due to the time constraints associated with the nasopharyngeal EMG technique, only one contraction at each intensity was permitted. Therefore participants were not specifically requested to control DHF but were encouraged to perform the correct cranio-cervical flexion action.
For CFD tests, participants were asked to attempt to lift their head off the supporting surface such that their forehead pushed into the padded block. Participants were also instructed that during CFD, they were neither to tuck their chin in or let their chin protrude so as to keep the cranio-cervical spinal region in a neutral position. For both CCFD and CFD, participants first performed an IMVC sustained for three to five seconds, followed by an IMVC\textsubscript{20} contraction for 10 seconds, followed by a IMVC\textsubscript{50} contraction for 10 seconds. EMG signals were recorded for all tests. Due to the time restraints associated with the nasopharyngeal suctioning technique, only ten seconds rest was given between the three contraction intensity levels. For the CCFT, the participants flexed the head on the neck so that the indicator needle of the pressure display unit moved from its starting position at the 20 mmHg to 24 mmHg and maintained the needle at 24 mmHg for ten seconds. EMG recordings were taken when the indicator needle was statically maintained at 24 mmHg. Ten seconds rest was given before the procedure was repeated at a pressure of 28 mmHg. During all testing procedures verbal encouragement as well as visual feedback was given.

4.3.4 Data Management and Statistical Analysis

To obtain a measure of EMG signal amplitude, the root mean square (RMS) was calculated for each muscle using a custom designed software program (Matlab (6.1))\textsuperscript{5}. Due to the short duration of the IMVC test, these values were calculated over a one second epoch for the IMVC data, and over a five second epoch for all IMVC\textsubscript{20,50} test data, CCFT data and normalisation manoeuvre data that were all sustained for a 10 second period. RMS values for the CCFD, CFD, and CCFT methods were normalised against the RMS values from the normalisation manoeuvre.

To analyse relative CCF (LC) to cervico-thoracic flexor (SCM, AS, HD) muscle use, the normalised RMS values of the LC muscle was compared to that of the SCM, AS, and HD muscles with paired t-tests. Additional comparisons were made within individual muscle recordings between isometric dynamometry tests (CFD and CCFD) at the same intensity.
of contraction (IMVC, IMVC<sub>50</sub>, IMVC<sub>20</sub>) using paired t-tests. The alpha level was set at P < 0.05.

4.4 Results

The primary statistical findings for the EMG data are reported below. For complete statistical output refer to Appendix F.2.

The between muscles' comparison under the two dynamometry test conditions indicated that at IMVC<sub>20</sub>, the LC muscle demonstrated significantly higher normalised RMS values compared to the SCM, AS, and HD muscles (P = 0.003, 0.012, 0.046, respectively) in the test with CCFD (Figure 4.2) but there were no significant differences between the LC and the other muscle groups (P = 0.338 - 0.339) when performing CFD. At IMVC<sub>50</sub> with CCFD, the LC demonstrated significantly greater activity than the SCM and AS muscles (P = 0.002 and 0.023, respectively) but not the HD muscles (P = 0.38). In contrast, at IMVC<sub>50</sub> with CFD, LC demonstrated significantly less activity than the SCM or AS muscles (P = 0.007 and 0.003, respectively), but not the HD muscles (P = 0.058). Muscle tests performed at IMVC revealed that LC had significantly greater activity than SCM (P = 0.033) only during CCFD and significantly less activity than AS (P = 0.017) only during CFD.

Figure 4.3 presents the relative EMG activity for all four muscles during the CCFT trials (24mmHg, and 28mmHg). The LC muscle at both test levels demonstrated significantly greater relative use than the SCM, AS, or HD muscles (P = 0.001- 0.035).

Table 4.1 presents the normalised RMS values (means and 95% confidence intervals) for the within muscle comparisons of the four muscles between dynamometry tests (CFD and CCFD) when performed at the same intensity of contraction (IMVC, IMVC<sub>50</sub>, IMVC<sub>20</sub>). Significantly greater activity was evident in the SCM (P < 0.001 - 0.002) and AS (P < 0.001 - 0.001) muscles in the CFD test conditions compared to CCFD at all intensities of muscular effort. HD muscles similarly demonstrated significantly greater activity during
CFD compared to CCFD but only in the IMVC\textsubscript{50} and IMVC\textsubscript{20} conditions (P = 0.007 and 0.02 respectively).

Figure 4.2 Means and 95\% confidence intervals of normalised root-mean-square values for the longus capitis (LC), sternocleidomastoid (SCM), anterior scalene (AS), and hyoid (HD) muscles across three levels of isometric muscular exertion (IMVC, IMVC\textsubscript{50}, IMVC\textsubscript{20}) when performing tests with the CCFD and the CFD. Exact values are presented in Table 4.1. Horizontal lines denote significant pair-wise differences (P < 0.05).
Figure 4.3 Means and 95% confidence intervals of normalised root-mean-square values for the longus capitis (LC), sternocleidomastoid (SCM), anterior scalene (AS), and hyoid (HD) muscles across two pressure levels (24 mmHg, 28 mmHg) of the CCFT. Exact values are presented in Appendix F.2. Horizontal lines denote significant pair-wise differences (P < 0.05).
Table 4.1 Mean normalized RMS values and 95% confidence intervals for the longus capitis (LC), sternocleidomastoid (SCM), anterior scalene (AS), and hyoid (HD) muscles during tests with CCFD and CFD. For both dynamometry methods, recordings are made at IMVC, IMVC$_{50}$, and IMVC$_{20}$. Greater activity for CFD tests was present in the SCM and AS muscles at all intensity levels, and in the HD muscles for IMVC$_{50}$ and IMVC$_{20}$ tests. Higher amplitude activity of the SCM and AS muscles in tests of CFD largely explains the contrasting muscle usage patterns of the dynamometry methods seen in Figure 4.2.

<table>
<thead>
<tr>
<th></th>
<th>CCFD</th>
<th>CFD</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMVC</td>
<td>180 (153 - 206)</td>
<td>158 (122 - 193)</td>
<td>0.23</td>
</tr>
<tr>
<td>IMVC$_{50}$</td>
<td>137 (103 - 171)</td>
<td>149 (119 - 179)</td>
<td>0.62</td>
</tr>
<tr>
<td>IMVC$_{20}$</td>
<td>101 (65 - 137)</td>
<td>112 (82 - 143)</td>
<td>0.61</td>
</tr>
<tr>
<td>SCM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMVC</td>
<td>129 (94 - 164)</td>
<td>200 (147 - 254)*</td>
<td>0.002</td>
</tr>
<tr>
<td>IMVC$_{50}$</td>
<td>71 (60 - 83)</td>
<td>272 (196 - 347)*</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>IMVC$_{20}$</td>
<td>32 (25 - 39)</td>
<td>136 (89 - 184)*</td>
<td>0.001</td>
</tr>
<tr>
<td>AS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMVC</td>
<td>166 (114 - 219)</td>
<td>273(194 - 351)*</td>
<td>0.001</td>
</tr>
<tr>
<td>IMVC$_{50}$</td>
<td>80 (56 - 104)</td>
<td>343 (257 - 429)*</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>IMVC$_{20}$</td>
<td>36 (24 - 48)</td>
<td>133 (93 - 174)*</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>HD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMVC</td>
<td>160 (86 - 234)</td>
<td>198 (95 - 300)</td>
<td>0.12</td>
</tr>
<tr>
<td>IMVC$_{50}$</td>
<td>107 (56 - 157)</td>
<td>298 (155 - 440)*</td>
<td>0.007</td>
</tr>
<tr>
<td>IMVC$_{20}$</td>
<td>45 (23 - 67)</td>
<td>153 (70 - 235)*</td>
<td>0.02</td>
</tr>
</tbody>
</table>
4.5 Discussion

The results of this study support the hypothesis that CCFD tests the CCF muscles more specifically than does CFD and therefore provides a more specific measure of their performance.

The results showed that at IMVC\textsubscript{20} with CCFD, significantly greater activity of the LC muscle was not only noted in relationship to the SCM and AS which are cervical flexors, but was also for the HD muscles which have both cranio-cervical and cervico-thoracic flexor attributes. The CCF attribute of the HD muscles became evident at IMVC\textsubscript{50} with CCFD, where it demonstrated similar activity levels relative to the LC muscle. Interestingly, during the IMVC CCFD test, LC showed significantly greater activity than the SCM muscle, but not the AS muscle. This finding may be consistent with the anatomical relationship of the LC and AS muscles. From a gross anatomical perspective these muscles form a continuous line of muscle from the first rib to the cranium with common attachments at the transverse processes of C3-6 vertebrae (Kamibayashi and Richmond 1998; Moore and Dalley 1999). It is feasible that greater AS activity is required at higher LC muscle efforts to provide a stable origin point on which the LC anchors.

Additionally, it was hypothesised that CFD with resistance at the forehead would not preferentially activate either the cranio-cervical or cervico-thoracic flexor muscles. The results however suggest that CFD preferentially activates the cervico-thoracic flexor muscles. As seen in Figure 4.2, for CFD tests, the LC muscle demonstrated the least relative muscle use of all four muscles at all intensities although only significantly so at the IMVC, and IMVC\textsubscript{50} intensities. No significant differentiation of muscle use was seen at IMVC\textsubscript{20} during CFD. Interestingly at IMVC\textsubscript{50} the primary cervico-thoracic flexor muscles (SCM, AS) showed significantly greater relative use than LC, the opposite of that found at IMVC\textsubscript{50} with CCFD. Only the AS muscle showed significantly greater use than LC at IMVC with CFD. These latter findings are indicative of the combined action
of the cranio-cervical and cervico-thoracic flexor muscles during CFD where resistance is applied at the forehead.

Within-muscle comparisons (Table 4.1) revealed that the differences in relative muscle use between the two methods of isometric dynamometry are largely due to substantial differences in the activation patterns of the cervico-thoracic flexor muscles. The SCM and AS muscles demonstrated significantly greater RMS values for CFD tests than for CCFD tests at all contraction intensity levels. This is also the case for the HD muscles at contraction intensities of IMVC_{50} and IMVC_{20}. LC on the other hand demonstrated no significant differences in RMS values between the isometric dynamometry methods at any contraction intensity levels.

Some previous studies utilizing CFD have instructed participants to initiate the test by tucking their chin in first before commencing flexion into the resistance at the forehead (Silverman et al. 1991; Placzek et al. 1999; Peolsson et al. 2001; Strimpakos et al. 2004). While these instructions possibly facilitate greater activity of the CCF muscles during these tests, the dynamometry method itself does not directly resist cranio-cervical flexion and is therefore not a specific test of this muscle group. It appears from the results of this study that separate dynamometry methods are required for the cranio-cervical and cervico-thoracic flexor muscle groups.

From the results, specificity of exposing CCF muscle impairment would appear to be optimal at lower intensities of muscle contraction as has been a finding in studies utilizing the CCFT (Jull et al. 1999; Jull 2000; Jull et al. 2004b; Falla et al. 2004b). As expected, the results showed that the isometric inner range hold of the CCFT yielded similar relative muscle use (Figure 4.3) to that of CCFD when performed at IMVC_{20} (Figure 4.2). Both these methods encourage the primary anatomical action of the CCF muscles. It is also evident from inspection of the muscle amplitude values that the CCFT is a low intensity contraction test even when performed at 28 mmHg. It is acknowledged that direct comparisons of EMG amplitudes between CCFD and the CCFT is made difficult by the fact that both tests are performed in slightly different points in the cranio-
cervical flexion range. CCFD was performed isometrically in the neutral spine position. EMG recordings were taken for the CCFT during an isometric hold in an inner range cranio-cervical flexion position. Importantly, an IMVC cannot be performed with the CCFT making direct comparisons of EMG amplitude at specified contraction intensities difficult.

The nasopharyngeal EMG electrode recording activity of LC was positioned at a level approximating the right C2/3 intervertebral disc, overlying the bulk of the right LC muscle (Kamibayashi and Richmond 1998; Moore and Dalley 1999). Signals from this electrode placement will also have been detected from the superior portion of the LCo muscle that also underlies this region at the C2/3 level. Nevertheless, the primary cranio-cervical flexion action of the LC muscles would support the contention that the EMG signals from the nasopharyngeal electrode during cranio-cervical flexion originated in large from the LC muscle. The superior portion of LCo may contribute by stabilising or flexing the upper cervical spine to C1, however by virtue of its attachments it is unable to flex the 0/C1 motion segment.

4.6 Summary - Muscle Specificity in Cranio-Cervical Flexion

Dynamometry and Prologue to Clinical Measurement Studies

The results of the study reported in this chapter have supported the concept under which the CCFD method was developed (Section 3.1). CCFD is more specific to the activation of the CCF muscles than CFD, and consequently should be a more specific test of their performance. In particular CCFD demonstrated preferential activation of the CCF muscles compared to the cervico-thoracic flexor muscles at both low (IMVC_{20}) and moderate (IMVC_{50}) contraction intensities. This is evidence that these intensities of muscle contraction are specific to the CCF flexor muscles, and justifies their inclusion in the CCFD test protocol for the clinical measurement studies.
The following Chapters 5-7 describe three clinical measurement studies that test the clinical application of the new CCFD method, inclusive of the finalized ICCF muscle performance test protocol. These finalized tests include:

- **Isometric Maximal Voluntary Contraction (IMVC) Tests**
  - Peak Torque (Newton-meters Units)

- **Sustained Contractions at 20% of IMVC (IMVC\textsubscript{20})**
  - Time to Task Failure (seconds duration)
  - Contraction Accuracy (percentage accuracy)

- **Sustained Contractions at 50% of IMVC (IMVC\textsubscript{50})**
  - Time to Task Failure (seconds duration)
  - Contraction Accuracy (percentage accuracy)

The three clinical measurement criteria nominated in this thesis to evaluate the clinical application of these CCFD measurements are test-retest reliability (Chapter 5), a capacity to quantify ICCF muscle impairment (Chapter 6), and a capacity to quantify a change in ICCF muscle performance (responsiveness) following an exercise intervention (Chapter 7). The following chapter (Chapter 5) will investigate the test-retest reliability of the CCFD measurements.
CHAPTER 5: THE TEST-RETEST RELIABILITY OF CRANIO-CERVICAL FLEXION DYNAMOMETRY

5.1 Abstract

Objective: To establish the test-retest reliability and associated measurement error over time of the cranio-cervical flexion dynamometry (CCFD) test protocol measurements.

Participants and Methods: Twenty-four symptomatic participants (average Neck Disability Index (NDI) of 18.9 ± 8.1) and 24 control participants (average NDI of 3.1 ± 2.7) completed the CCFD test measurements (IMVC peak torque, IMVC<sub>20,50</sub> measurements of time to task failure and contraction accuracy) on two separate occasions spaced two weeks apart. Reliability of each measurement was calculated using Intraclass Correlational Coefficients (ICC) and Standard Error of the Measurement (SEM) indices.

Results: All CCFD measurements demonstrated good reliability for the symptomatic participants (ICC 0.7-0.92). Control participants had poorer reliability for the IMVC<sub>20</sub> contraction accuracy measurement (control ICC 0.17, SEM 11.94%, symptomatic ICC 0.7, SEM 6.73%), and a substantially larger measurement error for the IMVC<sub>50</sub> time to task failure measurement (control SEM 21s, symptomatic SEM 10s) compared to symptomatic participants.

Discussion and Conclusion: The CCFD measurements have shown good test-retest reliability over time. Analysis of IMVC<sub>20</sub> contraction accuracy measures, and IMVC<sub>50</sub> time to task failure measures have to be interpreted with caution in control participants.
5.2 Background and Aims of Study

This Chapter will investigate the reliability of the cranio-cervical flexion dynamometry (CCFD) measurements in participants with a history of neck pain (symptomatic participants), and without a history of neck pain (control participants), and includes both relative and absolute reliability indices as both are considered important in physical therapy measurement (Rothstein 1985; Wilson and Murphy 1996). Reliability is the degree to which test scores are free from measurement error, and thus is a necessary consideration when comparisons in measurement are made between and within individual performance scores. Dynamometry measurements are vulnerable to instrument error, investigator error, and an inherent lack of consistency in the variable of interest (Rothstein 1985), in this case isometric cranio-cervical flexor (ICCF) muscle torque. Instrument error of the CCFD device was addressed separately in Section 3.2.4.

Relative reliability is given by the Intraclass Corrational Coefficient (ICC) (Shrout and Fleiss 1979). The ICC reflects the consistency of a measure to rank performance, accounting for inter-participant and intra-participant variance (Surburg et al. 1992). It determines if an individual’s scores have consistency of rank within a group when measures are repeated even if their actual scores changed from time to time (Domholdt 1993). ICC values range between -1.00 - 1.00, with values closer to 1 representing strong reliability. It is suggested that values above 0.75 are indicative of good reliability, and those below 0.75 poor to moderate reliability (Portney and Watkins 2000).

Absolute reliability is provided by the Standard Error of the Measurement (SEM), representing the standard deviation of measurement errors (Rothstein 1985). The SEM provides a number that represents the way in which a single score will vary if a test is administered more than once, and is expressed in the same units as the measurement. SEM scores allow clinicians to make meaningful evaluations regarding changes in muscle performance measurements based on the knowledge of the scores variability due to measurement errors (Domholdt 1993). For example if the SEM is 1 Nm then 96% of the time the true value could be expected to fall within +/- 1 Nm of the observed
measurement. SEM values allow meaningful comparisons for between participant measures (symptomatic and control participants) as will be calculated in Chapter 6, and within participant measures (pre to post rehabilitation) as will be calculated in Chapter 7.

This chapter will investigate the reliability of the CCFD measurements in both symptomatic and control populations. Both participant groups were included, as the subsequent study (Chapter 6) will compare muscle performance between these groups. It has been suggested that reliability studies should be performed on all population groups of concern (Rothstein 1985). It was hypothesized that all CCFD measurements would demonstrate good reliability in both symptomatic and control groups as indicated by the ICC and SEM.

Aims of study:

- To establish the consistency and associated error of the CCFD measurements over time.
- To determine if the reliability of the CCFD measurements are similar between symptomatic and control populations.
- A secondary aim of this study was to determine effect size and variances that would underpin the power calculations undertaken for sample size in the following study (Chapter 6).

5.3 Methods

5.3.1 Participants

Forty-eight participants were included in the study including 24 symptomatic participants and 24 control participants. Both participant groups were recruited by the same process as described in Chapter 3 (Section 3.3.6.3). See Appendix D.4 and D.5 for ethical clearance forms, participant information sheets, and consent forms for this study. Participant demographics are presented in Table 5.1.
Table 5.1 Group means ± SD (range) for the variables of age, height, weight, and Neck Disability Index (NDI) score. * indicates significant group difference (P < 0.05).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Symptomatic</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>27.3 ± 8.9 (18 - 52)</td>
<td>26.2 ± 5.2 (20 - 38)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>168.5 ± 6.4 (155 - 181)</td>
<td>167.3 ± 5.1 (155 - 175)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>62.3 ± 6.9 (52 - 74)</td>
<td>61.7 ± 9.1 (50 - 91)</td>
</tr>
<tr>
<td>NDI (score/100)</td>
<td>18.9 ± 8.1 (10 - 46)</td>
<td>3.1 ± 2.7 (0 - 8)*</td>
</tr>
</tbody>
</table>

5.3.2 Procedure

A test-retest design was employed. All 48 participants were tested on two separate occasions spaced two weeks apart to minimise any carry over effects, such as training or fatigue effects between sessions. CCFD procedures involving participant position and alignment of participant/dynamometer axes were performed as described in Chapter 3 (Figure 3.2), and was replicated on both sessions via the recorded web camera landmark recordings. The order of tests was the same on both testing sessions. The IMVC tests were performed first. Five minutes rest was then given before participants performed the IMVC<sub>20</sub> test, 10 minutes rest was given before participants performed the IMVC<sub>50</sub> test. All measurements were supervised by the same investigator.

5.3.2.1 IMVC Test Procedure

Participants were given standard instructions and practice for familiarization and warm up purposes. Participants were instructed to nod their head ('yes' type action) such that their jaw pushed down onto the padded bar as hard as they could. Their task was to maximally elevate the blue line up the visual display screen (Figure 3.4A). To avoid bias of performance, the visual feedback graph had no visible units or markings of scale so...
that for IMVC tests, participants were unable to grade visually, the distance the graph moved up the screen either between repetitions or between measurement sessions. That is, the feedback was a relative indicator of torque output within each contractile test. Participants were instructed to perform the test while keeping consistent pressure on the back of the head and while maintaining the teeth together. Warm up consisted of four sub-maximal repetitions, with each successive repetition at a greater intensity than the previous one. The fifth repetition was to their maximal ability. During the warm up procedure, participants practiced performing the ICCF contractions while minimizing the alarm that indicated their DHF had moved out of acceptable limits (Section 3.3.7). Due to the relative complexity of the dual task, participants performed three to five IMVC practice trials following warm-up until peak torque was observed to plateau. Five official IMVC trials were then performed with standardised verbal encouragement given. A rest period of one minute was given between repetitions. On the rare occasion that peak torque had not reached a plateau following the five official test trials, then additional trials were allowed until a plateau was achieved, at which point the IMVC trials were immediately ceased to minimize potential muscle fatigue. These additional trials were permitted to ensure that a valid IMVC peak torque measurement had been acquired as this was vital for the accurate administration of the IMVC$_{20}$ and IMVC$_{50}$ tests which followed.

The participant was asked to rate their level of perceived exertion on a ten point modified Borg Scale (Borg 1982) following each contraction. The sole purpose of this report was to allow the participant to self-reflect if they had performed the test to their maximal ability. The Borg score was not intended for analysis. Following completion of the five IMVC trials, the participant was asked again if they felt they had performed the tests to their maximal ability. If they perceived that they had not performed to their maximal, the participant was permitted further repetitions until they perceived their maximal effort had been achieved.
5.3.2.2 IMVC<sub>20</sub> and IMVC<sub>50</sub> Test Procedure

The IMVC<sub>20</sub> test was performed first. Participants were instructed to nod their head such that their jaw pushed downwards on the application pad of the dynamometer to elevate the live bar graph to the same level as the target bar graph which represented 20% of their measured IMVC (Figure 3.4B). Participants were asked to maintain this level of contraction effort with accuracy until their neck muscles felt too tired to hold it at that point any longer. When participants perceived their muscles had fatigued to this level they were to let the contraction go completely and relax. Participants were not given an expectation of any maximal time limit for the test. They were to maintain the contraction until their fatigue point.

If the alarm sounded during the test, it was an indication that the participant was increasing their DHF pressure on the supporting surface, and they were instructed to reduce their DHF slightly to stop the alarm while sustaining the ICCF effort. Participants were instructed to correct for this each time the alarm was sounded. It was emphasized that participants were to ensure their breathing remained continuous during the test and not to hold their breath and to ensure their teeth remained occluded. Participants were pre-warned that while some discomfort from the effects of muscle fatigue were to be expected with a sustained test, they were to terminate the test if they experienced pain, other than that from muscle fatigue, in their head, neck or upper limb during the test. Following the termination of the test, participants were asked to nominate if it was fatigue that stopped them from continuing the test or if it was other factors such as pain. At regular intervals (every 60 seconds) during the test, participants were given standardized verbal encouragement. Following completion of the IMVC<sub>20</sub> test, the participant was given ten minutes rest.

The IMVC<sub>50</sub> test was then performed. This test followed exactly the same procedure as for the IMVC<sub>20</sub> test with the exception that the target torque was set at 50% of IMVC.
5.3.3 Data Management and Statistical Analysis

The stored raw data was analysed off-line. CCFD measurements for each session were extracted and the reliability analysis performed in the following manner:

5.3.3.1 Exclusion of Data

Data was excluded for a CCFD measurement for the following reasons -

- Adverse effects – if the participant experienced any neck, head, or upper limb pain during the dynamometry procedure.
- Control of Dual Task - if a participant found it too difficult to control the dual task of ICCF and control of DHF.
- Time Limit Breach - if a participant sustained their IMVC\textsubscript{20} contraction for longer than the pre-determined ten-minute period at which the Labview program was set to default, their data was also excluded from analysis.

5.3.3.2 IMVC Data Management

The highest amplitude torque measurement (Nm) of the five IMVC trials was recorded as the IMVC peak torque score for the testing session.

5.3.3.3 IMVC\textsubscript{20} and IMVC\textsubscript{50} Data Management

Two measures were extracted from each trial:

**Time to Task Failure (Seconds):** The time in seconds until the participant terminated a test was recorded in seconds. This was calculated by dividing the total number of samples for which the contraction was sustained by the sampling rate (20 samples /second).

**Contraction Accuracy (% Accuracy):** The accuracy of the participant to sustain their contraction at the designated torque level was computed by calculating the percentage of the recorded samples that remained within set amplitude margins either side of the
expected torque task for the duration of the test. This calculation was performed offline using a custom written LabView program (LabView 6i Virtual Instruments\textsuperscript{14}). The first 200 samples (10 seconds) of data for each test was discarded as this time was permitted for the participant to reach and stabilise the contraction. As this procedure has not been performed previously on such data, margins were set at ±1%, ±3%, ±5%, ±7%, and ±9% either side of the expected torque measurement. For each trial a percentage accuracy score was yielded for each of the five margin levels. Preliminary data analysis had indicated that these margins covered the spectrum of possible 0-100% accuracy for both IMVC\textsubscript{20} and IMVC\textsubscript{50} tests. The intention was to investigate which margin yielded the best indication of deficits in ICCF muscle performance between symptomatic and control participant groups for both the IMVC\textsubscript{20} and IMVC\textsubscript{50} tests.

5.3.3.4 Reliability Analysis

Reliability analysis for symptomatic and control participant group data was analysed separately. Test-retest session means for all measurements was compared for consistency using paired t-tests. Reliability of the measures was expressed by Intraclass Correlational Coefficients (ICC\textsubscript{2,1}) and Standard Error of the Measurement (SEM) indices.

5.4 Results

The primary statistical findings for the reliability data are reported below. Results for both symptomatic and control participant groups are presented for each of the CCFD measurements, including means ± standard deviations (SD) for each testing session, and the calculated ICC and SEM values. For complete statistical output refer to Appendix F.3.

