The effect of a single application of Muscle Energy Technique on hip extension range of motion

Heather K Nicholls

A thesis submitted in partial requirement for the degree of Master of Osteopathy, Unitec Institute of Technology, 2011

ABSRACT

The aim of this study was to examine the effect of a single application of muscle energy technique (MET) compared with passive stretch on hip extension range of motion (ROM) over a 30 minute follow-up period. In an experimental repeated measures controlled cross-over trial, 18 healthy males aged between 18 and 45 with a positive Thomas test indicating a restriction in hip extension, were allocated to one of two groups (*n*=9). Both groups received both the MET and a control procedure (passive stretch) interventions in reverse order to each other with a 7 day interval between sessions. Measurements of passive hip extension in the modified Thomas position were taken immediately prior to and following the intervention, and at 5 minute intervals up until 30 minutes post intervention. The MET intervention produced a "moderate" effect, and the passive stretch produced a "small" effect immediately following the interventions. A "small" effect remained for both groups 30 minutes following the interventions. Therefore both MET and passive stretch appear to be effective in increasing hip extension ROM for a duration of up to 30 minutes.

Key words: Muscle energy technique; hip extension; range of motion; osteopathy

Declaration

Name of candidate: *Heather K Nicholls*

This Research Project is submitted in partial fulfilment for the requirements for the Unitec degree of Masters of Osteopathy

Candidate's Declaration

I confirm that:

- This Research Project 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: 2009-1026

Candidate Signature: Date:

Student number: 1098412

Acknowledgements

I would like to thank the following people who helped make this project come to completion;

All subjects who participated in the experimental data collection phase without whom this project would have been impossible. Thank your time and inclination.

Robert Moran — for his advice, support and guidance as research supervisor.

Derek Nash — for assistance as research supervisor in the early stages of the project.

Vivienne Dawson — who assisted with data collection by performing the experimental intervention.

My family and friends — for all the encouragement, love and support that helped keep me going to finally bring this project to completion.

My fellow osteopathic students, and tutors — who all helped keep me focused and enthusiastic.

Contents

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACR	Agonist contract-relax
CINAHL	Cumulative Index to Nursing and Allied Health Literature
CR	Contract-relax
CRAC	Contract-relax agonist contract-relax
d	Effect size (Cohen's d)
EMG	Electromyograph
HVLA	High velocity low amplitude (thrust)
ICC	Interclass correlation coefficient
LCL	Lower confidence limit
MET	Muscle energy technique
n	Sample size
PNF	Proprioceptive neuromuscular facilitation
PIR	Post isometric relaxation
RI	Reciprocal inhibition
ROM	Range of motion
s	Seconds
SD	Standard deviation
SDD	Smallest detectable difference
SEM	Standard error of measurement
SPSS	Statistical Package for the Social Sciences

Section 1: Literature Review

1. INTRODUCTION

Adequate range of motion is important for the comfortable completion of activities of daily living (Williams, Odley & Callahan, 2004). Basic functions such as standing from sitting, and walking, as well as more complex tasks are dependent on coordination between the trunk and the lower extremity for which hip joint flexibility is a necessary component (Eland, Singleton, Conaster, Howell, Pheley, Karlene & Robinson, 2002). A restriction in hip extension range of motion is common (Magee, 2006), possibly due to an increase in prevalence of seated work particularly if combined with sedentary leisure activities, and may lead to biomechanical compromise and musculoskeletal dysfunction.

The purpose of this review is to highlight current knowledge regarding the causes of a restriction in extension range of motion (ROM) of the hip joint, to discuss the implications of this restriction, and to review studies that have investigated various treatment approaches to address this restriction. A potential treatment option, muscle energy technique (MET), is a form of active stretch commonly used in manual therapy to increase range of motion (Goodridge, 1997; Greenman, 1996) and is explored in this review with regard to its mechanisms of effect, and efficacy, as this approach is investigated in the experiment reported in Section 2 of this thesis.

1.1 Literature search

A comprehensive literature search using electronic databases including Science Direct, Ebsco, Scopus, Academic Search Premier, CINAHL and the Medline databases was undertaken to identify literature relating to hip joint flexibility in extension range of motion and muscle energy technique. Additional studies were added by reviewing the reference lists of retrieved articles. Hand searching of osteopathic and related textbooks to identify relevant literature was also performed.

2. THE HIP JOINT

The structure of the hip is commonly described in anatomy text books as a stable but mobile 'ball and socket' joint which plays an integral role in supporting the body while allowing functional mobility. The hip joint consists of the head of the femur which articulates with the concave surface of the acetabulum of the pelvis. A rim of fibrocartilage known as the acetabular labrum deepens the socket and increases stability of the joint. The hip joint capsule is reinforced by three strong ligaments, the iliofemoral, pubofemoral and ischiofemoral ligaments as well as the tendon of the iliopsoas muscle. The structure of the hip joint permits a wide range of femoral motion in flexion, extension, abduction and adduction, as well as internal and external rotation. All of these movements are necessary to accommodate basic physical activities and gait (Hamill & Knutzen, 2003; Moore & Dalley, 1999; Standring et al., 2008). The 'close-packed' position of a joint is the position at which all the non-contractile structures such as joint capsule and ligaments are under full tension and the joint is at its most stable. The 'close packed' position occurs in the hip when in full extension (Hamill & Knutzen, 2003; Standring et al., 2008). The most unstable position of the hip joint occurs when the femur moves into flexion and adduction as the tension of the ligaments becomes slack and the joint is at its most vulnerable to dislocation (Kapandji, 2011).

2.1 Hip extension range of motion

Hip extension occurs when the lower limb moves posteriorly to the frontal plane (Kapandji, 2011), this movement is also sometimes referred to as hyper-extension (Alter, 1996; Hamill & Knutzen, 2003). From the supine position, movement of the thigh below the horizontal plane equates to degrees of extension and is measured with reference to the horizontal plane representing 0 degrees. The angle above the horizontal (or anterior to the frontal plane) represents the extent of hip flexion and is measured in degrees.

The reported magnitude of hip extension varies in anatomy and biomechanics text books and ranges from 10 to 15 degrees in active extension (Hamill & Knutzen, 2003; Magee, 2006), up to 20 degrees of passive hip extension (Alter,1996; Kapandji, 2011;

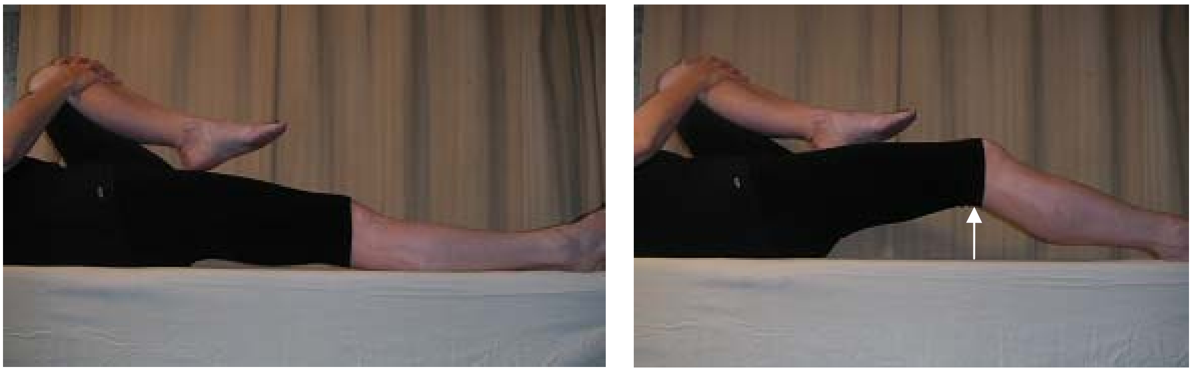
Standring et al., 2008), and up to 30 degrees with assisted stretch (Kapandji, 2011). Kapandji (2011) also notes functional hip extension may be increased by anterior tilt of the pelvis and lumbar spine extension.

Harvey (1998), and Ferber, Kendall and McElroy (2010), measured passive hip extension in the modified Thomas position with the aim to establish normative values. Harvey, (1998) examined a population of elite athletes and reported a mean (±SD) value of 11.9 degrees (±5.6) which was similar to the Ferber, et al, (2010) study of recreational athletes for which a mean (±SD) value of 10.6 degrees (±9.6) of hip extension range of motion (ROM) was reported. Schache, Blanch and Murphy (2000) also studied elite athletes and measured a mean hip extension of 17.4 degrees (range 7.5 to 25, SD not reported) in the Modified Thomas test position. Gabbe, Bennell, Wajswelner and Finch (2004) studied a population of university staff and students and reported a mean (±) of 1.7 degrees (±9.3) of hip extension ROM in the modified Thomas position. The collective findings of these studies suggest greater hip extension ROM is found in populations who are more active and a more restricted ROM in those who potentially spend more time seated.

