An investigation into normative responses for the upper limb neurodynamic test with radial nerve bias

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A research project submitted in partial fulfilment of the requirements for the degree of Master of Osteopathy, Unitec Institute of Technology, 2013
Acknowledgments

In loving memory of my mum, 12/10/1954 - 25/11/2012, you were a truly wonderful person who gave so much and asked for so little. I will forever remember your love, your strength, your dedication and your enduring patience. You taught me to believe in myself and that if I worked hard I could achieve anything I set my mind to. I hope I can manage to be half the person you were. Love you xx

To my Dad, and to my dearest friends, thank you for your endless encouragement and support, without you this study would not have been possible.

Thank you to my supervisors and Unitec staff, in particular to Catherine Bacon, for your patience and assistance. Catherine, I could not imagine doing such a project without your help.

I would also like to thank all the participants for their enthusiastic participation.
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Overview

The following research project is divided into the following sections:

1. Introduction to the Research Project

2. The literature review

3. A manuscript formatted in accordance for submission to the *Journal of Bodywork and Movement Therapies*. The format is available at:


4. Appendices;
   - A: Ethics approval for this project
   - B: Participant recruitment poster
   - C: Information sheet for participants
   - D: Consent form; and
   - E: Outcome measures
Introduction to the Research Project

Neurodynamics describes the inter-relationship of the mechanical and physiological functions of the peripheral nervous system (Shacklock, 1995a) and considers the relationship between neural tissue and the surrounding tissues (mechanical interface) (Butler, 1989; Butler & Gifford, 1989).

Neurodynamic techniques have been developed as a means of interacting with the peripheral nervous system (Butler, 2000; Shacklock, 2005) and can be applied in clinical practice as an assessment tool; assessing the interdependent mechanical and physiological functions of the peripheral nervous system and the presence of heightened neural mechanosensitivity (Greening, 2005; Martinez, Cubas, & Girbes, 2014; Schmid, 2009).

A positive response to a neurodynamic technique applied as an assessment tool, said to indicate heightened neural mechanosensitivity (Greening, 2005; Schmid, 2009), is commonly considered to be the production of a sensory response (for example; pain or paraesthesia) which differs from a known normative response, reproduction of the patient’s familiar pain and/or a decrease in the range of motion in the assessed limb (Butler, 2000; Shacklock, 1995a). Structural differentiation can be used to indicate whether the elicited symptoms are of neurogenic origin (Butler, 2000; Butler & Gifford, 1989; Nee, Jull, Vicenzino, & Coppieters, 2012; Shacklock, 2005).

Neural tissue is capable of producing these sensory and range of motion responses due to the presence of nervi nervorum in the connective tissue layers surrounding nerves (Asbury & Fields, 1984; Bove, 2008; Bove & Light, 1995; Hall & Elvey, 1999; Hromada, 1963; Sunderland, 1990). Nervi nervorum have mechanosensitivity, nociceptive and nocifensive functions and respond to mechanical, chemical and thermal stimuli (Bove...
through pain, local inflammation and altered range of motion responses (Asbury & Fields, 1984; Bove, 2008; Sauer et al., 1999).

Established normative responses for neurodynamic techniques provides a baseline to which responses elicited in a clinical setting can be compared, thereby assisting clinical decision-making (Covill et al., 2012; Martinez et al., 2014; Petersen et al., 2009).

The purpose of this research project was to investigate the normative responses to the ‘upper limb neurodynamic test with radial nerve bias’ when employed as an assessment tool to assess neural mechanosensitivity. In this study the standard neurodynamic sequence for the upper limb with radial nerve bias was applied (Shacklock, 2005) eliciting sensory and range of motion responses to the test. The elicited responses were examined to provide an understanding of normative responses that can add to current knowledge of normative responses for the upper limb neurodynamic test with radial nerve bias.
Section 1: Literature Review
**Introduction**

Clinical practice involves the application of assessment tools specifically designed to stress body tissues in order to ascertain the tissue causing symptom, the response to assessment is then considered as part of the diagnostic reasoning process (Magee, 2008; Martinez, Cubas, & Girbes, 2014). Neural tissues are capable of symptom production as a response to mechanical loading due to the presence of nervi nervorum in the connective tissue layers surrounding nerves (Asbury & Fields, 1984; Bove, 2008; Bove & Light, 1995; Hall & Elvey, 1999; Hromada, 1963; Sunderland, 1990) and can be assessed for heightened mechanosensitivity through the application of specifically designed neurodynamic techniques (Martinez et al., 2014; Shacklock, 2005).

The purpose of this review was to outline current knowledge on the clinical application of neurodynamic techniques when used for the assessment of neural mechanosensitivity, and to summarise the evidence base that exists regarding the relationship between mechanical loading of peripheral nerves and symptom production; examining the physiological and mechanical events that occur in neural tissue as a result of loading. A focus will be placed on the upper limb neurodynamic test with radial nerve bias.

**Neurodynamic Techniques: Assessing Neural Mechanosensitivity**

Neurodynamics describes the inter-relationship of the mechanical and physiological functions of the peripheral nervous system (Shacklock, 1995a) and considers the relationship between neural tissue and the surrounding tissues (mechanical interface) (Butler, 1989; Butler & Gifford, 1989). Neurodynamic techniques are designed to assess these interdependent mechanical and physiological functions and to evaluate neural mechanosensitivity by selectively increasing or decreasing mechanical load in neural
tissue (Byl, Puttlitz, Byl, Lotz, & Topp, 2002; Jaberzadah, Scutter, & Nazeran, 2005; Wright, Glowczewskie, Cowin, & Wheeler, 2005).

Mechanically loading neural tissue causes mild mechanical and physiological events to occur within the nervous system (Date, Teraoka, Chan, & Kingery, 2002; Driscoll, Glasby, & Lawson, 2002; Kerr, Vujnovich, & Bradnam, 2002; Kwan, Wall, Massie, & Garfin, 1992; Kerr et al., 2002; Wright et al., 2005), stimulating activity in the nervi nervorum (Bove & Light, 1995) with resultant assessable signs of sensory responses and temporary changes in the available range of motion (Ashbury & Fields, 1984; Bove, 2008).

Heightened neural mechanosensitivity is indicated by the production of a sensory response (for example; pain or paraesthesia) which differs from a known normative response, reproduction of the patient’s familiar pain and/or a decrease in the range of motion in the assessed limb (Butler, 2000; Shacklock, 1995a). Sensitising manoeuvres can be employed along with neurodynamic techniques, specifically increasing or decreasing the loading of neural tissue, allowing for structural differentiation of the involved tissues and confirmation of neural mechanosensitivity (Butler, 2000; Shacklock, 1995a).

**Common Neurodynamic Techniques: Assessing Neural Mechanosensitivity**

Neurodynamic techniques commonly used to assess for neural mechanosensitivity include the slump test, straight leg raise (SLR), prone knee bend (PKB), passive neck flexion (PNF) and the upper limb neurodynamic test (ULNT) (Shacklock, 2005).

Tests for upper limb neural mechanosensitivity were initially described by Elvey (1979) as the Brachial Plexus Tension Test (BPTT). The concept was developed further as the Upper Limb Tension Tests (ULTT) and test bias for the median, radial and ulnar nerves were described (Butler, 1991; Butler & Gifford, 1989; Elvey & Hall, 1997; Kenneally,
As understanding of neural mechanics and physiology advanced the concept shifted from the idea of tensioning the nervous system to the inter-relationship of the mechanical and physiological functions of the peripheral nervous system (Shacklock, 1995a). The umbrella term of neurodynamics was established and the techniques assessing neural mechanosensitivity of the upper limb were refined as upper limb neurodynamic tests (ULNTs) (Shacklock, 1995a).

The Upper Limb Neurodynamic Test: Assessing Neural Mechanosensitivity in the Upper Limb

The ULNT can be used as a means of assessing neural mechanosensitivity in the peripheral nerves of the upper limb (Butler, 1991; Elvey, 1986; Shacklock, 1995a). Four different sequences of movements have been developed, each sequence providing bias towards an individual upper limb peripheral nerve; median (ULNT1), median with modified positioning (ULNT2a), radial (ULNT2b) and ulnar (ULNT3) (Shacklock, 1995a; Shacklock, 2005). Normative response studies have been undertaken on all four of the ULNT nerve biases, showing that elicited responses to the variations of the ULNT differ in asymptomatic populations, including studies of; ULNT1 (Kenneally et al., 1988; Lohkamp & Small, 2012; Pullos, 1986; Heide et al., 2001), ULNT2a (Reisch, Williams, Nee, & Rutt, 2005), ULNT2b (Covill & Petersen, 2012; Petersen, Zimmerman, Hall, Przechera, Julian, & Coderre, 2009; Petersen & Covill, 2010; Yaxley and Jull, 1991; Yaxley and Jull, 1993) and ULNT3 (Flanagan, 1993; Martinez, Cubas, & Girbes, 2014).

Reliability studies have been conducted for upper limb neurodynamic tests, finding moderate to excellent intra-rater reliability and poor to excellent inter-rater reliability (Coppieters et al., 2002; Oliver & Rushton, 2011; Petersen et al., 2010; Reisch et al., 2005; Schmid et al., 2009; Selvaratnam et al., 1994) meaning that some neurodynamic test responses may be used interchangeably on different occasions, with
the same therapist or between therapists, while maintaining consistent, reliable and reproducible results.

Intra-rater reliability for the ULNT1 was found to be excellent in studies conducted by Coppieters et al., (2002), Oliver & Rushton (2011), and Selvaratnam et al., (1994) (ICC$_{2,1}$ 0.98 - 0.99, 0.96 - 0.98, & 0.83, respectively), while inter-rater reliability was found to be good (ICC$_{2,1}$ 0.89 & 0.80) (Coppieters et al., 2002; Oliver & Rushton, 2011). Good to excellent intra-rater reliability (ICC$_{3,k}$ 0.88, 0.94) was also seen for the ULNT2a in a study conducted by Reisch et al., (2005), however the inter-tester reliability in this study was found to be poor (ICC$_{2,k}$ 0.33). The authors determined that the poor inter-tester reliability seen in this study has limited applicability as methodological differences were found to exist in goniometric placement and in test application between the two examiners.

In the case of ULNT2b and ULNT3, good intra-tester reliability was found for the radial nerve (ICC$_{2,1}$ 0.75 - 0.81) and moderate for the ulnar nerve (ICC$_{2,1}$ 0.65 - 0.75) (Petersen et al., 2010). However the final movement applied in the ULNT2b sequence and joint range of motion measured in this study was elbow extension, thus the results of this study cannot be applied to ULNT2b techniques where shoulder abduction is the final movement in the sequence. A study by Schmid et al., (2009) found no significant difference to exist in reliability between ULNTs and afferent/efferent nerve function tests (sensory testing, reflexes, manual muscle testing).

A validity study conducted by Nee et al., (2012) found that ULNTs are plausible tests for detecting peripheral neuropathic pain when a positive response is defined as; at least partially reproducing the patient’s symptoms, and structural differentiation changes these symptoms. Alteration in range of motion was not supported as a valid indicator of a positive response due to measurement error for resistance to movement.
and the lack of discriminatory cut-offs for variation in range of motion between symptomatic and asymptomatic limbs (Nee et al., 2012). The study determined that significant differences in range of motion between symptomatic and asymptomatic limbs for group data do not help determine whether an individual patient has an abnormal deficit in ULNT range of motion (Nee et al., 2012).

The validity of the ULNT1, ULNT2b and ULNT3 was also assessed by Kleinrensink, Stoeckart, Mulder, Hoek, Broek, Vleeming, & Snijders, (2000) on embalmed cadavers by assessing sensitivity (defined in the study as the probability of testing positive if a nerve lesion is truly present) and specificity (defined in the study as the probability of testing negative if a nerve lesion is truly absent). Buckle force transducers were placed on the lateral, posterior and medial cords as well as the proximal aspects of the median, radial and ulnar nerves. The authors determined the ULNT1 to have both sensitivity and specificity, whilst the ULNT2b and ULNT3 were deemed to lack specificity as these techniques also generated tension in the median nerve. Further validity studies recording measurements at the distal aspects of the median, radial and ulnar nerves could be conducted to confirm these results.