\textsuperscript{14} National Instruments Corp, 11500 N Mopac Expressway, Austin, TX 78759.
5.4.1 IMVC Data

5.4.1.1 Adverse Effects

No participants reported pain during the IMVC trials.

5.4.1.2 Control of Dual Task

No data was excluded due to an inability to control the dual task of ICCF and DHF.

5.4.1.3 Reliability Analysis

As observed in Table 5.2, peak torque measurements yielded good ICC values and consistency between the groups for both ICC and SEM values, the symptomatic group showing slightly better reliability over time.

Table 5.2 Reliability analysis results for symptomatic and control participants for the measurement of IMVC peak torque. Results include group means ± SD for both measurement days (1 and 2) * indicates significant day effects (P=0.02).

<table>
<thead>
<tr>
<th>Peak Torque</th>
<th>Day 1 (±SD)</th>
<th>Day 2 (±SD)</th>
<th>ICC (i.i)</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sympt (n = 24)</td>
<td>5.92 ± 1.7</td>
<td>6.26 ± 1.8*</td>
<td>0.92</td>
<td>0.48 Nm</td>
</tr>
<tr>
<td>Control (n = 24)</td>
<td>6.48 ± 1.7</td>
<td>6.73 ± 1.6</td>
<td>0.8</td>
<td>0.74 Nm</td>
</tr>
</tbody>
</table>
5.4.2 IMVC\textsubscript{20} Data

5.4.2.1 Adverse Effects

The data from two control participants and four symptomatic participants were excluded due the onset of pain during the IMVC\textsubscript{20} test.

5.4.2.2 Control of Dual Task

No data was excluded due to an inability in controlling the dual task of ICCF and DHF.

5.4.2.3 Time limit Breach

The data from four control participants and three symptomatic participants were excluded due to their contraction effort lasting the 10-minute limit programmed for the test.

5.4.2.4 Reliability Analysis

Following the exclusion of data due to adverse effects and breach of the 10-minute time limit, reliability data for the IMVC\textsubscript{20} measures were calculated for 17 (71\%) symptomatic and 18 (75\%) control participants.

As observed in Table 5.3, the IMVC\textsubscript{20} time to task failure measure yielded good ICC values and consistency for both groups for both ICC and SEM values.

For the IMVC\textsubscript{20} contraction accuracy measurement (Table 5.3), only the 3\% margin for the symptomatic participants yielded a good ICC and an associated small SEM. In contrast the control participants yielded a poor ICC for the 3\% margin and a SEM almost twice as large as the symptomatic participants. As can be observed in Table 5.3, the other margins all yielded poor ICC values although ICC and SEM values were relatively consistent between symptomatic and control groups.
Table 5.3 Reliability analysis results for the symptomatic and control participant groups for the IMVC20 measurements of time to task failure and contraction accuracy. Results include group means ± SD for both measurement days (1 and 2) * indicates significant day effects (P < 0.04).

<table>
<thead>
<tr>
<th>IMVC20</th>
<th>X Day 1 (±SD)</th>
<th>X Day 2 (±SD)</th>
<th>ICC (z,t)</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time to Task Failure (seconds)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt (n = 17)</td>
<td>164.8 ± 93.7</td>
<td>161.5 ± 83.2</td>
<td>0.77</td>
<td>42.5 s</td>
</tr>
<tr>
<td>Control (n = 18)</td>
<td>212.4 ± 127.3</td>
<td>210.5 ± 110.3</td>
<td>0.84</td>
<td>47.9 s</td>
</tr>
<tr>
<td><strong>Contraction Accuracy (% accuracy)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1% Margin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt (n = 17)</td>
<td>17.5 ± 10.1</td>
<td>16.5 ± 7.2</td>
<td>-0.1</td>
<td>9.18 %</td>
</tr>
<tr>
<td>Control (n = 21)</td>
<td>12.9 ± 7.2</td>
<td>18 ± 7.6*</td>
<td>0.09</td>
<td>7.1 %</td>
</tr>
<tr>
<td>3% Margin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt (n = 17)</td>
<td>40.1 ± 10.2</td>
<td>49.5 ± 13.7*</td>
<td>0.7</td>
<td>6.73 %</td>
</tr>
<tr>
<td>Control (n = 21)</td>
<td>41.7 ± 13.9</td>
<td>48.6 ± 12.2</td>
<td>0.17</td>
<td>11.94 %</td>
</tr>
<tr>
<td>5% Margin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt (n = 17)</td>
<td>62.9 ± 14.6</td>
<td>68.6 ± 13.2</td>
<td>0.3</td>
<td>11.73 %</td>
</tr>
<tr>
<td>Control (n = 21)</td>
<td>59.6 ± 15.4</td>
<td>69.3 ± 12.7*</td>
<td>0.4</td>
<td>10.9 %</td>
</tr>
<tr>
<td>7% Margin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt (n = 17)</td>
<td>77.3 ± 12</td>
<td>82.9 ± 8.9</td>
<td>0.45</td>
<td>7.87 %</td>
</tr>
<tr>
<td>Control (n = 21)</td>
<td>76.1 ± 14.5</td>
<td>83 ± 8.9*</td>
<td>0.36</td>
<td>9.58 %</td>
</tr>
<tr>
<td>9% Margin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt (n = 17)</td>
<td>86 ± 10.2</td>
<td>90 ± 6.6</td>
<td>0.27</td>
<td>7.32 %</td>
</tr>
<tr>
<td>Control (n = 21)</td>
<td>82.4 ± 14.8</td>
<td>90.3 ± 7.9*</td>
<td>0.14</td>
<td>11 %</td>
</tr>
</tbody>
</table>
5.4.3 IMVC\textsubscript{50} Data

5.4.3.1 Adverse Effects

For the IMVC\textsubscript{50} test only one control participant was excluded due to the onset of pain during the test.

5.4.3.2 Control of Dual Task

No data was excluded due to an inability in controlling the dual task of ICCF and DHF.

5.4.3.3 Reliability Analysis

Following the exclusion of the one control participant due to adverse effects, 23 (96\%) control participants and 24 symptomatic participants were included in the reliability analysis of the IMVC\textsubscript{50} measure.

As depicted in Table 5.4, there was some inconsistency between groups in the reliability of the IMVC\textsubscript{50} time to task failure measure. Both groups demonstrated sound ICC values however SEM value was twice as large for the control group compared to the symptomatic group.

The 3\% margin yielded sound ICC values and consistency of ICC and SEM values between groups for the IMVC\textsubscript{50} contraction accuracy measure. All other margins yielded poor to moderate ICC values despite the reliability coefficients being relatively consistent between groups.
Table 5.4 Reliability analysis results for the symptomatic and control participant groups for the IMVC_{50} measurements of time to task failure and contraction accuracy. Results include group means ± SD for both measurement days (1 and 2) * indicates significant day effects (P < 0.05).

<table>
<thead>
<tr>
<th>IMVC_{50}</th>
<th>( \overline{X} ) Day 1 (±SD)</th>
<th>( \overline{X} ) Day 2 (±SD)</th>
<th>ICC (z,1)</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to Task Failure (seconds)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt (n = 24)</td>
<td>53.5 ± 26.4</td>
<td>52.5 ± 25.4</td>
<td>0.85</td>
<td>10.12 s</td>
</tr>
<tr>
<td>Control (n = 23)</td>
<td>67.2 ± 33.2</td>
<td>68 ± 41.8</td>
<td>0.7</td>
<td>21.22 s</td>
</tr>
<tr>
<td>Contraction Accuracy (% accuracy)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1% Margin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt (n = 24)</td>
<td>12.3 ± 7</td>
<td>15 ± 5.8*</td>
<td>0.59</td>
<td>4.08 %</td>
</tr>
<tr>
<td>Control (n = 23)</td>
<td>13.2 ± 7.1</td>
<td>16.6 ± 5.8*</td>
<td>0.59</td>
<td>4.16 %</td>
</tr>
<tr>
<td>3% Margin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt (n = 24)</td>
<td>34.1 ± 16.7</td>
<td>42 ± 15.4*</td>
<td>0.77</td>
<td>7.76 %</td>
</tr>
<tr>
<td>Control (n = 23)</td>
<td>37.9 ± 15.1</td>
<td>45.2 ± 10.4*</td>
<td>0.69</td>
<td>7.27 %</td>
</tr>
<tr>
<td>5% Margin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt (n = 24)</td>
<td>53.8 ± 21.2</td>
<td>61.6 ± 17.2*</td>
<td>0.58</td>
<td>12.48 %</td>
</tr>
<tr>
<td>Control (n = 23)</td>
<td>57.4 ± 15.7</td>
<td>66.5 ± 11.1*</td>
<td>0.65</td>
<td>8.03 %</td>
</tr>
<tr>
<td>7% Margin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt (n = 24)</td>
<td>67.6 ± 20.5</td>
<td>76.1 ± 14.9*</td>
<td>0.6</td>
<td>11.35 %</td>
</tr>
<tr>
<td>Control (n = 23)</td>
<td>73.2 ± 11.4</td>
<td>80.5 ± 9.7*</td>
<td>0.5</td>
<td>7.44 %</td>
</tr>
<tr>
<td>9% Margin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt (n = 24)</td>
<td>78 ± 17.4</td>
<td>85.6 ± 12.4*</td>
<td>0.64</td>
<td>9.05 %</td>
</tr>
<tr>
<td>Control (n = 23)</td>
<td>83.1 ± 9.5</td>
<td>89.2 ± 7.4*</td>
<td>0.5</td>
<td>6 %</td>
</tr>
</tbody>
</table>
5.5 Discussion

In this study, CCFD measurements were analysed for consistency when measured over a two-week time frame. For the purposes of the thesis, good reliability indices (ICC, SEM) that are consistent for both symptomatic and control participant groups are required to assist the CCFD measurement comparisons that will be made between the symptomatic and control groups in Chapter 6. Additionally, SEM values for the symptomatic participants were required to calculate reliable performance change measurements to be used to investigate the responsiveness of the measures in Chapter 7.

The CCFD measurements of IMVC peak torque (ICC 0.8-0.92), IMVC20 time to task failure (ICC 0.77-0.84), and IMVC50 contraction accuracy at the 3% margin (ICC 0.69-0.77) all show consistent good reliability for both symptomatic and control participant groups. This consistency between groups and sound reliability for symptomatic participants are positive preliminary findings for the group comparison study performed in Chapter 6, and the responsiveness study performed in symptomatic participants in Chapter 7, respectively.

Although the IMVC50 time to task failure measure has acceptable ICC values for both groups (ICC 0.7-0.85), larger SEM values for the control groups were noted. The IMVC20 contraction accuracy measure at the 3% margin yielded good reliability for the symptomatic participants, but poor reliability for control participants (ICC 0.17). Group comparisons of performance measurements of these later two tests (IMVC20 contraction accuracy at 3% margin, IMVC50 time to task failure) as will be performed in Chapter 6 will have to be drawn with some caution due to the group differences. However, the good reliability found for the symptomatic group for both these measures strengthens their use for the responsiveness study to be performed in symptomatic participants in Chapter 7. Overall the symptomatic group appeared to have marginally better reliability than the control group for most measurements, the reason for which is unclear. Both groups had similar exclusion rates for all measures. Perhaps it reflects a behavioral attitude with symptomatic participants taking an investigation of their impairment a little more
seriously than control participants who have no vested interest in assessment of their neck.

All other contraction accuracy margins (1%, 5%, 7%, 9%) for both the IMVC tests yielded poor ICC values for both groups. Although these other margins will be included in the following studies interpretation of their results will be made with extreme caution.

Despite strong suggestions within the literature of the value of familiarization in strength measurements to minimize fear and increase confidence preceding reliability trials (Highland et al. 1992; Berg et al. 1994; Wilson and Murphy 1996; Phillips et al. 2004), no separate session was performed in this reliability study as clinically it was not a realistic scenario. A primary goal of this thesis was to devise a method with realistic clinical utility. Thus participants were familiarized immediately prior to the recording of the measurements (Section 5.3.2), and measurements were performed and compared on the very first and second sessions as would be performed in clinical practice, and as would be the case in the clinical measurement studies reported in the following two chapters. It was considered that having a separate familiarization session was not a valid approach if the reliability measurements calculated in this study were to be considered clinically meaningful.

As patient motivation and confidence at the time of testing could potentially affect the consistency of the measures, great emphasis was placed on ensuring that all procedures were standardized for both sessions. It is feasible to suggest that measures should be better on the second session due to the improved familiarity and learning with the procedure resulting from the first session. For IMVC peak torque measurements (Table 5.2), the second session measurements were slightly higher but only significantly so for the symptomatic group ($P = 0.02$), despite this measurement showing good reliability (ICC 0.92). In contrast, the time to task failure measurement means (Table 5.3-5.4) were very similar over the two sessions with no apparent familiarization effect. Familiarization however appeared to have significantly affected the contraction accuracy measure (Table 5.3-5.4), with significant day effects ($P < 0.05$) for both groups at all margins for the
IMVC\textsubscript{50} test (P < 0.05), and for most margins at the IMVC\textsubscript{20} test (P < 0.04). These significant day effects reflect improved scores on the second measurement session in all cases, reducing the clinical utility of this measure to infer meaningful change in ICCF muscle performance over time.

All measurements in both reliability sessions were supervised by the same investigator, therefore this study has only investigated intra-rater reliability for these CCFD measurements. All CCFD measurements performed in the two studies described in the following two chapters were also supervised by the same investigator, therefore for the purposes of the thesis, intra-rater reliability of this investigator was considered the most important issue. Subsequent use of this dynamometry method in a clinical setting will require knowledge of its measurement consistency and measurement error when used by multiple investigators/clinicians. Notwithstanding this, for the purposes of the remaining studies of this thesis that are performed by the same investigator, acceptable intra-rater reliability for the CCFD measurements has been established. Inter-rater reliability of the CCFD measurements will be performed in future studies.

Some procedural steps of the CCFD method may have produced error that may have affected reliability. The axis of the dynamometer and the participant AOR landmark were aligned via a web camera (Figure 3.2), and reference points on the dynamometer and the participant's head were digitally recorded so that the position of all points could be replicated on subsequent sessions. In practice, realigning multiple points digitally was difficult in some cases and alignment error may have occurred, although great caution was taken to ensure this was minimized. Other factors such as parallax error with the web camera in alignment of the dynamometer/patient landmarks may contribute to error within the measure, but every precaution in the set up was taken to avoid this. Issues regarding CCFD methods are discussed in greater detail in Chapter 8.
5.6 Conclusion – Test-Retest Reliability of Cranio-Cervical Flexion Dynamometry

In this chapter the reliability of the CCFD measurements have been investigated and the associated measurement errors have been calculated. This was the first clinical measurement study. All measurements demonstrated good reliability in symptomatic participants which is a positive finding considering that is the patient population for which the method mostly may be used in the future. In only two of the measures was there questionable reliability for the control participants. The following chapter will take these reliability findings into consideration to examine the capacity of the CCFD measurements to quantify impairment of the CCF muscles.
CHAPTER 6: CAPACITY OF THE CRANIO-CERVICAL FLEXION DYNAMOMETRY MEASUREMENTS TO QUANTIFY IMPAIRMENT

6.1 Abstract

Objective: To establish if the cranio-cervical flexion dynamometry (CCFD) measurements can quantify impairment in isometric cranio-cervical flexor (ICCF) muscle performance in participants with symptomatic neck disorders compared to control participants with no history of neck disorders.

Participants and Methods: Forty-six symptomatic participants (average Neck Disability Index (NDI) of 22.8 ± 5.2) and 47 control participants (average NDI of 2.6 ± 2.6) completed the CCFD measurements (IMVC peak torque, IMVC_{20,50} measurements of time to task failure and contraction accuracy). Group comparisons were made for the IMVC peak torque measurement, and the IMVC_{20,50} measurements of time to task failure and contraction accuracy.

Results: Compared to the control participant group, the symptomatic participant group had a significant deficit (15.9 %) in their IMVC peak torque recordings, as well as a significantly reduced capacity to sustain ICCF muscle contractions to task failure, at both IMVC_{20} (35% deficit), and IMVC_{50} (27% deficit), contraction intensities. Symptomatic participants also demonstrated poorer contraction accuracy in maintaining their IMVC_{20} contraction at the nominated ICCF torque amplitude (P = 0.02), compared to control participants.

Discussion and Conclusion: The CCFD measurements have demonstrated an ability to quantify ICCF muscle impairment in persons with known cervical spine disorders.
6.2 Background and Aims of Study

The primary purpose of developing the cranio-cervical flexion dynamometry (CCFD) method was to quantify impairment of isometric cranio-cervical flexor (ICCF) muscle performance. The proof of concept study (Chapter 4) confirmed that the method preferentially activated the cranio-cervical flexor (CCF) muscles more so than the cervico-thoracic flexor muscles. Previous research has demonstrated that differences in ICCF muscle performance exist between participant groups with a history of neck pain and without a history of neck pain (Watson and Trott 1993; Jull et al. 1999; Jull 2000; Jull et al. 2004b). The aim of this study was to test if CCFD measurements would also quantify poorer performance of the CCF muscles in symptomatic compared to control participants. Participants were categorized as symptomatic based on accepted criteria including a score of 10 or greater out of a possible 100 points on the Neck Disability Index (NDI) (Vernon 1996) (Appendix C.2), and positive findings on a physical examination of the cervical spine (Jull 1994). It was hypothesised that the symptomatic participant group would demonstrate poorer CCFD measurement scores than the control group.

With regards to the $\text{IMVC}_{20,50}$ measurement of contraction accuracy, a secondary aim was to establish which of the set margins would quantify the most significant differences between the groups if differences existed. It was hypothesised that the smallest margin ($\pm 1\%$) would show the most significant differences due to the higher ICCF muscle skill required to sustain this level of contraction accuracy, and the high probability that symptomatic participants would have reduced skill levels.

Aims of the study:

- To establish if the CCFD measurements would quantify poorer ICCF muscle performance in persons with known cervical spine impairment compared to control participants.
• To establish if poorer ICCF performance would be found at all levels of contraction intensity (IMVC, IMVC\textsubscript{20}, IMVC\textsubscript{50}).

• To establish which of the contraction accuracy measurement margins would demonstrate the largest differences between symptomatic and control participant groups, if any.

6.3 Methods

6.3.1 Participants

Ninety-three female volunteers inclusive of 46 symptomatic participants and 47 control participants were included in the study. Participant groups were similar in their height and weight characteristics however a significant difference in age (P < 0.0001) existed. For this reason age was factored as a covariate the data analyses. Participant details are depicted in Table 6.1. All participants were females for this group comparative study to eliminate the confounding variables between males and females particularly with regard to strength differences (Jordan et al. 1999; Kumar et al. 2001; Portero and Genries 2003). Both participant groups were recruited by the same process as described in Section 3.3.6.3. Sample size was determined from group means and standard deviations generated from the reliability study (Chapter 5) assuming an alpha of 0.05 and power of 0.9.

Table 6.1 Group means ± SD (range) for variables of age, height, weight, and NDI score. * denotes a significant difference P < 0.0001. ** P < 0.05.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Symptomatic</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>37 ± 10.1 (20-55)</td>
<td>27.8 ± 7.7 (20 - 53)*</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>166.2 ± 6.7 (150 – 183)</td>
<td>167.5 ± 6.1 (153 – 181)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>64 ± 10.6 (45 – 97)</td>
<td>62.6 ± 9.3 (43 – 91)</td>
</tr>
<tr>
<td>NDI (score/100)</td>
<td>22.8 ± 5.2 (16-42)</td>
<td>2.6 ± 2.6 (0-8)**</td>
</tr>
</tbody>
</table>
6.3.2 Procedure

All 93 participants were tested on one occasion only during which they performed five IMVC trials, followed by sustained tests until task failure at IMVC_{20} and IMVC_{50}. All procedures during a test session follow those described for the reliability study in Chapter 5 (Section 5.3.2).

6.3.3 Data Management and Statistical Analysis

The stored raw data was analysed off-line. CCFD measurements for each session were extracted and the comparative analysis performed in the following manner:

6.3.3.1 Exclusion of Data

Data was excluded for a CCFD measurement for the following reasons -

- **Adverse effects** – if the participant experienced any neck, head, or upper limb pain during the dynamometry procedure.
- **Control of Dual Task** - if a participant found it too difficult to control the dual task of ICCF and control of DHF.

6.3.3.2 Data Management

IMVC (peak torque), and IMVC_{20,50}(time to task failure, contraction accuracy) data were extracted as described for the reliability study in Section 5.3.3.2 – 5.3.3.3.

6.3.3.3 Comparative Analysis

Group means (±SD) were computed for both the symptomatic and control participant groups for all measures. Between group comparisons were tested for significance using a general linear model univariate analysis for the IMVC peak torque measure (Nm), and a multivariate analysis for the IMVC_{20} and IMVC_{50} measures of time to task failure.
(seconds), and contraction accuracy at all set margins (% accuracy). All participant group comparative analyses included the age of the participants as a covariate to account for any discrepancies due to the significant age difference between the groups.

6.4 Results

The primary statistical group comparisons are reported below. Results for both symptomatic and control participant groups are presented for each of the CCFD measurements, including means ± standard deviations (SD), data range, and level of significance. For complete statistical output refer to Appendix F.4.

6.4.1 IMVC Data

6.4.1.1 Adverse Effects

All 93 participants completed the IMVC trials with no report of pain during these measures.

6.4.1.2 Control of Dual Task

No data was excluded due to an inability in controlling the dual task of ICCF and DHF.

6.4.1.3 Comparative Analysis

The symptomatic participants (n=46) had significantly less ICCF muscle strength (P = 0.037) than the control participants (n=47), demonstrating a deficit of 15.9 % of peak torque (Table 6.2). Age did not significantly affect this finding (P = 0.14).
Table 6.2 Group means ± SD (range) for the measurement of IMVC peak torque (Nm) for symptomatic and control groups. * denotes significant differences between groups (P < 0.03).

<table>
<thead>
<tr>
<th>IMVC</th>
<th>Symptomatic (n=46)</th>
<th>Control (n=47)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Torque (Nm)</td>
<td>5.3 ± 1.5 (2 – 9.6)*</td>
<td>6.3 ± 1.7 (3 – 10.6)</td>
</tr>
</tbody>
</table>

6.4.2 IMVC\textsubscript{20} Data

6.4.2.1 Adverse Effects

Thirty percent (14/46) of symptomatic participants and 17% (8/47) of control participants reported pain during testing, resulting in test termination during the IMVC\textsubscript{20} test. These data were excluded from analysis.

6.4.2.2 Control of Dual Task

Two percent (1/46) of symptomatic participants and 6% (3/47) of control participants were unable to perform the test due to an inability to simultaneously control the ICCF and DHF variables during the IMVC\textsubscript{20} test. These data were excluded from analysis.

6.4.2.3 Comparative Analysis

Between-group comparisons were made between 31 (68%) symptomatic and 36 (77%) control participants for the IMVC\textsubscript{20} test following the exclusion of data due to adverse effects and inability to control the dual task. Six of the control participants and two of the symptomatic participants maintained the contraction for the 10-minute time limit of the test. These data were retained in the analysis.
The time to task failure measure revealed that the symptomatic participants could not sustain the IMVC$_{20}$ contraction for as long as the control participants. The mean difference between the symptomatic and control participants was 86.7 seconds with the symptomatic group exhibiting a deficit of 35% ($P = 0.03$, Table 6.3).

**Table 6.3** Group means ± SD (range) for the measurement of IMVC$_{20}$ time to task failure (seconds), and group means ± standard deviations for the IMVC$_{20}$ contraction accuracy (%) measurement. Contraction accuracy measures are shown at all set margins either side of the expected torque amplitude for the duration of the test. * denotes significant differences between the symptomatic and control groups ($P < 0.05$).

<table>
<thead>
<tr>
<th>IMVC$_{20}$ Time to Task Failure</th>
<th>Symptomatic</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (s)</td>
<td>158.4 ± 154.2 (40 - 600) *</td>
<td>245.1 ± 198 (31.7 - 600)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IMVC$_{20}$ Contraction Accuracy at Set Margins</th>
<th>±1%</th>
<th>±3%</th>
<th>±5%</th>
<th>±7%</th>
<th>±9%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptomatic (%)</td>
<td>12.8 ± 9.7</td>
<td>33.1 ± 15.7*</td>
<td>51.7 ± 20.8</td>
<td>64.4 ± 21.4*</td>
<td>73.8 ± 21.9</td>
</tr>
<tr>
<td>Control (%)</td>
<td>13.5 ± 8.2</td>
<td>43.5 ± 14.5</td>
<td>61.5 ± 15</td>
<td>78.3 ± 13.4</td>
<td>85.1 ± 10.9</td>
</tr>
</tbody>
</table>

The contraction accuracy data is depicted in Table 6.3. Percentage accuracy data are shown at all margins either side of the expected torque amplitude for both participant groups. The control participants were significantly more accurate at sustaining the IMVC$_{20}$ contraction within both the ± 3% margin ($P = 0.02$), and ± 7% margin ($P = 0.02$) than the symptomatic participants, but no group differences occurred for the other margins (1%, 5%, 9%) ($P > 0.05$). On average, control participants maintained their ICCF muscle torque within the 3% margin 43.5% of the time compared to 33.1% for the
symptomatic participants, and within the 7% margin for 78.3% of the time compared to 64.4% achieved by the symptomatic participants.

6.4.3 IMVC\textsubscript{50} Data

6.4.3.1 Adverse Effects

Fifteen percent (7/46) of symptomatic participants and 2% (1/47) of control participants reported pain during this test, leading to test termination. These data were excluded from analysis.

6.4.3.2 Control of Dual Task

Four percent (2/46) of symptomatic participants, and 6% (3/47) of control participants were unable to perform the test due to an inability to simultaneously control the ICCF and DHF variables. These data were excluded from analysis.

6.4.3.3 Comparative Analysis

Between-group comparisons were made between 37 (81%) symptomatic and 43 (92%) control participants for the IMVC\textsubscript{50} test following the exclusion of data due to adverse effects and inability to control the dual task.

The symptomatic participants could not sustain the IMVC\textsubscript{50} contraction for as long as the control participants. The mean difference between the symptomatic and control participants was 17.8 seconds with the symptomatic group exhibiting a deficit of 27% (P = 0.002, Table 6.4).

