Normal sensory responses to variations in sequencing for the neurodynamic slump test

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DECLARATION

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This thesis entitled: Normal sensory responses to variations in sequencing for the neurodynamic slump test is submitted in partial fulfillment for the requirements for the Unitec degree of Master of Osteopathy.

Candidate’s declaration

I confirm that:

This thesis represents my own work;

- The contribution of supervisors and others to this work was consistent with the Unitec Regulations and Policies.
- Research for this work has been conducted in accordance with the Unitec Research Ethics Committee Policy and Procedures, and has fulfilled any requirements set for this project by the Unitec Research Ethics Committee.
- Research Ethics Committee Approval Number: 2011-1217

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Thesis Abstract

**Background:** The neurodynamic slump test is commonly used in all forms of manual therapy to evaluate the nerve mechanics and physiology of the central and peripheral nervous systems. Clinicians have proposed that the order of slump test sequencing is interchangeable and that neural structures will be subjected to different mechanical loads depending upon the order of joint movement. **Aims:** The aims of this study were to: (1) investigate the normative sensory responses (frequency, anatomical location, symptom intensity, symptom descriptors) associated with sequences of the slump test in asymptomatic participants; and (2) investigate the body segment angles associated with sequences of the slump test in asymptomatic participants.

**Methods:** Each asymptomatic male participant (n=24; mean age = 27 ± 2.3 y; mean BMI = 24.3 kg/m²) performed four variations of the slump test. Digital photography was used to measure 5 body segment angles. A body chart, visual analogue scale and 12 sensory descriptors were administered.

**Results:** There were no clinically important differences in the sensory responses, or significant differences (1-way ANOVA, all contrasts p≥0.77) for any body segment angles between variations of different sequences of the slump test. Nearly all participants (n=23/24) in all tests reported a sensory response with pain and/or discomfort most commonly located in the lower limb (> 80%). "Stretching" was the most common (50%) descriptor selected during the end stage of the slump test. Pooling all sequences, a majority of participants (n=85/96) experienced a decrease in intensity of symptoms with cervical extension, which was observed largely independent of the slump
sequence. **Conclusion:** A change in the sequence of a standardised slump test in asymptomatic participants did not meaningfully influence the outcome of the sensory responses or body segment angles in this sample. Secondarily, these findings indicate that a sensory response arising from slump occurs in people who are asymptomatic.

**Keywords:** Manual therapy; Slump test; Neurodynamic test; Neurodynamic sequencing; Musculoskeletal pain; Physical examination; Diagnosis.
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Introduction to thesis structure

This thesis consists of three sections:

- **Section 1: Literature review.** The review of relevant literature provides the theoretical basis and rationale for the study reported in the manuscript. This section also includes the primary and secondary aims of this study.

- **Section 2: Manuscript.** This section is a report of an investigation into the normal sensory responses to variations in sequencing for the neurodynamic slump test. The manuscript is prepared in the format specified in the ‘Guide for Authors’ section for *Manual Therapy*. *Manual Therapy* is a peer reviewed journal whose scope includes the publication of papers that “influence the body of evidence on mechanistic and diagnostic processes, patient care and guidelines for musculoskeletal therapies and musculoskeletal medicine”. *Manual Therapy* has previously published a number of papers in the field of neural mechanics and neurodynamic concepts.

- **Section 3: Appendices.** The appendices provide the ethics documentation and recruitment poster for this research. It also provides the consent form and the information sheet, screening questionnaire and Oswestry Disability Index that were used to screen for eligible research participants. Other documents in this section include the checklist used to record information during data collection and examples of the Numeric Pain Rating Scale and sensory descriptors that were presented to participants during the data collection process.
The appendices conclude with *Manual Therapy* ‘Guide for Authors’ which contain formatting conventions followed for Section 2 in this thesis.
Section 1: Review of literature
1. Introduction

Neurodynamic procedures or ‘tests’ are utilised by a range of clinicians working in the field of neuromusculoskeletal disorders to differentiate pain arising from neural versus non-neural structures. Neurodynamic tests are a group of physical examination and treatment procedures designed to engage the physical capabilities of the nervous system. Neurodynamic tests typically involve moving multiple joints of a limb and/or trunk to alter the length and dimensions of the nerve bed and surrounding neural structures (Nee & Butler, 2006). These tests provide a clinically accessible and non-invasive examination and treatment procedure.

The contemporary use of neurodynamic examination and treatment procedures stem from the concepts of ‘adverse neural tension’ and ‘neural provocation tests’ were first described by Breig (1978) and Butler (Butler & Jones, 1991) and were predominantly focused on mechanical aspects. The concept of adverse neural tension in the central nervous system was introduced and explained in great detail by Breig (1978). Breig reasoned from his clinical experience that unfavorable mechanical tensions in the nervous system had the potential to result in clinicopathological disturbances. Breig presented this information alongside new concepts of functional anatomy and physiology of the nervous system. This included the effect of gravity on the neural contents of the spinal cord and the relationship between cervical flexion and lumbosacral nerve root tension (Breig, 1978). His contribution in this field has been essential to the development of neurodynamic tests, as Breig’s early clinical and cadaveric studies have demonstrated how the
nervous system behaves with movements of the limbs and thorax (Neurodynamic solutions, 2012).

The term ‘clinical neurodynamics’ was first described by physiotherapist Michael Shacklock in the early 1990s (Shacklock, 1995) to describe the assessment and treatment of neural tissue using manual therapy. The neurodynamic concept has progressed to consider the relationship between nerve mechanics and nerve physiology (Shacklock, 2005). Neurodynamics was intended to integrate the current literature for clinicians who were interested in ‘mobilisation of the nervous system’. Michael Shacklock, a prominent author and physiotherapy clinician in the area of clinical neurodynamics, attributes much of the early developmental credit to the work of Gregory Grieve (1970), Geoffrey Maitland (1979), Robert Elvey (1979) and David Butler (1991; 2000). Today’s neurodynamic examination and treatment procedures stem from the concepts of ‘adverse neural tension’ and ‘neural provocation tests’ that were described by Breig (1978) and Butler and were predominantly focused on mechanical aspects.

The ability of the central and peripheral nervous system to tension and move within its adjacent anatomical space has been researched using cadaveric studies. Until recently, clinicians have been largely dependent on these cadaveric studies to support theories of neural movement in vivo.

In recent years, ultrasound imaging has emerged as an effective and reliable tool to investigate peripheral nerve movements in real time and in vivo (Ellis, Hing, Dilley, & McNair, 2008; Ridehalgh, Moore, & Hough, 2012). This non-invasive method of investigation has distinct advantages over cadaveric
investigations as the embalming process and dissection of certain tissues is known to alter normal mechanics (Boyd, Topp, & Coppieters, 2013). Ultrasound imaging is also a cost effective and portable option in comparison to other soft-tissue imaging techniques such as magnetic resonance imaging. To date, studies involving neurodynamics using ultrasound imaging have largely investigated sciatic and tibial nerve excursions during standardised movements of large joints (e.g. hip), with excellent levels of repeatability and reliability (Ellis et al., 2008; Ridehalgh et al., 2012; Shum, Attenborough, Marsden, & Hough, 2013). As a result, it has been identified that there are differences in sciatic nerve excursions between specific neural mobilisation exercises (Ellis, 2011).

The slump test is used clinically to evaluate the nerve mechanics and physiology of the central and peripheral nervous systems. This includes the meninges, the contents of the spinal canal, the peripheral nerves of the upper and lower limbs, and their related connective tissues (Shacklock, 2005). The slump test involves a sequential six-stage process that is closely controlled by monitoring a patients symptoms and body segment angles (Figure 1).

The clinical conditions in which slump testing is commonly indicated include headache (Fernández-de-las-Peñas, Arendt-Nielsen, & Gerwin, 2010), pain anywhere in the spine or pelvis (Magee, 2008), lower limb complaints in which symptoms are located in the distribution of the sciatic nerve and its extensions (Brukner & Khan, 2010), and assessment of the lumbar spine (Magee, 2008).
Figure 1. Panels A-F illustrate the sequential stages of a standard slump test. Panel A (starting position): The subject is seated on the table with knees together and legs uncrossed, the creases of the knees are in contact with the edge of the plinth and the hands are placed comfortably behind the subject's back. Panel B (thoracolumbar flexion): Thoracic and lumbar flexion are initiated while the subject continues looking forward. Panel C (cervical flexion): Cervical flexion is initiated by asking the subject to draw their chin to their chest. Panel D (knee extension): The knee is extended until full extension is reached. Panel E (ankle dorsiflexion): The ankle is dorsiflexed by “drawing the toes and ankle towards the head”. Panel F (cervical extension) While maintaining all other joint positions, neck extension is initiated by slowly “looking towards the ceiling”. (Image reproduced courtesy of Elsevier Ltd)

One of the keys to the successful interpretation of a neurodynamic test is described as ‘structural differentiation’ (Shacklock, 2005). This is also known as a ‘sensitising manoeuvre’ (Butler & Jones, 1991), and is controlled in a body segment remote from the location of the symptoms provoked. Each neurodynamic test has its own manoeuvre that aims to be specific to the neural structures being tested. Structural differentiation is commonly undertaken at the end stage of a slump test using the release of cervical flexion (Figure 1-F). A favourable change in symptoms (release of perceived ‘tension’ or other symptom) with this manoeuvre is interpreted clinically as being supportive of the presence of a neural mechanism for symptoms (Lew & Briggs, 1997; Shacklock, 2005). Lew and Briggs (1997) excluded the likelihood of a muscular contribution to posterior thigh symptoms during the slump test when they monitored electromyographic activity and strain of the
hamstring muscles during structural differentiation. Lew and Briggs showed that a change in posterior thigh symptoms with cervical flexion was due to a change in tension of a structure or structures with links to the cervical spine. However, the possibility remains that symptoms may also arise during neurodynamic procedures from other structures such as the local fascia, skin and blood vessels, and this clearly needs further investigation (Shacklock, 2005).

The extent to which symptomatic sensations are elicited during a neurodynamic test has been described as ‘mechanosensitivity’ and is known to cause symptoms in both normal and pathological states (Shacklock, 1995). The pathological mechanisms that produce mechanosensitivity are debatable (Ellis, 2011; Hall & Elvey, 2004). A small number of neurodynamic slump test studies have gathered sensory information from asymptomatic samples (Kuilkart, Woollam, Barling, & Lucas, 2005; Maitland, 1980; Walsh, Flatley, Johnston, & Bennett, 2007; Yeung, Jones, & Hall, 1997). These studies provide a clinical reference point to normative sensory responses by documenting the related prevalence of symptoms, symptom intensity, anatomical location, and a description of responses to standard slump procedures. The results of these normative studies are of value to practitioners when considering if the symptomatic responses to the slump test are within ‘normal’ limits, which is a key component in the process of clinically determining a positive neural test (Butler et al., 2000).

It has been suggested that neural structures will be subjected to different mechanical loads depending upon the order of joint movement during a neurodynamic test (Shacklock, 2005). Textbook authors have identified the
order of neurodynamic sequencing as being interchangeable, although limited research has been conducted into the sensory responses of these variations (Butler et al., 2000; Shacklock, 2005). Therefore the differences between positional responses that are generated through varying sequences are not well characterised. A number of authors have indicated that sequencing should be an area for further consideration (Davis, Anderson, Carson, Elkins, & Stuckey, 2008; Kuillart et al., 2005; Lew, Morrow, & Lew, 1994; Shacklock, 2005; Walsh et al., 2007; Yeung et al., 1997).

A small number of studies have investigated the effects of re-ordering sequences during upper and lower limb investigations and most have measured cadaveric nerve strains and excursions to draw conclusions (Alshami, Babri, Souvlis, & Coppieters, 2008; Boyd et al., 2013; Coppieters et al., 2006; Nee, Yang, Liang, Tseng, & Coppieters, 2010; Tsai, 1995). Sensory responses in asymptomatic and symptomatic people have also been investigated (Pahor & Toppenberg, 1996; Shacklock, 1989; Zorn, Shacklock, Trott, & Hall, 1995). There is limited evidence to indicate that the greatest increase in nerve strain is nearest the moving joint (Coppieters et al., 2006); but increases in nerve strain have also been identified where movement is first initiated (Tsai, 1995; Zorn et al., 1995); and can also be influenced by the position of the adjacent joint (Alshami et al., 2008). Experimental studies have also demonstrated that nerve strain is increased earlier and maintained for longer in the regions closest to the joint that was moved first (Boyd et al., 2013; Nee et al., 2010) and that the sequence of movements affects the distribution of sensory symptoms (Shacklock, 1989; Zorn et al., 1995).
To date, no research appears to have investigated variations in the order of slump test sequencing in asymptomatic people. Therefore, the sensory responses and characterisation of various sequences is not well understood. Subsequent research may influence a clinician’s decision to ‘re-order’ or alter the sequence of movements during a clinical scenario.

The primary aim of this study was to identify the normative sensory responses associated with variations of the slump test in asymptomatic subjects. Secondarily, this study aims to compare the body segment angles associated with variations of the slump test.
2. Literature Reviewed

The background information for this study was collected through Google Scholar, and the online EBSCOhost research databases including PubMed (MEDLINE), ScienceDirect and The Cochrane Collaboration. Key words included, but were not limited to: manual therapy, osteopathy, physiotherapy, neurodynamic test, clinical neurodynamics, slump test, structural differentiation, sensory response, normative data and variations in sequencing. The studies located were reviewed for any relevant data that may provide links to the proposed study. There are several seminal texts directly related to neurodynamic concepts including ‘Clinical Neurodynamics’ by Shacklock (2005), ‘Mobilisation of the Nervous System’ by Butler and Jones (1991) and ‘The Sensitive Nervous System’ by Butler (2000). These texts were reviewed and the reference lists hand searched. The literature is current up until September 2013.
3. Overview of neurodynamic concepts

In the 1990s Butler adapted Breig’s (1978) concept of ‘adverse mechanical tension’ and formed a concept that linked neurobiomechanics, neuropathology and neural mobilisation techniques. Butler has described these concepts in his texts entitled “Mobilisation of the Nervous System” (1991) and “The Sensitive Nervous System” (2000). The phrase ‘adverse neural tension’ was described by Butler (1991) as “abnormal physiological and mechanical responses produced from nervous system structures when their normal range of movement and stretch capabilities are tested” (p. 55). Butler explained how this alteration can either be intraneural (involving structures of the nervous system) and/or extraneural (an interface problem between the nerve and the tissue that surrounds it). Based on clinical observation, Butler proposed that a persistent increase in neural tension, will present with pain and decreased neural mobility, or in plain language: “If it cannot move, glide and stretch, then the nervous system’s cardinal function of conduction will be useless” (Butler et al., 2000, p. 98).