The Upper Limb Neurodynamic Test with Radial Nerve Bias: Assessing Neural Mechanosensitivity in the Radial Nerve

As with all neurodynamic tests the path of the neural tissue relative to joints is considered (Butler, 1989). The brachial plexus lies in the anteromedial aspect of the axilla and the radial nerve takes fibres from the posterior cord of the brachial plexus (C5, C6, C7 and C8, and a sensory branch from T1) (Kopell & Thompson, 1976; McNamara, 2003; Roles & Maudsley, 1972; Spinner, 1989). The radial nerve runs inferolaterally down the posterior aspect of the humerus spiralling near or in the spiral groove towards the lateral aspect of the humerus, it then passes between the brachialis and brachioradialis muscles, above the lateral epicondyle and turns anteriorly to run over
the anterior aspect of the humero-ulnar and radiohumeral joints (Kopell & Thompson, 1976; McNamara, 2003; Roles & Maudsley, 1972; Spinner, 1989). The radial nerve is tethered to the radiohumeral joint capsule by fascia; supplying the 3 heads of the triceps, the anconeus, brachioradialis, extensor carpi radialis and supinators muscles along its path (McNamara, 2003; Roles & Maudsley, 1972). Here the radial nerve divides into a deep branch (posterior interosseous nerve) and a superficial sensory branch (McNamara, 2003; Roles & Maudsley, 1972). The radial nerve (and its branches) enter the forearm lying close to the radioulnar joint, the posterior interosseous passes through the supinators to supply the extensor muscles of the forearm, while the sensory branch travels inferiorly in the forearm lying close to the radial bone to enter the posterior aspect of the hand, supplying the posterior hand, thumb, index and middle fingers (Kopell & Thompson, 1976; McNamara, 2003; Roles & Maudsley, 1972; Spinner, 1989).

Based on the path of the radial nerve a sequence specifically for the upper limb neurodynamic test with radial nerve bias (ULNT2b) has been developed and, as presented by Shacklock (2005), is as follows:

1. Scapular (Shoulder) depression
2. Elbow extension
3. Glenohumeral internal rotation & forearm pronation
4. Wrist and finger flexion
5. Glenohumeral abduction
6. Structural Differentiation

Scapular depression stretches the brachial plexus trunks (Kleinrensink et al., 2000) and has been shown to have a significant impact on ULNT elicited responses when compared to neutral scapular positioning (Legakis & Boyd, 2012), while glenohumeral internal rotation, elbow extension and forearm pronation likely elongates and thus
mechanically stresses the radial nerve as it spirals distally around the humerus and travels into the forearm (Shacklock, 2005). Wrist, finger and thumb flexion lengthen the nerve as it runs along the posterior aspect of the forearm, wrist and hand (Dallon & Mackinnon, 1986a; 1986b). Elbow extension, forearm pronation, and wrist flexion movements also compresses the deep branch of the radial nerve in the radial tunnel (Erak, Day, & Wang, 2004; Links et al; 2009). Glenohumeral abduction further elongates the nerve (Butler, 1991; Elvey, 1997a). Structural differentiation manoeuvres can be used to indicate whether the elicited symptoms are of neurogenic origin (Butler, 2000; Butler & Gifford, 1989; Nee et al., 2012; Shacklock, 2005).

**Structural Differentiation: Assessing Neural Mechanosensitivity**

While neurodynamic techniques act to load mechanical stress onto neural tissues as a means of assessing neural mechanosensitivity, clinicians also use additional sensitising or differentiating manoeuvres to alter the degree of tension developed in neural tissue (Butler, 1991; Butler & Gifford, 1989; Shacklock, 2005). These additional manoeuvres involve the movement of a distant body part, are applied while the neurodynamic sequence is maintained and act to specifically increase or decrease tension in the neural tissue being assessed without loading the mechanical interface, allowing for structural differentiation (Butler, 1991; Shacklock, 2005). This movement of a distant body part to evaluate a ULNT response is referred to as structural differentiation (Butler, 2000; Elvey, 1997; Hall & Elvey, 1999). Alteration in the patient’s symptoms as a result of structural differentiation are used to indicate whether the elicited symptoms are of neurogenic origin, and can be used to confirm neural mechanosensitivity (Butler, 2000; Butler & Gifford, 1989; Elvey, 1997; Kenneally et al., 1988; Nee et al., 2012; Shacklock, 2005).

Shacklock (2005) documents the sensitising movements for the ULNTs to include; contralateral lateral flexion of the cervical spine, scapular depression, glenohumeral
horizontal extension, glenohumeral external rotation, wrist flexion/extension, finger flexion/extension, and radial and ulnar deviation. Studies have shown that mechanical loading from wrist movement or cervical spine lateral flexion can spread along the entire length of an upper limb peripheral nerve supporting the use of these movements for structural differentiation of upper limb peripheral nerves (Coppieters & Butler, 2008; Dilley, Lynn, Greening, & DeLeon, 2003; Lewis et al, 1998).

The movements commonly used for structural differentiation when assessing the radial nerve are; contralateral lateral flexion of the cervical spine or release of scapular depression for distal symptoms, and release of wrist flexion for proximal symptoms (Shacklock, 2005).

**Mechanical Loading of Peripheral Nerves and Symptom Production**

**Anatomical, Physiological and Biomechanical Considerations**

Peripheral nerves are bundles of nerve fibres surrounded by layers of connective tissue that run from the spinal cord out into the trunk and along the limbs of the body (Sunderland, 1990). The outer connective tissue layer, the epineurium, is attached in places to adjacent body tissues (the nerve bed) (Sunderland, 1990). Nervous tissue gains blood supply through segmental arteries that periodically enter the epineurium along the length of the nerve (Sunderland, 1990).

While peripheral nerves innervate the tissues of the body carrying afferent (sensory) and efferent (motor) signals they themselves are also innervated, supplied with both sensory and sympathetic nerve fibres carried in the nervi nervorum (Hall & Elvey, 1999; Hromada, 1963; Sunderland, 1990). Nervi nervorum have mechanosensitivity, nociceptive and nocifensive function, meaning that they respond to mechanical,
chemical and thermal stimuli (Bove & Light, 1995). These stimuli trigger action potential activity in the nervi nervorum resulting in the sensory experience of pain (Asbury & Fields, 1984) and evoking local inflammation (Bove, 2008).

Peripheral nerves allow a degree of longitudinal and transverse movement, known as sliding or excursion, and have capacity for elongation; this allows peripheral nerves to move when a body part is moved (Beith, Robins, & Richards, 1997; Elvey, 1997a; McLellan & Swash, 1976; Shacklock, 2005). With points of fixation at either end, the nerve not only moves in relation to the surrounding tissues but also elongates, alters shape and experiences increases in pressure in response to tensile and compressive forces (Shacklock, 2005; Topp & Boyd, 2006). Additionally peripheral nerves are viscoelastic meaning that they resist shear and strain linearly with time when a stress is applied and exhibit time dependent strain (Bora, Richardson, & Black, 1980; Kwan et al., 1992; Sunderland & Bradley, 1961a; Sunderland & Bradley, 1961b;).

The mechanical loading of peripheral nerves can occur through body movements required for activities of daily living (Wright et al., 2005) and through the passive application of neurodynamic techniques (Butler, 1991) which interact with the nervous system by selectively increasing, or decreasing, strain in neural tissues (Butler, 1991). These body movements stimulate activity in the nervi nervorum present in the connective tissue layers of neural tissue (Hall & Elvey, 1999; Hromada, 1963; Sunderland, 1990) causing mild mechanical and physiological events to occur within the mechanically loaded peripheral nerve (Bove & Light, 1995).

**Mechanical Events Occurring in Mechanically Loaded Peripheral Nerves**

Peripheral nerves undergo mechanical events and morphological changes of neural sliding/excursion, pressurisation, elongation and tension in response to mechanical loading (Kwan et al., 1992; Wright et al., 2005). As the path of the nerve straightens
the nerve slides within its nerve bed (Goddard & Reid, 1965; McLellan & Swash, 1976) and the undulations within the nerve fibres and nerve fasciculi are taken up resulting in neural elongation (Sunderland, 1990). Excessive elongation of a peripheral nerve stimulates the nervi nervorum resulting in local inflammation and the perception of pain (Bove, 2008; Bove & Light, 1997).

Breig (1978) showed that during body movements spinal nerves are drawn distally from their intervertebral foramina and pulled taut. This was revealed by placing 1cm long markers on L4-L5 spinal nerves to indicate the nerves’ positions relative to intervertebral foramina during the movements of hip flexion combined with knee flexion. Morphological changes of excursion were shown to occur within the nerve as a result of these movements. Movement of neural tissue as a result of body movement was presented also by Goddard & Reid (1965) who found that pins inserted into the lumbo-sacral cord moved distally to fixed markers during their research into the movement of neural tissues during the straight-leg raise.

Similar excursion and elongation movements have been shown to exist in peripheral nerve tracts (Date et al., 2002; Topp & Boyd, 2006; Wright et al., 2005). Topp & Boyd (2006) showed that elbow extension elongates the nerve bed of the anterior lying median nerve, placing the median nerve under increased tensile stress and resulting in the excursion of the median nerve towards the elbow joint. Once the elbow joint was moved out of the extended position the nerve bed elongation and associated tensile stress was removed and the median nerve glided back to its original position moving away from the elbow joint (Topp & Boyd, 2006). The same movement of elbow extension was shown to relieve tension in the ulnar nerve bed and the medially lying ulnar nerve was seen to diverge from the elbow joint (Topp & Boyd, 2006).
The mechanical events of excursion and elongation have also been shown to occur in the radial nerve as a response to body movement. Date et al., (2002) showed that the radial nerve decreased in length during cadaver elbow flexion with a mean radial nerve length of 24.3 ± 1.3 cm, 23.3 ± 1.2 cm and 21.3 ± 1.2 cm at 0°, 45° and 90° of elbow flexion respectively. Wright et al., (2005) used laser calipers in cadavers to show radial nerve excursions of 4.3 mm and 8.8 mm during wrist and elbow movements; where the wrist was moved from 15° radial deviation to 30° ulnar deviation and the elbow extended from 10° to 90°. Radial nerve excursions of 9.4 mm at the wrist and 14.2 mm at the elbow were required when movements at the wrist, fingers, elbow, elbow and shoulder were combined (Wright et al., 2005).

The effects of stress, strain and stretch on a peripheral nerve was analysed in vitro and in vivo by Kwan et al., (1992) to establish the structural and mechanical properties of a nerve. Excised rabbit tibial nerves were loaded to failure (38.5 ± 2.0 % strain) from an established pre-zero load length while the load and tensile strain were measured by a sensitive load cell and video dimensional analyser respectively. The study found that nerves are easily extensible, exhibit non-linear stress strain characteristics and have visco-elastic properties. Mechanical events, such as neural sliding, pressurisation, elongation and tension, were found to occur at a strain of 15 % or greater. Kwan et al., (1992) also established that these changes are transient, as a rapid decrease of tension was seen to occur in the excised nerve after removal of the load.

Physiological Events Occurring in Mechanically Loaded Peripheral Nerves

Research undertaken to date has shown that mechanical stresses loaded onto neural tissue also provokes physiological responses within the nerve, including; an alteration in intra-neural blood flow (Driscoll, Glasby, & Lawson, 2002; Jou, Lai, Shen, & Yamano, 2000; Tanoue, Yamaga, Ide, & Takagi, 1996), a decrease in nerve conduction (Date et
al., 2002; Kwan et al., 1992), an alteration in alpha motor neuron excitability (Kerr et al., 2002) and local inflammation (Bove, 2008; Sauer, Bove, Averbeck, & Reeh, 1999).