Contraction accuracy at all margins either side of the expected IMVC\textsubscript{50} torque amplitude for both participant groups is shown in Table 6.4. Differences between the groups were not statistically significant for any of the margins (P > 0.6).
Table 6.4 Group means ± SD (range) for the measurement of IMVC$_{50}$ time to task failure (seconds), and group means ± standard deviations for the IMVC$_{50}$ contraction accuracy (%) measurement. Contraction accuracy measures are shown at all set margins either side of the expected torque amplitude for the duration of the test. * denotes significant differences between groups (P < 0.05).

<table>
<thead>
<tr>
<th>IMVC$_{50}$ Time to Task Failure</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Symptomatic</td>
</tr>
<tr>
<td>Time (s)</td>
<td>48.1 ± 23.6 (19.6 – 132)*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IMVC$_{50}$ Contraction Accuracy at Set Margins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Margins ±1% ±3% ±5% ±7% ±9%</td>
</tr>
<tr>
<td>------------------------------</td>
</tr>
<tr>
<td>Symptomatic (%)</td>
</tr>
<tr>
<td>Control (%)</td>
</tr>
</tbody>
</table>

6.5 Discussion

The primary hypothesis of this study was that symptomatic participants would demonstrate poorer CCFD measurements compared to control participants due to their impaired CCF muscle function as found in previous studies (Watson and Trott 1993; Barber 1994; Jull et al. 1999; Jull 2000; Jull et al. 2004b; Falla et al. 2004b). This hypothesis was based on the assumption that the CCFD measurements would reflect attributes of CCF muscle function that would be impaired in persons with symptomatic neck disorders, and that the CCFD measurements would have the precision to quantify the impaired performance. The results of this study support the primary hypothesis that the symptomatic participants will exhibit poorer performance in all three tests (IMVC, IMVC$_{20}$, IMVC$_{50}$).
With regard to IMVC measurements, the symptomatic participants demonstrated significantly less peak ICCF torque (5.3±1.5 Nm) than control participants (6.3±1.7 Nm), symptomatic participants showing a mean deficit of 15.9%. This is consistent with the findings of Watson and Trott (1993) who demonstrated a 14.6% reduction in the isometric strength of the CCF flexors in cervicogenic headache sufferers compared to control participants. It would appear from these studies that persons with neck pain disorders have a reduced capacity to generate maximal isometric tension of their CCF muscles in the middle range of cranio-cervical flexion. Consequently, it could be postulated that when head on neck orientation is challenged under larger loads, these muscles may be less capable of controlling cranio-cervical joint orientation and absorbing the forces of load.

A large significant deficit (35%) was shown in the capacity of the symptomatic participants to sustain an IMVC<sub>20</sub> contraction until task failure. On average, control participants sustained the contraction for 86.7 seconds more than the symptomatic participants before self-terminating the test due to perceived muscle fatigue. Similarly, a significant deficit (27%, P<0.002) was found for symptomatic participants in their capacity to sustain the IMVC<sub>50</sub> test to task failure. Despite this measure demonstrating some discrepancies in reliability (Chapter 5), control participants could sustain the contraction on average for 17.9 seconds longer than the symptomatic participants. This difference is larger than its standard error (SEM) in symptomatic participants (SEM 10s), and is just outside the error for control participants (SEM 21s), and consequently group differences are significant. Previous studies have shown ICCF muscle impairment in symptomatic individuals at maximal intensities (Watson and Trott 1993) and low intensities (Jull et al. 1999; Jull 2000; Jull et al. 2004b). This is the first study to demonstrate ICCF muscle impairment at moderate loads. The proof of concept study had demonstrated that the CCF muscles were the primary muscles recruited at both IMVC<sub>50,20</sub> contraction intensities (Chapter 4). The results of the IMVC<sub>20</sub> and IMVC<sub>50</sub> time to task failure measures would suggest that when the head on neck postural orientation is challenged over prolonged durations in a neck pain sufferer, the CCF muscles may not be
capable of controlling cranio-cervical orientation, which may make the cervical spine tissues vulnerable to abnormal or premature mechanical load.

This study also compared the IMVC\(_{20,50}\) contraction accuracy measurement between groups over the set margins as described in Section 5.3.3.3. It was hypothesised that the symptomatic participants would be less accurate at performing the test perhaps reflecting greater fatigue induced tremor compared to control participants. As this measure had not been used previously, several set margin amplitudes were tested. A secondary hypothesis was that the narrowest margin set (± 1%) would produce the largest group differences due to the high skill level and degree of difficulty observed in pilot trials. As expected the findings did demonstrate differences for both tests, but only significantly so for the IMVC\(_{20}\) test, and not at the 1% margin. The IMVC\(_{20}\) test demonstrated significant differences at the 3% and 7% margins between the participant groups. These findings suggest that the symptomatic participants were unable to sustain isometric torque with the same level of stability as control participants, perhaps reflecting a tremor attribute of muscle fatigue (Gandevia 2001). It is unknown why the 3% and 7% margins revealed significant differences when the other margins did not. The failure of the 1% margin to reveal differences may reflect normal physiological muscle tremor during a sustained contraction that was beyond the sensitivity of the smallest margin. It would appear that the 3% margin is the smallest most revealing contraction accuracy margin, demonstrating a 10.1% difference between symptomatic and control participants. This margin did have some group reliability discrepancies despite demonstrating the best reliability indices for symptomatic participants of any of the margins (Chapter 5). Notwithstanding this, the group difference found in this study for the 3% margin (10.1%), is larger than its standard error in symptomatic participants (SEM 6.7%), and is just outside the error for control participants (SEM 11.9%), consequently group differences are significant.

For all measurements (IMVC, IMVC\(_{20}\), IMVC\(_{50}\)), statistical comparisons were made with age as a covariate to account for the symptomatic group on average being 9.2 years older than the control participants. With regard to the IMVC measures, isometric cervical spine strength has been shown to decrease with age (Jordan et al. 1999; Garces et al. 2002),
however, perhaps not significantly so until the seventh decade (Jordan et al. 1999; Ylinen et al. 2004a). Barber (1994), using the same isometric dynamometry method for the CCF muscles as Watson and Trott (1993), demonstrated no significant effects of age on ICCF muscle strength in asymptomatic women over the age groups of 20-25 years (3.4 kp), 40-45 years (3.5 kp), and 60-65 years (3.4 kp) of age. In this current study, age did not have a significant effect on the IMVC peak torque measures ($P = 0.14$). With regard to the IMVC$_{20}$ and IMVC$_{50}$ measures, age was a significant variable for the IMVC$_{50}$ measure of time to task failure only ($P = 0.04$), but was not for any of the IMVC$_{20}$ measures ($P > 0.36$). This may reflect some reduced ability to sustain moderate ICCF muscle contractions with age, although group differences in this measure were still significant.

A far greater proportion of participants were excluded due to the onset of pain during the low load IMVC$_{20}$ test (30% of symptomatic participants, and 17% of control participants) than during the moderate load IMVC$_{50}$ test (15% of symptomatic participants, and 2% of control participants), or during the maximal load IMVC test (no exclusions). These findings may reflect the far greater duration for which the gentler IMVC$_{20}$ contractions were sustained. Perhaps pain sensitive neck structures adversely respond to gentler sustained mechanical load more so than loads that are more substantial in magnitude, but are of shorter duration. Interestingly, a high proportion of control participants (17%) also ceased the IMVC$_{20}$ test due to the onset of pain, these findings perhaps reflecting the difficulty participants have in distinguishing pain resulting from exercise-induced fatigue, to that perceived to be a signal of potential injury. Irrespective, the high proportion of data excluded from the IMVC$_{20}$ test due to pain, jeopardizes the tests clinical usefulness as measure of muscle fatigue.

It should be noted that the neck pain participants used in this study were of a mild symptomatic category according to the NDI score (Appendix C.2). Participants had an average NDI of 22.8 points out of a possible 100. We chose to use participants with only mild symptoms to optimally scrutinize the potential of the CCFD measures to quantify CCF muscle impairment. We could reasonably expect that participant populations with
greater NDI scores might show larger differences in measurements although this needs to be tested in future studies.

6.6 Summary - Capacity of the Cranio-Cervical Flexion Dynamometry Measurements to Quantify Impairment

This chapter has shown that the CCFD measurements can quantify poorer ICCF muscle performance in groups of neck pain sufferers compared to groups of control participants. Poorer performance was found in participants who had satisfied other accepted criteria (NDI, physical examination) of cervical spine impairment. These findings satisfy part of the criteria for the method to be considered a valid clinical test of ICCF muscle performance. In the next chapter, another vital attribute of a valid clinical test is examined, that is, the responsiveness of the measure to quantify a change in ICCF muscle performance following a period of rehabilitation.
CHAPTER 7: RESPONSIVENESS OF CRANIO-CERVICAL FLEXION DYNAMOMETRY MEASUREMENTS TO QUANTIFY A CHANGE IN MUSCLE PERFORMANCE

7.1 Abstract

Objective: To establish if the cranio-cervical flexion dynamometry (CCFD) measurements can quantify a change in isometric cranio-cervical flexor (ICCF) muscle performance in participants following a period of therapeutic exercise.

Participants and Methods: Fifty female participants with a history of neck pain participated in the study. CCFD measurements (IMVC peak torque, IMVC20,50 measurements of time to task failure and contraction accuracy) were recorded before and following a six-week exercise program. Twenty-seven of the participants performed a cranio-cervical flexion exercise (CCFEx) program, and twenty-three participants performed a cervical flexion exercise (CFEx) program. Changes in performance for all measurements were evaluated at an individual participant level with respect to reliable performance change thresholds, and tested at a group level for effects of time (pre-post exercise program), and time by group (CCFEx, CFEx) interactions using repeated measures ANOVA.

Results: All measures demonstrated an effect of time but no time by group interactions were found for any of the measures. At an individual level the CCFEx group demonstrated greater proportions of participants (33-40%) with reliable performance changes compared to the CFEx group (6-19%).

Discussion and Conclusion: The CCFD measurements have the capacity to detect changes in ICCF muscle performance following rehabilitation. These measurements appear to be better able to detect improvement in performance following rehabilitation that is specific to the action of cranio-cervical flexion.
7.2 Background and Aims of Study

This chapter investigated the responsiveness of the cranio-cervical flexion dynamometry (CCFD) measurements to quantify a change in isometric cranio-cervical flexor (ICCF) muscle performance following a six-week period of therapeutic exercise of the cervical flexor muscles. A vital attribute of any outcome measure is the ability to detect and monitor changes in performance following rehabilitation. Responsiveness refers to the capacity of the CCFD measurements to detect changes in performance between occasions other than changes expected by chance (Krishner and Guyatt 1985; Guyatt et al. 1987; Wilson et al. 1998), accounting for time dependent changes in performance scores as well as measurement error (Christensen and Mendoza 1986). Measurement error (Standard Error of the Measurement (SEM)) was calculated for each CCFD measurement in Chapter 5.

The responsiveness of a measure gives an estimate of the smallest amount of change in that measure that can be considered to represent true improvement (Jacobsen et al. 1984; Guyatt et al. 1987; Wilson et al. 1998). Performance change scores (smallest change score needed to indicate real change) were calculated for each CCFD measurement based on the measurements SEM value. An individual's change in performance pre to post rehabilitation can therefore be directly evaluated for reliable change based on the reliable change performance score for that measure.

The responsiveness of the CCFD measurements were investigated by comparing measures before and after a 6-week program of rehabilitative exercise of the cervical flexor muscles. Participants in this study were part of a larger clinical trial performed within the research institution15, investigating mechanistic effects of rehabilitative exercise. Two forms of exercise were administered. One was a cranio-cervical flexion exercise (CCFEx) protocol (Jull et al. 2002; Jull et al. 2004a) that emphasised retraining of the cranio-cervical flexion movement pattern and low load ICCF muscle endurance.

---
The second form of exercise was a cervical flexion exercise (CFEx) protocol that combined the action of the cranio-cervical and cervico-thoracic flexor muscles (head lift), with an emphasis on retraining higher load muscle endurance and strength. Based on the results of our proof of concept study (Chapter 4), both CCFEx and CFEx forms should activate the CCF muscles when performed at similar intensities of contraction. The difference is the greater relative use of the cervico-thoracic flexor muscles in the CFEx action, and that this exercise protocol involves the use of head weight and is consequently a higher load exercise.

The primary hypothesis was that CCFD measurements would quantify a change in ICCF muscle performance following the six weeks of rehabilitation irrespective of the rehabilitation group. It was hypothesised that a greater proportion of participants in the CFEx group would show reliable performance changes in the IMVC and IMVC\textsubscript{50} measures due to the higher load training characteristics of this exercise protocol. Consistent with this rationale, it was hypothesised that a greater proportion of the CCFEx group would show reliable performance changes in the IMVC\textsubscript{20} measures due to the low load nature of the CCFEx protocol.

In contrast, if the specificity of muscle action characteristic of the exercise protocols had more impact on CCFD measurements than the exercise load characteristics, then a greater proportion of the CCFEx group should demonstrate reliable performance changes on all CCFD measures. This alternative hypothesis was based on the fact that CCFEx program focused on a similar biomechanical action of cranio-cervical flexion as did the CCFD tests.

**Aims of the study:**

- to establish if the CCFD measurements can quantify reliable changes in performance following exercise programs to train the CCF muscles.
• to establish if CCFD measurements are more responsive to changes in muscle performance following rehabilitative exercise that utilizes the biomechanical action of cranio-cervical flexion.

7.3 Methods

7.3.1 Participants

Fifty female participants were included in this study. These women had consented to participate in a clinical trial performed within the research unit. The CCFD measurements performed in this study formed part of the battery of measurement outcomes in the clinical trial. The criteria for inclusion to the clinical trial included a history of neck pain of three months or greater, evidence of CCF muscle impairment based on poor performance on the clinical CCFT method (Jull et al. 2004a), and an agreement to complete the six-week exercise program to the best of their ability.

Participants were excluded if they had specifically trained their muscles previously using either the CCFEx or CFEx protocols, if they experienced neck pain from non-musculoskeletal causes, demonstrated neurological signs, or had any other medical disorder contra-indicating physical exercise. Following written consent each participant was randomly allocated to either of the two exercise groups by an independent authority. The investigator who conducted the pre and post rehabilitation measurement sessions was blinded to the training group allocation for all participants to avoid measurement bias.

Twenty-seven participants were randomly allocated to the CCFEx group and 23 participants to the CFEx group. This sample size was considered adequate to investigate CCFD measurement responsiveness to training effects, as these measures were previously shown to be reliable with respect to time in a sample of 24 symptomatic participants (Chapter 5).
Table 7.1 Group means ± SD (range) for the variables of age, height, and weight. There were no significant differences between groups for any of these variables (P > 0.05).

<table>
<thead>
<tr>
<th>Variable</th>
<th>CCFEx (n=27)</th>
<th>CFEx (n=23)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>36.9 ± 9.5 (20-55)</td>
<td>37.9 ± 11.3 (20-55)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>165.7 ± 7.5 (150-183)</td>
<td>166.2 ± 7.2 (152-179)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>67.1 ± 14.7 (45-97)</td>
<td>65.8 ± 9.2 (53-87)</td>
</tr>
</tbody>
</table>

7.3.2 Procedure

All 50 participants completed a testing session before and following a six-week rehabilitative exercise program. The description below is of the CCFD measurements. No other measurements taken in the clinical trial are included.

7.3.2.1 Pre-Rehabilitation Testing Session

All CCFD test procedures were identical to those described for the reliability study in Chapter 5 (Section 5.3.2). In this pre-rehabilitation testing session participants performed five IMVC trials, followed by sustained tests at IMVC_{0}, and IMVC_{50}.

7.3.2.2 Six-Week Training Protocols

All participants in both exercise groups attended one weekly session with an experienced musculoskeletal physiotherapist over the six-week duration for a total of six sessions. All physiotherapists were experienced in teaching, supervision, and progression of both of the exercise protocols described below. During the supervised sessions the physiotherapists would assess the current performance level attained by the participant in
the specific exercise and progress according to the exercise protocol of the trial. Participants in both groups were instructed to perform the exercise program twice daily. All exercise was performed free of any pain provocation. The physiotherapists closely monitored the patient’s responses to the exercise programs to ensure that unwanted accumulative muscle fatigue was avoided that may occur if the exercise program was progressed too aggressively. Participants were instructed in exercise only, no other form of physiotherapy intervention was provided.

**Cranio-Cervical Flexion Exercise (CCFEx) Program:** This participant group was instructed and practiced specific retraining of their CCF muscles in the supine position using the protocol described by Jull et al (2004a). In this program an emphasis was placed on first attaining the correct cranio-cervical flexion action, with minimal activity of the superficial cervical flexor muscles. Once the correct action had been achieved, participants then trained to progressively increase the pressure increment (22-30 mmHg) at which their ICCF muscle contraction could be sustained with control for a 10 second duration. Participants were instructed in the use of the pressure biofeedback device (Stabilizer, Chattanooga Group Inc, USA) to guide their training of the ICCF muscle contraction at the various incremental levels of pressure (ie progressively inner range positions). Participants were instructed to perform 10 repetitions of the exercise at the level they could achieve maintaining the correct CCF movement with short rest periods between. Participants were provided with a pressure biofeedback device so that exercises could be performed at home. Their aim was to train so that they could attain and maintain training at all pressure increments.

**Cervical Flexion Exercise (CFEx) Program:** This participant group was instructed and practiced specific retraining of all cervical flexor muscles by performing a controlled head lift exercise in the supine position. The emphasis of this exercise program was on improving the higher load endurance and strength of the cervical flexor muscles. The head lift exercise was taught ensuring that the cranio-cervical spine was maintained in a neutral position while the head was lifted off the supporting surface, combining the use of both the cranio-cervical and cervico-thoracic flexor muscles. Participants were initially
tested on their 12-repetition maximum (12RM). If the participant could perform 12 repetitions lifting head weight with fatigue experienced at the completion of the repetitions, they were instructed to begin lifting head weight only. If they were unable to perform 12 repetitions with head weight only they were put in progressively inclined positions to reduce the effects of gravity until 12 repetitions could be performed. Conversely, if 12 repetitions were performed easily, half-kilogram weight increments were added to the forehead until the 12-RM was found.

Over the first two weeks the participants performed an initial conditioning program of three sets of the 12-RM repetitions slowly building up to three sets of 15 repetitions. Over the final four weeks of the program the participant's 15-RM was found and practiced until three sets of 20 repetitions could be performed at this level, at which time the 15-RM level was reassessed and load progressed accordingly.

7.3.2.3 Post-Rehabilitation Testing Session

Following the six-week rehabilitation period, participants repeated the measurement session as for the pre-rehabilitation testing session. CCFD measurements were performed within the same order of tests within the clinical trial test battery to avoid differences in performance measurements based on an order effect of testing. As for the pre-rehabilitation testing session, CCFD tests involved five IMVC trials, followed by sustained tests at IMVC20, and IMVC50, however, the torque amplitude set for the IMVC20,50 tests were based on the IMVC peak torque measurement from the pre-rehabilitation testing session, not the peak torque measurement recorded in the post-rehabilitation testing session. In this manner, the IMVC20,50 measures over the pre/post rehabilitation sessions could be compared under the same load challenge and a direct analysis of performance change could be assessed.

7.3.3 Data Management and Statistical Analysis

The stored raw data was analyzed off-line. IMVC (peak torque), and IMVC20,50 (time to task failure, contraction accuracy) data was extracted as described for the reliability study
in Section 5.3.3.2 and Section 5.3.3.3. All data was grouped according to rehabilitative exercise group allocation ie. CCFEx, or CFEx groups.

7.3.3.1 Exclusion Data

Data was excluded for a CCFD measurement for the following reasons -

- Adverse effects – if the participant experienced any neck, head, or upper limb pain during the dynamometry procedure.
- Control of Dual Task - if a participant found it too difficult to control the dual task of ICCF and control of DHF.
- Time Limit Breach - if a participant sustained their IMVC_{20} contraction for longer than the ten-minute period at which the Labview program was set to default, their data was also excluded from analysis.

7.3.3.2 Statistical Analysis- Group Means

Group (CCFEx, CFEx) means and standard deviations for all CCFD measurements (IMVC, IMVC_{20}, IMVC_{50}) with respect to time (pre and post rehabilitation) were calculated. Changes in measurements with respect to time, and group by time interactions, were analyzed for statistical significance (P < 0.05) using a repeated measures ANOVA.

7.3.3.3 Statistical Analysis- Individual Performance Change Scores

All CCFD measurement performance change scores were calculated using the following equation (Christensen and Mendoza 1986) where 1.96 is a reliable change coefficient representing a 95% likelihood of a change in performance (Jacobsen et al. 1984), and SEM is the standard error of the measurement that was calculated for the specific CCFD measurement in Chapter 5 -

\[
\text{Performance change score} = 1.96 \times \sqrt{2 \times \text{SEM}^2}
\]
Performance change scores and SEM values for all CCFD measurements are depicted in Table 7.2. Raw change scores (difference between pre and post-rehabilitation measurements) for all measurements for all participants were calculated. These were plotted for all CCFD measurements for both rehabilitative training groups. The performance change score threshold for each measure was indicated on the graph so that the proportion of participants in each group demonstrating reliable changes in performance for each measure could be visually inspected.

Table 7.2 The performance change scores (smallest change score needed to indicate real change) calculated for each CCFD measurement and corresponding Standard Error of the Measurement (SEM) value. Contraction accuracy scores are shown for all margins (1-9%).

<table>
<thead>
<tr>
<th>Measure</th>
<th>SEM</th>
<th>Reliable Change Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMVC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak Torque</td>
<td>0.48 Nm</td>
<td>1.3 Nm</td>
</tr>
<tr>
<td>IMVC_{20}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time to Task Failure</td>
<td>42.5 s</td>
<td>117.8 s</td>
</tr>
<tr>
<td>Contraction Accuracy 1%</td>
<td>9.2 %</td>
<td>25.4 %</td>
</tr>
<tr>
<td>Contraction Accuracy 3%</td>
<td>6.7 %</td>
<td>18.7 %</td>
</tr>
<tr>
<td>Contraction Accuracy 5%</td>
<td>11.7 %</td>
<td>32.5 %</td>
</tr>
<tr>
<td>Contraction Accuracy 7%</td>
<td>7.9 %</td>
<td>21.8 %</td>
</tr>
<tr>
<td>Contraction Accuracy 9%</td>
<td>7.3 %</td>
<td>20.3 %</td>
</tr>
<tr>
<td>IMVC_{50}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time to Task Failure</td>
<td>10.1 s</td>
<td>28.1 s</td>
</tr>
<tr>
<td>Contraction Accuracy 1%</td>
<td>4.1 %</td>
<td>11.3 %</td>
</tr>
<tr>
<td>Contraction Accuracy 3%</td>
<td>7.8 %</td>
<td>21.5 %</td>
</tr>
<tr>
<td>Contraction Accuracy 5%</td>
<td>12.5 %</td>
<td>34.6 %</td>
</tr>
<tr>
<td>Contraction Accuracy 7%</td>
<td>11.4 %</td>
<td>31.4 %</td>
</tr>
<tr>
<td>Contraction Accuracy 9%</td>
<td>9.1 %</td>
<td>25.1 %</td>
</tr>
</tbody>
</table>
7.4 Results

The primary statistical findings for the data are reported below. Group results for both rehabilitative training groups (CCFEx, CFEx) for the pre and post rehabilitation measurement sessions are presented in Table 7.3 for each of the CCFD measurements (IMVC, IMVC\textsubscript{20.50} time to task failure, contraction accuracy). Results of statistical group comparisons and assessment of individual performance change scores are described below. For complete statistical output refer to Appendix F.5.

7.4.1 IMVC Data

7.4.1.1 Adverse Effects

There were no reports of pain during these measures.

7.4.1.2 Control of Dual Task

No data was excluded due to an inability in controlling the dual task of ICCF and DHF during the IMVC measures.

7.4.1.3 Exercise group Comparisons

The CCFEx group (n=27) had a gain in peak torque of 11\% and the CFEx group (n=23) 12.2\%. There was a significant effect of time for the peak torque measure (p < 0.001) but no group by time interaction (P = 0.98).