The term ‘clinical neurodynamics’ was later developed by Shacklock (1995, 2005) to integrate mechanical and physiological mechanisms in a way that makes it clinically accessible to apply neurodynamic techniques. The neurodynamic concept includes consideration of intraneural blood flow, mechanosensitivity, ion channel activity, neural inflammation, muscle responses and neuroplastic changes of the central nervous system rather than solely biomechanical observations. The concept of ‘adverse neural tension’ has been substituted with the terms ‘hypersensitivity’ and ‘tension’ to
illustrate the possibility of pathophysiological and/or mechanical origins of
dysfunction (Shacklock, 2005b). Therefore a ‘neural tension dysfunction’ may
contain both pathomechanical and pathophysiological aspects.

An important neurodynamic concept is that the nervous system is a
continuum. “The nervous system as a whole is a mechanically and
physiologically continuous structure from the brain to the end terminals in the
periphery” (Shacklock, Butler, & Slater, 1994, p. 21). The continuous nervous
system is interconnected through connective tissues, electrical impulses and
chemical neurotransmitters (Butler & Jones, 1991). Therefore, the nervous
system should be considered, in the context of manual therapy, as one
continuous tissue tract; where a change in part of the system will have an
impact on the whole system (Butler & Jones, 1991; 2000; Shacklock, 2005).

4. Neurodynamic testing

Neurodynamic testing involves sequential staging of increasingly provocative
movements that are intended to assess both the mechanics and physiology of
the continuous nervous system (Butler et al., 2000; Shacklock, 2005). This
form of examination seeks to identify the relationship between a patient’s
symptoms and pain sensitive neural structures. Therefore these tests aim to
examine and assess the neural contribution of a presenting complaint.
Shacklock (2005) has suggested that “[practitioner] sensitivity and attention to
detail in both technique and interpretation are crucial in effective application of
the test” (p. 141), although the accuracy of diagnosis is not easily established
given the apparent absence of a criterion standard.
Butler has argued that a definition of a ‘positive neurodynamic test’ can be considered as one that reproduces the patient’s symptoms, differs from a normal response, has abnormal unilateral responses, is supported by structural differentiation and is supported from other data such as history, area of symptoms, and imaging tests (Butler et al., 2000). Therefore Butler’s definition is only workable when the normative responses are known.

5. The use of neurodynamic tests in evaluating mechanosensitivity

One of the rationales offered for the use of neurodynamic tests is that they are considered capable of detecting an increase in nerve mechanosensitivity (Butler et al., 2000). Shacklock (2005) describes the phenomenon of mechanosensitivity as “the ease with which the neural tissues become active when mechanical force is applied to them. The more mechanosensitive the nerve is, the less force is needed to elicit activity and the more intense is the response” (p. 64). In an attempt to clarify and characterise this apparently complicated phenomenon, Nee and Butler (2006) published a review paper about the neurobiological mechanisms associated with musculoskeletal presentations of peripheral neuropathic pain. Nee and Butler describe ‘mechanosensitivity’ as a protective mechanism that allows nerves to respond to the mechanical stresses imposed upon them during movement. Examples of the stresses that are capable of irritating neural tissue include that of repetitive, compressive, tensile, friction and vibration forces acting near anatomically narrow tissue spaces (Butler & Jones, 1991; Sunderland, 1990).

Evidence from experimental animal studies illustrates that local neural inflammation is a key factor in neuropathic conditions (Dilley, Lynn, & Pang,
Dilley et al. (2005) examined the response of intact and damaged nerve fibres to pressure and stretch when a local neuritis was induced along the peroneal or sciatic nerves in a rat model (n=34). This study demonstrated that intact and damaged fibres can become mechanosensitive to pressure and stretch and suggests that inflammation could be a significant factor causing mechanosensitivity, even in the absence of physical nerve damage.

Peripheral nerve injuries attract immune cells, such as macrophages and T-lymphocytes to the site of injury (Moalem & Tracey, 2006). These immune cells release inflammatory mediators that lower the firing threshold of regenerating nociceptive afferent nerve fibers, and increase their ectopic excitability (Grossmann, Gorodetskaya, Baron, & Janig, 2009). Schmid et al. (2013) have identified that minor nerve compression is enough to induce an inflammatory process, which is associated with neuropathic pain behaviour.

The nervi nervorum are hypothesised to be important in the pathophysiology of neuropathic and musculoskeletal pain (Bove & Light, 1997). The nervi nervorum are described as small calibre nerve filaments that innervate the sheath of a larger nerve or nerve trunks (Sauer, 1999). The nervi nervorum have been identified as a direct source of mechanosensitivity when stimulated by mechanical and/or chemical means (Bove & Light, 1997; Hall & Elvey, 2004). In response to the experimental evidence, Bove (2008) describes nervi nervorum as “nociceptive and nocifensive, meaning that they are responsive to damaging stimuli by contributing to local inflammation, thus helping to defend and maintain the nerve’s local environment” (p.3.).
The phenomenon of mechanosensitivity has been used in the context of clinical reasoning to generate clinical hypotheses about the effects of neurodynamic techniques on neural structures, particularly inflammation and neural sensitivity. Early identification and suppression of an inflammatory response may assist in the prevention of mechanosensitivity following a peripheral nerve injury (Grossmann et al., 2009). A practitioner’s understanding of mechanosensitivity can therefore assist the clinical decision making process through the interpretation of symptoms produced during non-invasive neurodynamic testing procedures.

6. Slump testing

6.1 Initial development

More than seven decades ago, Inman and Saunders (1942) suggested a combination of spinal flexion and straight leg raising to localise adverse lumbar symptoms. Through cadaveric studies, Inman and Saunders noted the ability of the straight leg raise to cause a caudad movement of the spinal cord below the level of the third lumbar vertebrae. They also documented how spinal flexion affects the upper lumbar nerves by forcing them to move in a cephalad direction. It was therefore hypothesised that spinal flexion and straight leg raising may be useful to localise clinical signs of the lower back.

In the same year, James Cyriax’s (1942) article titled ‘Perineuritis’, described the ‘head and knee test’ to induce the pain of sciatic perineuritis. Cyriax had the seated patient extend the knee and flex the neck to induce their sciatic symptoms. This has obvious similarities to the neurodynamic slump test in contemporary use. His understanding, perhaps not explicitly, of the
continuous nervous system was also evident when he released the symptoms of neural tension by flexing the knee. Cyriax used this test to differentiate pain originating from the sciatic nerve and its sheath from non-neural tissues located in the buttock and posterior thigh.

In 1979 Geoffrey Maitland, an Australian physiotherapist, released a paper in *the Australian Journal of Physiotherapy* titled 'Negative disc exploration: positive canal signs' (Maitland, 1979). Maitland expressed the need for a non-invasive clinical test that could investigate, what at the time, were labeled as “pain sensitive” structures in the vertebral canal (specifically the dura mater and nerve root sleeves). Maitland identified that there were no satisfactory clinical tests of the time that moved and applied stretch to the above mentioned structures in order to prove a dural origin of symptoms. Maitland therefore created the five-stage slump testing procedure that has provided the mechanical framework for the slump test. Maitland ascribed the clinical relevance of this test to those who were suffering from lower back pain, tethering of pain sensitive vertebral canal structures (such as pre and post laminectomy patients), juvenile disc patients and those with headaches (Maitland, 1979).

Since its introduction in 1979, clinicians and authors such as David Butler and Michael Shacklock have used the slump test as both an examination procedure and method of treatment for patients with neural complaints. The original biomechanical movements of the slump test remain largely unchanged since its introduction in 1979 (Figure 1). During the slump test, both caudad and cephalad ends of the nervous system are elongated from each end of the body, applying tension to the neural tissues by increasing the
distance between each end of the neural tract (Shacklock, 2005). The slump procedure has therefore been described by both Butler (1991; 2000), and Shacklock (2005), as a ‘neurodynamic tensioner’ as it challenges the ability of the central and peripheral nervous system to respond to mechanical elongation. This elongation aims to activate viscoelastic, movement related and physiological functions in the nervous system.

Attention to detail, patient feedback, and subjective responses are now considered as important factors for an accurate slump test diagnosis (Shacklock, 2005). The slump test is broad in its application and has the ability to assess the effects of mechanosensitivity throughout the central nervous system and peripheral nervous system.

7. Cadaveric studies

Cadaveric studies have demonstrated how the central and peripheral nervous systems move in vivo. It has been identified that there is a 50 to 97mm elongation of the spinal canal when measuring movement from spinal flexion to extension (Adams & Logue, 1971; Blau & Logue, 1978; Inman & Saunders, 1942; Louis, 1981). During the movement of cadaveric hyperflexion, Louis (1981) observed neuromeningeal convergence points at areas of maximum mobility (C6 and L4). Louis also described areas that undergo forceful stretching during hyperflexion at C6, L4 and the roots of the cauda equina distal to L4.

The position of sciatic and tibial nerve bed excursion during the straight leg raise test (hip flexion with knee extension) with 20° of ankle dorsiflexion was
measured in 5 cadavers by Beith et al. (1994). Beith et al. observed an 89-124mm elongation of the sciatic and tibial peripheral nerve bed. Straight leg raising with the ankle in neutral has produced movement of the sciatic and tibial nerves as far distally as the foot (Breig & Troup, 1979; Coppieters et al., 2006), and ankle dorsiflexion has shown to produce distal movement of the tibial nerve as far proximally as the knee (Boyd, Puttlitz, Gan, & Topp, 2005; Coppieters et al., 2006). Collectively, these findings provide support for the concept of the ‘continuous nervous system’.

Maitland’s slump sitting test, for canal movement signs (1979) was inspired by other dural testing procedures of the time. Specifically, Lasegue’s test (straight leg raising) that was known to exert a caudad tractional force on the sciatic nerve, lumbo-sacral nerve roots and the dura (Goddard & Reid, 1965); and neck flexion, described by Reid (1960) as moving the cervical and thoracic dura in a cephalad direction. Maitland openly acknowledged that the abovementioned testing procedures were testing the pain sensitive structures of the vertebral canal; although he described these tests as somewhat “incomplete” (Maitland, 1980, p. 4).

Through cadaveric studies, a variety of single and multiple joint positions have been studied to demonstrate how the central and peripheral nervous system move within the body. This field of study has helped clinical researchers and clinicians to develop neural tests that aim to implicate symptomatic neural tissue.
8. **In vivo ultrasound investigations of the sciatic and tibial nerves**

Modern ultrasound imaging has enabled *in vivo* investigation under relatively controlled conditions. The main advantage of ultrasound imaging in relation to the progression of neurodynamic research is that of dynamic testing. The analytical technique of frame-by-frame cross correlation has made it possible to analyse high-frequency ultrasound image sequences (Dilley, Greening, Lynn, Leary, & Morris, 2001). Therefore the behavior and associated movement of the nervous system can now be non-invasively investigated in the limbs and thorax.

One of the earlier reports of using ultrasound to measure sciatic nerve excursion was undertaken by Ellis et al. (2008). Ellis et al. assessed the reliability of ultrasound to measure the movement of the sciatic nerve during a lower limb neural mobilisation technique (n=27). Here, the longitudinal movement of the sciatic nerve was assessed during the start (cervical flexion/ankle plantarflexion) and finishing positions (cervical extension/ankle dorsiflexion). The mean ± SEM longitudinal excursion of the sciatic nerve was recorded as 3.47 ± 0.79mm at the posterior mid thigh and 5.22 ± 0.05mm at the popliteal crease. The nerve moved distally during all longitudinal scans. The test-retest reliability of longitudinal nerve movement across three trials in the same session was described as being "excellent" at the posterior mid thigh (ICC=0.75; 95% CI 0.59 - 0.87), but reliability was unable to be calculated for the popliteal crease (due to the nerve moving beyond the field of the ultrasound image).
A similar imaging study was undertaken by Ridehalgh et al. (2012) who aimed to establish the repeatability of measuring longitudinal excursion of the sciatic nerve at the posterior thigh during a modified straight leg raise. From a sidelying position, the sciatic nerve (at the posterior thigh) was imaged during passive knee extension at 30° and 60° of hip flexion (n=18). This study provided new evidence regarding the longitudinal movements of the sciatic nerve that are induced by knee extension. During the first testing phase there was a mean ± SD longitudinal sciatic movement of 9.9 ± 2.2 mm and 12.4 ± 4.4mm at 30° and 60° of hip flexion. Excellent repeatability (hip flexion 30°; ICC=0.92, 95% CI 0.79-0.97; hip flexion 60° ICC=0.96, 95% CI 0.89-0.99) was demonstrated 48-hours later with measurements of 10.1mm and 12.5mm.

Due to the limited evidence regarding in vivo measurement of tibial nerve excursion, Carroll, Yau, Rome and Hing (2012) assessed the degree of longitudinal tibial nerve excursion. Here, the tibial nerve was assessed at the ankle in a weight bearing position, from plantar flexion to dorsiflexion. A mean (± SD) longitudinal excursion of 3.01 ± 0.97mm was recorded across the 16 asymptomatic participants. Comparisons were made against the biomechanical cadaveric studies of Coppieters et al. (2006) and Alshami et al. (2008) where a larger mean range of tibial nerve excursion was recorded (mean range 6.9 to 9.5mm). A major limitation of these cadaveric studies was that the Achilles tendon was transected to gain an experimental physiological range of motion. This comparison to cadavers also compromises generalisability, as findings derived from cadaveric studies may not be applicable in living humans. Although comparisons by Carroll et al. are of
interest as they identify differences in tibial nerve excursion between living and non-living humans.

Most recently, Shum et al. (2013) measured the proximal excursion of the tibial branch of the sciatic nerve at the popliteal fossa. Excursion was measured during a forward bending movement in an asymptomatic sample (n=24). The mean ± SD proximal excursion recorded during this test was 12.2 ± 2.2mm and the reliability of three repeat measurements was found to be excellent (ICC 0.97, 95% CI 0.93-0.99).

Ultrasound appears to be a reliable and repeatable non-invasive technology for measuring the excursion of the sciatic and tibial nerves. The clinical significance of investigating movements of peripheral nerves in real time and in vivo is invaluable to the progression of neurodynamic research. Future studies involving this form of analysis may advance understanding of neural behavior during neurodynamic procedures.