Rabbit tibial nerve was strained and stressed in situ and stimulated by electrode with the resulting conduction properties (action potential amplitude) recorded using a Cadwell 5200 unit by Kwan et al., (1992). The study noted that the application of small degrees of both strain and stress to the peripheral nerve resulted in a significant decrease in action potential amplitude (a decrease in nerve conduction); upon application of a 6% strain the action potential amplitude remained stable for 20 minutes then exhibited a steady decline to 60% of baseline, while application of a 12% strain produced an acute decrease in action potential amplitude to 65% of baseline with the measured amplitude declining to zero (or complete conduction block) within 1 hour (Kwan et al., 1992). The application of a small degree of stress (1MPa) significantly decreased action potential amplitude to 10% of baseline within 30 minutes, advancing to complete conduction block after 45 minutes (Kwan et al., 1992).

In another study the application of an 8.8% strain to rabbit sciatic nerve reduced blood flow in the nerve by up to 70% (Driscoll et al., 2002), while Jou et al., (2000) found reductions in intraneural blood flow of 30%, 65% and 80% at strains of 16%, 25% and 32% respectively. Pressures as low as 30mmHg have been shown to reduce axonal transport (Dahlin & McLean, 1986), noting that wrist flexion/extension movements have been shown to cause neural pressure increases of this level in asymptomatic subjects (Gelberman, Hergenroeder, Hargens, Lundborg, & Akeson, 1981). The study into the effects of stretch and strain on peripheral nerves undertaken by Kwan et al., (1992) also showed that peripheral nerves can be loaded to a moderate degree (15 - 20% strain) before any substantial mechanical tension or elongation occurs while physiological events begin to occur at low strain levels (6%).
Mechanical and Physiological Events evoked in Peripheral Nerves by Acute, Short Term and Long Term Mechanical Loading

A comparison of studies reveals that these mechanical and physiological events can be evoked in peripheral nerves by acute, short term, long term or repetitive mechanical loading of a nerve, and Shacklock (2005) advises that the sequence of movements in a neurodynamic technique generally be held for only a few seconds, so as not to unnecessarily provoke or harm. Physiological events such as decreased intraneural blood flow, decreased axonal transport and conduction disruption, as well as mechanical events such as the morphological changes of neural sliding, pressurisation, elongation and tension can result within minutes of neural loading (Rempel, Dahlin, & Lundborg, 1999).

Neural compression of 6.7 kilopascals applied for two minutes was shown to alter the shape of myelin sheaths (Dyck, Lais, Giannini, & Engelstad, 1990) while pressure loaded externally onto peripheral nerves for periods of between two to eight hours resulted in increased intraneural pressure that remained for at least 24 hours (Lundborg, Myers, & Powell, 1983). The application of 4 kilopascals of continuous pressure inhibited axonal transport and brought about intraneural oedema after four hours of pressure, reduced intraneural blood flow after eight hours, demyelination and Schwann cell necrosis after seven days and fibrosis, mast cell and macrophage invasion after twenty eight days (Dahlin & McLean, 1986; Lundborg et al., 1983; Myers, Mizisin, Powell, & Lampert, 1982; Powell & Myers, 1986).

Fluctuating pressure and vibration produce similar events; fluctuating pressure was shown to cause similar decreased nerve function as that seen with a constantly applied pressure of 4 kilopascals (Szabo & Sharkey, 1993) whilst oedema and structural changes were shown to occur as a result of acute vibration applied over a 5-day period (Lundborg et al., 1987).
**Mechanically Loading Peripheral Nerves through Body Movements**

Movements of the body loads mechanical stress, strain and stretch onto peripheral nerves with multiple joint positioning (the combination of movements, as is seen in the application of neurodynamic techniques), having a greater loading effect than single joint movements (Coppieters et al., 2001a; Jaberzadah et al., 2005; Wright et al., 2005).

Wright et al., (2005) conducted a cadaverine study into the excursion and strain of the radial nerve during limb movements associated with activities of daily living (ADLs). They found that an excursion of 4.3 mm was required to accommodate radial and ulnar deviations of the wrist, while 8.8 mm of radial nerve excursion occurred as the elbow was moved through the movements of flexion and extension. Combined movements at the wrist, fingers, elbow and shoulder required radial nerve excursions of 9.4 mm at the wrist and 14.2 mm at the elbow. The radial nerve experienced a 28 % strain as a result of excursion during flexion and extension movements of the elbow; a strain level at which both physiological and mechanical events have been shown to occur (Driscoll et al., 2002; Jou et al., 2000; Kwan et al., 1992). The movements of wrist flexion and ulnar deviation were also seen to traction the radial nerve in studies conducted by Dellon & Mackinnon (1986a; 1986b). Combined movements at the wrist, fingers, elbow and shoulder are used along with scapular depression in the ULNT2b sequence to mechanically load the radial nerve (Shacklock, 2005).

A study by Byl et al., (2002) further supports the concept of limb positioning sequences to specifically load or unload stress onto specific upper limb peripheral nerves. The ULNT1 and ULNT3 sequences were applied in situ using fresh unembalmed cadavers in order to quantify strain generated in the nerve and nerve excursion using a microstrain gauge and digital calipers respectively. Measurements of the radial nerve were not included in this study.
Excursion and strain measurements taken in the study by Byl et al., (2002) showed that the ULNT1 specifically generated tension in the median nerve, while the ULNT3 specifically generated tension in the ulnar nerve. The ULNT1 movements of glenohumeral external rotation, elbow extension, wrist extension and finger extension caused the median nerve to slide distally and generated a mean strain of 8.2 %; whilst the same ULNT1 movements resulted in an unloading and reduced neural tension (mean strain of 0.8 %) in the ulnar nerve (Byl et al., 2002). The ULNT3 movements of elbow flexion, wrist extension and finger extension caused the ulnar nerve to move distally and generated an overall mean strain in the ulnar nerve of 8.6 %, while the strain generated in the median nerve as a result of ULNT3 application was reduced (0.1 %) (Byl et al., 2002).

The generated mean strains of 8.2 % in the median nerve upon ULNT1 application and 8.6 % in the ulnar nerve upon ULNT3 application (Byl et al., 2002) are above the level known to trigger physiological events of decreased intra-neural blood flow (Driscoll et al., 2002; Jou et al., 2000; Tanoue et al., 1996), decreased nerve conduction (Date et al., 2002; Kwan et al., 1992), an alteration in alpha motor neuron excitability (Kerr et al., 2002) and local inflammation (Bove, 2008; Sauer et al., 1999) in neural tissue; 6 % as measured by Kwan et al., (1992) and 8 % as measured by Driscoll et al., (2002). Therefore the strain levels of 8.2 % and 8.6 % could result in activity of the nervi nervorum (Bove & Light, 1995) and the production of sensory responses (Asbury & Fields, 1984). While the measured strains of 0.8 % in the ulnar nerve upon ULNT1 application and 0.1 % in the median nerve upon ULNT3 application are below the level known to trigger physiological events in neural tissue and would not be expected to produce sensory responses (Kwan et al., 1992), suggesting that the ULNT1 specifically mechanically loads the median nerve, while the ULNT3 specifically mechanically loads the ulnar nerve.
The generation of tension specifically in the median nerve on the application of the ULNT1 was also seen in a study conducted by Lewis, Ramot, & Green (1998) who used a buckle force transducer to assess tension generated. They found that ULNT1 manoeuvres generated increased tension in the median nerve. Unfortunately the ULNT2b and the ULNT3 were not included in this study.

A cadaver study undertaken by Kleinrensink et al., (2000) documented tension changes in the brachial plexus cords and the proximal aspect of upper limb peripheral nerves upon application of the ULNT1, ULNT2b and ULNT3 variations. The authors found the ULNT1 to tension the medial cord and median nerve, while the ULNT2b tensioned the proximal aspect of both the radial nerve and the median nerve, transmitting varying degrees of tension to all 3 brachial plexus cords, and the ULNT3 generated nonspecific tension in the proximal aspects of the ulnar, radial and median nerves.

The findings of Kleinrensink et al., (2000) are in contrast to the findings of both Byl et al., (2002) and Lewis et al., (1998) who found the sequences used in the ULNT1 and ULNT3 to be nerve specific. However Kleinrensink et al., (2000) measured generated strain proximally at the brachial plexus and the most proximal aspects of the peripheral nerves, distal measurements were not taken. This differs to the studies of Byl et al., (2002) and Lewis et al., (1998) where generated strain was measured distally, at the distal aspects of the peripheral nerves. Furthermore Byl et al., (2002) and Lewis et al., (1998) conducted their studies on fresh unembalmed cadavers, while Kleinrensink et al., (2000) conducted their study on embalmed cadavers. Discrepancies between the studies in the application of the sequential positioning of the limb for the ULNTs are also found; Byl et al., (2002) and Lewis et al., (1998) applied the ULNTs according to common convention while Kleinrensink et al., (2000) did not apply scapular/shoulder depression, did not apply any finger positioning (flexion or extension), and applied the unconventional movement of shoulder retroflexion. Due to these methodological
differences comparisons between the study conducted by Kleinrensink et al., (2000) and the studies conducted by Byl et al., (2002) and Lewis et al., (1998) are difficult to make, and the relevance of the findings from the study undertaken by Kleinrensink et al., (2000) cannot be fully established.

An in-vivo study into the effects of shoulder and arm positioning on neural mechanosensitivity was conducted by Jaberzadah et al., (2005), where greater mechanosensitivity of the median nerve during ULNT1 application was indicated by increased EMG activity, elbow flexor torque, decreased elbow extension range and earlier onset of pain. The responses of twenty six asymptomatic subjects to passive elbow extension were assessed in both a neutral limb position and an ULNT1 position. Greater torque, earlier onset of pain, earlier pain limit and greater EMG activity were seen to occur when elbow extension was performed in the ULNT1 position compared to a neutral limb position (Jaberzadah et al., 2005). The authors suggest that these results indicate greater mechanosensitivity of the median nerve during passive elbow extension when the arm is in the ULNT1 position (Jaberzadah et al., 2005).

The studies conducted by Byl et al., (2002), Jaberzadah et al., (2005), Lewis et al., (1998) and Wright et al., (2005) show that body movement can mechanically load peripheral nerves and that this loading can be nerve specific. When a nerve is loaded to 6 % strain or greater physiological events occur within the nerve (Dahlin & McLean, 1986; Driscoll et al., 2002; Gelberman et al., 1981; Jou et al., 2000; Kwan et al., 1992;) while mechanical events occur at a strain of 15 % or greater (Kwan et al., 1992). Mechanical and physiological events occurring within the nerve as a result of mechanical nerve loading stimulate the nervi nervorum and result in the elicitation of sensory and altered range of motion responses (Asbury & Fields, 1984; Bove, 2008; Bove & Light, 1997; Bove & Light, 1995). Generated strain is unaffected by movement order if joints are moved through comparable ranges of motion (Nee et al., 2010).
Abnormal Responses to Upper Limb Neurodynamic Tests: Assessment of Neural Mechano-sensitivity

Several studies have investigated the links between neurodynamic tests and neurogenic disorders (Greening, Smart, Leary, Hall-Craggs, O'Higgins, & Lynn, 1999; Petersen et al., 2009; Quintner, 1990; Quintner, 1989; Shacklock, 1996; Yaxley & Jull, 1993) as neural tissue is known to be more highly sensitive to mechanical stimuli when in pathological states and therefore more likely to elicit a pain response (Kuslich, Ulstrom, & Cami, 1991). Pain related fear (pain catastrophizing) has also been shown to contribute to pain intensity during ULNT application (Beneciuk, Bishop, & George, 2010).