At an individual level, similar proportions of participants in both groups gained improvement in peak torque post rehabilitation (CCFEx 70\%, CFEx 74\%), however as depicted in Figure 7.1, a greater proportion of CCFEx participants (37\%) demonstrated a reliable increase in peak torque performance (change in peak torque \geq 1.33 \text{ Nm}) scores than did participants in the CFEx group (17\%).
Table 7.3 CCFD measurement means (pre and post rehabilitation) and raw performance change scores for both exercise groups

<table>
<thead>
<tr>
<th>Measure</th>
<th>Cranio-Cervical Flexion Exercise Group</th>
<th>Cervical Flexion Exercise Group</th>
<th>Change Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMVC</td>
<td>Pre-Rehab: 5.5 ± 1.6 Post-Rehab: 6.2 ± 1.5</td>
<td>Pre-Rehab: 212.9 ± 83.1 Post-Rehab: 133.8 ± 62.1</td>
<td>0.6 ± 1.1</td>
</tr>
<tr>
<td>IMVC&lt;sub&gt;£&lt;/sub&gt;</td>
<td>Pre-Rehab: 133.8 ± 83.1 Post-Rehab: 139.0 ± 83.1</td>
<td>Pre-Rehab: 212.9 ± 83.1 Post-Rehab: 133.8 ± 62.1</td>
<td>0.6 ± 1.1</td>
</tr>
<tr>
<td>Time to Fatigue</td>
<td>IMVC: 119.6 ± 93.9 IMVC&lt;sub&gt;£&lt;/sub&gt;: 212.9 ± 83.1</td>
<td>IMVC: 119.6 ± 93.9 IMVC&lt;sub&gt;£&lt;/sub&gt;: 212.9 ± 83.1</td>
<td>0.6 ± 1.1</td>
</tr>
<tr>
<td>Contract Accuracy 1% (%)</td>
<td>IMVC: 44.9 ± 15 IMVC&lt;sub&gt;£&lt;/sub&gt;: 44.9 ± 15</td>
<td>IMVC: 44.9 ± 15 IMVC&lt;sub&gt;£&lt;/sub&gt;: 44.9 ± 15</td>
<td>0.6 ± 1.1</td>
</tr>
<tr>
<td>Contract Accuracy 3% (%)</td>
<td>IMVC: 87.1 ± 17 IMVC&lt;sub&gt;£&lt;/sub&gt;: 87.1 ± 17</td>
<td>IMVC: 87.1 ± 17 IMVC&lt;sub&gt;£&lt;/sub&gt;: 87.1 ± 17</td>
<td>0.6 ± 1.1</td>
</tr>
<tr>
<td>Contract Accuracy 5% (%)</td>
<td>IMVC: 130.8 ± 25 IMVC&lt;sub&gt;£&lt;/sub&gt;: 130.8 ± 25</td>
<td>IMVC: 130.8 ± 25 IMVC&lt;sub&gt;£&lt;/sub&gt;: 130.8 ± 25</td>
<td>0.6 ± 1.1</td>
</tr>
<tr>
<td>Contraction Accuracy 7% (%)</td>
<td>IMVC: 45.5 ± 17 IMVC&lt;sub&gt;£&lt;/sub&gt;: 45.5 ± 17</td>
<td>IMVC: 45.5 ± 17 IMVC&lt;sub&gt;£&lt;/sub&gt;: 45.5 ± 17</td>
<td>0.6 ± 1.1</td>
</tr>
<tr>
<td>Contraction Accuracy 9% (%)</td>
<td>IMVC: 32.3 ± 12 IMVC&lt;sub&gt;£&lt;/sub&gt;: 32.3 ± 12</td>
<td>IMVC: 32.3 ± 12 IMVC&lt;sub&gt;£&lt;/sub&gt;: 32.3 ± 12</td>
<td>0.6 ± 1.1</td>
</tr>
</tbody>
</table>
Figure 7.1 Raw change scores (difference between pre and post rehabilitation – Y axis) for the measurement of IMVC peak torque in the CCFEx and CFEx groups. X-axis (y=0) represents zero change in performance. Top and bottom lines represent performance change score thresholds needed to represent a reliable change in peak torque performance (± 1.33Nm, P < 0.05). Percentage figures represent the proportion of participants within the cranio-cervical flexion exercise (CCFEx) or cervical flexion exercise (CFEx) groups demonstrating raw change scores above or below the performance change score thresholds.
7.4.2 IMVC$_{20}$ Data

7.4.2.1 Adverse Effects

Nine of the participants in the CCFEx group and seven in the CFEx group ceased the test due to the onset of pain.

7.4.2.2 Control of Dual Task

One participant in the CCFEx group was excluded due to an inability to simultaneously control the ICCF and DHF variables during the IMVC$_{20}$ test. This data was excluded from analysis.

7.4.2.3 Time Limit Breach

Two of the participants in the CCFEx group were excluded as they exceeded the 10-minute time limit pre-set for the test.

7.4.2.4 Exercise Group Comparisons

Following the exclusion of data due to adverse effects, time limit breaches, and inability to control the dual task, analysis was performed on 15 (56%) participants in the CCFEx group and 16 (70%) participants in the CFEx group.

IMVC$_{20}$ Time to Task Failure:

On average the CCFEx group improved their time of contraction hold by 59% and the CFEx group by 28%. There was a significant time effect (pre, post) ($P = 0.025$), but no time by group interaction effect ($P = 0.34$) was found.

Despite both groups having similar proportions of participants demonstrating improvements in time to task failure post rehabilitation (CCFEx 66%, CFEx 69%), as
depicted in Figure 7.2, a greater proportion of CCFEx participants (33%) demonstrated a reliable increase in time to task failure performance (change in time to fatigue ≥ 117.8 s) scores than did participants in the CFEx group (13%).

Figure 7.2 Raw change scores (difference between pre and post rehabilitation – Y axis) for the measurement of IMVC20 time to task failure. X-axis (y=0) represents zero change in performance. Top and bottom lines represent performance change score threshold needed to represent a reliable change in time to task failure performance (±117.8s, P < 0.05). Percentage figures represent the proportion of participants within the cranio-cervical flexion exercise (CCFEx) or cervical flexion exercise (CFEx) groups demonstrating raw change scores above or below the performance change score thresholds.
**IMVC<sub>20</sub> Contraction Accuracy:**

There was a significant time effect at all margins ($P = 0.0001-0.047$) but no time by group interaction ($P = 0.27 - 0.86$) were found for any of the margins.

Performance change scores are plotted in Figure 7.3 for the 3% margin only as this

![Graph showing IMVC<sub>20</sub> Accuracy (%) at 3% Margin](image)

**Figure 7.3** Raw change scores (difference between pre and post rehabilitation – Y axis) for the measurement of IMVC<sub>20</sub> contraction accuracy (3% margin). X-axis (y=0) represents zero change in performance. Top and bottom lines represent performance change score threshold needed to represent a reliable change in contraction accuracy performance ($± 18.6\%, P < 0.05$). Percentage figures represent the proportion of participants within the cranio-cervical flexion exercise (CCFEx) or cervical flexion exercise (CFEx) groups demonstrating raw change scores above or below the performance change score thresholds.
margin yielded the highest proportion of scores above the reliable change threshold and was the margin found to have the best reliability over time (Chapter 5). Despite a greater proportion of the CFEx group (75%) demonstrating improvement in this measure compared to the CCFEx group (67%), the CCFEx group (40%) had a greater proportion with reliable performance changes than the CFEx group (19%).

7.4.3 IMVC$_{50}$ Data

7.4.3.1 Adverse Effects

Six participants in the CCFEx group and four in the CFEx group ceased the test due to the onset of pain and were thus excluded from the analysis.

7.4.3.2 Control of Dual Task

One participant in the CCFEx group and two participants in the CFEx group were excluded due to an inability to simultaneously control the ICCF and DHF variables during the IMVC$_{20,50}$ test. This data was excluded from analysis.

7.4.3.3 Exercise Group Comparisons

Following the exclusion of data due to adverse effects and inability to control the dual task, analysis was performed on 20 (74%) participants in the CCFEx group and 17 (74%) participants in the CFEx group.

IMVC$_{50}$ Time to Task Failure:

The CCFEx group improved their time of hold at IMVC$_{50}$ by 37% and the CFEx group by 16%. This measure had a significant time effect ($P < 0.001$) but no time by group interactions were found ($P = 0.16$).
Eighty percent of CCFEx participants and 59% of CFEx participants had gains in time to task failure performance for the IMVC50 test. As depicted in Figure 7.4, a greater proportion of CCFEx participants (40%) demonstrated a reliable increase in time to task failure performance (change in time to fatigue ≥ 28 s) scores than did participants in the CFEx group (18%).

Figure 7.4 Raw change scores (difference between pre and post rehabilitation – Y axis) for the measurement of IMVC50 time to task failure. X-axis (y=0) represents zero change in performance. Top and bottom lines represent performance change score threshold needed to represent a reliable change in time to task failure performance (±28.1s, P < 0.05). Percentage figures represent the proportion of participants within the cranio-cervical flexion exercise (CCFEx) or cervical flexion exercise (CFEx) groups demonstrating raw change scores above or below the performance change score thresholds.
**IMVC<sub>50</sub> Contraction Accuracy:**

There was a significant time effect at all margins (P = 0.0001-0.01) but no time by group interaction (P = 0.34 - 0.71) for any of the margins.

Performance change scores are plotted in Figure 7.5 for the 3% margin only as this margin yielded the highest proportion of scores above the reliable change threshold as well as demonstrating the best reliability for the symptomatic subjects (Chapter 5). Data

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**Figure 7.5** Raw change scores (difference between pre and post rehabilitation – Y axis) for the measurement of IMVC<sub>50</sub> contraction accuracy (3% margin). X-axis (y=0) represents zero change in performance. Top and bottom lines represent performance change score threshold needed to represent a reliable change in contraction accuracy performance (±21.5%, P < 0.05). Percentage figures represent the proportion of participants within the cranio-cervical flexion exercise (CCFEx) or cervical flexion exercise (CFEx) groups demonstrating raw change scores above or below the performance change score thresholds.
for one of the CCFEx group participants was lost (irretrievably corrupted) therefore performance change scores are plotted for only nineteen CCFEx group participants. The CCFEx group demonstrated the higher proportion of participants above the reliable performance change score (21%) compared to the CFEx group (6%). The CFEx group had a larger proportion of participants with positive changes in performance (77%) compared to the CCFEx group (58%).

7.5 Discussion

The results of this study satisfy the primary hypothesis that CCFD measurements are responsive to changes in ICCF muscle performance following rehabilitation. Both participant groups demonstrated significant time effects for all measures (IMVC, IMVC<sub>20,50</sub> time to task failure, contraction accuracy) although at a group level there were no group by time interactions for any measure. At an individual participant level, the CCFEx group demonstrated greater proportions of change scores above the reliable change threshold, however the highest proportion of participants demonstrating reliable change in performance for any test was 40% of participants (IMVC<sub>20</sub> contraction accuracy, IMVC<sub>50</sub> time to task failure measure). This may reflect the sensitivity of the CCFD measurements to detect the specific training effects of the exercise protocols used in the clinical trial (Petersen et al. 1990; Abernethy et al. 1995).

Adaptations in the neuro-muscular system to training appear to be related specifically to the characteristics of the exercise, referred to as “specificity of training” (Conley et al. 1997). Changes in muscle performance may be specific to exercise characteristics such as movement pattern, velocity of contraction, type of contraction, joint angle (Rasch and Morehouse 1957; Moffroid and Whipple 1970; Lindh 1979; Caiozzo et al. 1981; Coyle et al. 1981; Sale and MacDougall 1981; Sargeant et al. 1981; Kanehisa and Miyashita 1983; Rutherford et al. 1986; Thepaut-Mathieu et al. 1988; Portero et al. 2001; Tsuyama et al. 2001). Isometric CCFD tests may not reflect certain characteristics of an exercise protocol, for example, there is evidence that isometric tests of muscular function are not
sensitive to dynamically induced training adaptations (Wilson and Murphy 1996; Portero et al. 2001) as may have been expected with the CFEx program. Neither of the exercise protocols in the clinical trial were identical in characteristics to the CCFD measurements. The CCFD measurements were all isometric cranio-cervical flexion contractions in the mid-range of cranio-cervical flexion. They included contractions at IMVC, and sustained contractions to fatigue at moderate (IMVC\textsubscript{50}) and low (IMVC\textsubscript{20}) load contraction intensities. The CCFEx exercise protocol while specific to the action of cranio-cervical flexion, included both concentric and sustained isometric components, the isometric component being sustained in a more inner range position than where the CCFD measurements were performed. Additionally the CCFEx program was relatively low load, similar to the IMVC\textsubscript{20} test but not the IMVC\textsubscript{50} or IMVC tests. In contrast the CFEx exercise program involved a different movement pattern (cervico-thoracic flexion) to CCFD, was a dynamic (concentric/eccentric) mode of contraction, but did include moderate to higher load that may have trained some strength and high load endurance components needed to improve the IMVC and IMVC\textsubscript{50} measurement outcomes. Therefore both exercise programs had some characteristics specific to CCFD tests but none were entirely identical.

It was hypothesised that the participants in the CFEx group would demonstrate the most gains in the IMVC, and IMVC\textsubscript{50} measurements due to the higher load nature of these tests being comparable to the strength and high load endurance attributes of the CFEx program. In contrast we speculated that the CCFEx group would show the best gains in the IMVC\textsubscript{20} test due to the comparable low load endurance nature of both the CCFEx training protocol and IMVC\textsubscript{20} test. These speculations were made with the thought that the comparable exercise/test load characteristic would affect measurement outcomes more than comparable exercise/test specificity of muscle action characteristic. Alternately, it was hypothesised that if the specificity of muscle action characteristic was a larger determinant of performance gains than the load characteristic, then the CCFEx group would show the largest gains in all measurements due to the comparable training/measurement biomechanical actions of cranio-cervical flexion. The alternate hypothesis appears to be the case.
When comparing change in performance at a group level (Table 7.3), both groups had similar gains in IMVC peak torque (0.6 Nm), but the CCFEx group had larger improvements in the time to task failure measure at IMVC20 (CCFEx group 79.1s, CFEx group 33.2s) and IMVC50 (CCFEx group 18.3s, CFEx group 8.6s) contraction intensities, but these differences were not sufficient to result in group by time interaction effects for any tests (IMVC, IMVC20, IMVC50). The lack of group by time interactions perhaps reflecting that improvement in both groups fell short of reliable performance change scores for the IMVC peak torque (1.3 Nm), IMVC20 time to task failure (117.8s), and IMVC50 time to task failure (28.1s) measures. Group performance changes for the contraction accuracy measures at the 3% margin were similar for both the IMVC20 (CCFEx group 9.6%, CFEx group 8.6%), and IMVC50 (CCFEx group 7.1%, CFEx group 9%), the improvements falling well short of the reliable change scores (IMVC20 18.7%, IMVC50 21.5%). Group results for the contraction accuracy measures at other margins (1%, 5%, 7%, 9%) were mixed with the CFEx group demonstrating larger group gains for most margins (Table 7.3), but contraction accuracy at these margins were shown to have poor reliability over time (Chapter 5) with significant gains noted in the second reliability measurement session. Consequently, conclusions drawn regarding the responsiveness of the contraction accuracy measures at these margins have to be made with caution.

When comparing change in performance at an individual level, the reliable change in performance graphs (Figures 7.1–7.5) indicate that a greater proportion of CCFEx participants realised significant gains in CCFD measurements than participants in the CFEx group. Proportions of participants demonstrating reliable change were relatively modest however (33-40%) suggesting that the CCFD measurements used in this thesis may need to be modified to be more specific to the training adaptations gained by these exercise protocols used in the clinical trial. Conversely, if the training protocols were specific in characteristics to the CCFD measurements (IMVC, sustained contractions at IMVC20,50) then larger gains in performance could be expected as measurement outcomes would be specific to the neuro-muscular adaptations gained from training. This will not
always be realistic in clinic and effective measurement outcomes must be sensitive to various training protocols.

It was also assumed in this study that all participants did experience neuro-muscular gains in the performance of their CCF muscles as a result of the exercise programs. This may not be the case for all participants with some participants showing poorer performance in CCFD measures in both groups as depicted in Figures 7.1-7.5. It would be expected that some participants would not have acquired significant gains in CCF muscle performance due to factors such as non-compliance to the exercise program and exacerbations of symptoms disrupting progression.

7.6 Summary - Responsiveness of CCFD Measurements to Quantify a Change in Muscle Performance

This study has shown that the CCFD measurements can quantify a change in ICCF muscle performance following rehabilitative exercise. The CCFD measurements appear to best reflect changes in muscle performance associated with exercise programs specific to the action of cranio-cervical flexion. These findings add strength to the validity of the method as a clinical test of ICCF muscle performance. This chapter concludes the clinical measurement studies performed within the thesis. The following chapter will discuss the relevance of the findings from the studies described in Chapters 4-7 to the overall aims of the doctoral project described in Chapters 1 and 2 and the basis for the development of the CCFD method as described in Chapter 3.
CHAPTER 8: DISCUSSION

This thesis has described an iterative process in the development of a physical measure of isometric cranio-cervical flexor (ICCF) muscle performance. The specific aims of the thesis as listed in Chapter 2 have been addressed. The new cranio-cervical flexion dynamometry (CCFD) method is specific to the CCF muscles (Chapter 3 and 4), is reliable in the measurement of ICCF muscle performance (Chapter 5), can quantify poor ICCF muscle performance in impaired CCF muscle states (Chapter 6), and can respond to improved isometric performance in trained CCF muscles (Chapter 7). Additionally we postulate that the CCFD measurements performed in this thesis mimic at least in part, the static postural function of the CCF muscles, inferring their capacity to perform this function under various loads. Thus a new method has been developed that has potential clinical application as a measurement of physical impairment in the cervical spine that reflects daily CCF muscle function, fulfilling the general aims of the thesis as listed in Chapter 1. The following is a discussion of the implications of the findings of the thesis to issues of validity concerning the CCFD method as a clinical measure of CCF muscle performance.

8.1 Specificity of Muscle Action

CCFD is a physical measure of the contractile performance of the CCF muscles. It was proposed that this would best be derived by measuring these muscles’ primary biomechanical action on the skeletal system, which is the production of torque about the C0/l motion segment. Two mechanical attributes of the dynamometry device made its measurement output specific to the contractile performance of the CCF muscles. The first was the resistance of the CCF action at the undersurface of the mandible, and the second was the resolution of the torque measurement to the primary cranio-cervical articulation. This was in contrast to conventional cervical flexion dynamometry (CFD) that resisted
cervical flexion at the forehead and resolved torque measurements to the cervico-thoracic junction, combining and measuring the action of both cranio-cervical and cervico-thoracic flexor muscles. This construct was supported by the proof of concept EMG study reported in Chapter 4. This study confirmed that CCFD preferentially activated the CCF muscles more than the cervico-thoracic flexor muscles, offering a more selective challenge to their contractile performance. In contrast, CFD activated both cranio-cervical and cervico-thoracic flexor muscles, with a tendency to bias the cervico-thoracic flexor muscles, suggesting this measure was not specific to CCF muscle contractile performance.

The coordination of both cranio-cervical and cervico-thoracic muscles is vital to the stability and postural orientation of the cervical spine. Nevertheless, their distinct anatomical division, as described in Section 2.1, supports the case that these muscle groups require separate measurements of contractile performance. The distinct differences in the EMG activation patterns found between the dynamometry methods (Chapter 4) confirm these anatomical predictions for the tests. Specificity of muscle action was further confirmed by the similarities found between the muscle pattern during the cranio-cervical flexion test (CCFT) and CCFD when performed at IMVC<sub>20</sub>, and although less so, at IMVC<sub>50</sub>. The specificity of the CCFT to the activation of the CCF muscles has been demonstrated previously (Falla et al. 2003a) and is an accepted clinical test of their performance (Jull et al. 1999; Jull 2000; Jull et al. 2002; Jull et al. 2004b; Jull et al. 2004a) despite not being a direct measure of their biomechanical action.

Now that the cervical flexor muscle usage patterns have been investigated in control participants, a further study should be performed in symptomatic participants to establish if similar patterns exist to those found for control participants. For the purposes of this thesis, muscle usage patterns were investigated to compare dynamometry methods only, not to compare symptomatic to control participant responses. Muscle usage patterns during CCFD were compared to that during CFD and the CCFT. Impaired cervical flexor muscle coordination, as has been previously shown in symptomatic participants (Jull 2000; Jull et al. 2004b; Falla et al. 2004b) would have been a confounding variable to the
accurate analysis of muscle usage patterns. A future study comparing the muscle usage responses in symptomatic and control participants during CCFD is now warranted. An investigation to determine if poorer performance during CCFD tests in symptomatic participants corresponds to alterations in CCF muscle activation patterns will be helpful in clarifying the mechanism underlying the test outcomes. Alterations in the activation patterns of the CCF muscles corresponding with poorer performance of the CCFT has previously been shown in neck pain patients (Falla et al. 2004b).

Of additional interest from the results of the EMG study described in Chapter 4, is the use of specific muscle patterns and load to target specific muscle groups for therapeutic exercise. The most selective activation of the deep CCF muscles was found during the specific cranio-cervical flexion action at low load (IMVC20), although specificity was still present at moderate load (IMVC50). A specific low load cranio-cervical flexion therapeutic exercise approach to bias the activity of the joint-protective deep cervical flexor muscles has been a suggested approach in the rehabilitation of neck pain and cervicogenic headache (Jull et al. 2004a), and for which there is high level evidence (Jull et al. 2002). The results of this study support these clinical strategies. However, it should be noted that while these strategies may be important particularly in the early phases of rehabilitation, ICCF muscle performance deficits were also demonstrated at maximal, moderate, and low contraction intensities (Chapter 6). These findings suggest that therapeutic exercise needs to address a range of loads, not just low load.

8.2 Clinical Measurement Attributes

Theoretically, impaired CCF muscles should demonstrate less ability to exert or sustain torque about C0/I compared to unimpaired muscle. Conversely, trained CCF muscle should have greater capacity to exert and sustain torque than untrained muscle. CCFD was developed with the knowledge that persons with neck pain had previously demonstrated deficits in the contractile performance of their CCF muscles (Watson and Trott 1993; Jull et al. 1999; Jull 2000; Jull et al. 2004b; Falla et al. 2004b), and that retraining of the CCF muscles was efficacious in reducing the painful symptoms of
cervicogenic headache (Jull et al. 2002). Additionally, poor CCF muscle function has been linked to abnormal cranio-cervical postural form that potentially contributes to mechanical pain (Watson and Trott 1993; Grimmer and Trott 1998). Thus the CCFD tests were developed to mimic postural muscle function as it was thought this would provide clinically useful measures of functional CCF muscle performance.

In the reliability study (Chapter 5) the CCFD measures were shown to have sound test-retest reliability. The implications from the findings of Chapters 6 and 7 investigating the clinical capacity of the CCFD measures in quantifying impairment in ICCF muscle performance, and a change in ICCF muscle performance, respectively will now be discussed.

8.2.1 Capacity to Quantify ICCF Muscle Impairment

To assess the capacity of the CCFD measures to quantify muscle impairment, CCFD measures were compared between symptomatic and control participants categorised according to other measures of cervical spine impairment criteria (Chapter 6). Specifically, symptomatic participants were selected according to a Neck Disability Index (NDI) score of ten points or greater. The NDI is sensitive to levels of severity in neck disorders (Vernon and Mior 1991). Consequently, poorer CCFD performance outcomes in symptomatic participants would indicate a form of agreement between the CCFD measures and an accepted measure of cervical spine impairment. The measures of participants with mild neck disorders (mean NDI score of 22.8) to that of control participants (mean NDI score of 2.6) were compared to optimally scrutinize the capacity of the measures to quantify impairment even though larger deficits in performance may be found in symptomatic groups with larger NDI scores who potentially have more substantial muscle impairment issues.

With regard to IMVC, the CCFD method quantified on average a 15.9% deficit in symptomatic compared to control participants. This figure is consistent with the 14.6% reduction found by Watson and Trott (1993) for the CCF muscle group in similar
participant populations. These deficits are not as large as some of those reported for the cervical flexor muscles (29–57% deficits) using CFD methods (Silverman et al. 1991; Vernon et al. 1992; Barton and Hayes 1996; Ylinen et al. 2004a), however larger deficits may be expected in more severe neck pain groups with larger NDI scores. Notwithstanding this, it would appear that the CCFD method has the capacity to reliably quantify deficits in isometric strength of the CCF muscles.

Consistent with previous research (Jull et al. 1999; Jull 2000; Jull et al. 2004b), the CCFD method was able to demonstrate a deficit in symptomatic participants to sustain ICCF muscle contractions at low load. The CCFD method quantified both a deficit in contraction time to task failure (35% deficit), and poorer contraction accuracy during the low load IMVC<sub>20</sub> test (Chapter 6). Similarly, for the IMVC<sub>50</sub> test, on average a 27% deficit was found in the time to task failure in symptomatic individuals compared to control participants, but no differences were noted in the contraction accuracy measure between the groups. This is the first time that specific measurements of ICCF muscle performance have been investigated at moderate load. The findings from the IMVC<sub>20,50</sub> tests reflect greater fatigability of the CCF muscles in symptomatic participants compared to control participants at low and moderate loads of muscular effort.

Poorer performance of the CCF muscles to exert and sustain torque in the presence of musculoskeletal impairment as found in this thesis may be intrinsic to the muscle tissue itself, or due to other factors such as neural drive. Positive correlations have been found between isometric strength and the cross-sectional area (CSA) of neck muscles (Mayoux Benhamou et al. 1989; Tsuyama et al. 2001). Although no changes have been found in the CSA of the CCF muscles in neck pain disorders, reductions in CSA of cranio-cervical extensor muscle (semispinalis capitis) coinciding with reductions in isometric extensor strength have been found in cervicogenic headache sufferers (Amiri 2004). Atrophy and fatty infiltration has also been previously found in the deep suboccipital muscles in patients with chronic neck pain using magnetic resonance imaging (Hallgren et al. 1994; McPartland et al. 1997; Andrey et al. 1998).
Deficits in the performance of the CCF muscles in symptomatic participants could also be attributed to altered neural drive and motor output associated with painful disorders (Moseley 2003). Such changes in motor output have been demonstrated in painful neck disorders at low load during the performance of the CCFT (Jull et al. 1999; Jull 2000; Jull et al. 2002; Jull et al. 2004b; Falla et al. 2004b). Falla et al (2004b) showed that, compared to controls, participants with neck pain recruited less activity of the primary CCF muscles (longus capitis) and greater activity of their cervico-thoracic flexor muscles (sternocleidomastoid, anterior scalene) during the CCFT. Potentially, similar altered patterns of muscle usage may occur in symptomatic participants during the low load IMVC\textsubscript{20} test that may account for the poorer performance outcomes found in symptomatic participants in this thesis. It is reasonable to expect that reduced activity of the primary CCF muscles during the IMVC\textsubscript{20} test would reduce the time to task failure, as well as reduce the accuracy of the contraction as was found in Chapter 6. Similarly the reduced time to task failure measures in the symptomatic group at the moderate load IMVC\textsubscript{50} test may reflect altered activity of the CCF muscle synergy. Certainly the results of the EMG study (Chapter 4) confirmed that at IMVC\textsubscript{50} in control participants, the CCF muscles were still preferentially activated over the cervico-thoracic flexor muscles. While such changes in motor output as found by Falla et al (2004b) could conceivably alter the capacity of the CCF muscles to sustain torque, this hypothesis will need to be tested in future EMG studies investigating the muscle usage pattern of the cervical flexor muscles in symptomatic participants during the IMVC\textsubscript{20,50} tests.

In summary, the results of the study detailed in Chapter 6 confirmed that the CCFD method is able to quantify impairment in ICCF muscle performance in persons who currently have symptomatic neck disorders according to the NDI and positive findings on a physical examination of the cervical spine. This finding provides some argument for the validity of the CCFD method as a clinical measure of CCF muscle performance. It has to be acknowledged that the investigator was not blinded to the group status of the participant at the time of testing even though standardized procedures, instructions, and feedback were followed for all participants irrespective of neck disorder status. Future studies will now need to be performed during which the investigator is blinded to the
status of the participant so that the sensitivity and specificity of the measures to discriminate symptomatic from control participants based on the CCFD measures alone can be investigated. The measurement error calculated (Chapter 5) and group performance measurements (Chapter 6) reported in this thesis have now provided a foundation from which criteria scores can be formed to distinguish symptomatic from control participant measures.