2.2 Assessment and measurement of hip extension ROM

2.2.1 The Thomas Test

The Thomas test is commonly used to assess hip extension range of motion (Lee, Kerrigan, Della Croce, 1997; Magee, 2006; Peeler & Anderson, 2006) and is a physical assessment utilizing a pass/fail or positive/negative scoring system which is employed to determine the presence of dysfunction (Magee, 2006). The patient lies supine and the examiner flexes one of the hips bringing the bent knee to the chest to eliminate lumbar spine extension and anterior rotation of the pelvis. If the extended (straight) leg rises off the examination table this is interpreted as an indication of a restriction in hip extension or a 'positive' test for the side tested (Magee, 2006). The Thomas test is illustrated in figure 1.



A **B**

Figure 1: The Thomas test
A. A "negative" Thomas test; the test leg remains flat on the table, indicating no evidence of a restriction in hip extension.
B. A "positive Thomas test; the test leg rises off the table (arrow) indicating a restriction in hip extension.

In a reliability study for the Thomas test, Peeler and Anderson (2006) reported "poor" intra-rater (ICC= 0.43 to 0.59) and inter-rater (ICC=0.50 to 0.71) reliability for goniometric measurements of hip extension range of motion although Hopkins (2002), describes ICC within these ranges as "moderate" (0.3-0.5) to "high" (0.5-0.7). The chance corrected Kappa statistic for pass/fail scoring was on average lower for both the intra-rater (0.33 to 0.72) and inter-rater (0.31 to 0.47) reliability. Methodological flaws were however evident in the study. Although the examiners received two 1 hour training sessions for the Thomas test procedure, the data collection was conducted over 6 months during which the participants (*n*=54) were recruited. The extended trial time may have contributed to inconsistencies in examiner assessment. Peeler and Anderson (2006) also reported difficulties with goniometric measurement, with inconsistency in identification of landmarks and alignment of the arms of the goniometer and resorted to trigonometric equation to quantify ROM. Attempting to measure ROM in the Thomas test position would have contributed to their difficulties as although the Thomas test is a useful screening test, the position requires the lower limb of the side being tested to remain resting on the table, full passive hip extension is therefore prevented and consequently is not an appropriate position from which to measure actual ROM. Peeler and Anderson (2006) failed to identify the Thomas test position as a source of error for measurement but suggested digital photography as a better method of measuring the angle of hip extension.

2.2.2 The Modified Thomas Test

The modified Thomas test is used as a screening test to identify a restriction in hip extension and although similar to the Thomas test requires the lower limb of the side being tested to hang off the end of the table (Clapis, Davis & Davis, 2008; Harvey, 1998; Ferber, Kendall & McElroy, 2010). In the case of the modified Thomas test, the inability of the hanging limb to extend to, or drop below, the horizontal (while the untested limb is held to the chest in full flexion), indicates a positive test and a restriction in hip extension ROM (Ferber et al, 2010; Tyler, Nicholas, Mullaney & McHugh, 2006). Assessment regarding ilio-tibial band (ITB) and rectus femorus tightness may also be made in this test position by observing the extent of abduction of the thigh and the angle of the knee respectively (Harvey, 1998). The modified Thomas position allows full passive extension at the hip joint while controlling for lumbar spine extension and anterior pelvic rotation and is therefore a position commonly used in quantitative assessment of hip extension ROM.

A **B**

Figure 2: the modified Thomas test
A. A "negative" modified Thomas test; the test leg drops below horizontal (line) indicating no evidence of a restriction in hip extension.
B. A "positive" modified Thomas test; the test leg fails to drop below horizontal (line) indicating a restriction in hip extension.

Inter-rater reliability for measurement of hip extension ROM in the modified Thomas test position has been shown to be "very high" (ICC=0.86 to 0.92) whether using a standard goniometer or inclinometer (Clapis, et al., 2008) or an electronic inclinometer; (ICC=0. 88 to 0.97) (Gabbe, et al., 2004). Ferber, et al., (2010) reported 95% agreement between examiners for subjective (pass/fail) assessment of hip extension although this statistic should have been Kappa corrected to allow for chance.

Intra-rater reliability for the Modified Thomas test has also been found to be “very high” with Clapis et al, (2008) and Harvey (1998) reporting ICC values between 0.91 to 0.94. However in the study by Gabbe et al., (2004) the intra-rater reliability of the 2 examiners (ICCs of 0.63 and 0.75) was lower than for both the Clapis, et al, (2008) and Harvey (1998) studies, the researchers suggested their lower reliability measures may have been due a smaller and more heterogeneous participant group although this is not a valid reason as repeatability within subjects would not be effected by these factors.

The objective of the study by Ferber et al., (2010) was to establish normative and critical criteria for flexibility. The authors suggested a critical value threshold for pass/fail of the modified Thomas test of 9.7 degrees (for which less than 9.7 degrees of extension equated to testing positive to a restriction in hip extension), a cut-off the authors described as a “conservative value”.

2.3 Factors limiting range of motion of the hip joint

A number of factors can limit the ability of a joint to move through its range of motion which include, the structural elements of the joint complex, and musculotendinous tissues associated with, or crossing the joint (Magee, Zachazewski & Quillen, 2007). Whether the motion is performed actively or passively, as well as whether tension is increased or lessened in muscles that cross more than one joint is also a factor (Levangie & Norkin, 2005). Connective tissue properties, neurological factors, age, temperature and gender may also effect ranges in joint motion for an individual.

2.3.1 Structural factors

The bony structure of a joint will determine the parameters of joint movement and the end point in ranges of movement(Alter, 1996; Ballantyne, Fryer & McLaughlin, 2003; Levangie & Norkin, 2005; Prentice & Voight, 2001), in the hip joint this will include the orientation of the acetabulum and shape of the femoral head. Magee (2006) advises that the normal ‘end feel’ to passive hip extension should be that of ‘tissue stretch’ (as opposed to an abrupt bony end feel) which is interpreted as indicating that soft tissue structures determine end range in the hip joint.

The soft tissue structures associated with the joint such as the joint capsule and ligaments are a limiting factor of joint ROM (Alter, 1996; Magee et al., 2007). The joint capsule attaches around the acetabular margin proximally and the base of the femoral neck distally and is reinforced by the iliofemoral, pubofemoral and ischiofemoral ligaments (Standring et al., 2008). The iliofemoral ligament is considered to be the strongest ligament in the body, it reinforces the hip joint anteriorly and restricts extension ROM (Hidaka, Aoki, Muraki, Izumi, Fujii & Miyamoto, 2009). The pubofemoral ligament also reinforces the anterior aspect of the joint while the ischiofemoral ligament reinforces the joint capsule posteriorly. During hip extension all three ligaments wrap around the femoral neck and become taut (Kapandji, 2011).

2.3.2 Muscular factors

Muscles associated with or acting on the joint are also soft tissue elements that influence ROM. Weak extensor muscles will limit the active range of hip extension (Alter, 1996). There are two main groups of muscles that produce active hip extension, the gluteal and the hamstring muscles. The gluteal muscles, primarily gluteus maximus, and the posterior fibres of gluteus medius and minimus extend and externally rotate the thigh and support the trunk and pelvis particularly during gait function involving an incline (Hamill & Knutzen, 2003; Kapandji, 2011). Gluteus maximus exerts its maximal extension force from approximately 70 degrees of hip flexion (Levangie & Norkin, 2005). The hamstring muscles (biceps femoris, semitendinosus and semimembranosus) are bi-articular, crossing both the hip and knee joints and therefore their effect on the hip depends on the position of the knee joint (Hamill & Knutzen, 2003; Kapandji, 2011; Levangie & Norkin, 2005) as when the knee is flexed, the efficiency of the hamstrings as active hip extensors is reduced (Hamill & Knutzen, 2003; Kapandji, 2011). The maximal leverage of this group of muscles for hip extension occurs at approximately 35 degrees of hip flexion with an extended knee (Levangie & Norkin, 2005).

Poor extensibility of hip flexors will limit both active and passive hip ROM (Alter, 1996). There are a number of muscles that act as hip flexors which include the iliopsoas, rectus femorus, sartorius and tensor fasciae latae (TFL), the most powerful of which is iliopsoas. Accessory hip flexors include the adductors (pectineus, adductor longus and gracilis) as well as the anterior fibres of gluteus medius and minimus (Kapandji, 2011).

Iliopsoas is the primary hip flexor and is composed of psoas major, psoas minor and iliacus (Moore & Dalley, 1999; Standring et al., 2008). The psoas major muscle consists of over lapping segmental fascicles that lie lateral to the lumbar vertebrae with its attachments on the transverse processes and lateral bodies of vertebral segments T12-L5 as well as the intervening discs (Bogduk, Pearcy & Hadfield, 1992). The muscle extends infero-laterally over the superior pubic rami, deep to the inguinal ligament and attaches to the lesser trochanter of the femur. Iliacus lies in the iliac fossa forming a triangular shaped muscle that is orientated more vertically than psoas, passing over the anterior capsule of the hip joint, it blends into the tendon of psoas major and inserts onto the lesser trochanter (Moore & Dalley, 1999; Standring et al., 2008). Psoas minor attaches at spinal segments T12 to L1 and inserts onto the iliopectineal eminence on the pelvis and is therefore not directly implicated in hip flexion (Moore & Dalley, 1999).