Six studies on ULNTs found that application of these tests in symptomatic populations produced responses that differed from known asymptomatic responses when applied in cases of neurogenic disorders; four studies examined the ULNT1 (Greening et al., 1999; Quintner, 1990; Quintner, 1989; Shacklock, 1996), one considered the ULNT3 (Shacklock, 1996), and two studies assessed the ULNT2b (Petersen et al., 2009; Yaxley & Jull, 1993).

Greening et al., (1999) compared nerve mobility with nerve excursion in subjects with clinically diagnosed non-specific arm pain (repetitive strain injury) by comparing ULNT1 responses with quantified median nerve excursion measurements taken using a magnetic resonance scanner at the carpal tunnel. They found the results of the ULNT1 to correspond with the findings from the magnetic resonance scanner; in all cases the ULNT1 showed a moderate to severe reduction in range of joint motion along with mild to marked symptom production, whilst the magnetic resonance scanner recorded a reduction (mean reduction, 69 %) in transverse excursion movement of the median nerve when compared to the control population. Greening et al., (1999) found this
result to be suggestive of a relationship between reduced joint ROM and reduced nerve excursion.

Quintner (1989) compared the use of ULNT1 sequence in symptomatic and asymptomatic patients, where symptomatic patients had clinical evidence of arm pain and paraesthesia following motor vehicle accident and asymptomatic patients had no clinical evidence of current or previous neck or nerve pathology. Familiar upper arm symptoms were reproduced by the ULNT1 in 55 of the 61 symptomatic subjects whilst asymptomatic subjects reported responses consistent with the known normative responses, as described by Kenneally et al., (1988). One subject reported no sensory responses.

Quintner (1990) conducted a further study of ULNT1 responses, this study considered patients with symptoms of persistent neurogenic arm pain. The ULNT1 reproduced patient symptoms in all 26 symptomatic patients, whilst the responses of 16 of the 18 asymptomatic patients corresponded with known asymptomatic responses to the ULNT1 (Kenneally et al., 1988; Quintner, 1990). Two responses were equivocal.

A case study undertaken by Shacklock (1996) explored the use of ULNT1 and ULNT3 as diagnostic tools in a case of surgically proven ulnar nerve disorder. Responses evoked by the ULNT3 pre-surgical intervention reproduced the patient’s familiar pain, differed from known asymptomatic responses (Flanagan, 1993; Kenneally et al., 1988; Martinez, Cubas, & Girbes, 2014) and were consistent with anecdotally known positive responses to the ULNT3 (Shacklock, 1996). Application of the ULNT1 did not evoke the patient’s familiar pain and responses were not consistent with anecdotally known positive responses to the ULNT1 or to the ULNT3. Responses provoked by both the ULNT1 and ULNT3 post-surgical intervention were concordant with known asymptomatic responses to these two tests (Kenneally et al., 1988; Martinez, Cubas, & Girbes, 2014). This case
study showed that the ULNT3 can identify ulnar nerve neuropathy and that the ULNT1 and ULNT3 can be used to differentiate between the median and ulnar nerves when neurogenic disorders are present (Shacklock, 1996).

Yaxley & Jull (1993) conducted a study into neural tension of the radial nerve in subjects suffering symptoms of tennis elbow. The study aimed to examine neural tissue mechanics in tennis elbow syndrome by differentiating between a neurogenic response and a muscle stretch response. Muscle stretch was examined through full stretch tests of wrist and finger extensor and flexor muscles, while neurogenic responses were examined through the application of ULNT2b with contralateral lateral flexion as the sensitising movement, elicited symptoms were recorded. This study consisted of a small sample population of 20 subjects (11 female, 9 male) aged between 15 to 60 years old (mean age 43.5 years). The tests were conducted on both the symptomatic and asymptomatic upper limbs of each participant.

Both the full flexor muscle stretch tests and the ULNT2b elicited stretching pain, experienced in the posterior wrist and the radial aspect of the proximal forearm (Yaxley & Jull, 1993). Comparison of the location and frequency of ULNT2b elicited responses found no significant difference to exist between the symptomatic and asymptomatic limbs. Application of a sensitising movement increased the intensity of ULNT2b elicited responses in both the asymptomatic and symptomatic populations, by 70% and 75% respectively (Yaxley & Jull, 1993). A mean difference of 12.45° (p<0.001) was found to exist in glenohumeral abduction range of motion between symptomatic and asymptomatic limbs upon application of the ULNT2b (36.6° ± 4.87° and 24.15° ± 3.08° respectively) (Yaxley & Jull, 1993). The authors concluded that the findings of reduced glenohumeral abduction, stretch sensation over the radial aspect of the proximal forearm and increased intensity in arm symptoms upon application of
sensitising movements was suggestive of neural system involvement in the condition of tennis elbow (Yaxley & Jull, 1993).

Petersen et al., (2009) conducted a study of responses to the ULNT2b in a symptomatic population. Sixty subjects, aged between 21 - 69 years, with non-specific cervical or unilateral upper extremity pain were included in the study. Sensitising movements of contralateral lateral flexion of the cervical spine and ipsilateral lateral flexion of the cervical spine were applied during screening to divide the symptomatic subjects into two groups; in group 1 were subjects whose symptoms were altered by structural differentiation (n = 36), while group 2 was comprised of subjects whose symptoms were not altered by structural differentiation (n = 24). A further 60 asymptomatic subjects (group 3) were also included in the study. Both left and right limbs were tested, and stabilisation devices were used.

Both symptomatic and asymptomatic subjects reported the sensations of stretch, followed by tingling, numbness, pain and pressure, located in the radial aspect of the proximal forearm and the dorsal aspect of the wrist (the exact percentage of incidences and frequency of responses were not supplied by the study) (Petersen et al., 2009). Stretch was more commonly reported by the asymptomatic group (group 3) while pain was more frequently reported by group 1, no statistical difference was seen in tingling and numbness frequencies, or in symptom location between the groups (Petersen et al., 2009). Sensations were reported to occur earlier in the ULNT2b sequence by group 1 subjects. Mean shoulder abduction was also seen to differ between group 1 and group 3, with measurements of $31^\circ \pm 11.2^\circ$ and $37.3^\circ \pm 12.0^\circ$, respectively (Petersen et al., 2009). The authors suggested that the sensory and range of motion variations seen were due to the presence of heightened neural mechanosensitivity in group 1 participants, as had been defined through structural differentiation during participant screening (Petersen et al. 2009).
Normative studies of the Upper Limb Neurodynamic Test with Radial Nerve Bias

Normative data studies undertaken for the ULNT2b (radial nerve bias) sequence have been undertaken by Covill et al., (2012), Petersen et al., (2009), Petersen et al., (2010), Yaxley & Jull (1991) and Yaxley & Jull (1993). Normative responses to the ULNT2b have been described by Shacklock (1995a; 1995b) to be a pulling sensation in the lateral elbow region extending into the forearm and sometimes a stretch in the back of the wrist, whilst the range of motion can vary considerably between individuals from between almost no abduction to 50°.

Yaxley & Jull (1991) applied the ULNT2b sequence to 50, right hand dominant, asymptomatic subjects, aged between 18 to 30 years. The sample population was drawn from university staff and students. Subjects were secured to the table in 3 locations (hip, chest and chin) and contralateral lateral flexion was restricted with a block. A standard handheld goniometer was used to measure range of motion. The test sequence was applied to both left and right limbs (n = 100). A normal response to the ULNT2b in the study population was found to be a strong painful stretch over the radial aspect of the proximal forearm and elbow (84 % of responses), followed by a stretch pain in the lateral upper arm (32 %), the region over the biceps brachii (14 %) and the dorsal hand (12 %) and a mean range of glenohumeral abduction of 41.45° ± 4.06° degrees (Yaxley & Jull, 1991). Gender and side tested did not influence results. Contralateral lateral flexion was applied as a sensitising movement and was found to increase the intensity of the elicited responses in 86 per cent of subjects (right arm tested) and 90 per cent of subjects (left arm tested).

Similar results in asymptomatic subjects were found by Yaxely and Jull (1993) when investigating radial nerve tension in the symptomatic and asymptomatic limbs of
subjects suffering symptoms of tennis elbow. The sample population consisted of 20 subjects (11 female, 9 male) aged between 15 to 60 years old (mean age 43.5 years). Each subject had one symptomatic limb (defined as tennis elbow syndrome) and one asymptomatic limb. Again a standard handheld goniometer was used to measure range of motion. Stabilisation/fixation devices were used to secure the subjects in 3 locations (hip, chest and chin) and cervical spine contralateral lateral flexion was restricted with a block. Responses elicited in the asymptomatic limbs were found to be; the sensation of full stretch in the posterior wrist (45 %) and radial aspect of the proximal forearm (10 %), and a glenohumeral range of motion of $36.60 \pm 4.87^\circ$. The sensitising movement of contralateral lateral flexion was seen to increase the intensity of sensory responses in 70 per cent of the asymptomatic subjects.

The ULNT2b was assessed in an asymptomatic population by Petersen et al., (2009) when examining ULNT2b and ULNT3 reliability, and again by Petersen et al., (2010) when examining responses to the ULNT2b in symptomatic and asymptomatic subjects. In the 2009 study (Petersen et al., 2009) the ULNT2b was applied to 60 asymptomatic subjects aged between 22 and 45 years (mean age $25.9 \text{ years } \pm 5.2$), 42 of the subjects were female, 18 were male, and 55 were right handed. All subjects were deemed to be in a healthy weight range with a mean BML of $22.1 \pm 2.8$. Stabilisation devices were used on the subjects and range of motion was measured using a $360^\circ$ goniometer. Responses to the ULNT2b in the asymptomatic population were found to be a stretch sensation, followed by tingling, numbness, pain and pressure (the exact percentage of incidences were not supplied by the study) predominately located in the radial aspect of the proximal forearm and the dorsal aspect of the wrist (again exact percentages of symptom location were not supplied by the study). Mean shoulder abduction was measured to be $37.3^\circ \pm 12.0^\circ$. Both the right and left limbs were tested, although the influence of side tested and gender were not examined. Sensitising manoeuvres were
applied at the initial screening stages of the study but not as a component of ULNT application for structural differentiation.

In the 2010 study (Petersen et al., 2010) the ULNT2b was applied without the use of external fixation devices to 45 asymptomatic subjects (34 female, 11 male) aged between 22 to 53 years (mean age 25.1 years ± 5.75), 43 with right hand dominance and two with left hand dominance. However elicited sensory responses to the test were not recorded and, in contrast to Yaxley and Jull (1991; 1993) and Petersen et al., (2009), elbow extension range of motion was measured rather than glenohumeral abduction. Elbow extension ROM was reported to be $7.07^\circ \pm 7.67^\circ$ and $6.55^\circ \pm 7.57^\circ$ for the right limb (trial 1 and trial 2 respectively) and $9.74^\circ \pm 9.62^\circ$ and $9.13^\circ \pm 12.13^\circ$ for the left limb (trial 1 and trial 2 respectively). The study found the ULNT2b to have good intra-tester reliability ($ICC_{2,1} 0.75 - 0.81, 95 \% CI$) when elbow extension is the range of motion is measured.