### 8.2.2 Capacity to Quantify a Change in ICCF Muscle Performance

The CCFD method is responsive to a change in ICCF muscle performance following rehabilitative exercise (Chapter 7). This investigation was vulnerable to the ‘specificity of training’ effects in that neuromuscular adaptations appear to be related to characteristics of the exercise program (Conley et al. 1997a). The characteristics of the rehabilitation programs in Chapter 7 were not specific to the CCFD measurements characteristics, but rather had some similar components with respect to muscle group (CCF muscles, cervico-thoracic flexor muscles), contraction type (static, dynamic), contraction intensity load (low, moderate), and duration of contraction (sustained, oscillations). The most promising finding was that the CCFD measurements were most responsive to the exercise program that biased the retraining of the CCF muscles irrespective of load. Significant gains were noted in a reasonable proportion of participants. Possibly greater gains would be expected if the exercise programs had been carried out using exercise protocols that were identical in characteristics to the CCFD measurements, or if the CCFD measurements had been modified to better replicate the exercise protocols. This is not always the realistic clinical scenario, and measurement methods must be responsive to various forms of rehabilitative programs if widespread clinical use is to be accepted.

Future studies will also need to investigate the underlying physiological mechanisms associated with improvements in CCFD performance following therapeutic exercise programs. Gains in isometric strength have been correlated with increases in CSA of neck muscles following rehabilitation (Conley et al. 1997b; Portero et al. 2001). However, gains in ICCF muscle performance following only six-weeks of therapeutic exercise as
performed in the study described in Chapter 7, may be more associated with neuromuscular adaptations such as greater synchronization of motor units (Milner-Brown et al. 1975), altered sensitivity of muscle receptors (Komi et al. 1978), and reduced recruitment of non-primary muscles (Conley et al. 1997a). EMG studies comparing the muscle usage patterns of the cervical flexor muscles during the CCFD tests, before and after a period of therapeutic exercise, will provide useful information regarding the underlying mechanisms of a change in performance.

8.3 Advantages Over Current Methods of Measurement

The advantages of the CCFD method over CFD with regards to specificity of muscle action have been discussed in Section 8.1. The CCFD method in its measurement of torque about a specified AOR landmark also addresses problematic issues with the measurement of muscle force (Section 2.4.2) such as in the method described by Watson and Trott (1993). The design of the CCFD device also permits tests to be performed in any position in the available cranio-cervical flexion range (Section 3.2.1), and with appropriate modifications would permit dynamic through range measurements.

Although demonstrating similar patterns of muscle usage, CCFD affords some advantages over the CCFT. Firstly, CCFD directly opposes and measures the biomechanical action of the CCF muscles (torque about C0/I), compared to the CCFT that measures a secondary effect of cranio-cervical flexion, the flattening of the cervical lordosis. Secondly, as demonstrated in the EMG study (Chapter 4) the CCFT even when performed at the second highest pressure increment (28mmHg) is a low load test when muscle amplitudes are compared to those achieved at IMVC20 with CCFD. IMVC measurements cannot be performed with the CCFT, consequently measurements of ICCF muscle performance at specified contraction intensities is not possible, affording CCFD advantages over the CCFT as a test of ICCF muscle contractile performance. Another factor is that substitution strategies to enhance CCF muscle performance such as increasing dorsal head force (DHF) on the supporting surface is subjectively monitored by the clinician during the CCFT and is therefore vulnerable to the skill level of the
clinician. Changes in DHF during CCFD is monitored with electronic sensors that eliminates the need for a high-level of skill by the clinician, and can give the participant immediate feedback of any unwanted substitution strategies via an alarm.

8.4 Issues with the CCFD Method

There are several issues concerning the format of the CCFD measurements as performed in this thesis. Primary issues to be addressed pertain to the high data exclusion rate particularly during the IMVC\textsubscript{20} test, and to a lesser degree the IMVC\textsubscript{50} test. During the clinical measurement studies (Chapter 5-7), data for the IMVC\textsubscript{20} test was excluded for 29-44\% of the symptomatic participants, and 23-25\% of the control participants. For the IMVC\textsubscript{50} test, data was excluded for 4-26\% of symptomatic participants, and 0-8\% of control participants. These substantial exclusion rates, particularly for the IMVC\textsubscript{20} data, not only weakens the statistical inferences that can be made from this data, but also suggests that these measures may not be clinically useful in a proportion of patients. Data was excluded on the grounds of adverse effects, difficulty controlling the dual task of ICCF and DHF, or breaching the upper 10-minute time limit for the sustained test to task failure. Details concerning the exclusion of data and other issues relating to the measurements are discussed below.

8.4.1 Adverse Effects

No serious adverse effects resulting from the dynamometry testing in this project were experienced.

At the time of performing the tests, participants were instructed to discontinue the tests if pain was experienced other than that of the discomfort associated with muscle fatigue. Of the 120 symptomatic participants in the clinical measurement studies (Chapters 5-7), no participants reported pain during the IMVC test, 28\% (34/120) of participants reported pain as the cause of them ceasing the IMVC\textsubscript{20} test, and 15\% (18/120) of participants
reported pain as the cause of them ceasing the IMVC_{50} test. Of the 71 control participants in the clinical measurement studies (Chapters 5-7), no participants reported pain during the IMVC test, 14% (10/71) of participants reported pain as the cause of them ceasing the IMVC_{20} test, and 3% (2/71) of participants reported pain as the cause of them ceasing the IMVC_{50} test. The lack of adverse effects during CCFD IMVC tests is surprising considering the high incidences of pain at the time of testing that has been reported during CFD IMVC tests (Ylinen et al. 2004b). With regard to the IMVC_{20} and IMVC_{50} tests, especially the former, these are quite high adverse effect proportions considering these adverse effects make the data redundant. This issue as it relates to the clinical measurement validity of the CCFD method is discussed further in Section 8.4.3.

In nearly all cases any onset of pain experienced during a CCFD test ceased immediately following the termination of the test. Four participants reported moderate aggravation of their neck symptoms following the dynamometry procedure that resolved within 48-72 hours. Several participants reported discomfort at the under-surface of the mandible associated with sustained pressure of their mandible on the application pad of the dynamometer lever arm. This later issue will be addressed by more extensive padding of the application pad for future studies. Although some participants did report pressure through the teeth associated with the pressure through the mandible at the time of testing, no reports of discomfort from this forced occlusion were reported. Several participants reported delayed onset of muscle soreness that resolved over the following 48 hours.

8.4.2 Control of Dual Task of ICCF and DHF

The primary aim of this thesis was to develop a method of ICCF muscle performance measurement that was simple to use and results easy to analyse. The preliminary study in Chapter 3 (Section 3.3.6) demonstrated that when not controlled, DHF on the supporting surface was excessive during CCFD tests and needed to be controlled in order to optimise the accuracy of the ICCF muscle torque measurement. Alterations in DHF during ICCF muscle dynamometry tests had been a concern in the method of Watson and Trott (1993). These investigators reported that they monitored and controlled their participants DHF to
ensure an isolated cranio-cervical flexion action, but they did not stipulate to what degree DHF was controlled. Based on the results of the preliminary study, a margin of ± 20% of the resting DHF for the IMVC tests, and a margin of + 10% of the resting DHF for the IMVC$_{20}$ and IMVC$_{50}$ tests was allowed in studies in this thesis. Results from the study reported in Chapter 6 confirmed that imposing DHF control to this degree resulted in significant differences in ICCF muscle performance measurements between symptomatic and control participants. A negative consequence of controlling DHF during ICCF muscle tests is that it presents the participant with a complex dual task that is at times difficult for some people to perform, particularly during rapid maximal tests such as IMVC tests where the participant's entire concentration should be on achieving a maximal muscle effort. Despite this factor, no participants in the clinical measurement studies ($n=191$) (Chapter 5-7) were excluded from the IMVC tests due to an inability to perform the dual task. Additionally, the reliability measurements of IMVC (ICC 0.8-0.92) found in the reliability study (Chapter 5), were similar to those found for IMVC when DHF was not controlled (ICC 0.91-0.92) in a preliminary study (Appendix B.1).

During the IMVC$_{20}$ and IMVC$_{50}$ tests in the clinical measurement studies, an inability to perform the dual task adequately, accounted for only a small proportion of the test results being excluded. Only 2% (2/120) of symptomatic participants and 4% (3/71) of control participants were excluded due to an inability to control the dual task during the IMVC$_{20}$ test. Similarly only 4% (5/120) of symptomatic participants and 4% (3/71) of control participants were excluded due to an inability to control the dual task during the IMVC$_{50}$ test. While this level of data exclusion is acceptable, a large proportion of participants did require persistent reminding from the investigator during the tests to ensure they maintained focus on the ICCF torque task while they adjusted for DHF. This slightly weakens the ease of use in the application of the method as it increases the degree of involvement from the investigator.
8.4.3 Sustained Tests to Task Failure

The IMVC<sub>20</sub> and IMVC<sub>50</sub> tests were performed until the patient perceived that their muscles were fatigued to the point that they were no longer able to sustain the predetermined ICCF torque task. The duration of this time in seconds was the score given for these tests. Watson and Trott (1993) performed sustained contractions at IMVC, and had set the termination point of the test to be the instant at which the ICCF force fell below 50% of the IMVC force. The current study required participants to sustain contractions at 20% and 50% of their IMVC amplitude. Setting a test termination point at 50% of these sustained contraction efforts was considered impractical for the IMVC<sub>20,50</sub> tests as they would be very prolonged due to the low intensity nature of the contraction efforts. Consequently, the task failure point was set at the instant that the participants reported to be fatigued. Inherent in this mode of test termination are confounding CNS variables to perform a prolonged task, particularly at IMVC<sub>20</sub>. Consequently, a large range of scores were noted for both symptomatic (31-600 seconds) and control (40-600 seconds) participants in the clinical measurement study in Chapter 6 for the IMVC<sub>20</sub> test, with some participants (6 control, 2 symptomatic) reaching the pre-determined upper limit of ten-minutes.

As discussed in Section 8.2.1, factors other than the intrinsic fatigue of the CCF muscle group would contribute to the time to task failure measurement including multiple neural contributions (Hunter et al. 2004), and supraspinal influences (Gandevia 2001). Additionally, muscle endurance measured by the time for which a given torque output can be sustained is influenced by factors such as pain tolerance, boredom, determination, competitiveness and fear-avoidance (Vlaeyen and Linton 2000; Mannion et al. 2001). Underperformance in a similar muscle endurance test in the lumbar spine, the Biering-Sorensen Test (Biering-Sorensen 1984), has been shown to correlate significantly with psychological disturbance measures (Mannion et al. 1996). Mannion et al (2001) contends that this psychological dimension to these tests limits their use as objective measures of muscle performance. Alternative methods of determining a participants time to task failure, other than their own perception of fatigue, are currently being explored for
future studies. Potentially a “closed loop” test (Gandevia 2001) where the test is terminated via more objective criteria (e.g., inability to sustain contraction at predetermined accuracy), rather than the participants own nominated fatigue point will minimise unwanted psychological contributions.

Participants were also asked to discontinue the test if they experienced neck pain other than that due to muscle fatigue. As reported in Section 8.4.1, a large proportion of participants (28% symptomatic, 14% control) terminated the IMVC20 test due to pain, not fatigue. These exclusion rates are much larger than for the IMVC50 test (15% symptomatic, 3% controls). The greater levels of reported pain onset during the gentler contraction may reflect the much longer duration of the test at IMVC20 than IMVC50. Consistent with this finding is the absence of reported pain during the IMVC test that only lasts three to five seconds, suggesting the onset of pain during CCFD is more dependent on the duration of a test than the intensity of the muscle contraction. This perhaps reflects sustained mechanical pressure on irritable tissues, and ischaemia of soft tissues such as muscles during prolonged sustained holds. It is acknowledged that the IMVC20 test was always performed before the IMVC50 test during this project and consequently the number of tests terminated due to pain may have been different if the test order was randomized. Notwithstanding this, considering the irritability of sensitive tissues with repeated mechanical stress one would expect the second test performed (IMVC50) to result in greater pain onset rates which was far from the case in the clinical measurement studies.

Irrespective of the cause, the large exclusion rate of participants due to pain onset, especially during the IMVC20 test, hinders the clinical validity of the test as a measure of ICCF muscle performance as the test was not terminated due to muscle fatigue but rather pain. It may be argued that time of onset of pain may also be a functional measure, possibly reflecting the pain-sensitive status of tissues, and changes with repeated tests over time may reflect improvement or worsening of the condition. For the purposes of this project individuals who ceased the test due to pain were excluded in an effort to limit the test to one of ICCF muscle endurance. A measurement of time to pain onset during
these sustained tests may have clinical application, however future studies would need to establish the reliability of a time until pain onset measure in symptomatic participants and determine if the measure parallels changes in the status of the neck disorder.

The reporting of pain onset other than that of muscle fatigue is also difficult for participants and investigators to interpret. Participants were asked to differentiate between pain due to muscle fatigue and that due to the onset of pain in their neck, jaw, head, or upper quarter. This was at times confusing for participants to differentiate between the two categories of pain. Of interest was that control participants also reported the onset of neck pain as the cause of them stopping the test in 14% of the IMVC_{20} tests and in 3% of the IMVC_{50} tests. The fact that the control participants were not neck pain sufferers confirms the difficulty in differentiating the source of pain in these tests.

8.4.4 Contraction Accuracy Measure

The contraction accuracy measure was meant to reflect fatigue-induced tremor (Gandevia 2001) measurable as a poorer ability to maintain the contraction within certain set margins either side of the expected torque amplitude. A simple method was used to calculate the percentage of time participants were able to maintain their ICCF muscle torque within set margins either side of the expected torque amplitude. This measure accounted for tremor amplitude only, not tremor frequency, but did demonstrate deficiencies in the symptomatic group compared to the control group for the IMVC_{20} test (Chapter 6). The results of the clinical measurement studies indicated that the 3% margin had the best reliability, could best quantify impairment, and responded to individual changes in performance, when used to evaluate the performance of the CCF muscles. It is acknowledged that future studies may need to investigate more sophisticated methods of data analysis that may provide more accurate measures of fatigue-induced tremor.
8.5 Future Directions for the Dynamometry Method

Abernethy et al. (1995) makes the salient point that muscle testing protocols and dynamometry development is an ongoing process. The development of good dynamometry is contingent on improving our understanding of mechanisms underpinning muscle performance, which in turn is partially contingent on good dynamometry. One of the aims of this PhD project was to establish directives that would improve the new CCFD procedure for future studies. It would appear that a primary difficulty with the current method lies in the control of the dual task of ICCF and DHF control that is a necessary factor when performing the test in supine. The CCFD design used in this project was performed in supine, consistent with the previous CCF physical test methods (Watson and Trott 1993; Jull et al. 2004a), eliminating the participant having to hold the head against gravity when performing the tests. The dual task may be eliminated to a degree by performing the test in sitting, although translation of the head in the sagittal plane would still have to be controlled so as to stabilize the AOR landmark in alignment to the dynamometer axis. Potentially the test in sitting, as has been performed in other neck dynamometry methods (Jordan et al. 1999; Portero and Genries 2003), may be more comfortable, may provide better trunk stability, and is theoretically more functional, replicating the action of the CCF muscles in the upright position. Alternatively the test could be performed in standing as has been reported previously for other neck dynamometry methods (Vernon et al. 1992; Ylinen and Ruuska 1994). Modifications to the device are currently underway to test the methods application in the upright position.

While the focus of this thesis was on the isometric performance of the CCF muscles, the measurement of torque about an AOR gives the new method the potential to be used in various points in the cranio-cervical flexion range, or with modification to be used through range as an isokinetic test of CCF muscle performance. Additionally, the same method can be used to measure the torque produced about C0/1 from active contraction of the cranio-cervical extensor muscles by positioning the resistance arm of the dynamometer on the top surface of the mandible. As stated in the introduction (Chapter 1), for the purposes of simplicity within the thesis, and to avoid the potential adverse
effects of multidirectional testing, the project only concentrated on the CCF muscles. This is not to suggest that they are more important than the cranio-cervical extensor muscles. Pathological changes have been reported in the cranio-cervical extensor muscles of persons with chronic neck disorders (Hallgren et al. 1994; McPartland et al. 1997; Andrey et al. 1998) that could potentially affect their ability to generate and sustain isometric tension. Future studies are planned to investigate the capacity of this new cranio-cervical dynamometry method to measure cranio-cervical extensor muscle performance.

With regard to the isometric exercise protocol used in this thesis, there is much room for exploration in future studies. ICCF muscle contraction intensities were chosen at maximal, and 20% and 50% of maximal to cover a large spectrum of contraction intensities that may be expected when posture of the cranio-cervical region is challenged in daily life. However, other contraction intensities may demonstrate more significant findings of impairment. Other combinations of ICCF muscle contraction durations, intensities, and repetitions that perhaps reflect other CCF muscle functions, will need to be explored in future studies to determine alternative useful CCFD clinical measures.
Neck pain is of significant cost to society and physiotherapists are under substantial pressure to develop useful measurements of physical impairment to justify and monitor intervention. This doctoral thesis developed a clinically suitable method of isometric dynamometry specific to the cranio-cervical flexor (CCF) muscles that can quantify impairment and improvement in isometric cranio-cervical flexor (ICCF) muscle performance. This body of work is a significant contribution to the field of physiotherapy as the CCF muscles are known to be problematic in persons with neck related pain disorders, and therapeutic intervention based on their rehabilitation has proven effective in reducing painful neck symptoms. Notwithstanding this, no measurement method existed that evaluated the primary biomechanical function of the CCF muscles, that is the exertion of torque about the cranio-cervical junction. This project has provided such a method, providing a new measurement of muscle performance and enhancing our knowledge of cervical muscle impairment.

Perhaps the most interesting observation from this thesis was the deficit in ICCF muscle performance found at all intensities of contraction (isometric maximal voluntary contraction (IMVC), 20% of IMVC, 50% of IMVC) (Chapter 6). These findings have significant clinical implications for the rehabilitation of neck pain, suggesting that the CCF muscles require exercise over a variety of loads for comprehensive rehabilitation. These findings add to the growing evidence base implicating impairment of the CCF muscles in neck pain disorders, and provide further directives for their rehabilitation.

Another interesting observation from this thesis was the ability to bias the activation of specific muscle groups using the combination of resistance point application and load as shown in the electromyography proof of concept study (Chapter 4). These findings have implications for assessment of muscle impairment and in the prescription of therapeutic
exercise, as well as contributing to the understanding of cervical spine muscle mechanisms under static load.

With regard to the new cranio-cervical flexion dynamometry (CCFD) method, this thesis has merely scratched the surface in the investigation of its capacity to measure CCF muscle impairment. Further modification and experimentation of both the dynamometry device and the testing protocol are now required in the pursuit of the optimal physical impairment measure of the CCF muscles.
REFERENCES


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APPENDIX A – Equipment Specifications

Appendix A.1 - Mechanical Specifications of the Cranio-Cervical Flexion Dynamometer

The following diagrams are the mechanical specification part drawings (GWG Creative Engineering, Brisbane, Australia) for the dynamometer developed and used in the doctoral project. International Patent Application filed on 20th September, 2004 (PCT/AU2004/001279).
Appendix A.2 - LabView Block Diagram for Isometric Maximal Voluntary Contraction (IMVC) Program
Appendix A.3 - LabView Block Diagram for Isometric Sustained Sub-Maximal Voluntary Contraction (IMVC20,50) Program
APPENDIX B – Preliminary Study Manuscript

Appendix B - A New Method of Isometric Dynamometry for the Cranio-Cervical Flexors: Technical Report

Abstract

Background and Purpose. A new method of dynamometry has been developed to measure the performance of the cranio-cervical (C-C) flexor muscles, by recording the torque that these muscles exert on the cranium about the C-C junction. This report describes the method, specifications of the instrument, and preliminary reliability data. Participants and Methods. For the reliability study, 20 participants (12 participants with a history of neck pain, 8 participants without a history of neck pain) performed isometric maximal voluntary contraction (IMVC) tests of C-C flexion in 3 positions within the C-C flexion range, and sub-maximal sustained tests (20% and 50% of IMVC) in the mid range, on two occasions. Reliability coefficients were calculated to establish the test-retest reliability of the measures. Results. The method demonstrated good reliability over two sessions in the measurement of IMVC (ICC 0.83 - 0.91, SEM 0.7 – 1.1 Nm), and in the measurement of steadiness (standard deviation of torque amplitude) of a sustained contraction at 20% IMVC (ICC 0.77, SEM 0.01 Nm), but not at 50% IMVC (ICC 0.25, SEM 0.09Nm). Discussion and Conclusion. The new dynamometry method to assess the performance of the C-C flexor muscles has shown sound reliability in the measurement of IMVC and sustained contractions at low load.
Introduction

Functionally, motion at the specialised cranio-cervical (C-C) articulations can occur independently of the remainder of the cervical spine, and is particularly important for fine control of head orientation serving the visual, vestibular, and proprioceptive systems. Accordingly, the morphology of the C-C flexor muscles differs to that of the cervico-thoracic flexor muscles. The longus capitis and rectus capitis anterior muscles attach deeply to the front of the cervical spine and insert superiorly onto the cranium and therefore have flexion moments at the C-C spine. Of these muscles only the longus capitis can affect cervical motion segments other than 0/Cl due to it's most inferior attachment to the C6 vertebrae. In contrast, cervico-thoracic flexor muscles either have an extensor moment at the C-C spine (sternocleidomastoid), or attach inferiorly to the cranium so that they are unable to flex the C-C junction (longus coli and anterior scalene muscles). The only other muscles that are capable of flexing the C-C junction are the hyoid muscle group. The hyoid group have extensive attachments originating from the sternum, clavicle, and scapula, with intermediate attachments to the hyoid bone and thyroid cartilage before inserting on the mandible and styloid process. Consequently these muscles flex all regions of the cervical spine, not selectively the C-C region.

Due to their specific function there has been a trend in research and in clinical practice to evaluate the C-C flexor muscles separately from the cervico-thoracic flexors. When compared to participants with no history of neck pain, deficits in the contractile capacity of the C-C flexor muscles have been shown in persons with idiopathic and traumatic onset neck disorders. Such deficits include reductions in isometric strength, and deficits in the capacity to sustain maximal and sub-maximal cranio-cervical flexion contractions. However, as yet there is a lack of methodology that permits the performance of the C-C flexor muscles to be measured over a range of contraction intensities that potentially could be used in a clinical setting. We consider that conventional cervical flexion dynamometry methods that resist muscle forces at the forehead may not bias contraction of the C-C flexors specifically enough to adequately assess their performance.
Watson and Trott\textsuperscript{16} described a dynamometry method in supine to specifically assess C-C flexor muscle performance. This method measured the force the C-C flexor muscles could exert on a force sensitive metal bar at the undersurface of the mandible. A pressure sensor, placed under the supporting surface of the head, simultaneously monitored changes in the head pressure on the supporting surface to ensure an isolated C-C flexion action. Using this method Watson and Trott\textsuperscript{16} demonstrated good intra-examiner reliability ($r = 0.93$) and found significant reductions in the isometric maximal voluntary contraction (IMVC) of the C-C flexor muscles in cervicogenic headache sufferers compared to participants with no history of neck pain. However, as Mayhew and Rothstein\textsuperscript{20} point out, the measurement of muscle force can be problematic in that it is dependent on the distance the resistance is applied from the axis of rotation (AOR) about which the muscles act. Force measurements may vary considerably unless the device is applied at the exact anatomical position for each test even if muscle tension is identical. Consequently, it may be difficult to compare measurements of force in different points of range within individuals, or at the same point in range between individuals, and compromises the method's potential to be used in the future for dynamic through range muscle tests.

The purpose of this technical report is to describe a new dynamometry method designed to measure the torque-generating capacity of the C-C flexors about the AOR of 0/C1, with the intent of ascertaining their performance. Muscle forces exert torque to the skeletal system about articular axes. Isometric dynamometry measures torque exerted by muscle groups on the static skeleton in a single plane. In complex multi-segmental regions such as the cervical spine, the torque-generating capacity of planar muscle groups can be simplified by resolving all moments to a single point.\textsuperscript{18,19,21} Several studies have used this method for the cervical flexor muscles by resisting forces at the forehead and resolving moments to the cervico-thoracic junction (C7/T1),\textsuperscript{18} the C7 vertebrae,\textsuperscript{19} or to the level of the C4 vertebrae.\textsuperscript{21} These methods refer to isometric tests of cervical flexor muscle performance that, if unrestrained, would produce flexion of the head and cervical spine together on the thorax (cervico-thoracic flexors) as is the case with conventional cervical flexion dynamometry. The method of isometric dynamometry described in this
technical report resists forces at the undersurface of the mandible that, if unrestrained, would produce flexion of the head on the cervical spine (C-C flexors), while resolving all moments to the 0/CI motion segment, the principle articulation of C-C flexion. It is considered that this is the most appropriate method to physically measure the contractile performance of the C-C flexor muscles and has potential to be used in the future as a clinical measure of these important muscles.

This paper is in two parts, the first describes the specifications of the device and calibration procedure, and the second part relates to the reliability of the method in C-C flexor muscle performance tests. Muscle performance tests include the measurement of isometric C-C flexor muscle strength (IMVC) at three different points in the C-C flexion range, and measurement of the steadiness of a sustained isometric contraction (standard deviation of the sustained torque amplitude) at low (20% IMVC) and moderate (50% IMVC) intensities of contraction in the middle range. Isometric strength of this muscle group has previously been investigated as have tests of sustained sub-maximal contractions. We believe the muscle performance tests as performed in this paper using this new technology may reflect aspects of daily C-C flexor muscle function and therefore are potential clinical tests of their performance.