Although rectus femorus helps flex the hip, its primary function is extension of the knee joint. Due to proximal attachments on the anterior, inferior iliac spine, and the tibial tuberosity by way of the patella tendon distally (Moore & Dalley, 1999; Standring et al., 2008), the rectus femoris muscle crosses both the hip and knee joint. Therefore, if the knee is flexed, tension in the muscle will be increased and thus may limit passive hip extension (Levangie & Norkin, 2005).

Skeletal muscles are made up of bundles of muscle cells or fibres that are wrapped in fascial (connective tissue) sheaths. Individual muscle cells are surrounded by endomysium, bundles of muscle cells, known as fascicles are wrapped in perimysium and groups of fascicles are wrapped together in epimysium to make up the named muscle (Hamill & Knutzen, 2003; Standring et al., 2008). The endomysium, perimysium and epimysium sheaths blend with the tendon to provide strong attachment with the muscle (Standring et al., 2008). With respect to muscle extensibility it has been demonstrated that a sarcomere (the contractile unit of the muscle fibre) may be stretched to 150% of its original resting length (Wang, McCarter, Wright, Beverly, & Raminrez-Mitchel, 1991), therefore it appears that the greatest limiting factor to muscle extensibility is the connective tissue elements investing the contractile elements (Alter, 1998).

2.3.3 Connective tissue properties

Connective tissue is the most widely distributed tissue in the body (Alter, 1998). It provides a meshwork within and around tissues, surrounds organs, separates structures and creates body compartments (Standring et al., 2008). Structures such as bone, articular cartilage, joint capsules, ligaments tendons and muscle fascia are comprised of connective tissue (Levangie & Norkin, 2005; Standring et al., 2008).

Connective tissue is made up of both cellular and extracellular components. The cells, primarily fibroblasts, produce the extracellular components of collagen, elastin and reticular fibres which provide the framework of the tissue. The fibroblasts also produce glycosaminoglycans (GAGs) which attract water and provide lubrication and spacing within the tissue (Lederman, 2005; Standring et al., 2008).

Collagen fibres are strong, rigid and non-elastic, providing great tensile strength while the crimped structure permits stretching of up to 10-15% (Standring et al., 2008). Elastin, as its name suggests provides elasticity within a tissue thus allowing extensibility (Levangie & Norkin, 2005) and recovery from deformation (Standring et al., 2008). The proportions of the extracellular components determines the mechanical properties of the tissue and varies depending on the structure (Magee et al., 2007). For example, collagen is the main constituent of ligaments and tendons however ligaments have a greater proportion of elastic tissue particularly in the vertebral column as do the connective tissue elements and fascial sheaths associated with muscle tissue (Alter, 1996). Cross-links created by chemical bonds exist within and between the fibrous components of the connective tissue which also contribute to the structure and physical properties (Alter, 1996; Lederman, 2005; Magee, et al., 2007; Standring et al., 2008).

According to Johns and Wright (1962), with respect to flexibility of a joint, the joint capsule and ligaments are the greatest limiting factors, contributing 47% in resistance to stretch. Muscle and fascia contribute 41% , tendons 10%, and skin 2% of the resistance to stretch.

2.3.4 Neurological factors

Active (myoelectric) resistance to stretch will prevent extensibility of a muscle and is controlled by neuromuscular mechanisms as well as the central nervous system (CNS). In the peripheral nervous system (PNS) muscle spindles provide information regarding muscle length and the rate of change of its length and are involved in the myotatic or muscle stretch reflex (Guyton & Hall, 2000). The stretch reflex is activated when the muscle is stretched suddenly, stimulating the muscle spindle and causing a reflex contraction of the same muscle as well as other closely associated synergistic muscles (Guyton & Hall, 2000). This reflex is thought to protect the muscle from potential damage from over-stretching and injury (Alter, 1998; Levangie & Norkin, 2005). Noxious stimulus of sensory receptors associated with joint structures are also considered to have an effect on muscle activity through modulation by the central nervous system (Levangie & Norkin, 2005) presumably to effect avoidance behaviour as a protective mechanism against injury.

Stress and musculoskeletal disorders have been strongly linked (Whysall, 2008). Psychological stress and anxiety will influence muscle tone and can lead to difficulty for an individual to “relax” (Basmajian, 1978 as cited in Lederman, 2005) and thus may affect the assessment of ROM. The mechanism by which muscle tone or strength is increased in this instance will be through the sympathetic nervous system (SNS) which is highly activated by mental and emotional stress (Guyton & Hall, 2000).

2.3.5 Age related factors

The aging process brings about a number of physiological changes including muscle atrophy and connective tissue changes which effect strength and flexibility (Cristopoliski, Barela, Leite, Fowler & Rodacki, 2007; Magee et al., 2007). Changes that have been observed include an increased collagen content in tendons, joint capsules and muscle (Magee et al., 2007), deposition of fatty tissue within the muscle (Alter, 1996), deposition of calcium in elastin fibres (Standring et al., 2008), loss of GAGs and water content, as well as increased adhesions and cross links in the connective tissues, all of which contribute to loss of extensibility and increased rigidity of the tissue (Lederman, 2005; Magee et al., 2007). Age related changes in the tissues appear to be increased and accelerated by inactivity (Magee et al., 2007; Suetta et al., 2009) as aged individuals who remain active, maintain greater mobility than those who have more sedentary lifestyles (Magee et al., 2007). Aged individuals also have a reduced ability to recover from periods of inactivity or immobilization compared with their younger counterparts (Suetta et al., 2009).

2.3.6 Temperature

An increase of body temperature is thought to increase the ability of the collagen and elastin to deform (Prentice & Vought, 2001). Temperatures of above 37˚C allow cross links between collagen fibrils to break more easily and thus increase extensibility of connective tissue more rapidly (Magee et al, 2007). The viscoelastic behaviour of muscle and related tissues is also likely be effected by changes in temperature. As temperature increases, viscosity decreases (Alter, 1996), and is probably related to "Thixotropy" which is "the property of a tissue to become more liquid after motion and return to a stiffer, gel-like state at rest" (Spernoga, Uhl, Arnold, & Gansneder, 2001). O'Sullivan, Murray and Sainsbury (2009) demonstrated that a 5 minute 'warm-up' of treadmill running produced significant increases in passive knee extension which was reduced (but not fully reversed) following 15 minutes of rest. Although O'Sullivan et al., (2009) did not record body or tissue temperature, the muscle activity during the exercise would have generated heat and therefore would support the theory that temperature changes effect joint range of motion.

2.3.7 Gender

Anecdotally women are generally considered to have greater flexibility than men (Hoge, Ryan, Costa, Herda, Walter, Stout, & Cramer, 2010; Kato, Oda, Chino, Kurihara, Nagayoshi, Fukunaga, & Kawakami, 2005). This is largely attributed to differences in connective tissue as well as hormonal factors, however, the mechanisms contributing to these differences are not well understood (Hoge et al., 2010). Greater changes in the length of muscle have been demonstrated for women compared with men in a study utilizing ultrasound examination of the excursion of the muscle-tendon junction of the

Achilles tendon following passive stretch (Kato et al., 2005). Hoge et al., (2010) also found evidence that men had greater stiffness of the musculo-tendinous unit and that women responded to (passive) stretch with greater changes in ROM. Harvey (1998) and Peeler and Anderson (2006) examined hip extension ROM in the modified Thomas and Thomas test positions respectively. Both studies failed to demonstrate statistically significant (*p* values not reported) differences between gender, although results of the later study are questionable due to methodological flaws (see previous section 2.2.1).

2.4 Causes of loss of hip extension ROM

A reduction in hip extension is the most common loss in ROM of the hip joint (Magee, 2006) and anecdotally is commonly observed by musculoskeletal practitioners. A number of different mechanisms can lead to loss in range of motion or reduced flexibility of a joint that include inactivity and immobilization, scar tissue contracture, central nervous system disorders and orthopaedic conditions. In the hip joint a restriction in extension ROM may be a result of a shortening of the hip flexor muscles which can occur by maintaining positions that approximate the origin and insertion of the muscle such as sitting, or bending forward (Ward, 2003), repetitive hip flexion activities such as kicking or rowing (Harvey, 1998), and sudden deceleration trauma as may occur as a result of motor vehicle accidents or fall to the buttocks (Ingber, 1989).