9. **Sciatic nerve excursion during seated neural mobilisation exercises**

   (‘sliders’ and ‘tensioners’)

Using high-resolution ultrasound imaging, Ellis (2011) investigated the effect of neural mobilisation exercises on the sciatic nerve in an asymptomatic sample (n=31). Here they measured longitudinal sciatic nerve excursion at the posterior mid-thigh during four separate seated neural mobilisation exercises (defined as Technique A, B, C or D). Although not a complete slump test, the components of movements used in this study are involved in its application.
The testing procedures used by Ellis (2011) utilised single joint movements and combinations of passive knee extension and active cervical flexion movements. In the field of neurodynamics these movements are known as ‘tensioners’ and ‘sliders’ (Shacklock, 2005). A tensioner involves simultaneous elongation of the nerve bed from one or both ends of the neural system, whereas, a slider can be used to move neural structures at one end of the neural system (one-ended slider) or to create tension at one end of the nervous system while tension is released at the other (two-ended slider) (Shacklock, 2005).

Technique A involved the movements of simultaneous passive knee extension and active cervical extension (two-ended slider mobilisation). Technique B involved the movement of passive knee extension alone (one-ended tensioner mobilisation). Technique C involved the movement of active cervical flexion alone (one ended tensioner mobilisation), and technique D involved the movements of simultaneous active cervical flexion and passive knee extension (two-ended tensioner mobilisation). As hypothesised, differences in sciatic nerve excursion were apparent between these neural mobilisation exercises (p<.001).

Two-ended sliding techniques are documented in clinical texts as producing a large degree of movement as tension is produced at one end of the nervous system and ‘let go’ at the other (Shacklock, 2005). This was evident in Ellis’ results as sciatic nerve excursion was greater during the two-ended slider mobilisation (mean excursion 3.2 mm) compared to either the single-joint mobilisation generated at the knee (2.6 mm), the cervical spine (-0.1 mm) or the two-ended tensioner mobilisation (2.6 mm) (Ellis, 2011). This study
provides insight into the real time excursion of the sciatic nerve during neurodynamic movements. This is important to practitioners and researchers as neural sliders and tensioners are commonly used as neurodynamic treatment techniques. These techniques attempt to decrease inflammatory cycles of the nervous system, control pain produced by the central nervous system and improve a neural structure’s ability to respond to tension changes (Shacklock, 2005).

For future studies, Ellis (2011) suggested a standardised method of passive cervical spine motion, rather than the active movement used in this study. This may increase the internal validity of the study, but with the trade-off of decreasing external validity. The study was documented as relevant for the future design of clinical trials, which will further examine the therapeutic efficacy of neural mobilisation.

10. Slump test sensory investigations

One aspect of receiving a neurodynamic test is the recipient is required to report their ‘sensory responses’, which are the self-reported descriptors (e.g. ‘sharp’) used by test recipients during the performance of the test.

One of the earliest reported investigations into sensory responses to slump was undertaken by Maitland (1980). Maitland investigated the pain patterns of 25 asymptomatic physiotherapy students, using incremental steps from the position of standing to a fully slumped position. Although no statistical data was reported, Maitland concluded that at the end-stage of a slump test, pain behind the knees, in the hamstring area and at the level of the 9th thoracic
vertebrae were a "normal response". Although of limited scope, size, and methodological rigour, this study provided the first data from which to base asymptomatic sensory investigations.

Kuilart et al. (2005) investigated the prevalence and location of symptoms provoked by the slump test in a sample of subjects with perceived right hamstring tightness (n=42). For comparative reasons, the inclusion criteria demanded a knee flexion angle greater than 15° (as measured by the active knee extension test). The participants were asked to report the anatomical location of their sensory response at the end stage of the slump procedure (full neural tension). Here, a high prevalence of lower extremity symptoms was documented in comparison to those in the axial skeleton. A majority, 66.7% (n=28) of the subjects reported symptoms in the posterior knee, 35.7% (n=15) reported symptoms in the posterior thigh and 33.3% (n=13) reported symptoms in the posterior leg.

A similar study by Walsh et al. (2007) gathered normative sensory data during the slump test in an asymptomatic sample (n = 84). Here, the prevalence, symptom intensity, anatomical location, and description of responses were recorded after each stage of the procedure (slumped sitting, knee extension, ankle dorsiflexion, and cervical extension). At conclusion of the last movement (ankle dorsiflexion) nearly all subjects (97.6%) reported a sensory response. The responses were most commonly located at the posterior knee (n=30, 35.7%), posterior calf (n=27, 32.1%), and/or posterior thigh (n=23, 27.4%). The description of the response at the end-stage of the slump test was left open to individual interpretation, with the most common descriptors being “stretch,” (38%) “tight,” (25%), “pull” (11%) and “strain” (5%). A number of
other descriptors were used less commonly such as tingling (5%), “sharp” (4%), “pain” (4%), “discomfort” (2%), “tension” (2%), “nervy” (2%) and “burn” (2%).

Yeung et al. (1997) assessed the response of the slump test between symptomatic females with neck symptoms associated with whiplash injury (n=20) and an asymptomatic control group (n=40). The symptomatic participants were included in this study if they had been involved in a rear end collision that caused a whiplash type injury over the past 12-months. The control group provided a degree of asymptomatic sensory information that may be useful when making comparisons to similar slump studies.

Participants reported the anatomical locations of sensory responses during each stage of the procedure by means of a numbered body chart and each limb was tested individually. At the end stage of the slump test, a total of 82.5% of asymptomatic participants complained of pain in the mid thoracic area. A further 80% complained of posterior left sided thigh pain compared to 92.5% for the right limb. Less frequent sensory locations included the cervical, lower thoracic and lumbar regions, although these were poorly reported as no specific data for these regions were reported in the article.

A notable result of this study was, in regards to the left limb, those participants with a history of whiplash reported a higher frequency (85%) of cervical pain at the end-range of the slump test, compared to 7.5% of the control group; although no significant differences between the groups were found for the right limb. The authors suggested that this difference may be explained by ‘accommodation’ as the left limb was consistently tested first. Unfortunately,
the authors failed to operationally define “accommodation”, although it seems to be the development of tolerance to pain and discomfort after experiencing multiple tests. This finding underscores the importance of presenting randomized, or balanced, orders in sequences in order to control for potential bias arising from the effects of ordering.

11. Structural differentiation during the neurodynamic slump test (cervical extension)

For reasons of clinical relevance, Shacklock (2005b) emphasised the importance of the differentiating manoeuver to all clinicians and neurodynamic researchers. It was also emphasised that a positive finding should not be made on structural differentiation alone, as there are both normal and abnormal responses to neurodynamic tests. Butler et al. (2000) stated that a test is positive if: it reproduces symptoms; and structural differentiation supports a neurogenic source, and there are differences left to right and to known normal responses; and there is also support from other data such as history, area of symptoms and imaging tests. The satisfaction of a combination of these criteria may lead to a neural diagnosis, although there appears to be little discussion in any neurodynamic literature about how many of these criteria need to be satisfied for a diagnosis to be made.

A pilot study by Maitland (1980) investigated 25 asymptomatic physiotherapy students during the slump test procedure. This study aimed to mechanically stress the pain sensitive structures in the vertebral canal in an effort to gather information about normal slumping responses. The most significant observation was the disappearance of posterior knee and thigh pain when
cervical flexion was released at the end stage of the slump test (full neural loading). This decrease in pain was also accompanied by an increase in knee extension and ankle dorsiflexion. Maitland concluded that this pain and concurrent limitation of movement was related to neural structures between the sacrum and skull, not tight posterior thigh musculature. Therefore the range of motion and pain response of a slump test was found to be influenced by the head position.

Specific neurogenic involvement during the cervical extension phase of the slump test has been investigated by Lew and Briggs (1997). Their study monitored the electromyographic activity and strain of the hamstring muscle during the cervical extension phase at the end-stage of a slump test. Here, 20 of the 22 asymptomatic subjects (91%) recorded an increase in their posterior thigh pain at full cervical flexion when compared to cervical extension. The increase in pain was not associated with an increase in electromyographic readings or tension within the hamstring muscle. This data supported the involvement of non-contractile structures when pain is felt over the posterior thigh at the end stage of the slump test. Lew and Briggs (1997) indicate that neural structures were the most likely source of pain, although further research needs to be conducted to rule out the involvement of other pain sensitive structures such as the deep fascia, blood vessels and skin.

Yeung et al. (1997) used structural differentiation (cervical extension) at the terminal stage of a slump test to implicate neural involvement and to monitor sensory responses. This differed from other studies as a comparison was made between a symptomatic whiplash group (n=20) and an asymptomatic control group (n=40). The Fisher’s exact test showed that with the release of
cervical flexion, the whiplash group had a greater degree of decreased mid-thoracic pain (left limb p=0.032; right limb p=0.003), although there was a similar decrease in pain between groups in the cervical and posterior thigh regions. These findings reinforce the clinical value of structural differentiation during the physical examination process. The findings also inform asymptomatic slump investigations and provide a baseline of symptomatic whiplash responses. A potential limitation of the study was that the whiplash group may have had other pathological and psychological mechanisms contributing to their symptoms, although the possible presence of pathologies within the sample does increase the representativeness of the sample given that such pathologies may also co-present in clinical practice. Another potential limitation of this study was the unmonitored use of overpressure, which may have influenced the intensity of the participant’s symptoms, however, this is another example of the compromise between internal and external validity (Godwin et al., 2003).

A study by Kuilart et al. (2005) aimed to establish the prevalence and location of symptoms induced by the slump test in asymptomatic subjects with perceived hamstring tightness. Here, a positive slump test was defined by symptoms that were completely or partially relieved with neck extension, whereas during a negative test symptoms remained unchanged. The sensitising manoeuvre (cervical extension) followed the final end-stage movement of the slump test (ankle dorsiflexion). Five out of 42 participants had no change in symptoms, nineteen had partial relief of symptoms and sixteen had complete relief of symptoms. This data supports the hypothesis that neural mechanosensitivity may play a role in explaining ‘perceived
hamstring tightness’ and that this perception cannot simply be explained by reduced hamstring extensibility. The likelihood of non-neural structures and ‘hamstring tightness’ contributing to the findings were further excluded by average knee extension angles of 32.2°. This average knee extension angle was considered as ‘normal’ when compared to other similar normative studies (Youdas et al., 2005).

Walsh et al. (2007) aimed to obtain normative slump test data by investigating the sensory responses of asymptomatic subjects (n=84). At the terminal stage of the slump test (full neural loading) the structural differentiation manoeuver of cervical extension was performed. Here, 79.2% of participants indicated a positive test (demonstrated by a complete or partial relief of their current symptoms). This result further reinforced the argument that non-pathological neurogenic tissue can be the source of sensory symptoms in an asymptomatic sample during the slump test.

A key issue in the field of neurodynamics is the definition of a ‘positive’ neurodynamic test. Therefore, to limit confusion, both normal and abnormal neurodynamic tests need to be clearly defined and understood. To date, this issue has not received much attention in the literature. The importance of defining what constitutes of ‘positive’ test is demonstrated by a study published by Davis et al. (2008) and the subsequent correspondence of Ellis (2009). Davis et al. (2008) investigated the prevalence of “false positive” slump tests in an asymptomatic sample (n = 84). Since all participants were determined to be asymptomatic, every positive test was considered a “false-positive” result. Here only 33.3% (n=28) of subjects displayed complete or partial relief of symptoms during cervical extension at the terminal stage of the slump test.
slump test. This low prevalence of “false positive” results prompted the authors to question the current criteria for determining a positive slump test. They proposed that a positive test should be determined using range of motion cut-off scores. These conclusions invoked a response by (Ellis, 2009) who, writing in a Letter to the Editor, raises the point that the definitions used by Davis et al. did not adequately reflect the true intention of this neurodynamic test, and argued that the definition of a positive neurodynamic test should not be made on structural differentiation alone but should also include a reproduction of a patient's symptoms, an abnormal unilateral response and should be supported by other data such as history, location of symptoms and imaging tests (Butler et al., 2000).

This low percentage of positive tests reported by Davis et al. (2008) in comparison to the 83.3% reported by Kuilart et al. (2005) and the 79.2% reported by Walsh et al. (2007) may have also been influenced by the use of a modified version of the slump test. Davis et al. performed cervical flexion and ankle dorsiflexion before knee extension. Passive guidance of ankle dorsiflexion and knee extension was also applied until sensory symptoms were elicited. These methods were implemented to allow for the comparison of subjects based on an isolated knee joint angle. It is unclear if a different test sequence would affect Davis et al's low “false positive” rate.

Neurodynamic studies involving asymptomatic samples have identified that predictable sensory responses can be expected in the absence of neural pathology. Therefore the type of sensory response, including the anatomical location, symptom intensity, symptom descriptor, outcome of structural differentiation and bilateral comparisons can be important factors to consider.
during the clinical reasoning process. Clinicians need to be aware that structural differentiation cannot be the only measure of neural involvement, although it is an important component of a neurodynamic test’s ability to detect a “neural contribution” (Shacklock, 2005b) as part of a presenting complaint.

12. Neurodynamic sequencing

Several proponents in the field of neurodynamics have identified the order of neurodynamic sequencing as being interchangeable (Butler et al., 2000; Shacklock, 1989, 2005), although limited research has been conducted in regards to the sensory responses of these variations. Therefore the differences between positional responses that are generated through varying sequences have not been comprehensively explored to date. A number of authors have indicated this as an area for consideration, including: Kuliart et al. (2005) who indicate that a modified slump sequence may produce varying sensory results; Lew et al. (1994) who suggest that slump sequencing may alter the degree of spinal cord tension; Davis et al. (2008) who believe that the order of a test may influence the direction of neural glide and sensory reproduction; Walsh et al. (2007) who indicate that the order of neural testing may influence an individual sensory response; and Yeung et al. (1997) who believe that the sequence in which movements are applied may influence the neural system’s movement and tension.

Neurodynamic sequencing has been defined as “the performance of a set of particular component body movements so as to produce specific mechanical events in the nervous system, according to that sequence (or order) of
component movements” (Shacklock, 2005, p. 20). It is theorised that neural structures will be subjected to different mechanical loads depending upon the order of joint movement during a neurodynamic test. A small number of studies have investigated the effects of re-ordering sequences during upper (Nee et al., 2010; Tsai, 1995; Zorn et al., 1995) and lower limb investigations (Alshami et al., 2008; Boyd et al., 2013; Coppieters et al., 2006; Pahor & Toppenberg, 1996; Shacklock, 1989). Shacklock (2005) has identified the principles of neurodynamic sequencing as being “universal”, which appears to mean that the principles of sequencing applies to both upper, lower and axial structures of the central and peripheral nervous systems. The majority of these studies (Alshami et al., 2008; Boyd et al., 2013; Coppieters et al., 2006; Nee et al., 2010; Tsai, 1995) have employed investigations using cadaveric nerve strains and excursions to draw conclusions. However, the obvious limitation of these studies is the use of embalmed and unembalmed cadavers and absence of conscious responses and description of sensation. The outcomes of symptomatic responses in relation to re-ordering sequences in humans are not well understood.