Methods

Part 1: Dynamometer Specifications and Calibration

The NeckMetrix* dynamometer records 2 simultaneous measurements; isometric C-C flexion torque in Newton-meters (Nm), and the dorsal force of the head on the supporting surface in Newtons (N). The primary feature of the device is an axis and lever arm system to measure the torque-generating capacity of the C-C flexor muscle group about the AOR of 0/CI (Figure 1). The AOR for 0/CI sagittal plane motion occurs about the mastoid process, varying from the centre of the mastoid process, anterior mastoid process, to an area slightly dorsal and cranial to the mastoid process. The concha of

* NeckMetrix™, Unquest Pty Ltd, Road, University of Queensland, Brisbane, Australia.
the ear, a depression immediately posterior to the bony external acoustic meatus, was chosen as the landmark adjacent to which the dynamometer axis was aligned. This landmark approximates the mastoid process that is otherwise difficult to localise to one point and is occluded from direct vision by the ear.

**Figure 1.** Dynamometry device for the measurement of C-C flexor muscle torque about the axis of rotation (AOR) of the 0/Cl motion segment. Figure A is a line diagram from an anterolateral perspective. Figure B depicts a participant performing C-C flexion against the resistance of the dynamometer. The following components of the device are numbered. 1. Dynamometer axis that was aligned to the participant’s 0/Cl AOR, the dynamometer axis was locked at various angles to the load cell deflection arm allowing torque measurements at the inner, middle, and outer C-C flexion positions. 2. Dynamometer resistance arm: lever arm and application pad. The lever arm was extended to a distance (D) from the dynamometer axis so that the application pad sat comfortably at the under-surface of the mandible. When the participant performed C-C flexion they exerted a force (F) to the dynamometer application pad at a lever arm distance (D) resulting in torque (T = F x D) at the dynamometer axis. 3. Adjustment housing for dynamometer axis. 4. Load cell deflection arm and Load cell 1- for the measurement of C-C flexor torque. 5. Padded head support platform supported on ball bearings to minimise friction at the point of head contact. 6. Load cell 2- for the measurement of dorsal head force. 7. Web camera. 8. Visual display unit.

**Isometric C-C Flexion Torque Measurement**

The dynamometer has an adjustable axis permitting alignment to the participants’s 0/Cl AOR landmark. The dynamometer resistance arm consists of two metal arms at right
angles. One arm is the lever arm that is extended from the axis to a distance such that the adjoining application pad sat under the inferior border of the participant’s mandible (Figure 1B). This resultant lever arm length was is adjustable to accommodate different sized individuals.

A participant’s C-C flexion effort was resisted at the inferior border of the mandible by the application pad of the dynamometer. The force that the mandible exerted on the application pad was transferred via the lever arm, producing torque at the dynamometer axis that was locked to the load cell deflection arm of the dynamometer. This torque was transferred via the load cell deflection arm to deflect one end of a thin beam load cell (TBS Series\(^1\)) causing a change in voltage across the load cell. The voltage change was amplified (PM4-SG-240-5E-A\(^2\)) and transmitted to a personal computer equipped with a custom written Labview (LabView 6i Virtual Instruments\(^3\)) program calibrated to convert the amplified voltage to the corresponding torque measurement in Newton-meters. The data were recorded and displayed in real time at a rate of 20 Hertz. Additionally the dynamometer axis was adjustable such that it could be freely rotated to the appropriate point in the C-C flexion range and then locked to the load cell deflection arm allowing torque to be measured at the inner, middle, and outer positions of C-C flexion range. To account for the effects of gravity on the lever arm at different positions relative to the horizontal, the Labview software was programmed to negate the effects of gravity on the lever arm prior to any torque measurements. The measurement of torque exerted by a participant to the dynamometer axis could then be accurately measured.

**Dorsal Head Force Measurement**

A secondary feature of the device was a force sensitive supporting surface for the head. Changes in dorsal force on the supporting surface by the head due to flexion (a reduction in force) or extension (an increase in force) of the head and neck together in the sagittal plane was measured by a second load cell (ESP Series\(^4\)) attached under the head platform.

\(^1\) Transducer Techniques, 42480 Rio Nedo, Temecula, CA 92590.
\(^2\) Davidson Measurement Pty. Ltd., 1-3 Lakewood Boulevard, Braeside, VIC, 3195 Australia.
\(^3\) National Instruments Corp, 11500 N Mopac Expressway, Austin, TX 78759.
of the dynamometer. The head platform was secured to one end of the load cell while the other end of the load cell was secured to the bench. The dorsal force that the head exerted on the head platform deflected one end of the load cell causing a change in the voltage across the load cell that was amplified and converted to the appropriate force in Newtons (N). Additionally the supporting surface of the head platform was positioned on ball bearings to allow C-C flexion effort with minimal frictional effects at the head-platform interface.

**Calibration and Linearity of the Instrument**

Amplified voltage outputs of the instrument were recorded for known torque increments at the dynamometer axis, achieved by positioning calibrated weights on the horizontal dynamometer resistance arm at staged distances from the axis. Mass ranging from 0.5 – 15 kilograms was used over lever arm distances of 75 - 135 millimetres. These parameters adequately covered the range of the lever arm length / force variables observed in pilot trials. The relationship between voltage output recordings and torque increments was modeled by linear regression to determine the least squares regression equation for the voltage data. The Labview program used this equation to convert the amplified voltage to the appropriate torque measurements. The accuracy and linearity of the dynamometer / computer software instrument to measure static torque was then tested by reapplying the weights at various lever arm lengths. The relationship between the recorded and expected torque was modeled by linear regression. The measurement system demonstrated excellent linearity (R > 0.99) with minimum offset (−0.072Nm).

**Part II: Test-Retest Reliability Study**

**Participants**

Twenty participants (15 women, 5 men) participated in the study. Participants were recruited via written and electronic advertising within the university. The participants’ mean age was 27.9 years (range 18-47 years) and included 12 individuals with neck pain
and a control group of 8 individuals with no history of neck pain. Both participants with and without neck pain were included as the intended use of the technology is to compare C-C flexor muscle performance between these groups in future studies, and as such the reliability of the method in both participant groups requires investigation. Participants in the neck pain group were included if they were currently suffering neck pain of greater than 3 months duration, scored 10 (out of a possible 100) or greater on the neck disability index (average 20.4, range 0-8), and demonstrated signs of cervical spine dysfunction on a physical examination of the neck. Participants in the control group were included if they reported no history of neck pain, scored less than 10 on the neck disability index (average 3.5, range 12-46), and had no signs of cervical spine dysfunction on a physical examination of the neck. Volunteers were not considered if they demonstrated neck pain from non-musculoskeletal causes, neurological signs, any medical disorder that contraindicated physical exercise, or a history of surgery to the cervical spine. After receiving verbal and written information each participant signed a consent form. This study was granted ethical clearance by the Institute Review Board.

Experimental Procedure

A test-retest design was employed. All 20 participants were tested on two separate occasions spaced two weeks apart to minimise training or fatigue effects between sessions. In each session IMVC recordings were made in the inner, middle, and outer range of C-C flexion. Sustained sub-maximal test recordings (20% and 50% IMVC) were made in the middle range only. The IMVC recordings were always completed first and the order of testing was randomised between participants but was consistent within participants between sessions. The same investigator conducted all measurement sessions.

All tests were performed in a supine position. To minimise the effects of limb movements on C-C flexor muscle performance, the legs were suspended on slings such that the knees and the hips were flexed to 45 degrees and the arms folded across the chest. Soft straps were attached to the supporting surface and were secured lightly over the participant's
shoulders to avoid movement of the trunk on the supporting surface. Alignment of the participant's AOR landmark (concha of the ear) and the dynamometer axis was performed with the head in a neutral C-C flexion/extension position according to a standard anthropometric neutral position of the head (Frankfort Plane - a vertical line bisects the orbitale and the tragion). The dynamometer/participant axes were aligned with the aid of a web camera (QuickCam Pro 4000) erected perpendicular to the axis of the dynamometer (Figure 1). Custom written software (Visual Basic 6.0) permitted the location of anatomical landmarks on the head (AOR landmark and nostril) and dynamometer reference points (dynamometer axis and lever arm) to be recorded from the web camera image and replicated on subsequent sessions.

Once the dynamometer lever arm was fitted in a C-C spine neutral position, the location of the anatomical and dynamometer reference points were recorded as the position for isometric torque measurements in the middle C-C flexion range. For inner range measurements, the participant's head and lever arm was positioned in 10° of head flexion from the neutral position. For outer range measurements, the participant's head and lever arm was positioned in 10° of head extension from the neutral position. The location of the anatomical and lever arm reference points was recorded for each 3 positions in the C-C flexion range. Ten degrees either side of the neutral C-C position was chosen to represent inner and outer C-C flexion ranges based on reported 0/C1 extension to flexion ranges of motion in the vicinity of 20° (18.63° ± 1.51°).

A visual display unit was then set up in the participant's view. When the participant performed a C-C flexion effort against the dynamometer resistance arm, a visual feedback graph was displayed on the screen, increasing or decreasing in accordance with torque production. To avoid bias of performance, the visual feedback graph had no visible units or markings of scale so that for IMVC tests participants were unable to grade visually the distance the graph moved up the screen either between repetitions or between measurement sessions. For sustained sub-maximal tests (20% and 50% IMVC) visual

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1 Logitech, Australia Computer Peripherals Pty Ltd., Level 2, 633 Pittwater Road AUS Dee Why NSW 2099, Australia.
2 Microsoft Corporation, One Microsoft Way, Redmond, WA 98052-6399, USA.
Indicators were then displayed on the visual display unit so that the participant knew how intensely they had to perform a C-C flexor contraction to achieve contraction intensities of 20% and 50% of their peak IMVC effort.

All participants were given standard instructions, familiarisation and a standard warm up in all 3 ranges immediately before the trial in that range. Participants were instructed to nod their head such that their mandible pushed downwards on the application pad of the dynamometer to elevate maximally the visual display column. They were asked and practiced performing the task ensuring that the head remained in contact with the surface upon which it rested, and that the teeth remained occluded to minimise the potential contribution of the mandibular depressors. Warm-up consisted of four sub-maximal repetitions, with each successive repetition at a greater intensity than the previous one and a fifth repetition to their maximal ability. Three IMVC trials were then performed with 60 seconds rest between each maximal effort. Each contraction lasted between 3-5 seconds. Participants were instructed to completely relax between repetitions ensuring no active force was placed on the application pad of the dynamometer until commencement of the next trial. The peak of the 3 IMVC trials was recorded as the IMVC score for the range for the session. Additionally the corresponding change in dorsal head force (at peak torque – resting) was recorded. This was repeated in all 3 ranges (inner, middle, outer) with 5 minutes rest between each range.

A further 5 minutes rest was given before participants performed sustained C-C flexor contractions in the middle range position at 20% and 50% of the middle range IMVC score. Firstly the contraction at 20% of IMVC was sustained for 65 seconds. Two minutes rest was given before the participant sustained the 50% of IMVC for 35 seconds. The participant was allowed 5 seconds to reach the requested isometric C-C flexor torque amplitude in both sustained tests. Data for this initial 5-second period was discarded, and thus data from the sustained tests at 20% and 50% of IMVC were analysed for a 60s and 30s period, respectively.
For all tests, participants were blinded to the measurement of dorsal head force. Instead the focus of the participant was on production of C-C flexion torque with visual and standardised verbal encouragement given.

**Data Management and Statistical Analysis**

For the IMVC tests, means and 95% confidence intervals for both testing sessions (day 1 and 2) were calculated for C-C flexor peak torque and corresponding change in dorsal head force in each range for the symptomatic group, the control group, and for both groups pooled together (pooled data).

The steadiness of the contraction was measured by computing the standard deviation (SD) of the torque amplitude for the 60s and 30s contraction periods, respectively for the sustained tests of 20% and 50% of IMVC. Corresponding dorsal head force data were transformed to a change value in Newtons by calculating the difference between the dorsal head force measurement at rest immediately before commencing the test, and the dorsal head force measurement recorded over the first and final 5-second period of the sustained tests. Means and 95% confidence intervals for both SD and dorsal head force data were calculated for both measurement sessions for the symptomatic group, the control group, and for both groups pooled together (pooled data).

Reliability for all measures was expressed for symptomatic and control groups separately and for pooled data by Intraclass Correlational Coefficients (ICC$^{2,1}$), and Standard Error of the Measurement (SEM) indices.

**Results**

Day means and 95% confidence intervals for C-C flexor IMVC and change in dorsal head force for symptomatic and control groups as well as pooled data are displayed in Table 1. IMVC measurements demonstrated sound test-retest reliability with minimal disparities between the ICC, and SEM reliability coefficients calculated for the
symptomatic and control groups (Table 2). Change in dorsal head force demonstrated at peak torque demonstrated large disparities between the symptomatic and control group reliability coefficients as well as large measurement error. Very poor consistency of the dorsal head force measurement was noted for the control group in the inner range, and for the symptomatic group in the outer range.

Day means and 95% confidence intervals for C-C flexor torque SD and corresponding change in dorsal head force during the sustained tests at 20% and 50% of IMVC for symptomatic and control groups as well as pooled data are displayed in Table 1. As depicted in Table 2, the SD (torque amplitude) measure demonstrated sound reliability for the 20% IMVC test, but large disparities were found between the symptomatic and control groups for the 50% IMVC test, the control group demonstrating very poor reliability coefficients. Dorsal head force measurements at the initial and final 5s periods both had sound test-retest reliability.
Table 1. Group means and 95% confidence intervals (CI) for Day 1 (X₁) and Day 2 (X₂) reliability sessions (inner, middle, outer C-C flexion range) for measurement of C-C flexor IMVC torque (Nm) and corresponding change in dorsal head force (DHF) (N). Data is reported for symptomatic, control, and pooled (symptomatic + control) groups.

<table>
<thead>
<tr>
<th></th>
<th>Symptomatic (n=12)</th>
<th>Control (n=8)</th>
<th>Pooled (n=20)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X₁ (95% CI)</td>
<td>X₂ (95% CI)</td>
<td>X₁ (95% CI)</td>
</tr>
<tr>
<td>IMVC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inner torque (Nm)</td>
<td>8.4 (6.8 - 9.9)</td>
<td>8.4 (6.8 - 10.1)</td>
<td>7.8 (6.3 - 9.2)</td>
</tr>
<tr>
<td>Middle torque (Nm)</td>
<td>10.6 (8.7 - 12.5)</td>
<td>11 (9.1 - 12.8)</td>
<td>9.7 (7.8 - 11.7)</td>
</tr>
<tr>
<td>Outer torque (Nm)</td>
<td>10.5 (8.7 - 12.3)</td>
<td>11 (9.2 - 12.9)</td>
<td>10 (8.5 - 11.5)</td>
</tr>
<tr>
<td>Inner DHF (N)</td>
<td>71.6 (39.2 - 104)</td>
<td>84.3 (55.9 - 113.8)</td>
<td>70.6 (38.2 - 104)</td>
</tr>
<tr>
<td>Middle DHF (N)</td>
<td>53 (25.5 - 80.4)</td>
<td>76.5 (55.9 - 98.1)</td>
<td>81.4 (53 - 109.8)</td>
</tr>
<tr>
<td>Outer DHF (N)</td>
<td>58.8 (16.7 - 101)</td>
<td>68.6 (42.2 - 94.1)</td>
<td>68.6 (36.3 - 102)</td>
</tr>
<tr>
<td>20% IMVC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD (Nm)</td>
<td>0.07 (0.05 - 0.09)</td>
<td>0.06 (0.05 - 0.07)</td>
<td>0.06 (0.04 - 0.08)</td>
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<tr>
<td>DHF first 5s (N)</td>
<td>15.4 (10.3 - 20.5)</td>
<td>15.4 (11.1 - 19.7)</td>
<td>11.5 (5.8 - 17.2)</td>
</tr>
<tr>
<td>DHF final 5s (N)</td>
<td>17.8 (12.6 - 23.4)</td>
<td>17.9 (12.1 - 23.8)</td>
<td>15.5 (9.2 - 21.7)</td>
</tr>
<tr>
<td>50% IMVC</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>SD (Nm)</td>
<td>0.15 (0.11 - 0.19)</td>
<td>0.14 (0.09 - 0.18)</td>
<td>0.12 (0.08 - 0.16)</td>
</tr>
<tr>
<td>DHF first 5s (N)</td>
<td>39.5 (26.1 - 52.9)</td>
<td>45.3 (34.3 - 56.4)</td>
<td>31.9 (21.2 - 42.5)</td>
</tr>
<tr>
<td>DHF final 5s (N)</td>
<td>43.8 (28.4 - 59.3)</td>
<td>49.2 (37.4 - 61)</td>
<td>41.6 (29.3 - 53.8)</td>
</tr>
</tbody>
</table>
Table 2.
Intra-Class Correlational Coefficients (ICC), and Standard Error of the Measurement (SEM) values for the measurements of C-C flexor IMVC (peak torque and corresponding change in dorsal head force (DHF)), and sustained tests at 20% and 50% of IMVC (torque SD and change in DHF over initial and final 5s periods). Values are reported for symptomatic (n=12), control (n=8), and pooled (symptomatic + control) (n=20) data.

<table>
<thead>
<tr>
<th></th>
<th>ICC(2,1)</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Symptomatic</td>
<td>Control</td>
</tr>
<tr>
<td>IMVC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inner torque</td>
<td>0.93</td>
<td>0.89</td>
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<tr>
<td>Middle torque</td>
<td>0.91</td>
<td>0.92</td>
</tr>
<tr>
<td>Outer torque</td>
<td>0.87</td>
<td>0.79</td>
</tr>
<tr>
<td>Inner DHF</td>
<td>0.87</td>
<td>0.49</td>
</tr>
<tr>
<td>Middle DHF</td>
<td>0.79</td>
<td>0.96</td>
</tr>
<tr>
<td>Outer DHF</td>
<td>0.09</td>
<td>0.57</td>
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<tr>
<td>20% IMVC</td>
<td></td>
<td></td>
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<tr>
<td>SD</td>
<td>0.8</td>
<td>0.74</td>
</tr>
<tr>
<td>DHF first 5s</td>
<td>0.86</td>
<td>0.8</td>
</tr>
<tr>
<td>DHF final 5s</td>
<td>0.91</td>
<td>0.77</td>
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<tr>
<td>50% IMVC</td>
<td></td>
<td></td>
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<tr>
<td>SD</td>
<td>0.76</td>
<td>0.07</td>
</tr>
<tr>
<td>DHF first 5s</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>DHF final 5s</td>
<td>0.85</td>
<td>0.82</td>
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</table>
Discussion

The difference between this new method of dynamometry and conventional cervical flexion dynamometry methods is the measurement of torque about the C-C flexion AOR. Previous methods have measured torque about the cervico-thoracic junction\textsuperscript{18,19} that, when unrestrained, results in cervico-thoracic flexion. This new method records torque about the C-C junction that, when unrestrained, results in C-C flexion (i.e., a nodding action of the head on neck). It needs to be acknowledged that resolving torque measurements to a single axis may be an oversimplified model of the multi-articular and multi-muscular C-C spine junction. Notwithstanding this, the alignment of the dynamometer axis to the AOR of O/Cl has been shown in this study to be a consistent method of measuring isometric C-C flexor muscle output and consequently has potential clinical application.

The results of this study demonstrated that this new method has good reliability in the measurement of IMVC (ICC of 0.83-0.92) with a relatively small SEM (0.7-1.1 Nm). These reliability coefficients are similar to those found by Watson and Trott\textsuperscript{16} in their measurement of IMVC force of the C-C flexors ($r = 0.93$) however, unlike our experiment, they\textsuperscript{16} ensured that the dorsal head forces remained steady during C-C flexor force measurements. Dorsal head force was not controlled in this present study and participants were blinded to this measure as we wished to determine the spontaneous dorsal head force response in this preliminary study. A consistent finding across all tests was one of substantial increases in dorsal head force increasing by 154 – 180\% of resting dorsal head force during IMVC tests, and by 38\% and 97\% by the final 5s period of the sustained 20\% and 50\% IMVC tests, respectively. This increase in dorsal head force may be a strategy to improve the neuromuscular efficiency of the C-C flexors to gain maximal torque and to sustain torque over time. In this preliminary investigation this strategy would appear to be an inconsistent response during IMVC tests and a consistent response during sustained sub-maximal tests. Future studies using this new method to compare C-C flexor muscle performance will investigate, in large cohorts of individuals with and without neck pain, if dorsal head force needs to be controlled (as well as the degree of control) to prevent any compromise to the sensitivity of the C-C flexor torque measurement in detecting muscle impairment. We are cautious about adding the control of dorsal head force to
the method as it is expected that it will add complexity to the test and may compromise its potential clinical application.

The reliability of a measure of contraction steadiness during sustained sub-maximal C-C flexor muscle tests was also assessed by computing the standard deviation (SD) of the torque amplitude over the test periods. This measure may reflect the capacity of the C-C flexor muscle group to sustain torque as may be required in prolonged postural tasks. The measurement showed sound reliability for the 20% IMVC test but very poor reliability for the 50% IMVC test. Again the implications of not controlling dorsal head force during these tests are unknown at this stage.

We included both participants with and without a history of neck pain in the study as subsequent studies will compare muscle performance between these groups and it has been suggested that reliability studies should be performed on population groups of concern. The dynamometer appeared to be equally reliable for both participant groups indicating that meaningful comparisons of C-C flexor muscle performance can be made in future studies between neck pain and non-neck pain groups. However, meaningful group comparisons cannot be made regarding C-C flexor muscle performance from this data set as groups were not age, weight, or gender matched. This device appears to have application in the evaluation of neck pain and neck muscle impairment.

The technology described in this report is currently a research tool and is not commercially available for clinical application. Participant to device modifications, the technology has the potential to be used for both C-C flexion and extension as well as for isotonic muscle evaluation, giving it considerable value for future clinical application in assessment and exercise.

**Conclusion**

A new method of dynamometry for the C-C flexor muscles has been described. The new method has been shown to have good reliability in the measurement of IMVC of the C-C flexor muscles at three points in range when dorsal head forces are not controlled. Studies that further investigate the validity of the method as a measurement of C-C flexor muscle performance are required.
References


APPENDIX C – Participant Recruitment

Appendix C.1 - Participant Screening Form

SCREENING EXAMINATION

Name: _______________________________ DOB: _______________________________
Address: _______________________________
Phone: Home __________________ Work __________________ Mobile __________________
Sex: ___________________ Occupation: ___________________
Date: ___________________ Affected Side: ___________________

[Diagram of human anatomy showing P&N, Numb, and VBI]

Aggravating Factors: ___________________ Current History: ___________________

24 HR: ___________________ Past History: ___________________
Physical Examination

Posture:

Active movement:

Flexion upper
Extension upper
Rotation upper
Lateral flexion

Articular Findings:

PPIVMS:
PAIVMS:

Other palpation findings:

Muscle function:

INCLUSION: YES / NO
Appendix C.2 - Neck Disability Index

The NDI is a 10-item self-reporting instrument for the assessment of physical disability of participants with neck pain and has been shown to be reliable and sensitive to severity levels and to changes in severity over time (Vernon and Mior 1991; Stratford et al. 1999). NDI disability categories when scaled out of a possible 100 points are 0-8 (no disability), 10-28 (mild disability), 30-48 (moderate disability), 50-68 (severe disability), 68+ (complete disability). Changes in the NDI of 10 points or more are considered to be clinically meaningful (Stratford et al. 1999).

Neck Disability Index

This questionnaire has been designed to give us information as to how your neck pain has affected your ability to manage in everyday life. Please answer every section and mark in each section only the one box that applies to you. We realise you may consider that two or more statements in any one section relate to you, but please just mark the box that most closely describes your problem.

Section 1: Pain Intensity
- □ I have no pain at the moment
- □ The pain is very mild at the moment
- □ The pain is moderate at the moment
- □ The pain is fairly severe at the moment
- □ The pain is very severe at the moment
- □ The pain is the worst imaginable at the moment

Section 2: Personal Care (Washing, Dressing, etc.)
- □ I can look after myself normally without causing extra pain
- □ I can look after myself normally but it causes extra pain
- □ It is painful to look after myself and I am slow and careful
- □ I need some help but can manage most of my personal care
- □ I need help every day in most aspects of self care
- □ I do not get dressed, I wash with difficulty and stay in bed

Section 3: Lifting
- □ I can lift heavy weights without extra pain
- □ I can lift heavy weights but it gives extra pain
- □ Pain prevents me lifting heavy weights off the floor, but I can manage if they are conveniently placed, for example on a table
- □ Pain prevents me from lifting heavy weights but I can manage light to medium weights if they are conveniently positioned
- □ I can only lift very light weights
- □ I cannot lift or carry anything
Section 4: Reading
- I can read as much as I want to with no pain in my neck
- I can read as much as I want to with slight pain in my neck
- I can read as much as I want with moderate pain in my neck
- I can’t read as much as I want because of moderate pain in my neck
- I can hardly read at all because of severe pain in my neck
- I cannot read at all

Section 5: Headaches
- I have no headaches at all
- I have slight headaches, which come infrequently
- I have moderate headaches, which come infrequently
- I have moderate headaches, which come frequently
- I have severe headaches, which come frequently
- I have headaches almost all the time

Section 6: Concentration
- I can concentrate fully when I want to with no difficulty
- I can concentrate fully when I want to with slight difficulty
- I have a fair degree of difficulty in concentrating when I want to
- I have a lot of difficulty in concentrating when I want to
- I have a great deal of difficulty in concentrating when I want to
- I cannot concentrate at all

Section 7: Work
- I can do as much work as I want to
- I can only do my usual work, but no more
- I can do most of my usual work, but no more
- I cannot do my usual work
- I can hardly do any work at all
- I can’t do any work at all

Section 8: Driving
- I can drive my car without any neck pain
- I can drive my car as long as I want with slight pain in my neck
- I can drive my car as long as I want with moderate pain in my neck
- I can’t drive my car as long as I want because of moderate pain in my neck
- I can hardly drive at all because of severe pain in my neck
- I can’t drive my car at all

Section 9: Sleeping
- I have no trouble sleeping
- My sleep is slightly disturbed (less than 1 hr sleepless)
- My sleep is mildly disturbed (1-2 hrs sleepless)
- My sleep is moderately disturbed (2-3 hrs sleepless)
- My sleep is greatly disturbed (3-5 hrs sleepless)
- My sleep is completely disturbed (5-7 hrs sleepless)
Section 10: Recreation

- I am able to engage in all my recreation activities with no neck pain at all
- I am able to engage in all my recreation activities, with some pain in my neck
- I am able to engage in most, but not all of my usual recreation activities because of pain in my neck
- I am able to engage in a few of my usual recreation activities because of pain in my neck
- I can hardly do any recreation activities because of pain in my neck
- I can't do any recreation activities at all

Score: /50 Transform to percentage score x 100 = %points

Scoring: For each section the total possible score is 5: if the first statement is marked the section score = 0, if the last statement is marked it = 5. If all ten sections are completed the score is calculated as follows: Example: 16 (total scored) 50 (total possible score) x 100 = 32% If one section is missed or not applicable the score is calculated: 16 (total scored) 45 (total possible score) x 100 = 35.5% Minimum Detectable Change (90% confidence): 5 points or 10 %points

APPENDIX D – Ethics Documents

Appendix D.1 - Ethical Clearance Statement For Preliminary Study and Proof of Concept Study

### Institutional Approval Form For Experiments On Humans Including Behavioural Research

<table>
<thead>
<tr>
<th>Chief Investigator:</th>
<th>Shaun Patrick O’Leary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Title:</td>
<td>The immediate effects of specific therapeutic exercise on the pain system and the muscular system - 02/06/03 - AMENDMENT</td>
</tr>
<tr>
<td>Supervisor:</td>
<td>Dr Bill Vicenzino, A/Prof Gwendolen Jull, Ms Tina Savills</td>
</tr>
<tr>
<td>Co-Investigator(s):</td>
<td>Mr Trevor Russell, Mr Atit Paungmali, A/Prof Paul Hodges, Ms Deborah Falla</td>
</tr>
<tr>
<td>Department(s):</td>
<td>Physiotherapy</td>
</tr>
<tr>
<td>Project Number:</td>
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<tr>
<td>Granting Agency/Degree:</td>
<td>PhD</td>
</tr>
<tr>
<td>Duration:</td>
<td>07th May 2006</td>
</tr>
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</table>

**Comments:**

Change of title to: Dynamometry of the cranio-cervical flexor muscles in neck pain.