2.4.1 Immobilization and inactivity

Inactivity and immobilization may occur as a result of a sedentary lifestyle, pain, illness or injury or casting of an injured limb (Magee et al., 2007). Immobilization in a shortened position can result in changes in the tissues including a shortening of muscle and connective tissue that leads to a restriction in joint ROM (Alter, 1996; Lederman, 2005; Magee et al., 2007; Prentice & Voight, 2001; Trudel & Uhthoff, 2000). Lederman (2005) asserts that a restriction in the range of movement in immobilized joints is often caused by a shortening of the muscle tissue. Animal models have been used to investigate the effect of immobilization on muscle tissue and findings have indicated a reduction in the number of sarcomeres occurs as a result of immobilization in a shortened position (Baker & Matsumoto, 1988; Williams & Goldspink, 1973). Baker and

Matsumoto (1988) found that immobilization of muscle in a shortened position caused tissue changes within 2 days which progressed to degenerative changes of the sarcomeres and myofibrils including necrosis of the fibres that was continuous with the connective tissue of the tendon. After 4 weeks of immobilization the tissue appeared to be regenerated in the shortened position with loss of sarcomeres. Baker and Matsumoto (1988) also found that immobilization in a neutral position led to less dramatic changes, however, necrosis and atrophy of the myofibrils was evident.

Within connective tissue, immobilization changes include abnormal turnover and random deposition of collagen fibres with excessive cross linkages and a reduction of GAGs resulting in a loss of fluid content and adhesion formation between gliding surfaces (Lederman, 2005; Magee et al., 2007). Within (human) tendons, changes in collagen synthesis and degradation of the tissue has been observed at 8 weeks (Christensen et al, 2008a) but not 2 weeks (Christensen, Dyrberg, Aagaard, Kjaer & Langberg, 2008b) suggesting that tendons are more resilient than muscle to the effects of immobilization.

Trudel and Uhthoff (2000) investigated arthrogenic changes in the immobilized rat knee and found an increasing role of joint stiffness in restriction of ROM from 2 weeks onward. Within the joint, deposition of fibro-fatty tissue (pannus formation), adhesions between the synovial folds (Trudel, Seki, & Uhthoff, 2008) and an increase in joint capsule stiffness has been observed (Magee et al., 2007) of which synovial adhesions appear to be the predominant mechanism of restriction (Trudel et al., 2008).

Following damage from injury or surgery the repair process produces 'scar tissue' which is characterized by differences in the repaired connective tissues (Lederman, 2005). During the repair phase collagen fibres are laid down randomly; during the remodelling phase the collagen is aligned according to the direction of loading of the tissue (Alter, 1996; Lederman, 2005).The bonds between the collagen molecules are stronger in scar tissue than in normal connective tissue and excessive cross linking and adhesions may form particularly in conjunction with immobilization, reducing the extensibility of the tissue resulting in a loss elasticity (Alter, 1996; Lederman 2005; Prentice & Voight, 2001).

2.4.2 Pathological

The presence of excessive myoelectric activity can lead to muscle 'tightness' (Gossman, Sahrmann & Rose, 1982). Central nervous system disorders such as cerebral palsy (Lee, Kerrigan & Della Croce, 1997; Novacheck, Trost, & Schwartz, 2002; Spruit & Fabry, 1997; Westhoff, Seller, Wild, Jaeger & Krauspe, 2003), Parkinsonism, stroke, traumatic brain injury and multiple sclerosis have been associated with hip joint flexion contracture (Lee, et al., 1997).

Certain orthopaedic conditions are also known to cause a restriction in hip extension range of motion, most commonly osteoarthritis (Hurwitz, Hulet, Andriacchi, Rosenberg & Galante, 1997; Shimada, 1996). In the case of osteoarthritis limited range of motion is caused by intra-articular and periarticular structural damage. The hip joint is typically held in flexion, abduction and external rotation (Porth, 2002) which represents the 'loose-pack' position of the joint and thus the position of comfort. Maintenance of this flexed position may contribute to contracture of the tissues further preventing the ability to achieve full extension.

2.5 Implications of restricted hip extension ROM

Loss of range of motion, frequently described as "stiffness" is a common clinical presentation (Lederman, 2005). A decrease in hip extension ROM is considered to have biomechanical consequences that effect posture (Shimada, 1996), gait (Hurwitz, Hulet, Andriacchi, Rosenberg & Galante, 1997; Lee, Kerrigan & Della Croce, 1997), athletic activities such as kicking (Young, Clothier, Otago, Bruce & Liddell, 2003), and may cause pain (Tyler, Nicholas, Mullaney & McHugh, 2006).

2.5.1 Postural

The most commonly observed postural compensation patterns that have been associated with a restriction in hip extension are an anterior pelvic tilt (Lee et al., 1997; Shimada, 1996), and an increased lumbar lordosis (Hurwitz et al., 1997; Shimada 1996). An increased knee flexion during both stance and gait (Lee et al., 1997; Shimada, 1996) together with an increase in thoracic kyphosis (Shimada 1996) have also been observed in individuals with hip flexion contracture. A scoliosis of the spine has been observed by Shimada (1996) in association with a leg length discrepancy although it was unclear as to whether the discrepancy was actual or apparent or if it was associated with a unilateral restriction in the hip. The observed compensatory patterns appear to indicate that a restriction in hip extension effects body alignment both above and below the hip, potentially creating abnormal loading and dysfunction in other joint complexes.

2.5.2 Gait

Full extension of the hip is required during gait as the heel lifts from the ground (Hamill & Knutzen 2003). Although the angle of extension considered sufficient has not been specified in the literature, Hamill and Knutzen (2003) suggest that a flexion-extension arc of 35 to 40 degrees is required. Lee et al., (1997) observed that the primary compensatory mechanism for a restriction in hip extension during gait was anterior pelvic tilting. Other gait compensation patterns described in the literature include a forward pitching of the trunk, an abduction and external rotation of the femur, and an upward hitching of the pelvis on the effected side to overcome the restriction (Shimada, 1996). Reduced dynamic hip extension during gait has also been associated with an increased energy cost for the individual (Wert, Brach, Perera, & Van Swearingen, 2010).

Hurwitz et al., (1997) examined gait compensations in osteoarthritic patients. They found that loss of passive hip extension ROM correlated to loss of dynamic range, and a decreased stride length. The gait pattern was not smooth and a hesitation or reversal of motion occurred at the point of full (restricted) hip extension which was theorized to be due to flexion of the pelvis over the hip with an accompanying compensatory increase in lumber lordosis and that loss of range in one joint is compensated for in other joints. A reduction of other parameters of hip ROM and knee flexion was also observed for the osteoarthritic patients. Increased disability was correlated with increased pain however the researchers concluded that the gait compensations observed in their study were not a result of pain avoidance behaviour.

2.5.3 Athletic

Many investigations in relation to sports activities are concerned with performance and injury prevention, consequently biomechanical relationships are of interest to both trainers and athletes. However there appears to be little research in this field in relation to hip extension ROM. Young et al., (2003) investigated hip extension and knee flexion ROM in relation to hip angles during kicking in Australian-rules football players. The researchers found a moderate correlation indicating that greater flexibility enabled greater dynamic hip extension during kicking. Whether hip flexibility helped generate greater kicking velocity and reduced risk for injury was not clear and the authors recommended further research to investigate these factors.

2.5.4 Pain

Tyler et al., (2006) proposed that a decrease in hip strength and flexibility was related to patellofemoral pain syndrome (PFPS) due to the role of the iliopsoas muscle as a secondary external rotator of the femur. Alterations in tension of the iliopsoas and ITB was thought to influence patella tracking through the trochlear groove of the femur during activity. In their study, participants symptomatic of PFPS were assessed using a visual analog scale (VAS) for pain, the modified Thomas test and Ober test (for ITB tightness) and underwent a 6 week program of hip strengthening and flexibility exercises. Of the 43 limbs examined 31 (72%) demonstrated a positive modified Thomas test prior to intervention. Of the 31 limbs positive to the modified Thomas test, 20 (65%) "normalized"[1] following the intervention programme while 11 (35%) remained positive. Of the 20 limbs with a "normalized" modified Thomas test, 80% (or 16 limbs) demonstrated significant improvements in VAS pain scores ($p \leq 0.001$) while only 18% of the group that remained positive to the Thomas test had significant improvement for VAS scores. The researchers reported "excellent results" for participants demonstrating improvements in strength and flexibility of hip flexors, however, the investigation did not include a control or a non treatment group and correlation statistics were not calculated to demonstrate a relationship between PFPS and strength and flexibility of the hip flexors.