12.1 Nerve strain and excursion

Nerve strain has been described as a deformation or change in nerve length that is produced by tensile stress (Topp & Boyd, 2006). Neurodynamic tests and treatment procedures are based around an understanding of the degree of nerve excursion and strain of the peripheral and central nervous system.

In an unpublished thesis, Tsai (1995) (as reported in Shacklock, 2005) analysed the strain of the ulnar nerve at the elbow during the ulnar neurodynamic test of the upper limb. Tsai (1995) observed three different
sequences in human cadavers (elbow first, proximal to distal and distal to proximal). The separation of the ulnar nerve was measured using thread markers that were positioned in the nerve. A 20% increase of ulnar nerve strain was consistently observed when the sequence was initiated at the elbow compared to proximal to distal and distal to proximal sequences. The clinical relevance of the findings from Tsai’s data, are that different loading sequences may be capable of producing higher or lower amounts of nerve strain during the ulnar neurodynamic test of the upper limb.

Coppieters et al. (2006) investigated the hypothesis that strain in the nerves around the ankle and foot caused by ankle dorsiflexion can be further increased with hip flexion (modified straight leg raise test). Coppieters et al. used embalmed cadavers (n=8) in an attempt to clarify this test’s clinical utility in the diagnosis of distal neuropathies. Strain in the sciatic, tibial, and plantar nerves was measured during the different components of straight leg raise test. In the first stage of the procedure, the ankle was moved from plantar flexion into dorsiflexion. In the second stage, the hip was flexed while the ankle was maintained in dorsiflexion (with an extended knee). The initial movement of ankle dorsiflexion was associated with an increased strain in the tibial nerve around the ankle compared to the length of the arbitrary reference position (mean increase=3.3%; p=0.0002; distal excursion=9.5mm). The addition of hip flexion furthered the excursion of the tibial nerve by 6.5mm and increased the strain by +2.3%. These results show that, at least in cadavers, the greatest increase in nerve strain was nearest the moving joint and that hip flexion (following ankle dorsiflexion) increased the mechanical forces acting on the tibial nerves in the tarsal tunnel.
In a similar type of study, Alshami et al. (2008) demonstrated in a small number of embalmed cadavers (n=10) that the position of adjacent joints has a substantial impact on the amount of strain in the tibial and plantar nerves during movements of the foot and ankle. Here, four different hip and knee positions were used to measure tibial and plantar nerve strain at the ankle during ankle dorsiflexion and toe extension (hip neutral with knee flexion, hip neutral with knee extension, hip flexion, knee flexion and hip flexion with knee extension). Alshami et al. reported that tibial nerve strain increased with ankle dorsiflexion (mean increase: 3.9%) and strain was higher when the nervous system was pre-tensioned by either knee extension or hip flexion (p ≤0.011). Strain was even higher when the nerve bed was elongated at both the hip and knee (p ≤0.006) before performing dorsiflexion. These results suggest that the amount of nerve strain at the foot and ankle is clearly influenced by the position of the neighboring joint and that strain in the tibial nerve (at the tarsal tunnel) is the lowest when the positions of both the hip and knee do not pretension the sciatic or tibial nerve.

A recent study by Boyd et al. (2013) investigated the differences in sciatic nerve strain and excursion during two common variations of the straight leg raise test in embalmed cadavers (n=10). These variations consisted of a proximal to distal movement (hip flexion followed by ankle dorsiflexion) and a distal to proximal movement (ankle dorsiflexion followed by hip flexion). In both sequences, the hip was moved from neutral to maximal flexion and the ankle from maximal plantarflexion to maximal dorsiflexion. The results did not support their hypothesis that nerve strain and excursion will be greater at the ankle if dorsiflexion was performed first. Results show that strain in the tibial
nerve (at the ankle) was greater with the proximal to distal sequence ($p = .008$), but the magnitude of the difference in strain between the sequences was small (0.8%). This finding is interesting clinically, because it suggests that nerve strain was increased earlier and was maintained for longer in the regions closest to the joint that was moved first.

Nee et al. (2010) investigated the impact of re-ordering the median nerve upper limb neurodynamic test. The aim was to assess how sequences of movement affected the patterns of median nerve strain and net longitudinal excursion. Using unembalmed (fresh frozen) human cadavers ($n=7$), the median nerve upper limb neurodynamic test was performed in three sequences (standard, distal to proximal and proximal to distal). The results of Nee et al. (2010) were similar to Boyd et al. (2013) as the strain and relative position of the nerve at the end of a test did not differ between sequences. Nee et al. (2010) concluded that the pattern of strain during progressive stages of a test was influenced by the test sequence. Therefore, a selected sequence, such as distal to proximal, placed a higher strain on the distal nerve segment for a longer period of time. These findings may influence a clinician’s decision to re-sequence a neurodynamic test and may be beneficial as judicious application of test sequencing may enable better control over the duration of strain on a particular neural segment.

### 12.2 Symptomatic sensory responses to re-ordering sequences

The following studies, although few in number are based on the symptomatic sensory responses produced by reordering neural testing sequences. Therefore, this research is clinically oriented and relies on an individual’s
perceived response to draw conclusions, rather than an objective measure of nerve strain and excursion.

Shacklock became interested in sequencing by observing variations of the same neurodynamic test and explored this using a straight leg raise test. Shacklock (1989) investigated the effects of varying the order of a straight leg raise test within an asymptomatic sample. Shacklock concluded that the frequency of symptoms during this test were greater at the point where they were moved first or were moved with more force. These early findings provided a platform and significant reasoning for further sensory and biomechanical research in this area.

Zorn et al. (1995) compared the symptomatic sensory responses of three variations of the upper limb tension test in a sample (n=90) of asymptomatic volunteers. This testing procedure consisted of shoulder abduction, extension and external rotation, elbow extension, forearm supination, wrist and finger extension and contralateral cervical lateral flexion. Test A was performed proximal to distal, test B used a combination of movements ending with elbow extension (without bias to proximal or distal components) and test C was performed using a distal to proximal sequence. Results suggest that tests A and B produced sensory responses in similar locations. While test C (distal to proximal) produced more symptoms in the forearm and hand. These findings are of interest to clinicians examining patients with suspected distal neuropathies; however, comparisons need to be considered, with some caution, as this data was not derived from a symptomatic sample.
Using the slump testing procedure, Pahor and Toppenberg (1996) assessed the sensory responses of 18 participants with a recent (≤6 month) inversion sprain of the ankle. Three different foot and ankle positions (neutral, dorsiflexion and plantarflexion with inversion) were used during performance of the slump test. Comparisons of sensory responses could be made as both the injured and uninjured limbs were investigated. In regards to the injured limb, all 18 participants reported lateral ankle pain during the slump test with plantarflexion and inversion; whereas sensory responses were similar between limbs in the neutral and dorsiflexed positions. Therefore plantarflexion with inversion during the slump test may be a useful variation to make inferences about neural involvement in people presenting with symptoms associated with ankle inversion sprains. A limitation of this study was that there was no control group, therefore comparisons as to what can be considered ‘normal sensory responses’ during these variations could not be made.

Research in the area of neurodynamic sequencing may influence a clinician’s decision to re-order the sequence of the test during physical examination. Recent evidence indicates that the order of sequencing may control the duration of strain on a particular neural segment (Boyd et al., 2013; Nee et al., 2010), thus allowing a clinician to provoke symptoms by managing the amount of time that a neural structure is under tension. This may be useful to clinicians by way of increasing the accuracy of a neurodynamic test and permit clinical reasoning about the proximal or distant location of putative neural dysfunction. Increasing symptom intensity during the process of applying a neurodynamic test may be due to the period of time that a nerve is
strained rather than a variation’s ability to cause a greater amount of nerve excursion (Boyd et al., 2013; Coppieters et al., 2006; Nee et al., 2010; Tsai, 1995).

The re-ordering of testing sequences may allow a practitioner to reproduce specific symptoms during a neural testing procedure and increase the ability to detect abnormalities. Therefore, a range of available sequences may permit more options to reproduce positions that are linked to symptoms. Thirteen years ago, Butler et al. (2000) recommended that clinicians develop their skills by altering neurodynamic sequences to replicate the order of movement used by patients during symptomatic activities. Since this time, there has been a small amount of studies that have investigated the effects of neurodynamic sequencing, although these studies do not provide conclusive evidence to support the role of re-ordering a sequence in a clinical environment.

13. Conclusion

The review of the current evidence strongly suggests that further studies need to be conducted to explore the influence of sequencing when using the neurodynamic slump test. A small number of studies have investigated the sensory responses of the neurodynamic slump test in an asymptomatic population, however, no studies appear to have investigated the normative sensory responses associated with variations of the slump test in asymptomatic subjects. As a practitioner, it is necessary to have knowledge of normal responses before determining a test as positive, as a positive and/or abnormal neurodynamic response is partly classified as one that differs from those that occur in normal subjects (Butler et al., 2000; Shacklock, 2005).
Therefore, the aims of the investigation reported in Section 2 of this thesis were: 1) to identify the normative sensory responses associated with variations of the slump test in asymptomatic subjects; and 2) to identify the body segment angles associated with variations of the slump test.
14. Reference List


(Unpublished masters thesis), University of South Australia, Adelaide, Australia.


Section 2: Manuscript

Note: This manuscript has been prepared in accordance with the instructions for authors for the journal *Manual Therapy* [See Appendix 9 for Guide for Authors]. For the purposes of presenting as a component of this thesis, the word count guidelines from *Manual Therapy* have not been followed.
Normal sensory responses to variations in sequencing for the neurodynamic slump test

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1 ABSTRACT

**Background:** The neurodynamic slump test is commonly used in all forms of manual therapy to evaluate the nerve mechanics and physiology of the central and peripheral nervous systems. Clinicians have proposed that the order of slump test sequencing is interchangeable and that neural structures will be subjected to different mechanical loads depending upon the order of joint movement. **Aims:** The aims of this study were to: (1) investigate the normative sensory responses (frequency, anatomical location, symptom intensity, symptom descriptors) associated with sequences of the slump test in asymptomatic participants; and (2) investigate the body segment angles associated with sequences of the slump test in asymptomatic participants. **Methods:** Each asymptomatic male participant (n=24; mean age = 27 ± 2.3 y; mean BMI = 24.3 kg/m²) performed four variations of the slump test. Digital photography was used to measure 5 body segment angles. A body chart, visual analogue scale and 12 sensory descriptors were administered. **Results:** There were no clinically important differences in the sensory responses, or significant differences (1-way ANOVA, all contrasts p≥0.77) for any body segment angles between variations of different sequences of the slump test. Nearly all participants (n=23/24) in all tests reported a sensory response with pain and/or discomfort most commonly located in the lower limb (> 80%). "Stretching" was the most common (50%) descriptor selected during the end stage of the slump test. Pooling all sequences, a majority of participants (n=85/96) experienced a decrease in intensity of symptoms with cervical extension, which was observed largely independent of the slump sequence. **Conclusion:** A change in the sequence of a standardised slump
test in asymptomatic participants did not meaningfully influence the outcome of the sensory responses or body segment angles in this sample. Secondarily, these findings indicate that a sensory response arising from slump occurs in people who are asymptomatic.

**Keywords:** Manual therapy; Slump test; Neurodynamic test; Neurodynamic sequencing; Musculoskeletal pain; Physical examination; Diagnosis.
INTRODUCTION

The neurodynamic slump test (or ‘slump’ test) is a commonly used physical examination procedures used in several styles of manual and musculoskeletal therapy (Magee, 2008; Brukner and Khan, 2010). The slump test is used to evaluate nerve mechanics and physiology of the central and peripheral nervous systems including the meninges, the contents of the spinal canal, the peripheral nerves of the upper and lower limbs, and their related connective tissues (Shacklock, 2005). Clinical conditions in which slump testing is indicated include headache (Fernández-de-las-Peñas et al., 2010), pain anywhere in the spine or pelvis (Magee, 2008), lower limb complaints in which the pain is located in the distribution of the sciatic nerve and its extensions (Brukner and Khan, 2010); and assessment of the lumbar spine (Magee, 2008). Butler (2000) has argued that a definition of a ‘positive neurodynamic test’ can be considered as one that reproduces the patient’s symptoms, differs from a normal response, has abnormal unilateral responses, is supported by structural differentiation and is supported from other data such as history, area of symptoms and imaging tests. Therefore, Butler’s definition is premised on knowledge of normative responses.

The slump test involves a sequential six-stage process that is closely controlled by monitoring a patient’s symptoms and body segment angles (see Figure 1).
Figure 1 Panels A-F illustrate the sequential stages of a standard slump test. Panel A (starting position): The subject is seated on the table with knees together and legs uncrossed, the creases of the knees are in contact with the edge of the plinth and the hands are placed comfortably behind the subject’s back. Panel B (thoracolumbar flexion): Thoracic and lumbar flexion are initiated while the subject continues looking forward. Panel C (cervical flexion): Cervical flexion is initiated by asking the subject to draw their chin to their chest. Panel D (knee extension): The knee is extended until full extension is reached. Panel E (ankle dorsiflexion): The ankle is dorsiflexed by “drawing the toes and ankle towards the head”. Panel F (cervical extension) While maintaining all other body segment angles, neck extension is initiated by slowly “looking towards the ceiling”.

A small number of studies have investigated the effects of re-ordering sequences during upper and lower limb investigations although most have measured cadaveric nerve strains and excursions (Tsai, 1995; Coppieters et al., 2006; Alshami et al., 2008; Nee et al., 2010; Boyd et al., 2013). Sensory responses in asymptomatic and symptomatic people have also been investigated (Shacklock, 1989; Zorn et al., 1995; Pahor and Toppenberg, 1996). There is experimental evidence to indicate that the greatest increase in nerve strain is nearest the moving joint (Coppieters et al., 2006), where movement is first initiated (Tsai, 1995; Zorn et al., 1995), and nerve strain is influenced by the position of the adjacent joint (Alshami et al., 2008).