Covill et al., (2012) recorded the mean range of motion for ULNT2b during their study into within-subject between-limb range of motion asymmetry during application of ULNTs. The study was conducted on 61 asymptomatic subjects (42 females and 19 males), aged from 22 to 55 years (mean age 26.9 ± 8 years). 59 were right hand dominant and two were left hand dominant. Stabilisation devices were not used on the subjects and range of motion was measured using uniaxial electrogoniometers. Structural differentiation movements were not applied. In contrast to Yaxley and Jull (1991; 1993) and Petersen et al., (2009) but consistent with the study conducted by Petersen et al., (2010), elbow extension range of motion was measured. A mean range of motion of $8.07^\circ \pm 9.39^\circ$ was reported for the right limb and $9.56^\circ \pm 10.46^\circ$ for the left limb (Covill et al., 2012), these measurements are comparable with those found by (Petersen et al., 2010).
Overall, normative studies for the ULNT2b (radial nerve bias) have consistently reported the sensory responses of a strong stretch over the radial aspect of the proximal forearm, and occasionally over the dorsal wrist and hand (Petersen et al., 2009; Yaxley & Jull, 1991; Yaxley & Jull, 1993). Variation is seen in shoulder abduction measurements across the studies with measurements of $41.45^\circ \pm 4.06^\circ$ (Yaxley & Jull, 1991), $36.60^\circ \pm 4.87^\circ$ (Yaxley & Jull, 1993), and $37.3^\circ \pm 12.0^\circ$ (Petersen et al., 2009), while Shacklock (1995a; 1995b) reports that glenohumeral ROM can vary from $0^\circ$ to $50^\circ$ in asymptomatic populations. Fixation and stabilisation devices were used to secure the subjects in the studies conducted by Petersen et al., (2009), Yaxley & Jull, (1991) and Yaxley & Jull (1993). Two studies measured elbow extension ROM during ULNT2b with measurements of $7.07^\circ \pm 7.67^\circ$ (Petersen et al., 2010), $6.55^\circ \pm 7.57^\circ$ (Petersen et al., 2010), $9.74^\circ \pm 9.62^\circ$ (Petersen et al., 2010), $9.13^\circ \pm 12.13^\circ$ (Petersen et al., 2010), $8.07^\circ \pm 9.39^\circ$ (Covill et al., 2012) and $9.56^\circ \pm 10.46^\circ$ (Covill et al., 2012); external fixation devices were not used in the studies by Covill et al., (2012) and Petersen et al., (2010).

When comparing asymptomatic studies with symptomatic studies it can be found that the location and frequency of sensory responses are not substantially different between these groups for the ULNT2b (Petersen et al., 2009; Yaxley & Jull, 1991; Yaxley & Jull, 1993). However a greater intensity of sensory response has consistently been seen to exist in the symptomatic group (Petersen et al., 2009; Yaxley & Jull, 1993), as has an earlier onset of sensory response and an earlier onset of pain limit (Petersen et al., 2009). ULNTs have been shown to reproduce familiar symptom responses in subjects with known neurogenic disorders (Quintner, 1989; 1990; Shacklock, 1996).

Glenohumeral abduction range of motion also differs between symptomatic and asymptomatic populations, although the degree of difference varies between studies
with ranges of $37.3^\circ \pm 12.0^\circ$, $36.60^\circ \pm 4.87^\circ$, and $41.45^\circ \pm 4.06^\circ$ reported for asymptomatic populations by Petersen et al. (2009), Yaxley & Jull (1993), and Yaxley & Jull (1991), respectively, while ranges of $31^\circ \pm 11.2^\circ$ (Petersen et al., 2009) and $24.15^\circ \pm 3.08^\circ$ (Yaxley & Jull, 1993) were reported in symptomatic populations.

The sensitising movement of contralateral lateral flexion has been shown to increase the intensity of responses in both asymptomatic and symptomatic populations (Yaxley & Jull, 1993), which may suggest that asymptomatic individuals have a certain level of nerve mechanosensitivity (Nee et al., 2012).

**Summary**

Overall, the review has found that neurodynamic techniques are designed to assess the interdependent mechanical and physiological functions of the peripheral nervous system and can be used to evaluate neural mechanosensitivity by selectively increasing or decreasing mechanical load in neural tissue (Byl et al., 2002; Jaberzadah et al., 2005; Wright et al., 2005).

Nervous tissue has the capacity to elongate and slide with body movements and can permit a degree of mechanical loading, however when the load generated in a nerve exceeds strain thresholds, physiological and mechanical events occur within the nerve (6% strain threshold and 15% strain threshold respectively). These include the mechanical events of neural sliding/excursion, pressurisation, elongation, and tension (Kwan et al., 1992; Wilgis & Murphy, 1986; Wright et al., 2005), and the physiological events of an alteration in intra-neural blood flow (Driscoll, Glasby, & Lawson, 2002; Jou et al., 2000; Tanoue et al., 1996), a decrease in nerve conduction (Date et al., 2002; Kwan et al., 1992), an alteration in alpha motor neuron excitability (Kerr et al., 2002), and local inflammation (Bove 2008; Sauer et al., 1999). Collectively, these
physiological and mechanical events stimulate the sensory nerve fibres carried in the
nervi nervorum and result in the production of sensory responses and altered range of
motion in the assessed limb (Asbury & Fields, 1984; Bove, 2008; Bove & Light, 1997;
Bove & Light, 1995; Sauer et al., 1999).

The sequences of body movements associated with upper limb neurodynamic
techniques can specifically load the upper limb peripheral nerves (Byl et al., 2002;
Jaberzadah et al., 2005; Lewis et al., 1998; Wright et al., 2005). The ULNT2b
mechanically loads the radial nerve (Wright et al., 2005) and can be used to assess
radial nerve mechanosensitivity (Shacklock, 2005) evoking sensory and altered range
of motion responses (Asbury & Fields, 1984; Bove, 2008; Bove & Light, 1997; Bove &
Light, 1995; Sauer et al., 1999) of; a strong/full stretch over the radial aspect of the
proximal forearm, and occasionally over the dorsal wrist and hand (Petersen et al.,
2009; Yaxley & Jull, 1991; Yaxley & Jull, 1993). Glenohumeral abduction range of
motion responses for the ULNT2b can vary considerably between individuals from
almost no abduction to 50° (Petersen et al., 2009; Petersen et al., 2010; Shacklock,

In clinical practice it is useful to have fast, cost effective and easy to apply diagnostic
tests to help assess the health and functioning of patients’ tissues. Additionally, it is
important to have normative data to which signs and symptoms seen in clinical practice
can be compared (Martinez, Cubas, & Girbes, 2014). Established normative data is also
required before valid studies can be undertaken on symptomatic patients.

The study outlined in the next section aims to investigate the normative responses to
the ‘upper limb neurodynamic test with radial nerve bias’ (ULNT2b) when employed
as an assessment tool, and to provide an understanding of normative responses that
can add to current knowledge of normative ULNT2b responses.
References


Section 2: Manuscript

Note: This manuscript has been prepared in accordance with the Guide for authors for submission to the Journal of Bodywork and Movement Therapies [http://www.elsevier.com/journals/journal-of-bodywork-and-movement-therapies/1360-8592/guide-for-authors].
AN INVESTIGATION INTO NORMATIVE RESPONSES FOR THE UPPER LIMB NEURODYNAMIC TEST WITH RADIAL NERVE BIAS
Abstract

This study assessed the normative responses to the upper limb neurodynamic test with radial nerve bias (ULNT2b) without the use of subject fixation and stabilisation devices, on 100 asymptomatic participants recruited from the local community. Range of motion shoulder abduction measurements were taken in a neutral limb position and in the ULNT2b test position, sensory responses evoked by the ULNT2b were recorded.

The ULNT2b was found to repeatedly elicit the sensory responses of stretching in the lateral forearm (62 %) and posterior wrist (24 %). Significantly less glenohumeral abduction was seen in the ULNT2b test position (T-ROM; 62.2° ± 16.5°) than in the pre-test neutral limb position (P-ROM; 77.9° ± 13.2°) (mean difference = 15.7° ± 13.2, p < 0.001 at 95 % confidence). Participant characteristics did not influence observed responses, suggesting that the ULNT2b has scope for use on diverse clinical practice populations. The results of this study can be used to enhance understanding of normative responses to the ULNT2b against which responses elicited in a clinical setting can be compared.
**Introduction**

Neurodynamics describes the inter-relationship of the mechanical and physiological functions of the peripheral nervous system (Shacklock 2005). Neurodynamic techniques can be employed in clinical practice to assess these interdependent mechanical and physiological functions (Butler 2000) and to evaluate neural mechanosensitivity by selectively increasing or decreasing mechanical load in neural tissue (Byl et al 2002; Jaberzadah et al 2005; Lewis et al 1998; Wright et al 2005).

Neural tissues are capable of symptom production due to the presence of nervi nervorum in the neural connective tissue, giving mechanosensitive, nociceptive and nocifensive function (Asbury & Fields 1984; Bove 2008; Bove & Light 1995; Hall & Elvey 1999; Hromada 1963; Sunderland 1990). Mechanically loading neural tissue causes it to undergo mechanical events; morphological changes of neural sliding, pressurisation, elongation, and tension (Date et al 2002; Kwan et al 1992; Topp & Boyd 2006; Wright et al 2005), as well as physiological events; altered intra-neural blood flow (Driscoll et al 2002; Jou et al 2000; Tanoue et al 1996), decreased nerve conduction (Date et al 2002; Kwan et al 1992), altered alpha motor neuron excitability (Kerr et al 2002), local inflammation and the perception of pain (Bove, 2008; Bove & Light, 1997; Sauer et al 1999).

Collectively, these physiological and mechanical events trigger action potential activity in the sensory nerve fibres carried in the nervi nervorum (Bove & Light 1995) eliciting the clinically assessable signs of sensory responses and an altered range of motion (ROM) in the assessed body part (Ashbury & Fields 1984; Bove 2008; Bove & Light 1997; Byl et al 2002; Date et al 2002; Kerr et al 2002; Kwan et al 1992).

Healthy neural tissue has the capacity to elongate and slide with body movements, and can permit a degree of mechanical loading (Byl et al 2002; Wright et al 2005).
Neurodynamic testing of healthy neural tissue can evoke minor localised sensory and altered ROM responses (Bove 2008; Bove & Light 1997) consistent with responses seen in asymptomatic subjects (Shacklock 1995a). Neural tissue, when in pathological states, is more highly sensitive to mechanical stimuli (heightened neural mechanosensitivity) and is therefore more likely to elicit a pain response (Kuslich et al 1991). A positive response to a neurodynamic test in a clinical setting, said to indicate heightened neural mechanosensitivity, is commonly considered to be; the elicitation of symptoms that differ from known asymptomatic responses, reproduction of the patient’s symptoms and/or alteration in joint range of motion (Shacklock 2005). Recent evidence has refined this definition of a positive response, showing that; a neurodynamic test should partially reproduce the patient’s symptoms and structural differentiation should change these symptoms (Nee et al 2012).

Upper limb neurodynamic techniques (ULNT) can be used as a means of assessing neural mechanosensitivity in the peripheral nerves of the upper limb (Butler 1991; Elvey 1986; Shacklock 1995a). Four different sequences of movements have been developed, each sequence providing bias towards an individual upper limb peripheral nerve; median (ULNT1), median with modified positioning (ULNT2a), radial (ULNT2b) and ulnar (ULNT3) (Shacklock 1995a; Shacklock 2005). Normative response studies have been undertaken on all four of the ULNT nerve biases, showing that elicited responses in asymptomatic populations differ for each of the ULNT variations, including studies on the ULNT1 (Kenneally et al 1988; Lohkamp & Small 2012; Pullos 1986; Heide et al 2001), ULNT2a (Reisch et al 2005), ULNT2b (Covill & Petersen 2012; Petersen et al 2009; Petersen & Covill 2010; Yaxley & Jull 1991; Yaxley & Jull 1993) and ULNT3 (Flanagan 1993; Martinez et al 2014). Studies in symptomatic populations have found ULNTs to elicit responses that differ from known asymptomatic responses and to reproduce familiar symptoms, when applied in cases of neurogenic disorders (Greening et al 1999;
Previous normative studies for the ULNT2b have reported the test to elicit the sensory responses of a strong stretch over the radial aspect of the proximal forearm and occasionally over the dorsal wrist and hand (Petersen et al 2009; Yaxley & Jull 1991; Yaxley & Jull 1993), these results are consistent with normative responses reported by Shacklock (1995a; 1995b). Variation is seen in shoulder abduction ROM measurements across the normative studies, with measurements of $41.45^\circ \pm 4.06^\circ$ (Yaxley & Jull 1991), $36.60^\circ \pm 4.87^\circ$ (Yaxley & Jull 1993), and $37.3^\circ \pm 12.0^\circ$ (Petersen et al 2009), although these measurements remain within the expected normative range reported by Shacklock (1995a; 1995b) of; almost no abduction to $50^\circ$. In the studies conducted by Petersen et al (2009), Yaxley & Jull (1991) and Yaxley & Jull (1993) fixation and stabilisation devices were used to secure the subjects.