Low back pain has been anecdotally linked with tight hip flexors, primarily the iliopsoas muscle (Ingber, 1989; Nourbakhsh & Arab, 2002; Stodolny & Mazur, 1989; Winters et al, 2004). Due to the anatomical attachments of the psoas major it has been speculated that

---

[1] The researchers specified a horizontal position of the thigh in the modified Thomas test position as a "normal" Thomas test result

reduced extensibility of this muscle is related to low back pain and will affect the biomechanics of the vertebral column. Detailed studies by Bogduk, Pearcy and Hadfield (1992) revealed that although not a prime mover of the lumbar spine, in the erect posture psoas major exerted a net extension of the upper three lumbar segments and flexion in the lower two, as well as side bending the lumbar spine ipsilaterally to a relatively minor degree. The most noted effect on the lumbar spine was however the considerable compression and anterior shear forces exerted by psoas on the spinal segments and discs, increasing in descending order to be greatest at the L5/S1 segment (Bogduk et al., 1992). It would be logical therefore to conclude that an alteration in tension of psoas major would exert altered forces across joint capsules and articulating surfaces of associated lumbar segments and intervertebral discs potentially leading to tissue damage and pain. However Nourbakhsh and Arab (2002) found that factors relating to the strength rather than the length of iliopsoas were associated with low back pain.

'Internal Snapping syndrome' is characterized by a painful 'snapping' sensation in the groin which occurs when the iliopsoas tendon snaps over the iliopectineal eminence and the femoral head when the thigh moves from flexion into extension (Byrd, 2005; Flanum, Keene, Blankenbaker & De Smet, 2007; Hoskins Burd, & Allen, 2004; Ilizalituri & Camacho-Calindo, 2010). Although no direct association between internal snapping hip and a restriction of hip extension has been verified in the literature, success of treatment approaches such as stretch (Konczak & Ames, 2005) of iliopsoas, surgical release and lengthening of the iliopsoas tendon (Byrd, 2005; Flanum et al., 2007; Hoskins et al., 2004; Ilizalituri & Camacho-Calindo, 2010) implies a relationship.

2.6 Techniques employed to improve hip extension ROM

Treatment of restriction in hip extension ROM include surgical release of the iliopsoas tendon (Novacheck, Trost, & Schwartz, 2002; Spruit & Fabry, 1997), injection of botulinum toxin A into the iliopsoas muscle (Molenaers, Eyssen, Desloovere, Jonkers, & De Cock, 1999; Westhoff, Seller, Wild, Jaeger, & Krauspe, 2003), and stretch (Cristopoliski, Barela, Leite, Fowler, & Rodacki, 2009; Winters, Blake, Trost, Marcello-

Brinker, Lowe, Garber, & Wainner, 2004). The chosen treatment is likely to depend on the severity and cause of the restriction although there are no clearly defined guidelines linking presentation and treatment.

2.6.1 Surgical

Surgery is considered to be the most effective way of gaining improvement in flexibility and function in cerebral palsy patients with a hip flexion contracture that compromises their ability to walk (Novacheck, Trost, & Schwartz, 2002; Spruit & Fabry, 1997). Surgical variations documented in the literature include complete iliopsoas tenotomy (Novacheck et al., 2002), psoas tenotomy (Spruit & Fabry, 1997), and more recently an intramuscular "Z-lengthening" of the iliopsoas muscle (Novacheck et al., 2002). The tenotomy procedures originally employed led to problems with debilitating weakness of the hip flexors which resulted in difficulty in the initiation of thigh movement particularly during walking and stair climbing (Novacheck et al., 2002). However the intramuscular "Z lengthening" techniques of the iliopsoas muscle and tendon subsequently developed have been shown to be effective while avoiding the problems of weakness associated with tenotomy (Novacheck et al., 2002). Novacheck et al., (2002) reported a 6.07 degree (SD not reported; p <0.01) reduction of hip flexion contracture and significant (p<0.01) improvements in the "Hip flexor index" (a quantitative measure incorporating static and dynamic aspects of pelvic tilt and hip flexion-extension angles and strength during gait and stance), at the 18 month follow-up period.

Surgical "release" or iliopsoas lengthening has also been documented as effective treatment for "internal snapping hip" when conservative treatment (rest, stretch and anti-inflammatory medications) have failed to bring about improvement (Byrd, 2005; Flanum, Keene, Blankenbaker & De Smet, 2007; Hoskins, Burd, & Allen, 2004). Hoskins et al., (2004) however, reported a 40% complication rate from surgery that included recurrence of "snapping", flexor muscle weakness, pain, and sensory deprivation in the distribution of the lateral cutaneous nerve of the thigh. Flanum et al., (2007) investigated an arthroscopic approach to surgical lengthening and reported fewer complications with symptomatic and functional improvements. No measurements of hip extension ROM were reported by Byrd (2005), Flanum et al., (2007) or Hoskins et al., (2004).

2.6.2 Injection of Botulinum toxin A

Injection of Botulinum toxin A has been used to treat muscle spasticity in patients with cerebral palsy including injection into the Iliopsoas muscle due to its association with hip flexion contracture (Molenaers et al., 1999; Westhoff et al., 2003). Molenaers et al., (1999) reported "clinically significant improvement" in hip extension and gait analysis. Westhoff et al., (2003) also reported that "all patients responded positively to the treatment and had improved function" (pg 830). Although neither study included actual results in their reports, both concluded that the injection of botulinum toxin A to be effective in the treatment of spasticity in cerebral palsy. The duration of the effectiveness of the treatment was not investigated and it is possible repeated treatments would be required to maintain the effects. .

2.6.3 Stretch

A search of the literature revealed only two studies investigating the effect of stretch of the anterior hip and hip flexor muscles on hip extension ROM. Winters et al., (2004) investigated the effect of active versus passive stretch exercises performed by young adults with lower extremity injuries and back pain who tested positive to the Modified Thomas test. The passive stretches involved a lunge performed by the participant and prone lying with the stretched leg passively raised posteriorly and supported by a bolster stretching the anterior aspect of the hip. The active stretches involved the participant lying prone and actively extending their leg posteriorly with either a straight leg or bent knee thus strengthening the hip extensors while stretching the anterior aspect of the hip. All stretches were held for 30 seconds and repeated 10 times, and were performed daily for 6 weeks. Measurement of hip extension ROM by goniometry in the modified Thomas position indicated significant ($p<0.001$) improvement for both active and passive stretches were equally effective with mean (±SD) gains of 12 degrees (±8) and 13 degrees (±5) respectively. The ROM gains were achieved by 3 weeks and maintained without further gain at 6 weeks. The researchers did not assess changes in relation to the participants' low back pain or injuries.

Cristopoliski et al., (2009) investigated the effect of a passive stretch programme of both hip flexors and extensors performed 3 times a week for 4 weeks on a group of healthy older adults. Comparison was made with a control group who received no intervention, and assessment involved ROM and gait analysis as outcome measures. Cristopoliski et al (2009) reported increases of ROM of the hip joint, faster gait, increased step length and a shorter double support duration for participants in the intervention group. Although poor presentation of the results made interpretation difficult, it appeared the participants presented with no extension range, rather a flexion contracture of 6.3 degrees (±2.1) that decreased to 2.0 degrees (±1.3) (*p* values not reported) for uniarticular flexors following intervention. The investigators reported that the gait variables measured following intervention were comparable to those recorded for younger adults and suggested that following a regular stretching protocol may help counteract some of the effects of aging related to mobility.

3. MUSCLE ENERGY TECHNIQUE

Muscle energy technique (MET) is a specialized stretching technique commonly used by osteopaths and other manual therapists that could potentially be effective in the treatment of a restriction in hip extension ROM. MET utilizes repeated, sub maximal, active resisted isometric contraction of a muscle followed by passive stretch in order to increase its extensibility and the range of motion (ROM) in the joint with which it is associated. MET is "a form of osteopathic manipulative treatment in which the patient's muscles are actively used on request, from a precisely controlled position, in a specific direction, against a distinctly executed counter force" (Goodridge, 1997, p. 692).

Isometric contraction of the target muscle at end range followed by passive stretch to the new barrier is the most frequently used form of MET (Fryer, 2006). This particular sequence of active stretch is also described as contract-relax (CR) or post isometric relaxation (PIR). Other forms of active stretch associated with MET involve contraction of the agonist at end range of stretch of the antagonist (target) muscle followed by passive stretch of the antagonist, a sequence known as agonist contract-relax (ACR) and is based on the principle of reciprocal inhibition (RI). These two methods have also been combined into a contract-relax agonist contract-relax (CRAC) combination followed by passive stretch. Proprioceptive neuromuscular facilitation (PNF) is also a form of active stretch that utilizes contract –relax sequences described above and is similar to MET (Fryer, 2006).

The primary aim of MET stretch techniques is to lengthen shortened muscle that may function as a biomechanical constraint preventing or restricting motion (Greenman, 1996). Variations of the technique utilizing isometric, concentric or eccentric contractions may be used depending on the treatment goals; for example concentric contractions may be used to strengthen a weakened muscle (by recruitment activation) particularly in the case of an asymmetry in strength (Greenman, 1996; Goodridge, 1997), where-as eccentric contractions may be used with the aim to reduce myofascial fibrosis (Chaitow, 2006). MET may also be used to reduce localized oedema and congestion as muscle contraction facilitates lymphatic and venous fluid exchange (Greenman, 1996).