Sequencing studies have also demonstrated that nerve strain is increased earlier, and maintained for longer, in the regions closest to the joint that was first moved (Nee et al., 2010; Boyd et al., 2013), and that the sequence of movements affects the distribution of sensory symptoms (Shacklock, 1989; Zorn et al., 1995). Knowledge of normal sensory responses during a range of different slump sequences may influence a clinician’s decision to re-order a neurodynamic test during clinical assessment or treatment. The clinical use of a range of loading options that are controlled through the order of sequence
may allow a practitioner to reproduce specific symptoms during a neural testing procedure therefore adding value to the clinical reasoning process.

Textbook authors have identified the order of neurodynamic sequencing as being interchangeable, although limited research has been conducted into the sensory responses of these variations (Butler et al., 2000; Shacklock, 2005). Therefore the differences between positional responses that are generated through varying sequences have not been well characterised. No research appears to have been conducted that investigates variations in the order of slump test sequencing in asymptomatic people. Therefore, the sensory responses and characterisation of various sequences is not well understood.

The aims of this study were to: (1) investigate the normative sensory responses (frequency, anatomical location, symptom intensity, symptom descriptors) associated with sequences of the slump test in asymptomatic participants; and (2) investigate the body segment angles associated with sequences of the slump test in asymptomatic participants.
3 METHODS OF DATA COLLECTION AND ANALYSIS

3.1 Design

A 4x4 Latin square design (Carter et al., 2011) was utilised to counterbalance the potential order effect associated with receiving slump test sequences. This counterbalancing of presentation order was intended to control for carry over or ordering effect that sequential interventions may have.

Four variations of the slump sequence (Sequence A to D) were performed on each participant (Table 1). The participants were assigned by random allocation (online randomisation algorithm: http://random.org) into 1 of 4 groups that correspond to their testing order (Table 2).

Table 1. Slump Test Variations

<table>
<thead>
<tr>
<th>Sequence</th>
<th>SP</th>
<th>TLF</th>
<th>CF</th>
<th>KE</th>
<th>AD</th>
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<tbody>
<tr>
<td>Sequence A</td>
<td>SP</td>
<td>TLF</td>
<td>CF</td>
<td>KE</td>
<td>AD</td>
</tr>
<tr>
<td>Sequence B</td>
<td>SP</td>
<td>AD</td>
<td>KE</td>
<td>CF</td>
<td>TLF</td>
</tr>
<tr>
<td>Sequence C</td>
<td>SP</td>
<td>CF</td>
<td>TLF</td>
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</tr>
<tr>
<td>Sequence D</td>
<td>SP</td>
<td>KE</td>
<td>AD</td>
<td>TLF</td>
<td>CF</td>
</tr>
</tbody>
</table>

Notes: SP= Starting Position; CF= Cervical Flexion; TLF= Thoracolumbar Flexion; KE= Knee Extension; AD= Ankle Dorsiflexion. Sequence A was the standard slump test as outlined by Butler et al. (2000). Sequences B, C and D were developed by calculating all variation possibilities for the four chosen standard movements (CF, TLF, KE, AD). These 24 variations were then reduced to 3 by the investigators through considering the potential clinical usefulness.
Table 2. Groups and Testing Order

<table>
<thead>
<tr>
<th>Group 1</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 2</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>A</td>
</tr>
<tr>
<td>Group 3</td>
<td>C</td>
<td>D</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Group 4</td>
<td>D</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
</tbody>
</table>

3.2 Study sample

Volunteers were invited to participate after responding to recruitment posters placed around Unitec’s Mt Albert Campus, a Facebook recruitment page, and by word of mouth.

3.2.1 Inclusion criteria

Inclusion criteria were structured to promote a degree of homogeneity in the sample, and participants were eligible to enroll in this study if they met all of the following criteria: 1) were male; 2) were aged between 18 and 40 years; 3) were able to read and understand English; 4) were able to attend one session lasting approximately 40 minutes.

3.2.2 Exclusion criteria

Prospective participants were not eligible for enrolment in the study, if they were: 1) suffering from current back or leg pain; 2) a score of $\geq 10$ units (20%) on the Oswestry Disability Index (Fairbank and Pynsent, 2000); 3) reported physical limitations or physical impairments that would inhibit slump performance; 4) reported a history of major trauma or surgery involving the lumbar spine and lower limb; 5) had been diagnosed with, or showed signs of
spinal pathology, or were known to have a congenital abnormality (e.g. spondylolisthesis).

3.3 Data Collection

3.3.1 Procedures

Data was collected over a 6-month period in a research laboratory, Department of Osteopathy, Unitec, New Zealand. A health screening questionnaire and Oswestry Disability Index was also administered to each participant to ensure their suitability. Demographic characteristics were collected including the participant’s age, weight, and height. Lower limb dominance was established by asking a participant if they were left footed, right footed, or unsure. All participants attended one session of 40-minutes duration.

3.3.2 Ethics

All participants received an information sheet outlining the study protocol and then signed a written consent form to participate in the research. The study was approved by the Unitec Research Ethics Committee (Approval No: UREC 2011-1217).

3.3.3 Active knee extension (AKE) test

Prior to slump testing an active knee extension test was administered to each participant’s right lower limb (Figure 2). The AKE test was included to allow comparisons with other studies. When conducted by one examiner under controlled conditions, the intra-tester reliability of the AKE test has been demonstrated to be excellent (Gajdosik and Lusin, 1983). Pre-defined
landmarks (lateral malleoli and the fibular head) of the participant’s limb were marked with adhesive markers to enable subsequent photographic analysis of body segment angles.

Each participant was positioned supine on a standard treatment table, keeping the non-dominant leg straight whilst the dominant hip was at 90° of flexion. A custom-made wooden box and restraining straps were used to ensure that 90° of hip flexion was maintained throughout the testing procedure. Participants were further instructed not to move the thigh away from the position of 90° at any time during the test. The thigh of the non-dominant limb was secured to the table with a cloth strap to ensure it did not lift as the alternate leg was maneuvered. The participant was then instructed to actively extend their leg as far as possible, whilst keeping their foot relaxed. At this time, the participant was instructed not to force the leg past the point of initial, mild resistance. The participant was then instructed to “very slowly flex the knee until muscle contractions (myoclonus) cease”. At the first point of no shaking a digital photograph was taken. The initial stretch sensation was used as an end point of the AKE test (Cameron and Bohannon, 1993; Turl and George, 1998; Kuilart et al., 2005). Three repetitions of knee extension were performed.

Digital photography analysis software (ImageJ, v1.4.6; (Rasband, 2012) was used to measure the knee flexion angle. For each image, a line was drawn on the posterior thigh at 90° of hip flexion. A second line bisecting the lateral malleoli and fibular head was drawn. The mean angle of the three active knee extension repetitions was used in subsequent analysis.
A familiarisation procedure took place before the commencement of data collection. This consisted of each participant’s first pre-assigned slump sequence. This aimed to familiarise the participant with the procedure and allowed time for any questions before formal data collection.
3.3.5 **Slump test procedure**

The right lower limb was used for all participants regardless of limb dominance. Standardised verbal instructions were given to each participant before the test began and throughout its course. The five slump test positions (Figure 1) were performed as outlined by Butler et al. (2000), although no overpressure was used following the cervical flexion phase. Clinical experience indicates that during the course of the slump test, small changes in participant body position can introduce ‘slack’, which was operationally defined as the tendency of participants to make subtle movements that have the potential to unload mechanical tension and therefore change symptoms. Therefore, whilst maintaining all positions, participants were instructed to “fully extend or straighten their right knee to take up the slack” following TLF in sequences B and D.

3.3.6 **Structural differentiation (cervical extension)**

After achieving a full slump position, participants were instructed to extend their neck by “slowly looking up towards the ceiling” (Figure 1, panel F). Participants were then asked whether this final movement reduced their symptoms and to what degree: completely or partially. All participant responses were recorded on a data sheet.

All four slump sequences (Table 1) were tested during the same session with a 2-min break between tests.
3.4 Outcome measures

At the endpoint of each slump sequence (full neural loading) the investigator gathered sensory information by recording the anatomical location, symptom intensity and symptom description of each participant’s perceived response.

3.4.1 Anatomical location

Figure 3 shows the colour coded anatomical body chart that was used to record location.

![Anatomical Body Chart](image)

Figure 3. Anatomical Body Chart. The anatomical location was recorded on a body chart that consisted of 9 pre-defined areas (neck, upper back, lower back, buttock, posterior thigh, posterior knee, posterior calf, ankle and foot). These areas were colour coded, numbered and labelled to increase the efficiency and clarity of each participant’s response.
3.4.2 Symptom intensity

The symptom intensity was verbally rated using an 11-point numeric pain rating scale (NPRS) for pain. The NPRS ranges from 0 for ‘no pain’, to 10 for ‘worst possible pain’. The NPRS scale has been shown to be a reliable measure of clinical pain and is considered a valid measure of pain intensity (Price et al., 1994).

3.4.3 Symptom descriptors

The symptom descriptors of the perceived sensory response were verbalised by the participant at the end stage of each slumping sequence. A list of 11 symptom descriptors were drawn from the Short Form McGill Pain Questionnaire (SF-MPQ) (Ho et al., 1996) (throbbing, shooting, stabbing, sharp, cramping, gnawing, hot-burning, aching, heavy, tender and splitting). The SF-MPQ has been identified as a valid and consistent pain questionnaire that is easily understood by adults (Ho, Spence & Murphy 1996). The sensory descriptor ‘stretching’ was added to the list as it has been identified as a common descriptor in other studies of neurodynamic tests (Walsh et al., 2007).

3.4.4 Measurement of body segment angle

Self-adhesive markers were positioned at pre-defined anatomical landmarks to enable photographic analysis of body segment angles (Figure 4).
Surface anatomy markers were placed upon the spinous process of the 7\textsuperscript{th} cervical vertebrae, spinous process of the 1\textsuperscript{st} lumbar vertebrae, spinous process of the 1\textsuperscript{st} sacral vertebrae, anterior to tragus, fibular head and the lateral malleoli. An acrylic footplate was secured to the plantar surface of the participant’s foot to determine the plantar angle.

\textbf{Cervical flexion measurement}

Cervical flexion was defined using a horizontal line through the seventh cervical vertebrae (C7) perpendicular to the ground. A second line was drawn through the tragus to create the angle of cervical flexion (Figure 5, panel A). 90° was then added to this measurement to create a final angle of interest.

\textbf{Thoracolumbar flexion measurement (thoracic component)}

The thoracic component of thoracolumbar flexion was defined using a horizontal line through the spinous process of the first lumbar vertebrae (L1), perpendicular to the ground. A second line was drawn from L1 to the C7 to create the angle of the thoracic component of the TLF measurement (Figure 5, panel B).
**Thoracolumbar flexion measurement (lumbar component)**

The lumbar component of thoracolumbar flexion was defined using horizontal line through the spinous process of the first sacral vertebrae (S1), perpendicular to the ground. A second line was drawn from S1 to L1 to create the angle of the lumbar component of the TLF measurement (Figure 5, panel C).

**Knee extension measurement**

Knee extension was defined using a horizontal line parallel to the posterior thigh. A second line was drawn through the lateral malleoli and fibular head to create the angle of knee extension (Figure 5, panel D). This measurement was then subtracted from 180° to create a final angle of interest.

**Ankle dorsiflexion measurement**

Ankle dorsiflexion was defined using a line through the fibular head and lateral malleoli to the base of the foot. A second line was drawn parallel with the plantar surface of the foot to create the angle of ankle dorsiflexion (Figure 5, panel E).

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**Figure 5.** Panels A-E illustrate the body segment angles measured for analysis. Panel A cervical flexion. Panel B thoracic component of thoracolumbar flexion. Panel C lumbar component of thoracolumbar flexion. Panel D knee extension. Panel E ankle dorsiflexion. See text for further detail.
3.5 Data Extraction and Analysis

Symptom responses were tabulated for frequency, location, intensity and descriptors and descriptive statistics calculated for each sequence. Joint ranges of motion were extracted from digital images and tabulated. One-way ANOVA with post-hoc contrasts was used to compare mean body segment angles between sequence A, B, C or D in terminal end range of motion for any of the body segment angles (CF, TLF flexion - thoracic component, TLF flexion - lumbar component, knee extension, ankle dorsiflexion). Bonferroni’s correction was used for post-hoc interpretation. All body segment angles derived from digital images were rounded to 1.d.p. Statistical significance was set at p<0.05. Microsoft Excel was used to tabulate all data and SPSS (v20, IBM Corp.) used for one-way ANOVA. Means presented in text are presented as mean ± SD.
4 RESULTS

All 25 participants enrolled in this study completed the initial written assessments (screening questionnaire and the Oswestry Disability Index (ODI)). One participant was withdrawn due to a high ODI score; this did not qualify him as being asymptomatic. Therefore, 24 participants, 96% of the original sample, completed variations of the Slump testing procedure for analysis.

4.1 Characteristics

The mean age of the 24 participants was 27 ± 2.3 years (range = 19-39 years). All participants were male. The mean Body Mass Index (BMI) was 24.3 ± 2.3kg/m² (range = 22-30.2) which is reported by the New Zealand Heart Foundation (2013) as within the normal range for a healthy weight (range = 18.5–24.9 kg/m²). All except one of participants (95.8%; n=23) reported to be right foot dominant, one participant was left foot dominant. Half of the 24 participants perceived themselves as having ‘tight hamstrings’ during the pre-screening questionnaire. Approximately half (n=13/24) of participants were undergraduate osteopathic students.

4.2 Active knee extension (AKE) test

The mean knee flexion angle of the AKE test was 37.39 ± 18.10°; range = 17.10°-72.45°.
4.3 Frequency of sensory response

A total of 96 slump tests were performed on 24 participants (4 variations per participant). Of the 96 slump tests performed, at least one sensory response was reported at the terminal stage in 94 tests (98%) slump tests, whereas no sensory responses were reported during 2 slump tests.

4.4 Location and intensity of sensory response

There were a total of 147 sensory responses recorded during 96 slump tests. A high frequency of these responses were felt in the lower body and were of a moderate to low intensity (table 3). This pattern was observed almost independently of the Slump sequence applied (Table 4).