**Name of responsible Committee:**
Medical Research Ethics Committee

This project complies with the provisions contained in the National Statement on Ethical Conduct in Research Involving Humans and complies with the regulations governing experimentation on humans.

**Name of Ethics Committee representative:**
Dr David Jenkins
Deputy Chairperson
Medical Research Ethics Committee

Date 3rd June 2003
Signature [Signature]
PARTICIPANT INFORMATION SHEET

TITLE: Reliability of the craniocervical flexor dynamometer in measuring craniocervical flexor muscle performance.

LAY TITLE: An evaluation of the accuracy of the repeated measures of neck muscle performance using a special testing device.

INVESTIGATORS:
Mr. Shaun O'Leary, PhD Candidate, Department of Physiotherapy, UQ.
Mr. Trevor Russell, PhD Student, Department of Physiotherapy, UQ.
Dr. Bill Vicenzino, PhD, Department of Physiotherapy, UQ. (Supervisor)
Ms Tina Souvlis, PhD Student, Physiotherapy Department, UQ. (Associate Supervisor)
Associate Professor Gwendolen Jull, PhD, Department of Physiotherapy, UQ. (Associate supervisor)

Aims and Objectives
The main aim of this research is to evaluate the accuracy and consistency of a testing device to measure your neck muscle performance repeatedly over several testing sessions. There is evidence that certain neck muscles in the front of the neck are weak in individuals suffering from painful chronic neck conditions and that exercise for these muscles relieves the pain associated with these neck disorders. This study will evaluate the ability of a device used to test neck muscle performance.

Your Involvement
To participate in the study you will need to attend up to three sessions at the University of Queensland. Each session will take approximately 1 hour. All procedures will be conducted in The Musculoskeletal Pain and Injury Research Unit, room 525, level 5, Department of Physiotherapy, Therapies Building, The University of Queensland, St. Lucia.
If you choose to participate in this study, the following assessments will be conducted:

**Assessment of the neck:** This will occur in the first session only and is the screening test to exclude neck problems. You will be required to answer questions regarding your neck and to fill out neck pain and disability questionnaires. A physical assessment of your neck will then be performed to determine if any joint and muscle dysfunction exists. These tests are all performed by an experienced manipulative physiotherapist.

**Craniocervical flexion muscle strength:** This test will be performed using specialized equipment designed to test the strength of your muscles at the front of your neck that perform a nodding ‘yes’ action. Soft velcro straps will be used to minimise movement between your trunk and the supporting surface and the chin bar and your head. You will be given instructions on the testing procedure using the dynamometer. You will then be given five practice trials as a warm up. Formal trials of muscle strength testing will then commence. You will be asked to perform the craniocervical flexion action against the resistance of the dynamometer increasing the force until you feel you have reached your maximal force. Each contraction will last between three to five seconds. The equipment used has force transducers attached to it and will give a read out of the muscle strength produced by your muscle contraction. After you have relaxed you will then be asked to record on a scale the level of exertion (see Borg scale below) you felt during the muscle testing. Three muscle maximal contractions will be performed. You will be given 1 minute rest between each contraction. All muscle strength assessments will be supervised by an experienced musculoskeletal physiotherapist trained in these procedures.

**Craniocervical flexion muscle endurance:** In this test we will determine how well your muscles can maintain a contraction over a specified time. This test has the same setup as for the above craniocervical flexion strength tests. Except this time we ask to reach a specified level of contraction and to maintain it for a period of time. A visual display unit will indicate the correct intensity of contraction. Two endurance tests will be performed in the middle range. The first will be at a low intensity level (20% of your maximal strength) and will be sustained for up to 60 seconds, the second will be at a moderate intensity level (50% of your maximal strength) and will be maintained
for up to 30 seconds. You will be given 2 minutes rest between each contraction. You will be asked to rate your perceived level of exertion following each contraction using a modified borg scale.

**Modified Borg Scale:** This is a scale used to score the level of exertion you felt you performed an exercise at. The scale consists of 10 intervals ranking from 0 (nothing at all) to 10 (very, very, strong). This scale will indicate to the investigators the level of exertion that you experienced during the contractions.

The data will be collected by the investigator and kept in our laboratory. Any personal information, medical history, or test results obtained from this experiment will be treated with the utmost confidentiality. Any publications resulting from this experiment will reveal the information in a manner which does not identify you. You have the opportunity to take a member of the family or a friend to be present while the project is explained to you and your privacy during participating in the study will be maintained at all times. You have the opportunity to withdraw from the study at any time without giving any reason. On request, feedback of individual assessment results and a summary of the overall measurement parameters will be available at the completion of data collection.

You are requested to avoid heavy exercise 4 hours prior to the experiment. If this is unavoidable, please inform the researcher and your testing time will be rescheduled. Mild levels of discomfort associated with maximal muscle contractions may be reproduced during the testing procedure but this should be short lived. Should any discomfort or pain be felt over an extended period of time you are required to inform the investigator who will arrange follow up care. There is minimal likelihood of injury as all exercises are performed following warm up procedures. If you feel discomfort, please tell the investigators immediately.

This research project is designed to obtain information that may benefit individuals with neck related pain syndromes but not necessarily you as a participant. Participation in the study may not benefit you directly. If you have any questions regarding further details of the research, please feel free to contact Mr. Shaun O'Leary on contact number (07) 3365 4567 or Dr. Bill Vicenzino of contact number (07) 3365 2781. We will be happy to provide more information for participants.
This study has been approved by one of the human ethics committees of The University of Queensland in accordance with the National Health and Medical Research Council's guidelines. Whilst you are free to discuss your participation in this study with project staff (Mr. Shaun O'Leary - (07) 3365 4567 (0407746299), Dr. Bill Vicenzino - (07) 3365 2781 (0409267247), if you would rather speak to an officer of the University not involved in the study, you may contact the Assistant Ethics Officer or Ethics Officer on (07) 3365 3924.

Thankyou for your interest in this research project.

Mr. Shaun O'Leary, Ph.D. Student of Physiotherapy, The University of Queensland.

Dr. Bill Vicenzino, Senior Lecturer, Department of Physiotherapy, The University of Queensland (Supervisor).
PARTICIPANT CONSENT FORM

TITLE: Reliability of the craniocervical flexor dynamometer in measuring craniocervical flexor muscle performance.

LAY TITLE: An evaluation of the accuracy of the repeated measures of neck muscle performance using a special testing device.

INVESTIGATORS:
Mr. Shaun O'Leary, PhD Candidate, Department of Physiotherapy, UQ.
Mr. Trevor Russell, PhD Student, Department of Physiotherapy, UQ.
Dr. Bill Vicenzino, PhD, Department of Physiotherapy, UQ.(Supervisor)
Ms Tina Souvlis, PhD Student, Physiotherapy Department, UQ.(Associate Supervisor)
Associate Professor Gwendolen Jull, PhD, Department of Physiotherapy, UQ.(Associate Supervisor)

I, _____________________________________________ (PLEASE PRINT) hereby consent to take part in the research project titled: Reliability of the craniocervical flexor dynamometer in measuring craniocervical flexor muscle performance.

I acknowledge that I have ready the participant information sheet provided, and that I have had the project, so far as it affects me, fully explained to my satisfaction by the investigators. I freely consent to my participation in the project.

The details of the procedure proposed has also been explained to me, including the anticipated length of time it will take, the frequency with which the tests will be performed, and an indication of any discomfort or possible risks which may be expected. I understand that the tests to be taken are as follows:

Assessment of the neck
Craniocervical flexion muscle strength
Craniocervical flexion muscle endurance
Although I understand that the purpose of this research is to improve the quality of medical care, it has also been explained that this is a research project and not a treatment program, and my involvement may not be of any direct benefit to me. I have the opportunity to have a member of my family or friend present while the project was explained to me. I give permission to the investigators to perform the tests described in the participant information sheet. I am informed that any parts of my personal history, medical records or the results of any tests involving me will be published in a manner which does not identify me and my privacy will be adhered to at all times. I have informed that I am free to withdraw from the study at any time without giving any reasons and it will not affect in any way of clinical management of my condition.

Signed: _____________________________ Date: ________________
(participant)

Signed: _____________________________ Date: ________________
(witness)

This study has been approved by one of the human ethics committees of The University of Queensland in accordance with the National Health and Medical Research Council’s guidelines. Whilst you are of course, free to discuss your participation in this study with the project staff (Mr. Shaun O'Leary - (07) 3365 4567 (0407746299), Dr. Bill Vicenzino - (07) 3365 2781), if you would like to speak to an officer of the university not involved in the study, you may contact the Assistant Ethics Officer or the Ethics officer on (07) 3365 3924.
PARTICIPANT INFORMATION SHEET

TITLE: Comparison of EMG activity of the anterior neck muscles during craniocervical flexion dynamometry versus cervical flexion dynamometry

LAY TITLE: An evaluation the muscles used during nodding of the head versus bending of the neck.

INVESTIGATORS:
Mr. Shaun O'Leary, PhD Student, Department of Physiotherapy, UQ.
Ms Deborah Falla, PhD Student, Department of Physiotherapy, UQ.
Dr. Bill Vicenzino, PhD, Department of Physiotherapy, UQ. (Supervisor)
Ms Tina Souvlis, PhD Student, Physiotherapy Department, UQ. (Associate Supervisor)
Associate Professor Gwendolen Jull, PhD, Department of Physiotherapy, UQ. (Associate supervisor)

Aims and Objectives
The main aim of this research is to evaluate the muscle usage when using two different devices to test the performance of the anterior neck muscles. There is evidence that certain neck muscles in the front of the neck are weak in individuals suffering from painful chronic neck conditions and that exercise for these muscles relieves the pain associated with these neck disorders. This study will evaluate which muscles are primarily being tested when using the two different devices.

Your Involvement
To participate in the study you will need to attend 1 session (approximately 1.5 hours duration) at the University of Queensland. All procedures will be conducted in The Musculoskeletal Pain and Injury Research Unit, room 525, level 5, Department of Physiotherapy, Therapies Building, The University of Queensland, St. Lucia.
If you choose to participate in this study, the following assessment procedure will be conducted:
Assessment of the neck:
You will be required to answer questions regarding your neck. A physical assessment of your neck will then be performed to determine if any joint and muscle dysfunction exists. This assessment of your neck is performed by an experienced musculoskeletal physiotherapist. Following the assessment of your neck we will instruct you on the dynamometry muscle performance procedures and give formal practice trials.

Familiarisation of dynamometry procedures:
These tests will be performed using specialized equipment designed to test the performance of your muscles at the front of your neck. The equipment used has force transducers attached to it and will give a read out of the muscle strength produced by your muscle contraction. You will first be given instructions on the testing procedure using the dynamometer and you will then be positioned on the device. Soft velcro straps will be used to minimise movement between your trunk and the supporting surface. You will then be given practice trials using each dynamometer as a warm up and to ensure that you are familiar with the procedure. You may first be asked to perform a rolling action of your head on the neck against a padded bar under your chin. This is the craniocervical flexion test. In the next test you will be asked to lift your head against the resistance of a padded bar across your forehead. This is the general cervical flexion test. During this familiarisation process we will practice both maximal voluntary contractions (maximal muscle contraction efforts) and sustained muscle contraction efforts at intensity levels of 20% and 50% of your maximal capabilities. A visual display unit will allow you to contract the muscles at the appropriate intensity levels. We will practice these procedures until you are familiar with the procedure. We will then attach the surface electromyography electrodes.

Surface electromyography:
To measure activity of muscles immediately under the skin surface electrodes will be placed on the skin overlying the muscles. Your skin will be cleaned with alcohol prior to attachment of self-adhesive electrodes to the skin. You will then be positioned on the dynamometer again and the electrode for the deep anterior neck muscles will be positioned.

EMG of the deep anterior neck muscles:
Recent work in the Department of Physiotherapy has led to the development of a new method, which will allow a direct measure of the deep neck muscles to be obtained. The electrodes are attached to the end of a small flexible tube, which is passed through the nose so that the tip of the tube lies on the back of the throat (just behind the tonsils). The electrodes are maintained on the back of the throat by a gentle suction pressure applied through the tube. The deep neck flexor muscles lie directly behind the back of the throat and therefore any deep muscle activity will be detected and recorded using this apparatus. Positioning the catheter in this way is very similar to a technique (called naso-pharyngeal suctioning) frequently used by physiotherapists in hospitals and therefore has very little risk attached to it. An anaesthetic spray will be applied to the back of your throat and nose to minimise any mild discomfort associated with this procedure. On the following page are a list of precautions and contraindications to having this procedure performed. Please notify the investigator if you have any of the following. Once the catheter is comfortably positioned we will commence dynamometry muscle testing procedures.

Dynamometry muscle tests:
Before any tests are performed with the dynamometer you will be asked to perform a chin tuck and head lift during which the EMG activity of your muscles will be recorded. This will be used to standardise all other EMG recordings. You will then perform tests of maximal voluntary contraction and endurance tests as practiced during the familiarisation test.

Modified Borg Scale:
This is a scale used to score the level of exertion you felt you performed an exercise at. The scale consists of 10 intervals ranking from 0 (nothing at all) to 10 (very, very, strong). This scale will indicate to the investigators the level of exertion that you experienced during the muscle contractions.

Precautions and Contraindications to the use of the Anaesthetic Spray:

I. Trauma or sepsis in the area of application (nostril and back of throat)
II. Various medical conditions:
    epilepsy
    impaired cardiac conduction
bradycardia
impaired liver function
severe kidney dysfunction

III. Pregnancy
IV. Various medications
antiarrhythmic drugs
enzyme-inducing drugs
antiepileptic drugs, eg phenytion

Individuals who met any of these criteria will be exempt from participating in this research.

Potential Risks of the Procedures:

Adverse Reactions to Anaesthetic Spray: The anaesthetic spray used in this project is a non-prescription medication and its use in this research is compatible with the intended use of the drug. The dosage to be applied in the study is less than one third of the maximum dosage for application of catheters and instruments into the respiratory tract. Adverse effects of the medication are documented as rare and risk of adverse effects are minimised by the exclusion criteria, use of low doses of the medication.

Although adverse responses are rare, possible reactions include: light-headedness, apprehension, euphoria, confusion and drowsiness, dizziness, vomiting, convulsions and in the worst case scenario, unconsciousness and respiratory arrest. Cardiovascular reactions include hypotension, myocardial depression, bradycardia and in extremely rare cases a cardiac arrest.

There have been some accounts of a local reaction at the application site. Sore throat and hoarseness of the voice have been reported post-laryngeal application. However, these symptoms should not occur as the anaesthetic will be applied to a localised area at the back of the throat, otherwise known as the pharynx.

Anaesthesia of the mouth can interfere with swallowing and consequently the risk of aspiration is increased. You will therefore be asked to avoid both food and drink for a duration of sixty minutes following testing. The anaesthetic also has the potential to have a mild effect on mental function and coordination, even though the doses used in
this study would be unlikely to cause such effects. Again as a precaution, you will be asked to avoid driving and / or the operation of machinery for sixty minutes after application.

Given the precautionary steps used prior to its application, the use of the anaesthetic in this study would be considered safe.

**Adverse reactions to muscle tests:** Maximal muscle tests have the potential risk of muscle strains. There is minimal likelihood of injury as all exercises are performed following warm up procedures. If you feel discomfort, please tell the investigators immediately.

Due to the muscle testing procedures you may experience aggravation of your symptoms following the testing procedures however these should be short lived. Should any discomfort or pain be felt over an extended period of time you are required to inform the investigator who will arrange follow up care.

You are requested to avoid heavy exercise 4 hours prior to the experiment. If this is unavoidable, please inform the researcher and your testing time will be rescheduled.

**Privacy of information:** The data will be collected by the investigator and kept in our laboratory. Any personal information, medical history, or test results obtained from this experiment will be treated with the upmost confidentiality. Any publications resulting from this experiment will reveal the information in a manner which does not identify you. You have the opportunity to take a member of the family or a friend to be present while the project is explained to you and your privacy during participating in the study will be maintained at all times. You have the opportunity to withdraw from the study at any time without giving any reason. On request, feedback of individual assessment results and a summary of the overall measurement parameters will be available at the completion of data collection.

This research project is designed to obtain information that may benefit individuals with neck related pain syndromes but not necessarily you as a participant. Participation in the study may not benefit you directly. If you have any questions regarding further details of the research, please feel free to contact Mr. Shaun O'Leary on contact number (07) 3365 4587 or Dr. Bill Vicenzino of contact number (07) 3365 2781. We will be happy to provide more information for participants.
This study has been approved by one of the human ethics committees of The University of Queensland in accordance with the National Health and Medical Research Council's guidelines. Whilst you are free to discuss your participation in this study with project staff (Mr. Shaun O'Leary - (07) 3365 4587 (0407746299), Dr. Bill Vicenzino - (07) 3365 2781 (0409267247), if you would rather speak to an officer of the University not involved in the study, you may contact the Assistant Ethics Officer or Ethics Officer on (07) 3365 3924.

Thankyou for your interest in this research project.

Mr. Shaun O'Leary, Ph.D. Student of Physiotherapy, The University of Queensland.

Dr. Bill Vicenzino, Senior Lecturer, Department of Physiotherapy, The University of Queensland (Supervisor).
PARTICIPANT CONSENT FORM

TITLE: Comparison of EMG activity of the anterior neck muscles during craniocervical flexion dynamometry versus cervical flexion dynamometry

LAY TITLE: An evaluation the muscles used during nodding of the head versus bending of the neck.

INVESTIGATORS:

Mr. Shaun O'Leary, PhD Candidate, Department of Physiotherapy, UQ.
Ms. Deborah Falla, PhD Student, Department of Physiotherapy, UQ.
Dr. Bill Vicenzino, PhD, Department of Physiotherapy, UQ.(Supervisor)
Ms Tina Souvlis, PhD Student, Physiotherapy Department, UQ.(Associate Supervisor)
Associate Professor Gwendolen Jull, PhD, Department of Physiotherapy, UQ.(Associate Supervisor)

I, ________________________________ (PLEASE PRINT) hereby consent to take part in the research project titled: Comparison of EMG activity of the anterior neck muscles during craniocervical flexion dynamometry versus cervical flexion dynamometry

I acknowledge that I have ready the participant information sheet provided, and that I have had the project, so far as it affects me, fully explained to my satisfaction by the investigators. I freely consent to my participation in the project.

The details of the procedure proposed has also been explained to me, including the anticipated length of time it will take, the frequency with which the tests will be performed, and an indication of any discomfort or possible risks which may be expected. I understand that the tests to be taken are as follows:

Assessment of the neck
Dynamometry of the neck muscles.
Surface electromyography
Electromyography of the deep anterior neck muscles
Modified Borg Scale

Although I understand that the purpose of this research is to improve the quality of medical care, it has also been explained that this is a research project and not a treatment program, and my involvement may not be of any direct benefit to me.
I have the opportunity to have a member of my family or friend present while the project was explained to me.
I give permission to the investigators to perform the tests described in the participant information sheet.
I am informed that any parts of my personal history, medical records or the results of any tests involving me will be published in a manner which does not identify me and my privacy will be adhered to at all times.
I have informed that I am free to withdraw from the study at any time without giving any reasons and it will not affect in any way of clinical management of my condition.

Signed: ________________________  Date: ______________
(participant)

Signed: ________________________  Date: ______________
(witness)

This study has been approved by one of the human ethics committees of The University of Queensland in accordance with the National Health and Medical Research Council’s guidelines. Whilst you are of course, free to discuss your participation in this study with the project staff (Mr. Shaun O'Leary - (07) 3365 4587 (0407746299), Dr. Bill Vicenzino - (07) 3365 2781), if you would like to speak to an officer of the university not involved in the study, you may contact the Assistant Ethics Officer or the Ethics officer on (07) 3365 3924.
Institutional Approval Form For Experiments On Humans Including Behavioural Research

Chief Investigator: Shaun Patrick O'Leary
Project Title: Dynamometry of the cranio-cervical flexor muscles in neck pain - 07/10/03 - AMENDMENT
Supervisor: Dr Bill Vicenzino, A/Prof Gwendolen Julj, Ms Tina Souvlis
Co-Investigator(s): Mr Trevor Russell, Mr Atit Paungmali, A/Prof Paul Hodges, Ms Deborah Falla
Department(s): Physiotherapy
Project Number: 2002000741
Granting Agency/Degree: Physiotherapy Research Foundation Grant 2002/PhD
Duration: 07th May 2006

Comments:

Name of responsible Committee:- Medical Research Ethics Committee
This project complies with the provisions contained in the National Statement on Ethical Conduct in Research Involving Humans and complies with the regulations governing experimentation on humans.

Name of Ethics Committee representative:- Dr David Jenkins
Deputy Chairperson
Medical Research Ethics Committee

Date 14/10/03 Signature [Signature]

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PARTICIPANT INFORMATION SHEET

TITLE: The validity of dynamometry to measure cranio-cervical flexor muscle performance.


INVESTIGATORS:
Mr. Shaun O'Leary, PhD Student, Department of Physiotherapy, UQ.
Dr. Bill Vicenzino, PhD, Department of Physiotherapy, UQ. (Supervisor)
Assoc. Professor Gwendolen Jull, PhD, Department of Physiotherapy, UQ. (Supervisor)
Ms Tina Souvlis, PhD Student, Physiotherapy Department, UQ. (Associate Supervisor)

The main aim of this research is to evaluate the ability of a testing device to measure your neck muscle performance. To participate in the study you will need to attend up to three sessions at the University of Queensland. Each session may take approximately 30-60 minutes. All procedures will be conducted in the Musculoskeletal Pain and Injury Research Unit, room 525, level 5, Department of Physiotherapy, The University of Queensland. If you choose to participate in this study the following assessments will be conducted by an experienced Musculoskeletal Physiotherapist trained in these procedures.

Neck Assessment: You will be required to answer questions regarding your neck and to fill out neck pain and disability questionnaires. A physical assessment of your neck will be performed to determine if any joint and muscle dysfunction exists.

Neck muscle strength: The purpose of this test is to measure the strength of the muscles at the front of your neck. You will be asked to perform a ‘Nodding Yes’ action of your head such that your jaw pushes down on the padded bar of the
dynamometer increasing the force until you feel you have reached your maximal force. Each contraction will last between 3-5 seconds. Three trials will be performed with a 60 second rest period between each trial. The equipment used has force transducers attached to it and will give a read out of the muscle strength produced by your muscle contraction. After you have relaxed you will then be asked to rate on a scale the level of exertion (see Borg scale below) you felt during the muscle testing.

**Neck muscle endurance:** The purpose of these tests is to measure the time period that your muscles can sustain a contraction before they become fatigued. These tests are performed in the same position as for the strength tests except this time we ask you to reach a specified level of contraction and to maintain it for as long as you can. A visual display unit will indicate the correct intensity of contraction. Two endurance tests will be performed. In the first endurance test you will be asked to sustain a low intensity level muscle contraction (20% of your maximal strength) for as long as you can. In the second endurance test you will be asked to maintain a moderate intensity muscle contraction (50%) for as long as you can. 10 minutes rest will be given between these two tests. Following each test you will be asked to rate your perceived level of exertion on the Modified Borg Scale (see below).

**Modified Borg Scale:** This is a scale used to score your level of exertion during a test. The scale consists of 10 intervals ranking from 0 (nothing at all) to 10 (very, very, strong). This scale will indicate to the investigators the level of exertion that you experienced during the contractions.

**Privacy of Information:**
The data will be collected by the investigator and kept in our laboratory. Any personal information, medical history, or test results obtained from this experiment will be treated with the upmost confidentiality. Any publications resulting from this experiment will reveal the information in a manner which does not identify you. You have the opportunity to take a member of the family or a friend to be present while the project is explained to you and your privacy during participating in the study will be maintained at all times. You have the opportunity to withdraw from the study at any time without giving any reason. On request, feedback of individual assessment results and a summary of the overall measurement parameters will be available at the completion of data collection.
Potential Risks of the Procedures:
Maximal muscle tests have the potential risk of muscle strains. There is minimal likelihood of injury as all exercises are performed following warm up procedures. If you feel discomfort, please tell the investigators immediately.