3.1 Proposed mechanisms of MET

The physiological mechanism by which CR techniques such as MET and PNF produces the observed increased ROM is largely speculative (Lenehan, Fryer & McLaughlin, 2003). Theories that have been suggested include post-isometric relaxation, viscoelastic property change in the muscle and associated connective tissue, and an increase in stretch tolerance (Fryer, 2006).

3.1.1 Post-isometric relaxation

A number of authors have suggested that MET produces a neurological reflex of muscle relaxation following isometric muscle contraction. This post-isometric relaxation has been theorised to cause an inhibition of motor activity (alpha motor neuron) via the Golgi tendon organ (Fryer, 2006; Greenman, 1996; Goodridge, 1997; Kuchera & Kuchera, 1994; Lenehan et al., 2003).

This post isometric relaxation theory is supported by several studies. Moore and Kukulka (1991) investigated alpha-motor neuron pool excitability of the soleus muscle following isometric contraction. They found a brief period of depression of myoelectric activity that was maximal for up to one second and lasting up to ten seconds. Prior to this, Etnyre and Abraham (1986) compared the effect of static stretch with two variations of CR techniques on alpha-motor neuron excitability also of the soleus muscle. They found little effect from static stretch, however, both CR techniques produced inhibition of this phenomenon lasting two seconds post contraction. More recently Carter, Kinzey, Chitwood, and Cole (2000) found a decrease in electromyographic (EMG) activity in biceps femoris in response to sudden stretch following a CR PNF technique.

Although the above studies support the post isometric relaxation theory, it is debatable whether low-level motor activity within the muscle limits passive stretch (Fryer, 2006). A number of studies have indicated that although a low level of motor activity appears to occur in relaxed muscles, it remains unchanged during passive stretch (Magnusson, Simonsen, Aagaard, Moritz & Kjaer, 1995; Magnusson, Simonsen, Aagaard, Sorensen & Kjaer, 1996a; Magnusson, Simonsen, Dyhre-Poulsen, Aagaard, Mohr & Kjaer, 1996b).

Furthermore a study by Taylor, Dalton, Seaber and Garret (1990) indicated there was no difference in response to stretch between innervated and denervated rabbit muscle. Magnusson et al., (1996b) subsequently found little difference between normal subjects and those with spinal cord injury with regards to EMG activity and resistance to stretch, or between passive stretch and stretch following isometric contraction (Magnusson, 1996c).

Osternig, Robertson, Troxel and Hansen (1990) observed EMG and ROM, comparing passive stretch with two variations of CR techniques on athletic participants with the aim to examine myoelectric characteristics of active stretch. Their study demonstrated an increased EMG activity associated with the active stretch techniques while achieving greater ROM and lead the authors to conclude that mechanisms other than muscle relaxation may be indicated. This apparent paradoxical effect was also observed by Ferber, Osternig and Gravelle (2002a) in a similar study on an older adult group. Furthermore, Mitchell, Myrer, Hopkins, Hunter, Feland and Hilton (2009) also studied EMG activity through surface and indwelling electrodes during CR and contract-relax agonist contract-relax (CRAC) stretches. Mitchell et al., (2009) found no evidence to support the theory of reciprocal inhibition when investigating neurophysiological effect of a CRAC procedure, again observing greater EMG activity during the active stretch techniques.

The above studies fail to support the idea that low level muscle activity contributes significantly to resistance to passive stretch, and that neurophysiological mechanisms of post-isometric relaxation and reciprocal inhibition are not a likely explanation for the observed increases in ROM following MET and other active stretch techniques.

3.1.2 Visco-elastic myofascial property change

It has also been theorized that the observed increase in muscle extensibility following the application of CR techniques may be due to the biomechanical response (mechanical elongation) to stretch of the tissue (Fryer, 2006). Mechanical elongation is attributed to the viscoelastic properties of connective tissue and muscle when put on stretch, and is related to the composition of both stiff and elastic fibres as well as the fluid/gel medium in which they are embedded (Lederman, 2005; Magee et al., 2007; Taylor et al., 1990). The response of the tissue when being stretched is classically described by the "stress-strain curve" (figure 3) with three phases; taking up the slack (the "toe" range), elongation of the elastic elements within physiological parameters (the elastic range) and failure or rupture of the tissue (the plastic range) (Lederman, 2005; Magee et al., 2007).

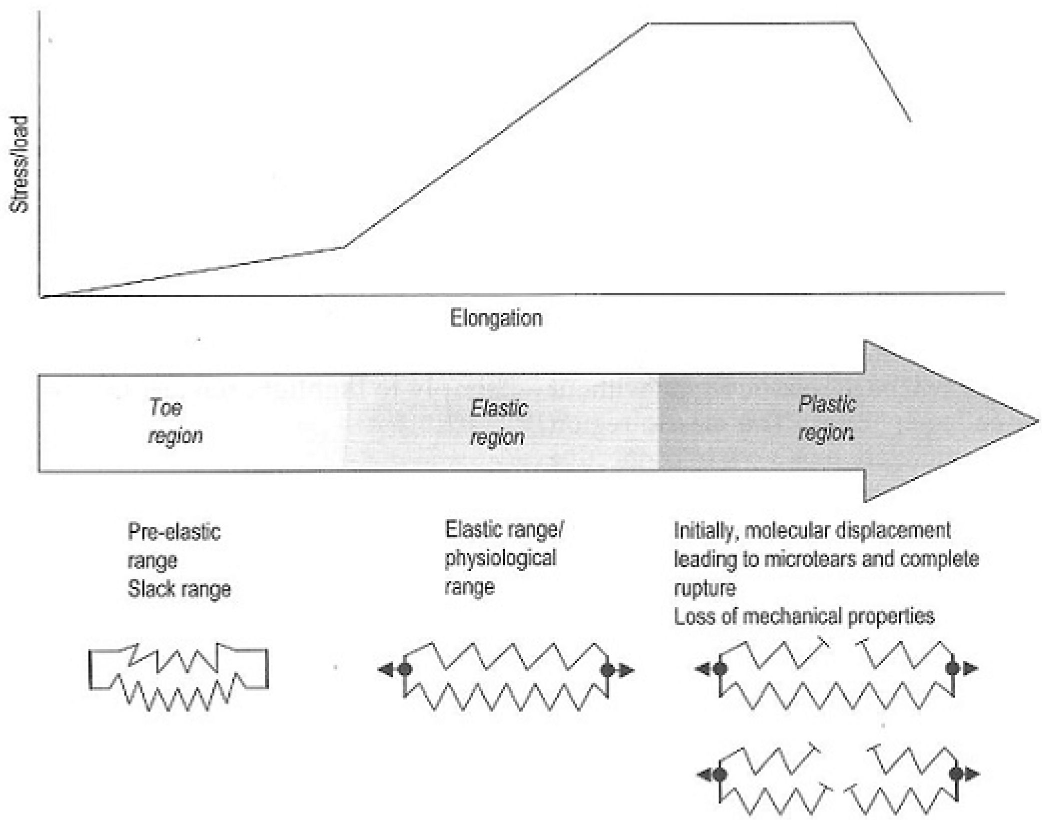


Figure 3: The different regions of the stress-strain curve The "Toe" region occurs pre stretch when taking up the slack in the tissue. The tissue will elongate within its physiological range without damage within the "Elastic" region. If the tissue is stretched beyond its' physiological range this is known as the "Plastic" region. This figure was published in: The Science and Practice of Manual Therapy. Lederman, L., Figure 5.2, Page 49. Copyright Elsevier (2005). Reproduced with permission from Elsevier Limited.

Creep deformation and force relaxation are characteristic properties of viscoelastic materials (Magee et al., 2007; Taylor et al., 1990); both occur during stretch within the elastic range if the tissue is held on stretch (refer figure 4). During creep deformation a slow elongation of the tissue occurs when held on stretch, which does not immediately return to its original length once released from stretch. During force relaxation there is a reduction in the force required to maintain the stretch (Lederman, 2005; Taylor et al., 1990).