Table 3. Location and intensity of sensory responses during the slump test

<table>
<thead>
<tr>
<th>Location</th>
<th>n=147</th>
<th>Mean Intensity (/10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>Upper Back</td>
<td>21</td>
<td>3.0</td>
</tr>
<tr>
<td>Lower Back</td>
<td>3</td>
<td>1.6</td>
</tr>
<tr>
<td>Buttock</td>
<td>10</td>
<td>4.2</td>
</tr>
<tr>
<td>Posterior Thigh</td>
<td>42</td>
<td>3.7</td>
</tr>
<tr>
<td>Posterior Knee</td>
<td>48</td>
<td>3.4</td>
</tr>
<tr>
<td>Posterior Calf</td>
<td>19</td>
<td>3.3</td>
</tr>
<tr>
<td>Ankle</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Foot</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
### Table 4. Location of symptoms and intensity induced during variations of the slump test (n=94)

<table>
<thead>
<tr>
<th>Location</th>
<th>Sequence A</th>
<th></th>
<th>Sequence B</th>
<th></th>
<th>Sequence C</th>
<th></th>
<th>Sequence D</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number (n=38)</td>
<td>Mean Intensity</td>
<td>Number (n=36)</td>
<td>Mean Intensity</td>
<td>Number (n=35)</td>
<td>Mean Intensity</td>
<td>Number (n=38)</td>
<td>Mean Intensity</td>
</tr>
<tr>
<td>Neck</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
<td>2</td>
<td>2.3</td>
</tr>
<tr>
<td>Upper Back</td>
<td>4</td>
<td>3.5</td>
<td>5</td>
<td>2.8</td>
<td>6</td>
<td>2.3</td>
<td>6</td>
<td>3.3</td>
</tr>
<tr>
<td>Lower Back</td>
<td>1</td>
<td>4.0</td>
<td>2</td>
<td>2.3</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Buttock</td>
<td>1</td>
<td>5.0</td>
<td>3</td>
<td>4.7</td>
<td>4</td>
<td>5.0</td>
<td>2</td>
<td>2.0</td>
</tr>
<tr>
<td>Posterior</td>
<td>11</td>
<td>3.5</td>
<td>10</td>
<td>3.7</td>
<td>10</td>
<td>3.6</td>
<td>11</td>
<td>3.8</td>
</tr>
<tr>
<td>Posterior Knee</td>
<td>15</td>
<td>3.4</td>
<td>10</td>
<td>3.8</td>
<td>11</td>
<td>3.4</td>
<td>12</td>
<td>2.8</td>
</tr>
<tr>
<td>Posterior Calf</td>
<td>5</td>
<td>2.8</td>
<td>5</td>
<td>4.7</td>
<td>4</td>
<td>3.0</td>
<td>5</td>
<td>2.7</td>
</tr>
<tr>
<td>Ankle</td>
<td>1</td>
<td>4.0</td>
<td>1</td>
<td>4.0</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Foot</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

### 4.5 Sensory descriptors

There were a total of 156 sensory descriptors identified throughout the 96 slump tests performed (Table 5). Participants commonly reported more than one sensory descriptor per test.
Table 5. Sensory descriptors for all locations (n=156)

<table>
<thead>
<tr>
<th>Descriptors</th>
<th>A (n=41)</th>
<th>B (n=38)</th>
<th>C (n=38)</th>
<th>D (n=39)</th>
<th>Frequency (n=156)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throbbing</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>0.6%</td>
</tr>
<tr>
<td>Shooting</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>1.3%</td>
</tr>
<tr>
<td>Stabbing</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Sharp</td>
<td>8</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>26</td>
<td>16.7%</td>
</tr>
<tr>
<td>Cramping</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>0.6%</td>
</tr>
<tr>
<td>Gnawing</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Hot-burning</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>7</td>
<td>4.5%</td>
</tr>
<tr>
<td>Aching</td>
<td>9</td>
<td>8</td>
<td>8</td>
<td>13</td>
<td>38</td>
<td>24.4%</td>
</tr>
<tr>
<td>Heavy</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>0.6%</td>
</tr>
<tr>
<td>Tender</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>2</td>
<td>1.3%</td>
</tr>
<tr>
<td>Splitting</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Stretching</td>
<td>20</td>
<td>19</td>
<td>20</td>
<td>19</td>
<td>78</td>
<td>50%</td>
</tr>
</tbody>
</table>

4.6 Structural differentiation

Cervical extension was used to interpret structural differentiation following the terminal stage of each slump test. The majority of participants reported partial or complete relief of symptoms, whereas a small number of participants reported no change (Table 6). This pattern was observed largely independent of the Slump sequence (Table 7).
Table 6. Symptomatic influence of cervical extension during last phase of the slump test (total) (n=96)

<table>
<thead>
<tr>
<th>Symptomatic influence of cervical extension during last phase of slump test</th>
<th>Subjects (n)</th>
<th>Subjects (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No change</td>
<td>9</td>
<td>9.4%</td>
</tr>
<tr>
<td>Partial/complete relief</td>
<td>85</td>
<td>88.5%</td>
</tr>
<tr>
<td>No symptoms</td>
<td>2</td>
<td>2.1%</td>
</tr>
<tr>
<td>Increased symptoms</td>
<td>0</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

Table 7. Symptomatic influence of cervical extension during last phase of slump test for all four variations

<table>
<thead>
<tr>
<th></th>
<th>Sequence A (n=24)</th>
<th>Sequence B (n=24)</th>
<th>Sequence C (n=24)</th>
<th>Sequence D (n=24)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No change</td>
<td>0</td>
<td>3 (13%)</td>
<td>2 (8%)</td>
<td>2 (8%)</td>
</tr>
<tr>
<td>Partial/complete relief</td>
<td>24 (100%)</td>
<td>20 (83%)</td>
<td>21 (88%)</td>
<td>22 (92%)</td>
</tr>
<tr>
<td>No symptoms</td>
<td>0</td>
<td>1 (4%)</td>
<td>1 (4%)</td>
<td>0</td>
</tr>
<tr>
<td>Increased symptoms</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

4.7 **Body segment angle analysis**

Descriptive statistics for body segment angles are shown in Table 8. There were no significant differences between sequence A, B, C or D in terminal end range of motion for any of the body segment angles (CF, TLF flexion - thoracic component, TLF flexion - lumbar component, knee extension, ankle dorsiflexion) (see Table 9).
Table 8. Descriptive statistics for mean (deg) ranges for each body segment

<table>
<thead>
<tr>
<th></th>
<th>Sequence</th>
<th>n</th>
<th>Mean (deg)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFAngle</td>
<td>A</td>
<td>24</td>
<td>112.4</td>
<td>10.8</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>24</td>
<td>110.6</td>
<td>12.4</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>24</td>
<td>114.0</td>
<td>12.2</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>24</td>
<td>108.7</td>
<td>12.9</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>24</td>
<td>54.0</td>
<td>6.2</td>
</tr>
<tr>
<td>TLF_Tspine</td>
<td>B</td>
<td>24</td>
<td>55.9</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>24</td>
<td>54.1</td>
<td>7.3</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>24</td>
<td>55.2</td>
<td>8.0</td>
</tr>
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<td></td>
<td>A</td>
<td>24</td>
<td>94.6</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>24</td>
<td>96.6</td>
<td>4.7</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>24</td>
<td>95.4</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>24</td>
<td>95.5</td>
<td>5.2</td>
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<td></td>
<td>A</td>
<td>24</td>
<td>16.4</td>
<td>8.4</td>
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<td></td>
<td>B</td>
<td>24</td>
<td>15.9</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>24</td>
<td>18.6</td>
<td>9.5</td>
</tr>
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<td></td>
<td>D</td>
<td>24</td>
<td>15.1</td>
<td>6.5</td>
</tr>
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<td></td>
<td>A</td>
<td>24</td>
<td>87.7</td>
<td>8.8</td>
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<td></td>
<td>B</td>
<td>24</td>
<td>87.5</td>
<td>8.9</td>
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<td></td>
<td>C</td>
<td>24</td>
<td>85.7</td>
<td>8.7</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>24</td>
<td>87.4</td>
<td>8.5</td>
</tr>
</tbody>
</table>

Notes: CFAngle = cervical flexion measurement; TLF_Tspine = thoracolumbar flexion measurement (thoracic component); TLF_LSpine = thoracolumbar flexion measurement (lumbar component); KE = Knee extension; AD = Ankle dorsiflexion. A, B, C, D refer to sequence of slump – see methods section for details.
Table 9. One-way ANOVA post-hoc contrasts for differences in mean joint angles between different slump sequences

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Notes: CFAngle = cervical flexion measurement; TLF_Tspine = thoracolumbar flexion measurement (thoracic component); TLF_Tspine = thoracolumbar flexion measurement (lumbar component); KE = Knee extension; AD = Ankle dorsiflexion. A, B, C, D refer to sequence of slump – see methods section for details.
5 Discussion

The main finding of this study is that, at least in this sample, there were no clinically important differences in the sensory response or body segment angles between variations of different sequences of the slump test. The secondary findings of this study were that the majority of participants identified at least one sensory response during all four sequences of the slump test, and experienced partial or complete relief of symptoms following cervical extension at the terminal stage of the slump test.

5.1 Sequencing

The results of this study indicate that a change in the sequence of a standardised slump test procedure does not appear to influence the outcome of the sensory responses in an asymptomatic sample. Although there are not any directly comparable studies that investigate slump test sequencing, there is however a study by Zorn et al. (1995) that investigated the sensory responses generated by upper limb sequencing; and two separate cadaveric studies by Nee et al. (2010) and Boyd et al. (2013) that investigate nerve strains and excursions during upper and lower limb sequences.

Zorn et al. (1995) investigated sensory responses that were generated during variations of an upper limb neural tension test (ULNT1 median) in an asymptomatic sample (n=90). Zorn et al. found that a distal to proximal sequence produced more symptoms in the forearm and hand than two other variations. Zorn et al.'s study was predicated on the clinical concept that the
initial site of joint movement has the greatest neural movement; therefore subsequent joint movements will “take up neural slack via the continuum of the neural tissue” (p. 166).

Using cadavers, Nee et al. (2010) identified that the start and end positions of the median nerve are similar during the same variations of sequence for the ULNT1 (median) that were investigated by Zorn et al. (1995). Therefore, the symptomatic response of the distal-to-proximal sequence observed by Zorn et al. were not explained by different median nerve excursions. A possible explanation to these upper limb sensory responses was that the median nerve was subjected to higher levels of strain for a longer period of time during the distal-to-proximal sequence when compared to the other two sequences (p < 0.005) rather than a larger amount of accumulated strain.

It is plausible to expect that similar mechanisms of nerve strain as occur in the upper limb also exist during the slump test. The straight leg raise test involves three movement components of the slump test, these include hip flexion, knee extension and ankle dorsiflexion. A lower limb cadaveric study (n=10) by Boyd et al. (2013) investigated tibial and sciatic nerve strain and excursion during two common variations of the straight leg raise test (SLR). It was identified that variations of the SLR did not substantially influence sciatic and tibial nerve strain and excursion. Although, during both sequences, nerve strain was increased earlier, and was maintained for longer, in the regions closest to the joint that was moved first. Therefore, during a clinical scenario, slump test sequencing may allow a clinician to reproduce symptoms by controlling the duration of strain on a particular neural segment. Although, the nerve excursion
produced when re-ordering a slump test sequence is yet to be comprehensively investigated.

5.2 Frequency of sensory responses

The current study found that a large majority of asymptomatic participants (98%) reported a sensory response at the terminal stage of a slump test sequence. This indicates that asymptomatic participants can, and often do, experience sensory responses to mechanical loading during the slump test. These findings are consistent with those of Walsh et al. (2007), who also found that 98% of asymptomatic participants reported a sensory response at the terminal stage of the slump test (n=84). This finding is also in agreement with Yeung, Jones, and Hall (1997), who found that the majority of asymptomatic participants reported a sensory response at the terminal stage of the slump test (n=40), although Yeung et al. do not provide a precise figure in their results. Comparisons between the current study and the findings of Yeung et al. need to be considered cautiously as the use of overpressure in Yeung et al.’s protocol is likely to have increased the incidence of a sensory response.

5.3 Anatomical location of sensory responses

A positive and/or abnormal neurodynamic response is partly classified as one that differs from those that occur in normal asymptomatic people, therefore, as a practitioner, it is of substantial clinical value to recognise a normal response before determining a test as ‘positive’ (Butler et al., 2000; Shacklock, 2005). The majority of pain and/or discomfort in the present cohort was located in the lower limb (> 80%) with symptoms most commonly located in the posterior knee.
(n=48, 33%), posterior thigh (n=42, 29%) and posterior calf (n=19, 13%).

Walsh et al. (2007) reported similar results to this study at the terminal stage of the same slump test with the most prominent sensory responses found at the posterior knee (n=30, 36%), calf (n=27, 32%), or thigh (n=23, 27%).

During the same slumping procedure as this study, Kuilart et al. (2005) also reported a large majority of lower limb symptoms with 67% of participants reporting symptoms in the posterior knee, 36% in the posterior thigh, and 33% in the posterior leg. The larger prevalence of posterior knee symptoms found by Kuilart et al. may have been due to their inclusion of participants that identified as having ‘hamstring tightness’; although, mean knee extension angles of 32.2° ± 14.2°; range 15.6° - 70°) during the active knee extension test were considered as normal. This was similar to the active knee extension test measurements found in the current study where, during a screening questionnaire, only 50% of the participants identified as having ‘tight hamstrings’.

The authors of this asymptomatic sample and those of Kuilart et al. (2005) and Walsh et al. (2007) reported a significantly lower prevalence of upper back symptoms in comparison to the 83% reported by Yeung et al. (n=40). This may be due to the use of overpressure by Yeung et al. to “bow the lumbar and thoracic curve” during the thoracolumbar flexion phase of the slump procedure. In a rudimentary pilot study of asymptomatic people, Maitland (1980) described the use of “firm overpressure” to “fully stretch” the thoracic and lumbar spines into “full flexion”. Maitland concluded that pain over T9 with trunk and neck flexion can be considered as normal. The force of the overpressure used by
Yeung et al. was not clarified, and was not identified as a limitation. Shacklock (2005) describes the use of “mild overpressure” during the slump test but advises practitioners about the possibility of irritability, as poor technique can unnecessarily provoke symptoms. Overpressure was not used in the current study because of the technical difficulties encountered with standardising the amount of force applied to different participants.

5.4 **Symptom descriptors of sensory responses**

During this study, “stretching” was the most common descriptor selected during the end stage of the slump test and was selected in 50% of all sequences; this was followed by “aching” (24%) and “sharp” (17%) as the most commonly used descriptors. Walsh et al. (2007) documented “stretch,” (38%) “tight,” (25%) and “pull” (11%) as the most commonly used symptom descriptors at the terminal stage of the slump test. In an attempt to minimise bias and to be more representative of the clinical scenario, the symptom descriptors recorded by Walsh et al. were not restricted to individual interpretation (open choice), whereas, in this study a list of 12 symptom descriptors were presented to each participant (fixed choice). It is noteworthy that under both open and fixed choice conditions, the symptom descriptor ‘stretch’ was the most prevalent symptom descriptor both with, and without, the use of visual aids.