Due to the muscle testing procedures you may experience aggravation of your symptoms following the testing procedures however these should be short lived. Should any discomfort or pain be felt over an extended period of time you are required to inform the investigator who will arrange follow up care.

This research project is designed to obtain information that may benefit individuals with neck related pain syndromes but not necessarily you as a participant. Participation in the study may not benefit you directly. If you have any questions regarding further details of the research, please feel free to contact Mr. Shaun O'Leary on contact number (07) 3365 4587 or Dr. Bill Vicenzino of contact number (07) 3365 2781. We will be happy to provide more information for participants.

This study has been approved by one of the human ethics committees of The University of Queensland in accordance with the National Health and Medical Research Council's guidelines. Whilst you are free to discuss your participation in this study with project staff (Mr. Shaun O'Leary - (07) 3365 4587 (0407746299), Dr. Bill Vicenzino - (07) 3365 2781 (0409267247), if you would rather speak to an officer of the University not involved in the study, you may contact the Assistant Ethics Officer or Ethics Officer on (07) 3365 3924.

Thankyou for your interest in this research project.

Mr. Shaun O'Leary, Ph.D. Student of Physiotherapy, The University of Queensland.

Dr. Bill Vicenzino, Senior Lecturer, Department of Physiotherapy, The University of Queensland (Supervisor).
PARTICIPANT CONSENT FORM

TITLE: The validity of dynamometry to measure cranio-cervical flexor muscle performance.


INVESTIGATORS:

Mr. Shaun O'Leary, PhD Student, Department of Physiotherapy, UQ.
Dr. Bill Vicenzino, PhD, Department of Physiotherapy, UQ. (Supervisor)
Associate Professor Gwendolen Jull, PhD, Department of Physiotherapy, UQ. (Supervisor)
Ms Tina Souvlis, PhD Student, Physiotherapy Department, UQ.(Associate Supervisor)

I, ____________________________ (PLEASE PRINT) hereby consent to take part in the research project titled: The validity of dynamometry to measure cranio-cervical flexor muscle performance.

I acknowledge that I have ready the participant information sheet provided, and that I have had the project, so far as it affects me, fully explained to my satisfaction by the investigators. I freely consent to my participation in the project.

The details of the procedure proposed has also been explained to me, including the anticipated length of time it will take, the frequency with which the tests will be performed, and an indication of any discomfort or possible risks which may be expected. I understand that the tests to be taken are as follows:

Neck assessment
Neck muscle strength
Neck muscle endurance
Modified Borg scale

Although I understand that the purpose of this research is to improve the quality of medical care, it has also been explained that this is a research project and not a treatment program, and my involvement may not be of any direct benefit to me.
I have the opportunity to have a member of my family or friend present while the project was explained to me.
I give permission to the investigators to perform the tests described in the participant information sheet.
I am informed that any parts of my personal history, medical records or the results of any tests involving me will be published in a manner which does not identify me and my privacy will be adhered to at all times.
I have informed that I am free to withdraw from the study at any time without giving any reasons and it will not affect in any way of clinical management of my condition.

Signed: ____________________________ Date: ________________
(participant)

Signed: ____________________________ Date: ________________
(witness)

This study has been approved by one of the human ethics committees of The University of Queensland in accordance with the National Health and Medical Research Council’s guidelines. Whilst you are of course, free to discuss your participation in this study with the project staff (Mr. Shaun O'Leary - (07) 3365 4587 (0407746299), Dr. Bill Vicenzino - (07) 3365 2781), if you would like to speak to an officer of the university not involved in the study, you may contact the Assistant Ethics Officer or the Ethics officer on (07) 3365 3924.
APPENDIX E – Modified Borg Scale

0  Nothing at all

0.5  Very, very weak  (just noticeable)

1  Very weak

2  Weak  (light)

3  Moderate

4  Somewhat strong

5  Strong  (heavy)

6

7  Very strong

8

9

10  Very, very strong  (almost max)

*  Maximal
APPENDIX F - Results

Appendix F.1 – Result Table from Preliminary Study (Chapter 3)

Table F.1.1 Independent t-test comparison (symptomatic n = 32, control n = 32, groups) for the measurements of IMVC peak torque, and change in DHF during the stages of the IMVC, IMVC<sub>20</sub>, and IMVC<sub>50</sub> tests (df = 62).

<table>
<thead>
<tr>
<th>Measures</th>
<th>Mean Diff</th>
<th>Std. Error</th>
<th>95% CI</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMVC Peak Torque</td>
<td>-0.55</td>
<td>0.96</td>
<td>-2.47 – 1.37</td>
<td>-0.57</td>
<td>0.57</td>
</tr>
<tr>
<td>DHF Measures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At rest</td>
<td>-0.03</td>
<td>0.17</td>
<td>-0.37 – 0.3</td>
<td>-0.19</td>
<td>0.85</td>
</tr>
<tr>
<td>IMVC - peak torque</td>
<td>-0.99</td>
<td>1.13</td>
<td>-3.25 – 1.27</td>
<td>-0.88</td>
<td>0.38</td>
</tr>
<tr>
<td>IMVC&lt;sub&gt;20&lt;/sub&gt; - 5 s</td>
<td>-0.11</td>
<td>0.28</td>
<td>-0.68 – 0.46</td>
<td>-0.39</td>
<td>0.7</td>
</tr>
<tr>
<td>IMVC&lt;sub&gt;20&lt;/sub&gt; - 65 s</td>
<td>-0.04</td>
<td>0.38</td>
<td>-0.81 – 0.72</td>
<td>-0.11</td>
<td>0.91</td>
</tr>
<tr>
<td>IMVC&lt;sub&gt;50&lt;/sub&gt; - 5 s</td>
<td>-0.0005</td>
<td>0.61</td>
<td>-1.22 – 1.22</td>
<td>-0.001</td>
<td>0.99</td>
</tr>
<tr>
<td>IMVC&lt;sub&gt;50&lt;/sub&gt; - 35 s</td>
<td>-0.28</td>
<td>0.63</td>
<td>-0.98 – 1.54</td>
<td>0.45</td>
<td>0.66</td>
</tr>
</tbody>
</table>
Table F.2.1 Paired t-test comparison of the normalised root-mean-square values for the longus capitis (LC) muscle to that of the sternocleidomastoid (SCM), anterior scalene (AS), and hyoid (HD) muscles across three levels of CCFD tests (IMVC, IMVC$_{50}$, IMVC$_{20}$) (df = 9).

<table>
<thead>
<tr>
<th>CCFD Muscle Comparisons</th>
<th>Paired Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>IMVC</td>
<td></td>
</tr>
<tr>
<td>LC-SCM</td>
<td>0.51</td>
</tr>
<tr>
<td>LC-AS</td>
<td>0.13</td>
</tr>
<tr>
<td>LC-HD</td>
<td>0.2</td>
</tr>
<tr>
<td>IMVC$_{50}$</td>
<td></td>
</tr>
<tr>
<td>LC-SCM</td>
<td>0.65</td>
</tr>
<tr>
<td>LC-AS</td>
<td>0.57</td>
</tr>
<tr>
<td>LC-HD</td>
<td>0.3</td>
</tr>
<tr>
<td>IMVC$_{20}$</td>
<td></td>
</tr>
<tr>
<td>LC-SCM</td>
<td>0.69</td>
</tr>
<tr>
<td>LC-AS</td>
<td>0.65</td>
</tr>
<tr>
<td>LC-HD</td>
<td>0.56</td>
</tr>
</tbody>
</table>
Table F.2.2 Paired t-test comparison of the normalised root-mean-square values for the longus capitis (LC) muscles to that of the sternocleidomastoid (SCM), anterior scalene (AS), and hyoid (HD) muscles across three levels of CFD tests (IMVC, IMVC$_{50}$, IMVC$_{20}$) (df = 9).

<table>
<thead>
<tr>
<th>CFD Muscle Comparisons</th>
<th>Paired Differences</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (Std. Dev.)</td>
<td>Std. Error Mean</td>
</tr>
<tr>
<td>IMVC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LC-SCM</td>
<td>-0.43 (0.64)</td>
<td>0.2</td>
</tr>
<tr>
<td>LC-AS</td>
<td>-1.15 (1.25)</td>
<td>0.4</td>
</tr>
<tr>
<td>LC-HD</td>
<td>-0.4 (1.5)</td>
<td>0.47</td>
</tr>
<tr>
<td>IMVC$_{50}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LC-SCM</td>
<td>-1.23 (1.12)</td>
<td>0.36</td>
</tr>
<tr>
<td>LC-AS</td>
<td>-1.94 (1.55)</td>
<td>0.49</td>
</tr>
<tr>
<td>LC-HD</td>
<td>-1.49 (2.17)</td>
<td>0.69</td>
</tr>
<tr>
<td>IMVC$_{20}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LC-SCM</td>
<td>-0.24 (0.74)</td>
<td>0.24</td>
</tr>
<tr>
<td>LC-AS</td>
<td>-0.21 (0.66)</td>
<td>0.21</td>
</tr>
<tr>
<td>LC-HD</td>
<td>-0.4 (1.26)</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Table F.2.3 Mean normalized RMS (%) values and 95% confidence intervals for the longus capitis (LC), sternocleidomastoid (SCM), anterior scalene (AS), and hyoid (HD) muscles during the CCFT at 24mmHg and 28mmHg.

<table>
<thead>
<tr>
<th>CCFT Pressure</th>
<th>LC</th>
<th>SCM</th>
<th>AS</th>
<th>HD</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 mmHg</td>
<td>61 (43 - 79)</td>
<td>20 (15-25)</td>
<td>27.1 (11 -43)</td>
<td>20.5 (9 - 31)</td>
</tr>
<tr>
<td>28mmHg</td>
<td>81 (50 -112)</td>
<td>28 (19 -39)</td>
<td>35 (19 -51)</td>
<td>28 (13-43)</td>
</tr>
</tbody>
</table>
Table F.2.4 Paired t-test comparison of the normalised root-mean-square values for the longus capitis (LC) muscle to that of the sternocleidomastoid (SCM), anterior scalene (AS), and hyoid (HD) muscles across two levels of the CCFT (24mmHg, 28mmHg) (df = 9).

<table>
<thead>
<tr>
<th>CCFT Muscle Comparisons</th>
<th>Paired Differences</th>
<th></th>
<th></th>
<th>95% CI</th>
<th>t</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>24mmHg</td>
<td></td>
<td>Mean</td>
<td>Std</td>
<td>Std. Error</td>
<td>Mean</td>
<td>4.5</td>
</tr>
<tr>
<td>LC-SCM</td>
<td>0.41</td>
<td>0.29</td>
<td>0.09</td>
<td>0.21 - 0.62</td>
<td>5</td>
<td>0.001</td>
</tr>
<tr>
<td>LC-AS</td>
<td>0.34</td>
<td>0.36</td>
<td>0.11</td>
<td>0.08 - 0.6</td>
<td>3</td>
<td>0.02</td>
</tr>
<tr>
<td>LC-HD</td>
<td>0.41</td>
<td>0.34</td>
<td>0.11</td>
<td>0.17 - 0.65</td>
<td>3.81</td>
<td>0.004</td>
</tr>
<tr>
<td>28mmHg</td>
<td></td>
<td>Mean</td>
<td>Std</td>
<td>Std. Error</td>
<td>Mean</td>
<td>4.5</td>
</tr>
<tr>
<td>LC-SCM</td>
<td>0.53</td>
<td>0.54</td>
<td>0.17</td>
<td>0.14 - 0.92</td>
<td>3.1</td>
<td>0.01</td>
</tr>
<tr>
<td>LC-AS</td>
<td>0.46</td>
<td>0.59</td>
<td>0.19</td>
<td>0.04 - 0.89</td>
<td>2.5</td>
<td>0.04</td>
</tr>
<tr>
<td>LC-HD</td>
<td>0.53</td>
<td>0.57</td>
<td>0.18</td>
<td>0.12 - 0.94</td>
<td>2.95</td>
<td>0.02</td>
</tr>
</tbody>
</table>
Appendix F.3 – Result Tables from Reliability Study (Chapter 5)

Table F.3.1 Results of reliability analysis for the CCFD measurement of IMVC peak torque for symptomatic and control participant groups. Results include paired t-test analyses, Intraclass Correlational Coefficient (ICC$_{2,1}$) 95% confidence intervals, and coefficient of variation (CV) calculations.

<table>
<thead>
<tr>
<th>IMVC Peak Torque</th>
<th>Paired Differences</th>
<th>ICC 95% CI</th>
<th>CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>df</td>
<td>Mean</td>
<td>Std. Deviation</td>
</tr>
<tr>
<td>Sympt</td>
<td>23</td>
<td>-0.34</td>
<td>0.68</td>
</tr>
<tr>
<td>Control</td>
<td>23</td>
<td>-0.24</td>
<td>1.04</td>
</tr>
</tbody>
</table>
Table F.3.2 Results of reliability analysis for the CCFD measurements of IMVC$_{20}$ time to task failure and contraction accuracy for symptomatic and control participant groups. Results include paired t-test analyses, Intraclass Correlational Coefficient (ICC$_{2,1}$) 95% confidence intervals, and coefficient of variation (CV) calculations.

<table>
<thead>
<tr>
<th>IMVC$_{20}$</th>
<th>Paired Differences</th>
<th>ICC 95% CI (%)</th>
<th>CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>df</td>
<td>Mean</td>
<td>Std. Deviation</td>
</tr>
<tr>
<td>IMVC$_{20}$ Time to Task Failure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt</td>
<td>16</td>
<td>3.3</td>
<td>60.1</td>
</tr>
<tr>
<td>Control</td>
<td>17</td>
<td>1.89</td>
<td>67.73</td>
</tr>
<tr>
<td>IMVC$_{20}$ Contraction Accuracy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1% Margin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt</td>
<td>16</td>
<td>0.95</td>
<td>12.98</td>
</tr>
<tr>
<td>Control</td>
<td>20</td>
<td>-5.12</td>
<td>10</td>
</tr>
<tr>
<td>3% Margin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt</td>
<td>16</td>
<td>-9.39</td>
<td>9.51</td>
</tr>
<tr>
<td>Control</td>
<td>20</td>
<td>-6.9</td>
<td>16.88</td>
</tr>
<tr>
<td>5% Margin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt</td>
<td>16</td>
<td>-5.63</td>
<td>16.59</td>
</tr>
<tr>
<td>Control</td>
<td>20</td>
<td>-9.7</td>
<td>15.4</td>
</tr>
<tr>
<td>7% Margin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt</td>
<td>16</td>
<td>-5.69</td>
<td>11.13</td>
</tr>
<tr>
<td>Control</td>
<td>20</td>
<td>-6.86</td>
<td>13.55</td>
</tr>
<tr>
<td>9% Margin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt</td>
<td>16</td>
<td>-4.05</td>
<td>10.35</td>
</tr>
<tr>
<td>Control</td>
<td>20</td>
<td>-7.87</td>
<td>15.55</td>
</tr>
</tbody>
</table>
Table F.3.3 Results of reliability analysis for the CCFD measurements of IMVC<sub>50</sub> time to task failure and contraction accuracy for symptomatic and control participant groups. Results include paired t-test analyses, Intraclass Correlational Coefficient (ICC<sub>1.1</sub>) 95% confidence intervals, and coefficient of variation (CV) calculations.

<table>
<thead>
<tr>
<th>IMVC&lt;sub&gt;50&lt;/sub&gt;</th>
<th>Paired Differences</th>
<th>ICC 95% CI (%)</th>
<th>CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>df</td>
<td>Mean</td>
<td>Std. Deviation</td>
</tr>
<tr>
<td><strong>Time to Task Failure</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt</td>
<td>23</td>
<td>0.97</td>
<td>14.31</td>
</tr>
<tr>
<td>Control</td>
<td>22</td>
<td>-0.87</td>
<td>3.0</td>
</tr>
<tr>
<td><strong>Contraction Accuracy</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1% Margin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt</td>
<td>23</td>
<td>-2.68</td>
<td>5.77</td>
</tr>
<tr>
<td>Control</td>
<td>22</td>
<td>-3.41</td>
<td>5.88</td>
</tr>
<tr>
<td>3% Margin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt</td>
<td>23</td>
<td>-7.93</td>
<td>10.97</td>
</tr>
<tr>
<td>Control</td>
<td>22</td>
<td>-7.27</td>
<td>10.29</td>
</tr>
<tr>
<td>5% Margin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt</td>
<td>23</td>
<td>-7.79</td>
<td>17.65</td>
</tr>
<tr>
<td>Control</td>
<td>22</td>
<td>-9.05</td>
<td>11.36</td>
</tr>
<tr>
<td>7% Margin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt</td>
<td>23</td>
<td>-8.5</td>
<td>16.05</td>
</tr>
<tr>
<td>Control</td>
<td>22</td>
<td>-7.27</td>
<td>10.53</td>
</tr>
<tr>
<td>9% Margin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sympt</td>
<td>23</td>
<td>-7.61</td>
<td>12.8</td>
</tr>
<tr>
<td>Control</td>
<td>22</td>
<td>-6.03</td>
<td>8.49</td>
</tr>
</tbody>
</table>
Table F.4.1 Results of univariate ANOVA for the CCFD measurement of IMVC peak torque. Results include group effects (symptomatic, control) and effect of age on measurement when included as a covariate (df = 1).

<table>
<thead>
<tr>
<th>IMVC</th>
<th>Factor</th>
<th>Mean Square</th>
<th>F</th>
<th>p - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Torque</td>
<td>Group</td>
<td>11.01</td>
<td>4.5</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>5.44</td>
<td>2.22</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Table F.4.2 Results of multivariate ANOVA for the CCFD measurements of IMVC20 time to task failure and contraction accuracy. Results include group effects (symptomatic, control) and effect of age on the measurements when included as a covariate (df = 1).

<table>
<thead>
<tr>
<th>IMVC20</th>
<th>Factor</th>
<th>Mean Square</th>
<th>F</th>
<th>p - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to Task Failure</td>
<td>Group</td>
<td>138911.35</td>
<td>4.71</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>24366.4</td>
<td>0.83</td>
<td>0.37</td>
</tr>
<tr>
<td>Contraction Accuracy</td>
<td>Group</td>
<td>21.93</td>
<td>0.3</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>8.33</td>
<td>0.11</td>
<td>0.74</td>
</tr>
<tr>
<td>1% Margin</td>
<td>Group</td>
<td>114</td>
<td>5.7</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>114.91</td>
<td>0.57</td>
<td>0.45</td>
</tr>
<tr>
<td>3% Margin</td>
<td>Group</td>
<td>685.55</td>
<td>2.5</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>36.22</td>
<td>0.13</td>
<td>0.72</td>
</tr>
<tr>
<td>5% Margin</td>
<td>Group</td>
<td>1438.77</td>
<td>5.97</td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>81.62</td>
<td>0.34</td>
<td>0.56</td>
</tr>
<tr>
<td>7% Margin</td>
<td>Group</td>
<td>717.01</td>
<td>3.43</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>17.69</td>
<td>0.09</td>
<td>0.77</td>
</tr>
</tbody>
</table>
Table F.4.3 Results of multi-variate ANOVA for the CCFD measurements of IMVC<sub>50</sub> time to task failure and contraction accuracy. Results include group effects (symptomatic, control) and effect of age on the measurements when included as a covariate (df = 1).

<table>
<thead>
<tr>
<th>IMVC&lt;sub&gt;50&lt;/sub&gt;</th>
<th>Factor</th>
<th>Mean Square</th>
<th>F</th>
<th>p -value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Time to Task Failure</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Group</td>
<td>8618.6</td>
<td>12.15</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>3193.8</td>
<td>4.5</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contraction Accuracy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1% Margin</td>
<td>Group</td>
<td>10.26</td>
<td>0.22</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>1.63</td>
<td>0.34</td>
<td>0.85</td>
</tr>
<tr>
<td>3% Margin</td>
<td>Group</td>
<td>43.34</td>
<td>0.17</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>11.76</td>
<td>0.05</td>
<td>0.83</td>
</tr>
<tr>
<td>5% Margin</td>
<td>Group</td>
<td>6.66</td>
<td>0.02</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>73.8</td>
<td>0.23</td>
<td>0.63</td>
</tr>
<tr>
<td>7% Margin</td>
<td>Group</td>
<td>6.4</td>
<td>0.000</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>50.65</td>
<td>0.2</td>
<td>0.65</td>
</tr>
<tr>
<td>9% Margin</td>
<td>Group</td>
<td>0.945</td>
<td>0.005</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td>4.82</td>
<td>0.03</td>
<td>0.87</td>
</tr>
</tbody>
</table>
Appendix F.5 – Result Tables from Responsiveness Chapter (Chapter 7)

Table F.5.1 Results of repeated measures ANOVA for the CCFD measurement of IMVC peak torque. Results include time effects (pre-post rehabilitation), and time by group (CCFEx, CFEx programs) effects (df = 1).

<table>
<thead>
<tr>
<th>IMVC Factor</th>
<th>Mean Square</th>
<th>F</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Torque Time</td>
<td>9.317</td>
<td>16.69</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Peak Torque Time*Group</td>
<td>5.26-04</td>
<td>0.001</td>
<td>0.98</td>
</tr>
</tbody>
</table>

Table F.5.2 Results of repeated measures ANOVA for the CCFD measurements of IMVC_{20} time to task failure and contraction accuracy. Results include time effects (pre-post rehabilitation), and time by group (CCFEx, CFEx programs) effects (df = 1).

<table>
<thead>
<tr>
<th>IMVC_{20} Factor</th>
<th>Mean Square</th>
<th>F</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to Task Failure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>48812.82</td>
<td>5.57</td>
<td>0.03</td>
</tr>
<tr>
<td>Time*Group</td>
<td>8162.2</td>
<td>0.93</td>
<td>0.34</td>
</tr>
<tr>
<td>Contraction Accuracy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1% Margin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>310.71</td>
<td>4.3</td>
<td>0.05</td>
</tr>
<tr>
<td>Time*Group</td>
<td>92.81</td>
<td>1.28</td>
<td>0.27</td>
</tr>
<tr>
<td>3% Margin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>1321.27</td>
<td>10.97</td>
<td>0.002</td>
</tr>
<tr>
<td>Time*Group</td>
<td>3.9</td>
<td>0.03</td>
<td>0.86</td>
</tr>
<tr>
<td>5% Margin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>1876.4</td>
<td>12.97</td>
<td>0.001</td>
</tr>
<tr>
<td>Time*Group</td>
<td>74.69</td>
<td>0.52</td>
<td>0.48</td>
</tr>
<tr>
<td>7% Margin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>2705.22</td>
<td>18.22</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Time*Group</td>
<td>76.01</td>
<td>0.512</td>
<td>0.48</td>
</tr>
<tr>
<td>9% Margin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>1751.84</td>
<td>14.28</td>
<td>0.001</td>
</tr>
<tr>
<td>Time*Group</td>
<td>48.75</td>
<td>0.4</td>
<td>0.53</td>
</tr>
</tbody>
</table>
Table F.5.3 Results of repeated measures ANOVA for the CCFD measurements of IMVC<sub>50</sub> time to task failure and contraction accuracy. Results include time effects (pre-post rehabilitation), and time by group (CCFEx, CFEx programs) effects (df= 1).

<table>
<thead>
<tr>
<th>IMVC&lt;sub&gt;50&lt;/sub&gt;</th>
<th>Factor</th>
<th>Mean Square</th>
<th>F</th>
<th>p - value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time to Task Failure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time</td>
<td>3332.41</td>
<td>15.58</td>
<td>&lt;0.001</td>
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<td>Time*Group</td>
<td>436.67</td>
<td>2.04</td>
<td>0.16</td>
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<td>Contraction Accuracy</td>
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<tr>
<td>1% Margin</td>
<td>Time</td>
<td>395.73</td>
<td>17.66</td>
<td>&lt;0.001</td>
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<td>20.56</td>
<td>0.92</td>
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</tr>
<tr>
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<td>Time</td>
<td>1168.66</td>
<td>9.7</td>
<td>0.004</td>
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<td>17.05</td>
<td>0.14</td>
<td>0.71</td>
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<tr>
<td>5% Margin</td>
<td>Time</td>
<td>1301.49</td>
<td>9.84</td>
<td>0.004</td>
</tr>
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<td>Time*Group</td>
<td>108.92</td>
<td>0.82</td>
<td>0.37</td>
</tr>
<tr>
<td>7% Margin</td>
<td>Time</td>
<td>979</td>
<td>7.53</td>
<td>0.01</td>
</tr>
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<td></td>
<td>Time*Group</td>
<td>113.17</td>
<td>0.87</td>
<td>0.36</td>
</tr>
<tr>
<td>9% Margin</td>
<td>Time</td>
<td>868</td>
<td>9.46</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>Time*Group</td>
<td>85.79</td>
<td>0.94</td>
<td>0.34</td>
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Table F.5.4 Proportion of participants in the CCFEx and CFEx groups demonstrating reliable changes in performance (P < 0.05) pre to post rehabilitation in the contraction accuracy measures.

<table>
<thead>
<tr>
<th>Margins</th>
<th>1%</th>
<th>3%</th>
<th>5%</th>
<th>7%</th>
<th>9%</th>
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<tbody>
<tr>
<td>IMVC&lt;sub&gt;50&lt;/sub&gt;</td>
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</tr>
<tr>
<td>CCFEx</td>
<td>0%</td>
<td>6/16 (38 %)</td>
<td>2/16 (13 %)</td>
<td>4/16 (25 %)</td>
<td>3/16 (19 %)</td>
</tr>
<tr>
<td>CFEx</td>
<td>0%</td>
<td>3/16 (19 %)</td>
<td>1/16 (6 %)</td>
<td>4/16 (25 %)</td>
<td>3/16 (19 %)</td>
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<tr>
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<tr>
<td>CCFEx</td>
<td>3/19 (16 %)</td>
<td>4/19 (21 %)</td>
<td>1/19 (5 %)</td>
<td>1/19 (5 %)</td>
<td>1/19 (5 %)</td>
</tr>
<tr>
<td>CFEx</td>
<td>1/17 (6 %)</td>
<td>1/17 (6 %)</td>
<td>1/17 (6 %)</td>
<td>1/17 (6 %)</td>
<td>3/17 (18 %)</td>
</tr>
</tbody>
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