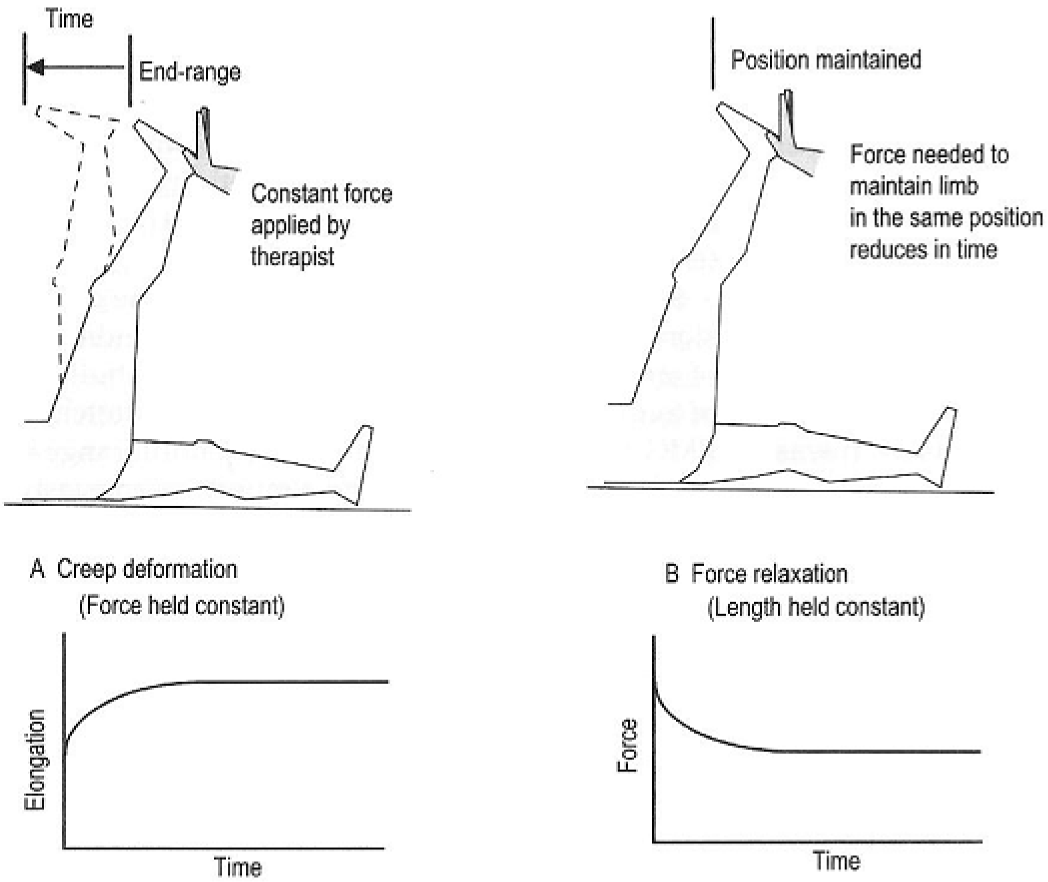


Figure 4: Creep deformation (**A**) and force relaxation (**B**) in soft tissue.
A. Creep deformation; slow elongation of the tissue occurs when a constant force is applied.
B. Force relaxation; a reduction of force is required to maintain a stretch of constant length. Both creep deformation and force relaxation are a result of a viscoelastic response of a tissue to stretch. This figure was published in: The Science and Practice of Manual Therapy. Lederman, L., Figure 5.5, Page 51. Copyright Elsevier (2005). Reproduced with permission from Elsevier Limited

Viscoelastic property change has been demonstrated by Magnusson et al., (1996b) to occur during passive stretch as well as following a CR protocol (Magnusson et al., 1996c) when a reduction of passive torque was observed in the hamstring held at a constant length. Taylor et al., (1990) also studied this phenomenon in rabbit muscle and concluded that "the behaviour of (skeletal) muscle in response to (passive) stretch could be explained by viscoelastic properties alone".

The myofascial structure of skeletal muscle consists of both series and parallel components of the connective tissue that invests the contractile muscle fibres. Lederman (2005) proposes that although both series and parallel components are put on tension during passive stretch, the more elastic parallel connective tissue fibres elongate more than the stiffer series fibres. During muscle contraction the tension is focused on the stiffer series components of the connective tissue (refer figure 5). Lederman (2005) suggests that due to the differences in tension in the connective tissue elements, muscle contraction at the end-range of passive stretch, followed again by passive stretch to the new end-range as performed during active stretch techniques such as MET, is theoretically likely to produce greater elongation of myofascial tissue.

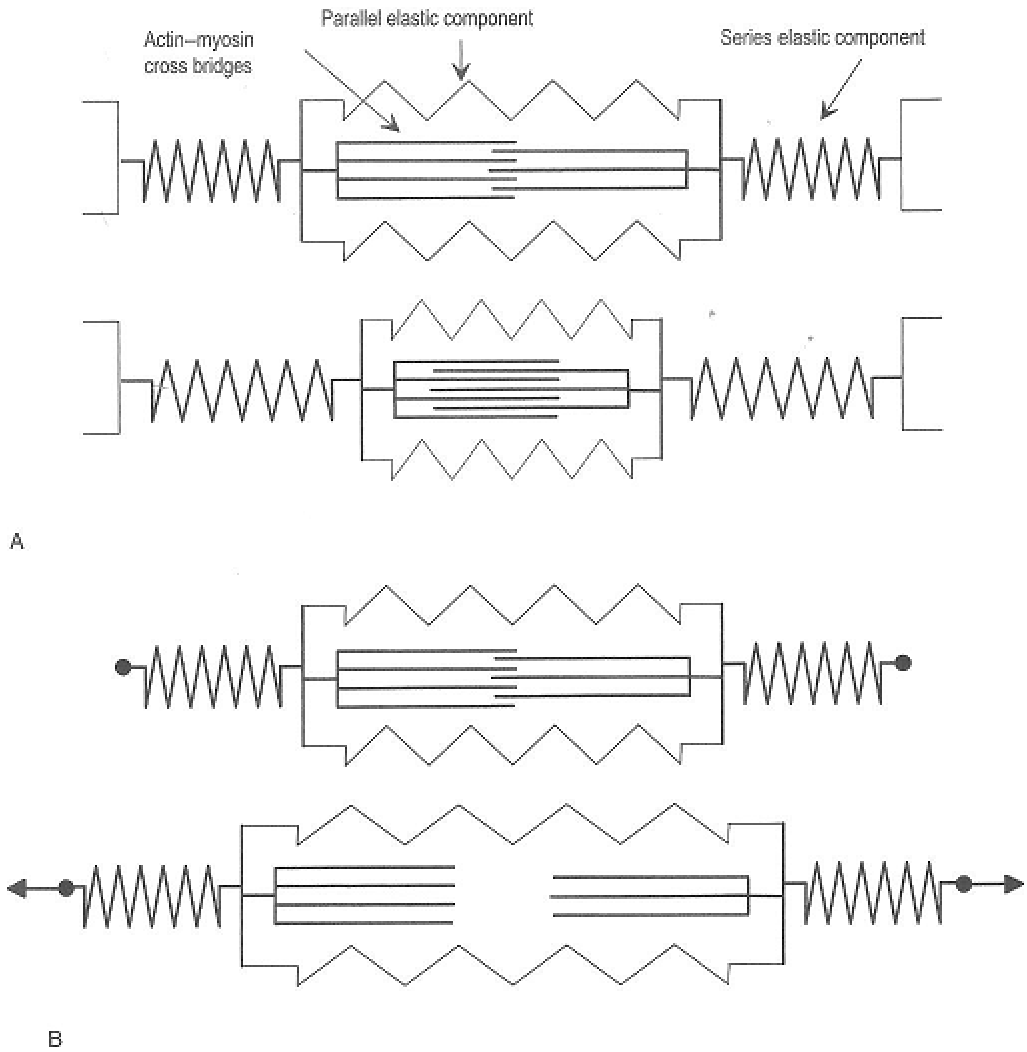


Figure 5: Changes in connective tissue during muscle contraction(**A**) and passive stretch (**B**)
A. During contraction the series elastic components are under tension and elongate while tension in the parallel elastic components is reduced.
B. During passive stretch both parallel and series elastic components are under tension, however the more elastic parallel fibres elongate more than the stiffer series components.
This figure was published in: The Science and Practice of Manual Therapy. Lederman, L., Figure 5.5, Page 51. Copyright Elsevier (2005). Reproduced with permission from Elsevier Limited

The Lederman theory appears to be a feasible explanation for larger increases in muscle extensibility and increased range of motion observed following active stretch techniques such as MET as compared with passive stretch, however, Magnusson et al., (1996c) found the viscoelastic (stress relaxation) response was unaffected by the type of stretch manoeuvre when they compared CR to passive stretch. They also found evidence to suggest that a greater degree of force was required to achieve the increased ranges gained with CR stretch and therefore altered stretch perception or an increased tolerance to stretch has been theorized. Investigations by Ballantyne, Fryer & McLaughlin (2003) support these findings.

3.1.3 Increased stretch tolerance.

Although viscoelastic stress relaxation has been demonstrated in human skeletal muscle while held at constant length (McHugh, Magnusson, Gleim, & Nicholas, 1992; Magnusson et al., 1995; 1996b; 1996c), studies measuring passive torque (the force required to passively stretch the muscle) have demonstrated that greater forces are required (and are tolerated by the individual) to achieve the increase in extensibility observed in CR stretch techniques (Magnusson et al., 1996a; 1996c; Ballantyne et al., 2003). If increases in ROM following CR stretch are due to viscoelastic change allowing greater muscle extensibility this would be achieved using a constant torque (Ballantyne et al., 2003), therefore these findings have lead to the general interpretation that an alteration in stretch perception or an increase in stretch tolerance occurs as a result of muscle contraction prior to stretch (Ballantyne et al., 2003 Magnusson et al., 1996a; 1996c).