5.5 **Structural differentiation (cervical extension)**

A large majority of participants (89%) experienced a change in symptoms (complete or partial relief) with cervical extension at the terminal stage of the slump test. This pattern was observed largely independent of the slump
sequence. This finding is comparable to Kuliart et al. (2005); where at the terminal stage of the slump test, following cervical extension, 83% of participants indicated partial or complete relief of symptoms (n=42). Similarly, Walsh et al. (2007) reported that the majority of participants reported either complete or partial decrease in symptoms (79%) with the cervical extension in an asymptomatic sample (n=84). The decrease in symptom intensity during the sensitising manoeuvre provides further evidence that cervical extension reduces the mechanical load on the tissues, although the specific involvement of neural tissue in this procedure has not been investigated. Lew and Briggs (1997) excluded the likelihood of a muscular contribution to posterior thigh symptoms during the slump test by measuring both electromyographic activity and tension of the hamstring muscle during structural differentiation. Here, 20 of the 22 asymptomatic participants (91%) reported a decrease in their posterior thigh pain at full cervical extension when compared to cervical flexion, with no significant electromyographic readings or tension within the hamstring muscle (biceps femoris). However, the possibility of symptoms arising from other innervated structures such as the fascia, skin and blood vessels has not been excluded and needs further investigation.

Shacklock (2005b) believes that structural differentiation should be included as an essential criterion to interpret slump outcomes, and Butler et al. (2000) emphasises that structural differentiation should not be the only tool used to identify a positive slump test. Importantly, the practitioner needs to determine if the symptoms of a slump test are part of a normal asymptomatic response. A
practitioner must also be aware of the possibility of normal symptoms arising from non-neural structures.

In contrast to the work of this study and that of Kuliart et al. and Walsh et al. a laboratory study by Davis et al. (2008) reported a much smaller response to cervical extension. Davis et al. investigated the prevalence of “false positive” slump tests in an asymptomatic sample (n = 84). Since all participants were asymptomatic, every positive test was considered a “false-positive” result with only 33% (n=28) of participants reporting complete or partial relief of symptoms during structural differentiation (cervical extension) at the terminal stage of the slump test. This was significantly lower than the 89% of participants in the current study that demonstrated complete or partial relief following cervical extension; or the 83% and 79% reported by Kuliart et al. and Walsh et al.

Direct comparisons to the results by Davis et al. are difficult due to Davis et al. using a modified version of the slump test. Here ankle dorsiflexion was performed before knee extension and passive (assisted) guidance of ankle dorsiflexion and knee extension was applied until sensory symptoms were reported. These methods were implemented to allow for the comparison of subjects based on an isolated knee joint angle. The sequence of slump test used by Davis et al. may be internally valid but does not reflect a typical clinical scenario. It is unclear if a different test sequence such as the standardised slump test used in this current study would affect the authors considerably low “false positive” rate.
5.6 Body segment angles

There was no difference in the range of cervical flexion, thoracic spine flexion, lumbar spine flexion, knee extension and/or ankle dorsiflexion between any of the different slump test sequences. This finding should be interpreted cautiously because, as a secondary aim, investigation of body segment angles was not powered to detect small differences. Furthermore, analysis was restricted to comparisons of ranges at joints without reference to commensurate changes that may be happening at other sites. Multivariate analysis to explore the relative contributions of different body segments to end range position would be useful.

5.7 Limitations

Approximately half of the participants were osteopathy students and may have had some previous exposure to neurodynamic principles in their undergraduate education. This prior exposure may have influenced expectations regarding sensory responses, although there were no observational differences between osteopathic and non-osteopathic students.

This study only included male participants, this was done purposely due to the biomechanical differences between males and females; as the ranges of motion for the SLR test have been found to be greater in females (Herrington et al., 2008; Boyd and Villa, 2012). This gender effect for SLR range implies there may also be reason to expect differences between genders for other neurodynamic procedures, such as slump, and given the small sample it was considered judicious to recruit just one gender.
The right limb was selected for all participants during all slump test procedures. The right limb was studied exclusively to limit the already large volume of data available for analysis. The aim of this experimental study did not require inter-limb comparisons. The use of one limb differs from a clinical scenario where it is routine practice to test both limbs (Butler et al., 2000; Shacklock, 2005). To date, there have been few studies that explore inter-limb differences in asymptomatic samples during neurodynamic procedures. A study by Boyd and Villa (2012) found that inter-limb differences during the neurodynamic straight leg raise test were less than 11° in 90% of the general population of healthy individuals.

This study elected not to use overpressure during the thoracolumbar flexion phase of the slump test procedure. This decision was made in order to minimise another variable, as it is technically challenging to control the amount of force used during the application of overpressure.

5.8 Implications for further research

Future studies in neurodynamic procedures should consistently include standard details of the sensory response (frequency, anatomical location, symptom intensity, symptom descriptors) and body segment ranges of movement through each position. This way, the relative contributions of each sequence to the terminal end range position will be further clarified. This study recruited younger, healthy males; future studies should be expanded to include a larger sample size including a wider range of ages, and include both genders in order to improve generalisability. In future studies, a symptomatic sub-group
should be used alongside an asymptomatic sample to draw comparisons between asymptomatic and symptomatic samples. The symptomatic subgroup should have a distinct diagnostic classification for which the slump test is indicated to include or exclude a neural contribution to the presenting complaint e.g. grade 1 repetitive hamstring strains (Turl and George, 1998). This type of research may enhance clinical reasoning about the nature of neurodynamic components and common musculoskeletal complaints. Care should be taken not to include heterogeneous conditions such as “back pain” without careful sub-grouping, as some presenting conditions (such as back pain) may include a range of different neurogenic conditions and would confound interpretation.
6 **CONCLUSION**

This study sought to investigate the sensory responses and body segment angles associated with different sequences of the slump test in a healthy asymptomatic sample. The main finding of this study is that the sequence of a standardised slump test procedure does not appear to influence the outcome of the sensory responses or body segment angles.

The majority of participants identified at least one sensory response during all four sequences of the slump test, and had complete or partial or complete relief of symptoms following cervical extension at the terminal stage of the slump test. These results indicate that a sensory response that is generated by the slump test does not necessarily identify symptomatic neural tissue. Therefore, as a practitioner, it is clinically important to know the range of sensory responses arising during different slump sequences, so comparisons with abnormal responses can be made.
7 REFERENCE LIST

Alshami AM, Babri AS, Souvlis T, Coppieters MW. Strain in the tibial and plantar nerves with foot and ankle movements and the influence of adjacent joint positions. Journal of Applied Biomechanics. 2008;24:368.


Tsai Y-Y. Tension change in the ulnar nerve by different order of upper limb tension test 3: (Unpublished masters thesis), Northwestern University, 1995.


Section 3: Appendices
Appendix 1:

Ethics Approval
Dear Brad,

Your file number for this application: **2011-1217**
Title: **What are the normal sensory responses to variations in sequencing for the neurodynamic slump test?**

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

**Start date:** 9.10.12  
**Finish date:** 27.10.13

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,

Gillian Whalley  
Deputy Chair, UREC

Cc: Rob Moran  
Cynthia Almeida
Appendix 2:

Recruitment Poster
Participants Needed for Osteopathic Research

We are looking for male participants between the ages of 18-45 to be involved in an osteopathic research project. Applicants should not be currently suffering from back or leg pain.

About this research
We are interested in finding out how body position influences flexibility and the feelings associated with these movements. This information is important as these movements are commonly undertaken in clinical practice. This project will involve a physical assessment procedure that is used to identify relationships between a patient’s complaint and structures of the nervous system.

If you are interested and can attend one (60 minute) session at the Unitec Osteopathic Clinic (gate 3, building 41) please email brad.oste@gmail.com or contact 0272555225. Information sheets are available on request or at reception (student osteopathic clinic).

UREC REGISTRATION NUMBER: 2011-1217
This study has been approved by the UNITEC Research Ethics Committee from 27 September 2011 to 26 September 2012. 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 3:

Information Sheet
What are the normal sensory responses to variations in sequencing for the neurodynamic slump test?

What we are doing?
You are invited to take part in a research project being undertaken by Bradley Timberlake as part of the Master of Osteopathy Degree. This information sheet aims to provide information regarding the nature of this research and what will happen should you choose to participate.

The research will involve a popular clinical slump test that is regularly used within the manual therapy professions (physiotherapy and osteopathy) as part of undertaking physical evaluation. The slump test enables us to assess some of the physical characteristics of muscles, nerves and other soft tissues of the lower limb, back and neck. From the seated position this test combines a series of simple movements (such as tucking your chin to your chest). We’re interested in the sensations you feel during these bending movements.

The researchers
The researcher is Bradley Timberlake, with supervision from Rob Moran.

Where is the study being conducted?
Unitec Osteopathic clinic
Entry 3, Building 41
Carrington Road, Mt Albert, Auckland

Who can be involved?
We are seeking male participants between the ages of 18-40 years who are able to read and understand English. Participants must be able to attend one session at Unitec (Mt Albert) lasting approximately one hour.

Unfortunately you cannot participate in this study if you are currently suffering from back or leg pain or have physical limitations in regards to bending of your back, neck, hips, knees or ankle. It’s not appropriate for you to participate in this study if you have previous or current medical conditions involving the spine or lower extremities or have a history of major trauma or surgery involving the lumbar spine and/or lower limb. We’ll talk to you about this in further detail.
What will happen?
On arrival you will complete two questionnaires regarding your relevant medical history and level of functional ability. This aims to ensure that you meet the inclusion criteria for the study. Following this you will be informed as to what the session involves. After you have had time to consider participating, you will be invited to sign a consent form to acknowledge that you understand what the study involves.

The research session will begin by marking pre-defined areas of your body with adhesive markers to enable the analysis of joint angles. This will require exposure of the upper body and legs and can be achieved by wearing suitable underwear or running shorts. Following this, a ‘practice run’ will take place to familiarise you with the procedure. A number of slump test variations will be conducted throughout the session with a two minute break between tests. At the end of each test you will be asked to verbalise the intensity, location and nature of the sensory responses that you are experiencing. The session will be filmed to aid in the collection of relevant sensory data and joint angle measurements.

Potential risks to participants
It should be understood that the slump test is regularly used by manual therapy practitioners as a screening tool for those with suspected musculoskeletal disorders. The documented risks associated with this test include temporary irritation of the nervous system (such as mild tingling or altered sensation in a foot or leg), irritation of a pre-existing disorder, dizziness, and minor disturbances to circulation (Butler & Jones, 1991). The researcher has undergone training in the safe application of this procedure and testing will cease if an abnormal response is detected. The risk to you is minimal as the screening associated with this research aims to exclude those with potential disorders.

Confidentiality
Confidentiality and your anonymity will be protected in the following ways:

- All consent forms and completed questionnaires will be seen only by researchers
- All hard copies and information will be stored in a locked file in a secure room. Only the researchers will have access to this file.
- Only anonymous data will be presented in reports relating to this research.
- Electronic files (including film) will be protected with a password
- Information gathered during this research will be held for 5 years before being destroyed.

Withdrawal
Participants may withdraw from this research up until the point at which data analysis is started (10 days after the data collection session). This will in no way affect access to the services provided by Unitec New Zealand or any other support service.

Who can you contact?
You have the right not to participate, or to withdraw from this research project until the day of final data collection. This can be done without providing any explanation by contacting Bradley Timberlake or Rob Moran at the telephone or email contacts below.

Please contact us if you require any more information or have further questions about this project.

Bradley Timberlake  Rob Moran
Tel: 027 2555225  Tel: 09 8154321 ext 8642
brad.osteo@gmail.com  rmoran@unitec.ac.nz

References

UREC REGISTRATION NUMBER: 2011-1217
This study has been approved by the UNITEC Research Ethics Committee from 9 October 2012 to 27 October 2013. 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 4:

Screening Questionnaire
PARTICIPATION SCREENING QUESTIONNAIRE

What are the normal sensory responses to variations in sequencing for the neurodynamic slump test?

Please answer the questions below to the best of your knowledge

Name of Participant: _______________________________

Date of birth: _____________________________________

Male ☐ Female ☐

If you circle YES to any of these questions please discuss further with Brad or Rob

Are you currently suffering from any physical limitations? Eg trouble lifting household objects

YES / NO

Are you currently suffering from back, neck or leg pain, or altered sensation in your hands, arms, legs, or feet?

YES / NO

Do you have a history of surgery to your back, neck or lower limbs?

YES / NO

Do you have a history of trauma/injury to your back or lower limbs?

YES / NO
Do you have any weakness or numbness in your back or lower limbs?
YES / NO

Have you ever been diagnosed with a spinal disorder that required consultation with a doctor?
YES / NO

Have you ever been diagnosed with a 'birth defect' of your back or neck?
YES / NO

Are you left or right footed?
RIGHT / LEFT / UNSURE

Do you think that you have tight hamstring muscles?
YES/ NO

Participant Name………………………………………….  Date  ……………….

(To be completed by the researcher)

Participant’s: Age___________ Weight _________kg Height_________cm

UREC REGISTRATION NUMBER: 2011-1217
This study has been approved by the UNITEC Research Ethics Committee from 9 October 2012 to 27 October 2013. 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 5:

Consent Form
What are the normal sensory responses to variations in sequencing for the neurodynamic slump test?

Consent Form

This research project investigates the effects of variations in the sequences of a popular ‘neurodynamic’ test – a procedure in which the sensations felt during the positioning of the body are noted. The research is being undertaken by Bradley Timberlake from Unitec New Zealand, and will be supervised by Robert Moran.

Name of Participant:............................................................................................

I have seen the Information Sheet dated.................................for people taking part in the study, titled: “What are the normal sensory responses to variations in sequencing for the neurodynamic slump test”?

I have had the opportunity to read the contents of the information sheet and to discuss the project with the researcher and I am satisfied with the explanations I have been given. I understand that taking part in this project is voluntary (my choice) and that I may withdraw up until the point at which data analysis is started (10 days after the data collection session) and this will in no way affect my access to the services provided by Unitec New Zealand or any other support service.

I understand that my participation in this project is confidential and that no material that could identify me will be used in any reports on this project.

I know whom to contact if I have any questions or concerns about the project.

Signature................................................. Participant ..................... (Date)

Project explained by.................................................................................................