Normative ROM measurements were also recorded for the ULNT2b in studies undertaken by Covill et al (2012) and Petersen et al (2009). In these studies elbow extension was the final movement in the sequence, with ROM measurements of $7.07^\circ \pm 7.67^\circ$, $6.55^\circ \pm 7.57^\circ$, $9.74^\circ \pm 9.62^\circ$, $9.13^\circ \pm 12.13^\circ$ (Petersen et al 2010), $8.07^\circ \pm 9.39^\circ$, and $9.56^\circ \pm 10.46^\circ$ (Covill et al 2012). Covill et al (2012) also considered the within-subject between-limb variation for ROM elicited during ULNT2b application, finding elbow extension range of motion asymmetry between limbs to be a normal occurrence and suggesting that ROM is not a good indicator of a positive response. The finding that ROM asymmetry is not a good indicator of a positive response is in line with Nee et al (2012) who found that significant differences in range of motion between symptomatic and asymptomatic limbs for group data do not help determine whether an individual patient has an abnormal deficit in ULNT range of motion.
The aim of this current study was to investigate the normative responses to the ULNT2b, when employed as a tool to assess neural mechanosensitivity without the use of subject fixation and stabilisation devices. In this study the standard ULNT2b sequence was applied (Shacklock 2005) eliciting sensory and range of motion responses to the test. A secondary aim of the study was to determine if within-limb ROM variation existed for glenohumeral abduction; in the neurodynamic test position compared to a neutral limb position. Within-subject, between-limb range of motion variation has been examined for the ULNT by Covill & Petersen (2012). To my knowledge, no study has documented the within-subject within-limb range of motion variation for the ULNT2b. The elicited responses were examined to provide an understanding of normative responses that can add to current knowledge of normative responses for the ULNT2b.
Methods

Participants and Recruitment

Participants for this study were men or women aged between 18 and 65 years of age recruited from Auckland, New Zealand by using advertising posters placed in public places of local cafes, libraries, universities, supermarkets and community notice boards. Attempts were made to recruit a broad cross-section of participants by placing the recruitment posters in locations that varied in socio-economic and demographic factors. Interested participants were contacted to confirm their eligibility. Prior to inclusion in the study participants completed a research participant questionnaire and an upper limb extremity disability index questionnaire (DASH; Disabilities of the Arm, Shoulder and Hand).

The upper limb extremity disability index questionnaire (DASH; Disabilities of the Arm, Shoulder and Hand) was answered by every participant. The DASH is considered to be a valid questionnaire suitable for asymptomatic people as well as patients with a wide variety of upper extremity complaints and is used to assess the level of difficulty of movement, the limitation of movement and the existence of pain in the upper limb (Jester et al 2005; SooHoo et al 2002). The DASH requires participants to rank their level of disability or symptom from 0 (no disability/no symptom) to 5 (unable to perform/extreme symptom) to 30 questions. An overall DASH Disability/Symptom Score is then calculated with a possible range of 0 (no disability/no symptom) to 100 (unable to perform/extreme symptom).

Participants were excluded from the study if they reported any of the following on the research participant questionnaire: known or expected pregnancy, known spinal or upper limb fracture, tumour or cancer, infection, ongoing neck or arm injury, ongoing tingling, or numbness in the hand, arm, shoulder or neck, if they were currently
receiving treatment for neck or arm injury, if they were unable to assume the test position due to upper limb joint restriction or if the participant recorded a DASH Score above 25. No respondents were excluded from the study. Included participants were defined as “asymptomatic” for the purposes of this study.

All participants were informed of the study procedures and participation requirements prior to enrolment in the study and gave written informed consent. The study was approved by Unitec Research Ethics Committee. Subject data of gender, age and handedness were collected via the research participant questionnaire to determine whether these factors had an effect on elicited responses.

**Methodology**

Data was collected from the left and right arms of all 100 participants (n=200). A postgraduate physical therapist with more than 5 years manual therapy training performed the testing procedures, and a research assistant with over 7 years experience in biomechanics conducted the range of motion measurements.

An initial demonstration of glenohumeral abduction (neutral limb position) and the sequence of movements for the ULNT2b were performed by the researcher on the research assistant to allow the participant to become familiar with the movements (Yaxley and Jull 1993). Participants were then positioned in supine without a pillow, on a standardised and firm-topped table. Unlike previous studies examining the ULNT2b with glenohumeral abduction (Petersen et al 2009; Yaxley & Jull 1991; Yaxley & Jull 1993) fixation and stabilisation devices were not applied to the participants. Test procedures were performed slowly and each movement was made to end of available range, or to the point of pain tolerance (Yaxley and Jull 1991). Participants were instructed to indicate when they reached a point of being too uncomfortable for the
test procedure to continue (point of pain tolerance) and were asked to inform the researcher of any symptoms evoked during application of the tests.

The initial test manoeuvre of glenohumeral abduction (neutral limb position) then was applied to the participant, with the scapular fixed to isolate glenohumeral movement (Clarkson 2005). The abduction movement was applied with the upper limb in a neutral position (participant hand facing medially) to end of available glenohumeral range (to the point prior to scapular engagement) (Clarkson 2005), or to the point of pain tolerance.

Glenohumeral abduction (neutral limb position) range of motion was measured using a single large plastic handheld goniometer, to establish a pre-neurodynamic test ROM measure (P-ROM). This P-ROM measure was recorded for later comparison with ULNT2b glenohumeral abduction ROM to determine if within-limb variation existed in the study participants. The participant’s arm was then returned to their side and a 5 minute break taken before proceeding with the next test manoeuvre, of ULNT2b.

The standard sequence of passive movements for the ULNT2b (Shacklock 2005) was applied, as follows:

1. Scapular (shoulder) depression
2. Elbow extension
3. Glenohumeral internal rotation & forearm pronation
4. Wrist and finger flexion
5. Glenohumeral abduction

Each movement was made to end of available range, or to the point of pain tolerance, and each movement was maintained while the next movement was sequentially applied. The range of motion available at the glenohumeral joint for the ULNT2b final sequencing movement was measured using a single large plastic handheld goniometer,
to establish an ULNT2b position ROM measure (T-ROM). The participant's arm was then returned to their side. Sensitising movements were not applied.

**Sensory Responses**

Participants reported sensory responses elicited by the application of the ULNT2b onto the McGill Pain Questionnaire; the description and location of the reported sensory responses were then recorded by the participant on a large body chart. The same body chart was used for left and right limbs. Nine categories of responses were reported (sharp, pinching, pressing, stretching/pulling, burning, tingling, numb, aching and no response) and 9 locations (posterior aspect of wrist, lateral aspect of hand, medial aspect of hand, lateral aspect of forearm, medial aspect of forearm, lateral aspect of upper arm, medial aspect of upper arm, shoulder, and scapular). The level of pain experienced during application of the ULNT2b was recorded by the participant onto the McGill pain questionnaire, which gives a 6-point pain scale of 0 — 5: where 0 represents no pain and 5 represents maximum pain. A 5 minute break was taken before repeating the test on the opposite limb.

**Measurement of Range of Motion**

Measurements for all participants were taken by a single measurer with over 7 years experience in biomechanics using a single large plastic handheld universal goniometer. Goniometers are generally accepted as valid and reliable clinical tools for measuring joint angles when using a standardised and strictly controlled goniometer measuring process (Lea & Gerhardt 1995; Leen T'Jonck et al 1997; Riddle et al 1987). Single plastic handheld universal goniometers have high intra-tester reliability when used to measure glenohumeral abduction (ICC$1.1$. 0.98) (Gajdosik & Bohannon 1987; Riddle et al 1987) even when undertaken in a clinical setting when goniometer placement is not strictly controlled (Gajdosik & Bohannon 1987). Plastic handheld universal goniometers have
high intra-tester reliability (ICC$_{1,1}$ 0.87) (Riddle et al 1987), regardless of the size of goniometer used and are unaffected by subject position (Gajdosik & Bohannon 1987). Measurements were taken from the anterior aspect of the subject, with the axis of the goniometer placed over the centre of the glenohumeral head (2.5 cm inferior to the lateral aspect of the acromion process), the fixed arm parallel to the sternum and the moving arm aligned with the longitudinal axis of the humerus (Clarkson 2005), consistent with previous ULNT2b studies where glenohumeral ROM was measured (Petersen 2009; Yaxely & Jull 1991; Yaxley and Jull 1993). The scale on the goniometer arms was marked in 1 degree increments. To ensure accuracy of the goniometer, the measured angles were checked against 5 computer generated angles randomly chosen between 0 and 180 degrees and were found to agree. Intra-rater tester reliability was not measured.

**Data Analysis**

Data were analysed using SPSS version 15 (SPSS Inc, Chicago IL). Descriptive analyses (sums, means, standard deviations and frequencies) were calculated for the elicited sensory responses and for the measurements of P-ROM and T-ROM. Inferential analyses (dependent t-tests and Pearson correlation coefficient) were used to compare P-ROM and T-ROM measurements and to determine the within-limb relationship. Chi square tests for independence were used to assess whether gender, age, handedness and side tested influenced the responses exhibited by the participants. For statistical tests, the level of significance was $p < 0.05$. 
Results

Of the 100 participants who responded to the posters; all were able to assume the test position and all were eligible to participate in the study. All participants were included in the analyses. Of these 56 were female and 44 were male, 88 were right handed while 12 were left handed. The participants ranged in age from 18 to 65 years (mean age 39.56 ± 12.07 years), and came from varied socio-economic and ethnic backgrounds. DASH scores ranged from 0 to 24.83 (mean DASH score 5.30 ± 5.81). The mean level of pain experienced during application of the ULNT2b procedure was reported as 1.89 ± 0.69.

Range of Motion

Mean glenohumeral abduction in a neutral limb position (P-ROM) was seen to be 77.9° ± 13.2° (mean ± SD), while glenohumeral abduction for the ULNT2b limb position (T-ROM) was 62.2° ± 16.5°. Dependant t-tests revealed a statistically significant difference in ROM between the neutral limb and ULNT2b positions, with a mean difference of 15.7° ± 13.2° (t[199] = 16.8, p < 0.001). Further, the effect size for this analysis (d = 1.05) was found to exceed Cohen’s (1988) convention for a large effect (large effect, d = 0.8; very large effect 1.10). Pearson r values showed a strong correlation to exist between the two ROM measurements (r = 0.6, p < 0.001) suggesting that glenohumeral abduction ROM in a neutral limb position and glenohumeral abduction ROM in an ULNT2b position are strongly related.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-ROM</td>
<td>200</td>
<td>115</td>
<td>92</td>
<td>77.9</td>
<td>13.2</td>
</tr>
<tr>
<td>T-ROM</td>
<td>200</td>
<td>45</td>
<td>20</td>
<td>62.2</td>
<td>16.5</td>
</tr>
</tbody>
</table>
Chi square tests for independence found that exhibited ROM was not influenced by variables of gender (P-ROM p = 0.7, T-ROM p = 0.1), age (P-ROM p = 0.4, T-ROM p = 0.2), handedness (P-ROM p = 0.2, T-ROM p = 0.4) and side tested (P-ROM p = 0.5, T-ROM p = 0.4).

**Sensory Responses to the ULNT2b**

All participants recorded a evoked sensory response in at least one of the nine areas with symptoms most frequently recorded for the lateral aspect of the forearm and the posterior aspect of the wrist (Table 2). Stretching was the most frequently reported sensory response (reported by 95 % of the study participants), followed by burning pain (20 %), sharp pain (12 %), pressing pain (10 %), numbness (6 %), tingling (4 %), achy pain (3 %) and pinching pain (0.5 %), (Figure 1).