Signature................................................. ............................................. (Date)

UREC REGISTRATION NUMBER: 2011-1217
This study has been approved by the UNITEC Research Ethics Committee from 9 October 2012 to 27 October 2013. 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 6:

Data Collection Checklist
HS Length:

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NATURE:

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<th>LEFT</th>
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NPRS:

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SYMPTOMS COMPLETELY OR PARTIALLY RELIEVED WITH NECK EXTENSION:

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<th>LEFT:</th>
<th>YES NO</th>
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<td>RIGHT:</td>
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Appendix 7:

Oswestry Disability Index
Oswestry Disability Index

This questionnaire has been designed to give us information as to how your back or leg pain is affecting your ability to manage in everyday life. Please answer by checking one box in each section for the statement which best applies to you. We realize you may consider that two or more statements in any one section apply, but please just shade out the spot that indicates the statement which most clearly describes your problem.

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

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

Section 3: Lifting
- I can lift heavy weights without extra pain
- I can lift heavy weights but it gives me extra pain
- Pain prevents me lifting heavy weights off the floor but I can manage if they are conveniently placed (eg. on a table)
- Pain prevents me lifting heavy weights but I can manage light to medium weights if they are conveniently positioned
- I can only lift very light weights
- I cannot lift or carry anything

Section 4: Walking*
- Pain does not prevent me walking any distance
- Pain prevents me from walking more than 1 mile
- Pain prevents me from walking more than ½ mile
- Pain prevents me from walking more than 100 yards
- I can only walk using a stick or crutches
- I am in bed most of the time

Section 5: Sitting
- I can sit in any chair as long as I like
- I can only sit in my favorite chair as long as I like
- Pain prevents me sitting more than one hour
- Pain prevents me from sitting more than 30 minutes
- Pain prevents me from sitting more than 10 minutes

Section 6: Standing
- Pain prevents me from sitting at all

Section 7: Sleeping
- My sleep is never disturbed by pain
- My sleep is occasionally disturbed by pain
- Because of pain I have less than 6 hours sleep
- Because of pain I have less than 4 hours sleep
- Because of pain I have less than 2 hours sleep
- Pain prevents me from sleeping at all

Section 8: Sex Life (if applicable)
- My sex life is normal and gives me no extra pain
- My sex life is normal but causes some extra pain
- My sex life is nearly normal but is very painful
- My sex life is severely restricted by pain
- My sex life is nearly absent because of pain
- Pain prevents any sex life at all

Section 9: Social Life
- My social life is normal and gives me no extra pain
- My social life is normal but increases the degree of pain
- Pain has no significant effect on my social life apart from limiting my more energetic interests e.g. sport
- Pain has restricted my social life and I do not go out as often
- Pain has restricted my social life to my home
- I have no social life because of pain

Section 10: Traveling
- I can travel anywhere without pain
- I can travel anywhere but it gives me extra pain
- Pain is bad but I manage journeys over two hours
- Pain restricts me to journeys of less than one hour
- Pain restricts me to short necessary journeys under 30 minutes
- Pain prevents me from travelling except to receive treatment
Appendix 8:
Symptom Descriptors
Symptom descriptors

- Throbbing
- Shooting
- Stabbing
- Sharp
- Cramping
- Gnawing
- Hot-burning
- Aching
- Heavy
- Tender
- Splitting
- Stretching
Appendix 9:

Numeric Pain Rating Scale (NPRS)
Appendix 10:

Guide for Authors (Manual Therapy)
Guide for Authors

The journal editors, Ann Moore and Gwen Jull, welcome the submission of papers for publication.

Submission to this journal proceeds totally online at http://www.elsevier.com/jnmath.

Use the following guidelines to prepare your article.

You will be guided stepwise through the creation and uploading of the various files. The system automatically converts source files to a single Adobe Acrobat PDF version of the article, which is used in the peer-review process. Please note that even though manuscript source files are converted to PDF at submission for the review process, these source files are needed for further processing after acceptance. All correspondence, including notification of the Editor's decision and requests for revision, takes place by e-mail and via the Author's homepage, removing the need for a hard-copy paper trail.

The above represents a very brief outline of this form of submission. It can be advantageous to print this "Guide for Authors" section from the site for reference in the subsequent stages of article preparation.

Submission of an article implies that the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, without the written consent of the Publisher. Reliability Studies will only be accepted if they are innovative and add to the current body of knowledge within manual therapy.

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Manuscripts should not exceed the following word counts:
- Original Research Articles using quantitative data - 3500 words (Abstract up to 250 words), Keywords, Acknowledgements and ‘in-text’ references are included in the word count.
- Original Research Articles using qualitative data - 4000 words (Abstract up to 250 words), Keywords, Acknowledgements and ‘in-text’ references are included in the word count.
- Reviews - 3500 words, but Systematic Reviews may be longer. Accept up to 4500 words (Abstract up to 250 words), Keywords, Acknowledgements and ‘in-text’ references are included in the word count.
- Technical and measurement notes - 2000 words (Abstract up to 250 words), Keywords, Acknowledgements and ‘in-text’ references are included in the word count.
- Case reports and professional issues - 2000 words (Abstract up to 250 words), Keywords, Acknowledgements and ‘in-text’ references are included in the word count.
- Letters to the Editor - 500 words

These word counts include Abstract, Keywords (where required), Acknowledgements and all the references contained within the article. The reference list at the end of the article, figures/tables, title and author information and Appendices are not included in the word count. Abstracts should be no more than 250 words.

Presentation of Typescripts
Your article should be typed on one side of the paper, double spaced with a margin of at least 3cm. One copy of your typescript and illustrations should be submitted and authors should retain a file copy. Rejected articles will not be returned to the author except on request. Authors are requested to include file numbers to their manuscript in word prior to submission.

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Papers should be set out as follows, with each section beginning on a separate sheet: title page, abstract, text, acknowledgments, references, tables, and captions to illustrations.

Title
The title page should give the following information:
- title of the article

http://www.elsevier.com/journals/manual-therapy/1356-689X/guide-for-authors
- Full name of each author.
- You should give a maximum of four degrees/qualifications for each author and the current relevant appointment.
- Name and address of the department or institution to which the work should be attributed.
- Name, address, telephone and fax numbers, and e-mail address of the author responsible for correspondence and to whom requests for offprints should be sent.

Keywords
Include three or four keywords. The purpose of these is to increase the likely accessibility of your paper to potential readers searching the literature. Therefore, ensure keywords are descriptive of the study. Refer to a recognised thesaurus of keywords (e.g. CINAHL, MEDLINE) whenever possible.

Abstracts
This should consist of 250 words summarising the content of the article. Abstracts should be used for Original Research, Professional Issues and Case Reports as well as for Technical and Measurement Notes papers.

Text
Headings should be appropriate to the nature of the paper. The use of headings enhances readability. Three categories of headings should be used:
- Major ones should be typed in capital letters in the centre of the page and underlined.
- Secondary ones should be typed in lower case (with an initial capital letter) in the left-hand margin and underlined.
- Minor ones typed in lower case and italicised.

Do not use "et al." first etc. where the sex of the person is unknown; say the patient etc. Avoid interrogative alternatives such as 'isn't he?'. Avoid sexist language.

References
The accuracy of references is the responsibility of the author. The journal uses the 'name and year' 'van der Cover' Reference style.

Reference management software
This journal has a standard template available in the reference management package EndNote (http://www.endnote.com/support/styles.asp). Using plug-ins to word-processing packages, authors only need to select the appropriate journal template when preparing their article and the list of references and citations to these will be formatted according to the journal style which is described below.

Citation in text
Please ensure that every reference cited in the text is also present in the reference list (and vice versa). Avoid citation of personal communications or unpublished material. Citations to material in press (i.e. accepted for publication) is acceptable. If these references are included in the reference list they should follow the standard reference style of the journal and should include a substitution of the publication date with either ‘Unpublished results’ or ‘Personal communication’. Citation of a reference as ‘in press’ implies that the item has been accepted for publication. Citation of material currently under consideration elsewhere (e.g. ‘under review’ or ‘submitted’) is not accepted.

In-text citations:
All citations in the text should refer to:
1. Single author: the author’s name (without initials, unless there is ambiguity) and the year of publication.
2. Two authors: both authors’ names and the year of publication.
3. Three or more authors: first author’s name followed by ‘et al.’ and the year of publication.

Citations may be made directly (or parenthetically). Groups of references should be listed first chronologically, then alphabetically.

Examples:
* Sensitivity and specificity (Kerry and Ruston, 2003; Gross et al., 2005; Ritcher and Reikng, 2006)*

Bibliographic list: References should be arranged first alphabetically and then further sorted chronologically if necessary. More than one reference from the same author(s) in the same year must be identified by the letters "a", "b", "c", etc., placed after the year of publication.

Examples:
Reference to a journal publication:

References to a book:

Reference to a chapter in an edited book:

Note shortened form for last page number, e.g., 51-9. For further details you are referred to "Uniform Requirements for Manuscripts submitted to Biomedical Journals" (J Am Med Assoc 1977;277:677-34), see also http://www.nlm.nih.gov/bsd/uniform_requirements.html

Journal abbreviations source
Journal names should be abbreviated according to the Index Medicus Journal abbreviations: http://www.nlm.nih.gov/tsd/serials/ij.html
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Number tables consecutively in accordance with their appearance in the text. Place footnotes to tables below the table body and indicate them with superscript lowercase letters. Avoid vertical rules. Be sparing in the use of tables and ensure that the data presented in tables do not duplicate results described elsewhere in the article. Ensure that each table is cited in the text.

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New guidance for Randomised controlled trials
Clinical Trials that commence after 1st June 2013 must be registered and considered for publication in Manual Therapy. Authors will be asked to state the trial registration number during the submission system as well as at the end of the manuscript file. From January 2014 Manual Therapy will not be able to accept any unregistered Clinical Trial papers. By 2015 the journal will not be able to publish any Clinical Trials that are unregistered prior to recruitment of the first participant.

All randomized controlled trials submitted for publication in Manual Therapy should refer to the Consolidated Standards of Reporting Trials (CONSORT) flow chart. Please refer to the CONSORT statement website at http://www.consort-statement.org for more information. It may be helpful to authors to complete the CONSORT checklist.

Manual Therapy has adopted the proposal from the International Committee of Medical Journal Editors (ICMJE) (see Editorial - Clinical trial registration in physiotherapy journals: Recommendations from the International Society of Physical Therapy Journal Editors,) which require, as a condition of consideration for publication of clinical trials, registration in a public trials registry. Trials must register at or before the onset of patient enrolment. The clinical trial registration number should be included at the end of the abstract of the article. For this purpose, a clinical trial is defined as any research project that prospectively assigns human subjects to intervention or comparison groups to study the cause and effect relationship between a medical intervention and a health outcome. Studies designed for other purposes, such as to study pharmacokinetics or major toxicity (e.g. phase I trials) would be exempt. Further information can be found at http://www.icmje.org.

Further initiatives:
To improve the quality of reporting of other categories of research, Manual Therapy supports the initiatives available through the EQUATOR Network (Enhancing the Quality and Transparency Of Health Research) which houses a database of all reporting guidelines for health research (http://www.equator-network.org). These include:

PRISMA: For systematic reviews and meta-analyses.
STARD: For tests of diagnostic accuracy.
MOOSE: For meta-analysis of observational studies.
COREQ: Consensus criteria for reporting qualitative research.
CHERRIES: Checklist for Reporting Results of Internet E-Surveys.

Submitting Case Reports
The purpose of the Case Report is to describe in reasonable detail the application of manual therapy to a clinical use. Cases of particular interest are those of an unusual presentation, rare conditions or unreported responses to treatment. The following points will assist authors in submitting material for consideration by the Editorial Board:

- The Case Report should be between 1500 - 2000 words in length excluding references and illustrations. Longer studies will be considered by the Editorial Committee if of an exceptional quality.
- An abstract is required and the introductory paragraph should provide the reader with an overview of the study in general.
- The method of presentation to the treating practitioner should be detailed along with the symptoms and their behaviour. A body chart illustrating the symptoms is considered essential.
- The history (present and past) should be reported. Relevant work and leisure activities should also be presented in this section.
- The objective examination findings should be detailed in a concise manner.
- Treatment of the condition should be reported along with results. It is essential to clearly state what was done to achieve the reported results.
- The management of the condition should then be discussed with references to the literature to support what was done. Authors should remember it is a reasoned article rather than a purely factual report.
- The Case Report should conclude with a brief summary.
- Case Reports should be submitted online at http://ees.elsevier.com/ymath

For further details on the Case Report section please contact: Jeffrey D. Boyle, Jeffrey Boyley Associates, LONDON, UK Tel: +44 (0) 7814 880 370 E-mail: jeffboyley@yahoo.co.uk

Submitting a Masterclass
The purpose of the Masterclass section is to describe in detail clinical aspects of manual therapy. This may relate to specific treatment techniques, a particular management approach or management of a specific clinical entity.

- The article should be between 3500 - 4000 words in length excluding references.
- A short summary should precede the main body of the article overviewing the contents.
- The introduction should review the relevant literature and put the subject matter into context.
- The main body of the text will describe the technique or approach in detail.
- Clinical indications and contraindications should be outlined when relevant.
- Illustrations are considered an essential part of the Masterclass in order to fully inform the reader and a minimum of six photographs or line drawings are required.
In addition, authors may wish to include supplementary material which would be available online only. This may include, for example, podcasts, videoclips, animation sequences, high-resolution colour images, author reflections on the masterclass, and background datasets. Please visit the Guide for Authors for further details at www.elsevier.com/track.

For further details and full instructions for authors for the Masterclass section please contact: Karen Beeson, Department of Hygiene, University of Hertfordshire, College Lane, HATFIELD, Herts, AL10 9AB, UK. Tel: +44 (0)1707 284141 Fax: +44 (0)1707 284977 E-mail: k.s.beeson@herts.ac.uk

Submitting a Professional Issue

The purpose of a Professional Issue is to raise an issue of professional importance that affects the national or international community. The issue may concern audits, continuing professional development, data collection methods, education, innovation in practice, professional practice, research goals, service delivery or treatment protocols around the globe. It should provide a solid foundation for the development of better patient outcomes whilst improving the quality of professional practice. The following points will assist authors in submitting material for consideration by the Editorial Board:

- The Professional issue should be no more than 2000 words in length excluding references and illustrations. Longer studies will be considered by the Editorial Board if of an exceptional quality.
- An abstract is required.
- The introductory paragraph should provide the reader with an overview of the issue in general.
- Each section of the text will set out the issue in a reasoned manner.
- The Professional issue should conclude with a brief summary and the implication to the professional practice of manual therapy.
- Professional Issues should be submitted online at http://ees.elsevier.com/mat

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