![Figure 1. Elicited sensory responses to the ULNT2b](image-url)
Table 2. Number of participants reporting elicited sensory responses to the ULNT2b by location

<table>
<thead>
<tr>
<th>Location</th>
<th>sharp</th>
<th>pinching</th>
<th>pressing</th>
<th>stretching</th>
<th>burning</th>
<th>tingling</th>
<th>numb</th>
<th>aching</th>
<th>no response</th>
</tr>
</thead>
<tbody>
<tr>
<td>posterior aspect of wrist</td>
<td>4</td>
<td>1</td>
<td>-</td>
<td>48</td>
<td>4</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>lateral aspect of hand</td>
<td>3</td>
<td>-</td>
<td>3</td>
<td>11</td>
<td>-</td>
<td>2</td>
<td>3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>medial aspect of hand</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>lateral aspect of forearm</td>
<td>8</td>
<td>-</td>
<td>-</td>
<td>123</td>
<td>48</td>
<td>3</td>
<td>4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>medial aspect of forearm</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>11</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>lateral aspect of upper arm</td>
<td>1</td>
<td>-</td>
<td>3</td>
<td>27</td>
<td>8</td>
<td>3</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>medial aspect of upper arm</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>16</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>shoulder</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>scapular</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total: Sensory response</td>
<td>18</td>
<td>1</td>
<td>8</td>
<td>248</td>
<td>63</td>
<td>10</td>
<td>12</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Application of the initial scapular depression movement elicited a sensory response in 4% of participants as a stretching pain over the region of the upper fibres of the trapezius muscle. No participants reported any symptoms below the elbow with this movement. No sensory responses were noted in any participant as a result of the application of movements 2 to 4 in the standard sequence of movements. Application of the 5th movement of glenohumeral abduction elicited responses in at least one area in all participants. A total of 362 sensory responses were reported by the 100 participants (from 200 arms). Overall, the ULNT2b most commonly elicited the sensory responses of lateral forearm stretch (62%), burning (24%), and posterior wrist stretch (24%) (Figure 2).
Responses to the final position of the ULNT2b

Figure 2. Elicited sensory responses to the ULNT2b; body chart
Discussion

This study aimed to establish normative responses to the ‘upper limb neurodynamic test with radial nerve bias’ when employed as an assessment tool to assess neural mechanosensitivity of the radial nerve. “Normative sensory responses” was used to indicate the responses reported by the asymptomatic study participants. In this study the standard neurodynamic sequence of scapular depression, elbow extension, glenohumeral internal rotation & forearm pronation, wrist and finger flexion and glenohumeral abduction was applied (Shacklock 2005). A secondary aim of the study was to determine if within-limb range of motion variation existed in the study participants for glenohumeral abduction (neutral limb position compared with neurodynamic test limb position).

The main findings were that the movement sequence applied in this study commonly elicited the sensory responses of lateral forearm stretch (62 %), burning sensation in the lateral forearm (24 %) and posterior wrist stretch (24 %) (Figure 2), and a mean glenohumeral abduction range of motion of 62.2° ± 16.5° (mean ± SD).

A primary aim of the study was to determine the normative sensory responses elicited upon application of the ULNT2b sequence. The initial movement in the sequence, of scapula depression, elicited a sensory response in 4 % of participants and did not elicit sensory responses below the elbow. This is consistent with Yaxley & Jull (1991) who noted that elicited responses to this initial movement were located only in the scapula and shoulder region and were disparate to responses elicited upon application of the full sequence of the ULNT2b. In both the Yaxley & Jull (1991) study and the study here, no sensory responses were elicited during the application of movements 2 – 4 in the movement sequence. Application of the 5th and final movement in the ULNT2b sequence, of glenohumeral abduction, elicited responses in all participants, in at least one area.
Sensory responses elicited upon application of the full movement sequence were experienced most frequently in the regions of the lateral forearm (65 %) and the posterior wrist (27 %), with the predominate response being a stretching sensation, followed by a burning sensation. These elicited sensory responses concur with clinical guidelines presented by Shacklock (1997) and with the findings of previous ULNT2b normative response studies (Petersen et al 2009; Yaxley & Jull 1991; and Yaxley & Jull 1993).

The glenohumeral abduction ROM response elicited upon application of the ULNT2b, of 62.2 ± 16.5 degrees, is somewhat greater than ROM measurements presented in previous studies, of 41.45° ± 4.06° (Yaxley & Jull 1991), 36.60° ± 4.87° (Yaxley & Jull 1993), and 37.3° ± 12.0° (Petersen et al 2009), and is slightly outside of the range reported by Shacklock (1995a; 1995b) of variation from almost no abduction to 50°. However the glenohumeral abduction range of motion measurement falls within the expected range of 60 – 90 degrees for glenohumeral abduction when the humerus is maintained in an internally rotated position, as opposed to the anatomical position (Culham & Peat 1993; Sharkey & Marder 1995; Watson 1989), suggesting that there is the possibility for a great degree of variation in this value. In the studies conducted by Petersen et al (2009) and Yaxley and Jull (1991; 1993) the test was conducted in a different manner to the current study as subjects there were strapped to the table in 3 locations (hip, chest and chin), whereas participant fixation and stabilisation devices were not employed in this study.

The use of structural differentiation as a sixth manoeuvre in the ULNT2b sequence to alter the degree of tension developed in neural tissue without loading the mechanical interface (Butler 1991; Butler & Gifford 1989; Shacklock 2005) could have indicated whether the symptoms elicited in this study were a result of mechanical loading on the radial nerve and were of neurogenic origin (Nee et al 2012; Shacklock 2005). However
manoeuvers for structural differentiation were not applied in this study therefore responses cannot be attributed to specific tissues. However there is strong evidence supporting the use of the ULNT2b movement sequence to mechanically load the radial nerve to strain levels (28 %) well above the threshold known to cause physiological and mechanical events to occur within a peripheral nerve (6 % and 15 % respectively) (Date et al 2002; Dellon & Mackinnon 1986b; Driscoll et al., 2002; Jou et al., 2000; Kwan et al 1992; Wright et al 2005).

This evidence base shows that mechanically loading the radial nerve through ULNT2b movements could cause mechanical and physiological events to occur within the peripheral nerve, of neural sliding/excursion, pressurisation, elongation and tension (Kwan et al 1992; Wilgis & Murphy 1986; Wright et al 2005), an alteration in intraneuronal blood flow (Driscoll et al 2002; Jou et al 2000; Tanoue et al 1996), a decrease in nerve conduction (Date et al 2002; Kwan et al 1992), an alteration in alpha motor neuron excitability (Kerr et al 2002) and local inflammation (Bove 2008; Sauer et al 1999). Leading to stimulation of the sensory nerve fibres carried in nervi nervorum and symptom production in the assessed limb (Bove & Light 1997; Bove & Light 1995; Byl et al 2002; Driscoll et al 2002; Jou et al 2000; Kwan et al 1992; Wright et al 2005).

Stretching responses elicited in the lateral forearm, lateral hand and posterior wrist could correspond to a stretch of subcutaneous and myofascial tissues as the arm is moved into glenohumeral internal rotation, forearm pronation and wrist and finger flexion (Schunke et al 2006), or could be a result of mechanical loading on the radial nerve (Asbury & Fields 1984; Bove 2008; Sauer et al 1999; Wright et al 2005). Participants did not report any sensation production during the application of the glenohumeral internal rotation, forearm pronation or wrist and finger flexion movements and sensory responses were not elicited in subjects until the application
of the final movement of glenohumeral abduction, with the exception of the few elicited scapula responses to the initial shoulder depression movement.

There were five participants who reported a tingling sensation on application of the ULNT2b. Three participants described tingling in a region down the posterior aspect of the arm, two reported tingling over the posterior hand and three reported a feeling of numbness in a small region on the posterior hand adjacent to the base of the thumb. These locations correspond to the sensory distribution of the radial nerve (Schunke et al. 2006) suggesting the possibility of mechanically induced strain on the radial nerve. The use of structural differentiation could have indicated whether these elicited symptoms were of neurogenic origin (Nee et al. 2012; Shacklock 2005).

A secondary aim of the study was to determine the within-limb variation in range of motion (neutral limb position compared to ULNT2b limb position). In this group of community participants who were not seeking treatment for shoulder pain and had no or minimal pain in the upper limb, the mean glenohumeral abduction in a neutral limb position was seen to be 78 degrees compared to a mean of 62 degrees for glenohumeral abduction in an ULNT2b limb position. The ULNT2b limb position ROM in this study was found to be an average of 16 degrees less than the neutral limb position. To my knowledge, no study has documented the within-limb range of motion variation for the ULNT2b in an asymptomatic population for comparison.

Caution therefore needs to be applied when assuming that similar within-limb reductions in ROM on ULNT2b application in a clinical setting indicates adverse neural mechanics. Furthermore, recent studies have questioned the use of range of motion variation responses within upper limb neurodynamic testing; Covill et al. (2012) suggested that ROM is not a good indicator of a positive response, finding range of motion asymmetry between limbs to be a normal occurrence, while Nee et al. (2012)
found an alteration in range of motion not to be a valid indicator of a positive response and that significant differences in range of motion between symptomatic and asymptomatic limbs for group data do not help determine whether an individual patient has an abnormal deficit in ULNT range of motion.

The main limitation to this study was that manoeuvres allowing for structural differentiation were not applied, thus no links between elicited responses and neural mechanosensitivity could be made; however the aim of the study was to establish normative baseline data for an asymptomatic population as a means of adding to current knowledge on normative responses. Another limitation was the experience of the researcher; a postgraduate student with little research experience. Intra-rater reliability calculations for range of motion measurements were not made, limiting the reproducibility. The use of the same body chart for both left and right limbs when recording elicited sensory responses could have led to bias in recording of the results. Application of the procedures was standardised but not measured, allowing for a margin of error to occur, as does the lack of use of fixation and stabilisation devices; however the study aimed to establish normative responses for comparison against clinical populations in which fixation and stabilisation devices would likely not be used.

The sampling methods used here aimed to recruit a broad cross-section of participants from varied socio-economic, ethnic and demographic backgrounds. Participant characteristics of gender, age, handedness, and side tested did not influence the observed ULNT2b responses, again in agreement with Yaxley & Jull (1991). These results suggest that ULNT2b has scope for use on diverse clinical practice populations. Nonetheless, the influence of socio-economic background and ethnicity on elicited responses was not assessed. To be fully confident about the generalisability of the results, further studies on larger population groups that include a diverse ethnic and socio-economic make-up, are warranted.
Conclusion

In summary, application of the ULNT2b without the use of fixation or stabilisation devices on the asymptomatic study participants was shown to elicit sensory responses of lateral forearm stretch, lateral forearm burning and posterior wrist stretch, supporting findings of previous studies (Petersen et al 2009; Yaxley & Jull 1991; Yaxley & Jull 1993). The mean glenohumeral abduction range of motion response for the ULNT2b was seen to be 62 degrees, which is slightly larger than the findings of Petersen et al (2009), Yaxley & Jull (1991) and Yaxley & Jull (1993) but still within an expected range of motion (Culham & Peat 1993; Sharkey & Marder 1995; Watson 1989). Glenohumeral abduction in the ULNT2b position showed a within-limb decrease of, on average, 16 degrees from a neutral limb position.

The sample population consisted of a broad cross-section of participants from Auckland New Zealand, males and females were well represented, and a wide age range was seen in the participants. Participant characteristics of gender, age, handedness, and side tested did not influence observed responses. The results of this study can add to current knowledge of normative responses to the ULNT2b against which responses elicited in a clinical setting can be compared.
References


Section 3: Appendices
Appendix A: Ethics Approval for this project
Nicola McLaren  
10/53 Bellevue Road  
Mt Eden  
Auckland

27 August 2009

Dear Nicola

Your file number for this application: 2009-980
Title: An investigation of normative data for the upper limb neurodynamic test with radial nerve bias

Your application for ethics approval has been reviewed by the Unitec Research Ethics Committee (UREC) and has been approved for the following period:

Start date: 24 August 2009  
Finish date: 24 August 2010

Please note that:
1. the above dates must be referred to on the information AND consent forms given to all participants
2. you must inform UREC, in advance, of any ethically-relevant deviation in the project. This may require additional approval.

You may now commence your research according to the protocols approved by UREC. We wish you every success with your project.

Yours sincerely

[Signature]

Deborah Rolland  
Deputy Chair, UREC

cc: Craig Hilton  
Cynthia Almeida
Appendix B: Participant Recruitment Poster
Are you interested in being a Research Participant?

Participants are needed for a study of a diagnostic test that assesses a nerve in the arm

If you are aged between 18 -65 and are interested then you may be eligible to participate in this study.

The purpose of the study is to investigate normal responses to a diagnostic test that assesses a nerve in the arm (the radial nerve). It involves moving the arm and establishing any sensations and any change in the distance the arm can move.

This study is part of meeting the requirements of research for the Masters of Osteopathy qualification.

The study has been approved by the UNITEC Research Ethics Committee.

IF YOU ARE INTERESTED IN PARTICIPATING IN THIS STUDY PLEASE CONTACT NICOLA MCLAREN on nicola_mclaren@hotmail.com
Appendix C: Information Sheet for Participants
PARTICIPANT INFORMATION FORM

My name is Nicola McLaren. I am currently enrolled in the Master of Osteopathy at UNITEC and I invite you to participate in the project which is part of meeting the requirements of research for a project which forms a substantial part of this qualification.

The aim of my project is:

To establish normal responses to a diagnostic test that assesses a nerve in the arm (the radial nerve).

The diagnostic test involves moving the arm in a particular way. The objective is to establish whether any sensation is experienced and whether the distance the arm can move changes when this test is applied to the arm.

I request your participation in the following way:

• First you will answer a standardised questionnaire to gather information on any disability you may have in your arm and to assess your appropriateness for your participation in this research.

• The tested arm will be turned so that the palm faces away from the body then moved out away from the body. The distance of the movement will be measured.

• Lastly you will answer a standardised pain questionnaire to report any feeling or sensation that occurred with the arm movement. Possible sensations include a pulling sensation and/or a stretch in the arm.

• These three steps will take no longer than thirty (30) minutes of your time and any effect (feeling, sensation, change in distance of movement) relating to the movement of the arm will cease when the arm is released.

Neither you nor your organisation will be identified in the project. The results of the research activity will not be seen by any other person without the prior agreement of everyone involved. You are free to ask me not to use any of the information you have given, and you can, if you wish, ask to see the project before it is submitted for examination. You have the right to withdraw from the project at any time up to two weeks prior to completion of the project (February 2010).

I hope that you will find participation in and discussion of the project of interest. If you have any queries about the project, you may contact my research supervisor at UNITEC.

My research supervisor is

Craig Hilton,
Phone (09) 8154321 ext. 8601 or email chilton@unitec.ac.nz

UREC REGISTRATION NUMBER: 2009-980
This study has been approved by the UNITEC Research Ethics Committee from (24th August 2009) to (24 August 2010). If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the UREC Secretary (ph: 09 815-4321 ext 6162). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.
Appendix D: Consent Form - Adults
CONSENT FORM - ADULTS

TO:

FROM:

DATE:

RE: An investigation of normative data for the upper limb neurodynamic test with radial nerve bias.

I have been given and have understood an explanation of this research for the Master of Osteopathy. I have had an opportunity to ask questions and have had them answered. I understand that neither my name nor the name of my organisation will be used in any public reports, and that I may withdraw myself or any information that has been provided for this project at any time (refer below), up to two weeks prior to completion of the project, without penalty of any sort.

I agree to take part in this project.

Signed: __________________________________________

Name: __________________________________________

Date: __________________________________________

UREC REGISTRATION NUMBER: 2009-980
This study has been approved by the UNITEC Research Ethics Committee from (24th August 2009) to (24 August 2010). If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the UREC Secretary (ph: 09 815-4321 ext 6162). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.
Appendix E: Outcome Measures
RESEARCH PARTICIPANT QUESTIONNAIRE

DATE:

1. Age:

2. Gender (circle one): M F

3. Handedness (circle one)

Left handed   Right handed   Ambidextrous

4. Occupation:

Sedentary       Moderately Active

5. Do you currently experience any of the following (circle):

- known or expected pregnancy,
- known spinal or upper limb fracture
- tumour or cancer
- infection
- ongoing neck or arm injury
- ongoing tingling, or numbness in hand, arm, shoulder or neck

6. Are you currently receiving treatment for any neck or arm injury? Yes / No
INSTRUCTIONS

This questionnaire asks about your symptoms as well as your ability to perform certain activities.

Please answer every question, based on your condition in the last week, by circling the appropriate number.

If you did not have the opportunity to perform an activity in the past week, please make your best estimate on which response would be the most accurate.

It doesn’t matter which hand or arm you use to perform the activity; please answer based on your ability regardless of how you perform the task.
## Disabilities of the Arm, Shoulder and Hand

Please rate your ability to do the following activities in the last week by circling the number below the appropriate response.

<table>
<thead>
<tr>
<th>Activity</th>
<th>NO DIFFICULTY</th>
<th>MILD DIFFICULTY</th>
<th>MODERATE DIFFICULTY</th>
<th>SEVERE DIFFICULTY</th>
<th>UNABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Open a tight or new jar.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2. Write</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3. Turn a key</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4. Prepare a meal</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5. Push open a heavy door</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>6. Place an object on a shelf above your head</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>7. Do heavy household chores (e.g., wash walls, wash floors)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>8. Garden or do yard work</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>9. Make a bed</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>10. Carry a shopping bag or briefcase</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>11. Carry a heavy object (over 10 lbs.)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>12. Change a lightbulb overhead</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>13. Wash or blow dry your hair</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>14. Wash your back</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>15. Put on a pullover sweater</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>16. Use a knife to cut food</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>17. Recreational activities which require little effort (e.g., cardplaying, knitting, etc.)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>18. Recreational activities in which you take some force or impact through your arm, shoulder or hand (e.g., golf, hammering, tennis, etc.)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>19. Recreational activities in which you move your arm freely (e.g., playing frisbee, badminton, etc.)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>20. Manage transportation needs (getting from one place to another)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>21. Sexual activities</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
# Disabilities of the Arm, Shoulder and Hand

<table>
<thead>
<tr>
<th></th>
<th>NOT AT ALL</th>
<th>SLIGHTLY</th>
<th>MODERATELY</th>
<th>QUITE A BIT</th>
<th>EXTREMELY</th>
</tr>
</thead>
<tbody>
<tr>
<td>22. During the past week, to what extent has your arm, shoulder or hand problem interfered with your normal social activities with family, friends, neighbours or groups? (circle number)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>NOT LIMITED AT ALL</th>
<th>SLIGHTLY LIMITED</th>
<th>MODERATELY LIMITED</th>
<th>VERY LIMITED</th>
<th>UNABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>23. During the past week, were you limited in your work or other regular daily activities as a result of your arm, shoulder or hand problem? (circle number)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Please rate the severity of the following symptoms in the last week: (circle number)

<table>
<thead>
<tr>
<th></th>
<th>NONE</th>
<th>MILD</th>
<th>MODERATE</th>
<th>SEVERE</th>
<th>EXTREME</th>
</tr>
</thead>
<tbody>
<tr>
<td>24. Arm, shoulder or hand pain.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>25. Arm, shoulder or hand pain when you performed any specific activity.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>26. Tingling (pins and needles) in your arm, shoulder or hand.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>27. Weakness in your arm, shoulder or hand.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>28. Stiffness in your arm, shoulder or hand.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>NO DIFFICULTY</th>
<th>MILD DIFFICULTY</th>
<th>MODERATE DIFFICULTY</th>
<th>SEVERE DIFFICULY</th>
<th>SO MUCH DIFFICULTY THAT I CAN’T SLEEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>29. During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand? (circle number)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>STRONGLY DISAGREE</th>
<th>DISAGREE</th>
<th>NEITHER AGREE NOR DISAGREE</th>
<th>AGREE</th>
<th>STRONGLY AGREE</th>
</tr>
</thead>
<tbody>
<tr>
<td>30. I feel less capable, less confident or less useful because of my arm, shoulder or hand problem. (circle number)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

DASH DISABILITY/SYMPTOM SCORE = [(sum of n responses) - 1] x 25, where n is equal to the number of completed responses.

A DASH score may not be calculated if there are greater than 3 missing items.
# Disabilities of the Arm, Shoulder and Hand

## Work Module (Optional)

The following questions ask about the impact of your arm, shoulder or hand problem on your ability to work (including homemaking if that is your main work role).

Please indicate what your job/work is: __________________________

- I do not work. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week. Did you have any difficulty:

<table>
<thead>
<tr>
<th></th>
<th>No Difficulty</th>
<th>Mild Difficulty</th>
<th>Moderate Difficulty</th>
<th>Severe Difficulty</th>
<th>Unable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. using your usual technique for your work?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2. doing your usual work because of arm, shoulder or hand pain?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3. doing your work as well as you would like?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4. spending your usual amount of time doing your work?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

## Sports/Performing Arts Module (Optional)

The following questions relate to the impact of your arm, shoulder or hand problem on playing your musical instrument or sport or both. If you play more than one sport or instrument (or play both), please answer with respect to that activity which is most important to you.

Please indicate the sport or instrument which is most important to you:

- I do not play a sport or an instrument. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week. Did you have any difficulty:

<table>
<thead>
<tr>
<th></th>
<th>No Difficulty</th>
<th>Mild Difficulty</th>
<th>Moderate Difficulty</th>
<th>Severe Difficulty</th>
<th>Unable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. using your usual technique for playing your instrument or sport?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2. playing your musical instrument or sport because of arm, shoulder or hand pain?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3. playing your musical instrument or sport as well as you would like?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4. spending your usual amount of time practicing or playing your instrument or sport?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

**Scoring the Optional Modules:** Add up assigned values for each response; divide by 4 (number of items); subtract 1; multiply by 25. An optional module score may not be calculated if there are any missing items.
# McGill Pain Questionnaire

**Patient's Name**

**Date**

**Time** am/pm

<table>
<thead>
<tr>
<th>PRI:</th>
<th>S (1-10)</th>
<th>A (11-15)</th>
<th>E (18)</th>
<th>M (17-20)</th>
<th>PRI(T) (1-20)</th>
<th>PPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flickering</td>
<td>11</td>
<td>Tiring</td>
<td>Exhausting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Quivering</td>
<td>12</td>
<td>Sickening</td>
<td>Suffocating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Pulsing</td>
<td>13</td>
<td>Fearful</td>
<td>Frightful</td>
<td>Terrifying</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Throbbing</td>
<td>14</td>
<td>Punishing</td>
<td>Gruesome</td>
<td>Cruel</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Beating</td>
<td>15</td>
<td>Pricking</td>
<td>Vicious</td>
<td>Vile</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Pounding</td>
<td>16</td>
<td>Boring</td>
<td>Unbearable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Jumping</td>
<td>17</td>
<td>Drilling</td>
<td>Urinary</td>
<td>Killing</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Flashing</td>
<td>18</td>
<td>Stabbing</td>
<td>Blinding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Shooting</td>
<td>19</td>
<td>Lancinating</td>
<td>Wretched</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Pricking</td>
<td>20</td>
<td>Pricking</td>
<td>Blinding</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**RHYTHMIC**

- Brief
- Momentary
- Transient

**CONTINUOUS**

- Periodic
- Intermittent
- Steady

**COMMMENTS:****

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