Mitchell, Myrer, Hopkins, Hunter, Feland and Hilton (2007) examined stretch tolerance by measuring force using a dynamometer while comparing a slow passive stretch with a CR stretch. The authors reported that a significantly (p=0.00086) greater stretch force was tolerated by the participants during the CR stretch (126.0 ±26.5 N) than for the passive stretch (108.4 ±28 N) while maintaining the same level of perceived discomfort (4 out of 10 on a verbal numeric rating scale). Force tolerance progressively increased for each successive CR cycle. Mitchell et al., (2007) concluded that muscle contraction prior to stretch appeared to alter stretch perception possibly by raising the pain threshold.

The mechanism for altered stretch perception is unknown, nociceptive nerve endings in the joint and muscle may play a role through neurotransmitter modulation or "gate control" (Magnusson, 1996c). Alternatively muscle and joint mechanoceptors and proprioceptors may be stimulated by isometric contraction and stretching to reduce the sensation of pain (Fryer, 2006).

3.2 MET protocols

Variations exist within the literature in the way MET is applied with regards to the duration of isometric contraction time, strength of the contractions, duration of the passive stretch between contractions, the number of CR cycles performed in an application as well as the particular contract-relax sequence used. A number of studies have investigated these factors.

3.2.1 Contraction duration

The duration of isometric contraction time was investigated by Fryer and Ruszkowski (2004) when examining the effect of a single application of MET on the Atlanto-Axial joint involving 3 repetitions of a CR protocol with sub-maximal contraction. The authors found that a 5 second (s) contraction produced the larger effect size (d=1.01) compared with a 20s contraction time (d=0.68) and that there appeared to be no advantage in using longer contraction times. Bonnar, Deivert and Gould (2004) also examined contraction duration, comparing 3s, 6s, and 10 second contraction times for a PNF CR protocol involving 3 cycles of maximal contraction of the hamstring muscles. No significant difference (p=0.76) was found between groups and all 3 contraction times produced significant gains (p<0.001) therefore Bonnar et al (2004) concluded that any contraction duration up to 10s was effective for hamstring extensibility.

3.2.2 Contraction strength

Optimal contraction strength has also been investigated. Feland and Marin (2004) examined the effect of a maximal strength isometric contraction (100%) compared with 60% or 20% of maximal contraction strength for a PNF CR protocol on hamstring extensibility. The authors found a significant effect for all groups (p≤0.01) but no significant difference (p=0.06) in increased hamstring extensibility between groups. A similar study conducted by Sheard and Paine (2010) targeting the hamstring muscles also found significant (p≤0.0001) increases in hip flexion ROM for all groups however significant differences were found between groups (p≤ 0.01). Sheard and Paine (2010) found that a peak correlation between contraction intensity and ROM occurred with a contraction intensity of 64.3% of maximal voluntary contraction. The use of sub-maximal contraction strength is generally thought to reduce the risk of treatment injury or injury aggravation (Feland & Marin, 2004) although there is no evidence in the literature to support this (Sheard & Paine, 2010). The use of sub-maximal contraction intensity was recommended by Feland and Marin, (2004) and Sheard and Paine, (2010) suggested a target contraction intensity of 65% of maximal contraction to achieve optimal gains in joint ROM.

3.2.3 Duration of post isometric stretch

Duration of the passive stretch applied by the operator following isometric contraction is another variable of the MET protocol. Goodridge (1997) does not specify any particular length of time, while Chaitow (2006) suggests a stretch of at least 30 s. Smith and Fryer (2008) investigated the effect of a 3 s post contraction passive stretch phase compared with a 30 s passive stretch phase following MET of the hamstring muscles. The authors reported no significant difference ($p = 0.95$) between the effect of a 3 s or a 30 s post contraction stretch phase on active knee extension and that both protocols were equally effective ($p < 0.01$). Smith and Fryer (2008) concluded that the duration of the post contraction passive stretch does not influence the efficacy of MET for increasing hamstring extensibility.

3.2.4 Contraction protocol

As described previously there are a number of contraction sequences utilized in MET and PNF protocols. The post isometric relaxation sequence, also known as the contract-relax (CR) protocol has been compared with the reciprocal inhibition or agonist contract-relax (ACR) protocol (Ferber, Gravelle, & Osternig, 2002a; Ferber, Osternig, & Gravelle, 2002b; Osternig, Robertson, Troxel, & Hansen, 1987; Osternig, Robertson, Troxel & Hansen, 1990; Wright & Drysdale, 2008). Ferber et al (2002a; 2002b) and Osternig et al, (1987; 1990) investigated the effect of CR compared with ACR on the hamstring muscles by measuring passive knee extension ROM and found that while both techniques produced significant increases, ACR produced a greater increase in ROM. The majority of participants (88%) in the study by Ferber et al (2002b) however reported the CR procedure to be more comfortable than the ACR and 77% of participants reported the ACR technique to be uncomfortable. The authors suggested that CR was a more straight forward procedure for participants to follow. Comfort and ease of application are likely to be the primary reasons that the CR protocol is most commonly utilized form of MET. More recently Wright and Drysdale (2008) compared a sham procedure with CR and ACR stretch protocols applied to the piriformis muscle by measuring internal rotation of the hip ROM. Wright and Drysdale (2008) found significant (p<0.0001) increases in ROM for both intervention groups and no statistical difference between the CR and ACR protocols.

3.2.5 Contraction repetitions

In textbooks describing MET protocols, the number of CR cycles utilized during an MET application is suggested to be between 2 and 4 repetitions (Goodridge, 1997) or 3-5 repetitions (Greenman, 1996). In the majority of investigative studies researchers have used applications of between 2 and 5 repetitions. There appears to have been little examination of the optimum number of contraction repetitions. Following an investigation into the alteration of stretch perception during a CR stretch protocol, Mitchell et al., (2007) recommended at least 4 repetitions of the CR cycles should be performed as they observed progressive increases in stretch tolerance for each of the 4 contraction cycles performed. ROM was not recorded however, therefore it is unknown if clinically relevant increases were also achieved for each contraction cycle.

3.3 Efficacy of MET

There have been a number of studies investigating the effect of MET and other isometric CR techniques on ROM which have been applied to the cervical, thoracic and lumbar regions. Examination of the effect of MET applied to peripheral muscles and joints has predominantly been focused on hamstring extensibility.

3.3.1 Effect of MET on cervical spine ROM

Schenk, Aldelman and Rousselle (1994) investigated the effects of MET on cervical range of motion compared with a control group for which intervention (or non intervention) was not specified. Seven sessions of MET were conducted over a four week period for the treatment group. MET was applied in the direction of rotational restriction, for 3 CR repetitions for a contraction duration of 5 s. The authors found significant mean (±SD) increases from baseline measurements in right (9 degrees±8.3; p=0.04) and left (7.2 degrees ±6.9; p=0.04) rotation in asymptomatic participants with limited ranges at the outset. Flexion, extension and side bending were also measured and although small increases were observed they were not significantly different (p=0.06 to 0.34) from baseline. The authors concluded that small increases in the other planes of movement could be expected due to the normal coupled motion that occurs during movement of the cervical spine and that MET was an effective method for treatment of a restriction in cervical ROM. In this trial the post-test measurements were taken one day following the final treatment session indicating that repeated treatments may have a lasting effect.

Burns & Wells (2006) also investigated range of motion of the cervical spine following either a single application of MET or a sham procedure on asymptomatic participants. MET was applied with 3-4 CR cycles and for a contraction duration of 3 to 5 s, in all three planes of motion, flexion/extension, side bending and rotation. The authors found immediate significant differences from baseline between groups (p<0.001),and mean increases in active ROM of the cervical spine in all ranges except for flexion and extension for the MET group (3.7 degrees ±1.0; p=0.2) compared with an overall decrease in ROM following the sham procedure (-1.0 degrees ±0.9; p value not reported). The greatest increase in ROM following MET occurred in rotation (7.2 degrees ± 1.9; p=0.002), results that are consistent with the study by Schenk et al., (1994).

Fryer & Ruszkowski (2004) examined atlanto-axial joint rotation following a single application of MET on asymptomatic participants with a minimal rotational asymmetry of 4 degrees or more. The researchers allocated participants into one of 3 groups to investigate the effect of different isometric contraction durations (5s and 20s) against a control involving a sham procedure. The MET intervention was performed in the direction of the participants' movement restriction. The authors found a significant mean increase in ROM for the participants receiving the 5 s contraction MET protocol (6.7 degrees ±6.6; p=0.03; d=1.01) compared with the sham control group. The findings of Fryer and Ruszkowski (2004) are comparable with those of Schenk et al., (1994) and further supported by Burns and Wells (2006).

3.3.2 Effect of MET on thoracic spine ROM

Lenehan, Fryer and McLaughlin (2003) examined the immediate effect of a single application of MET to the thoracic spine on participants exhibiting rotational restriction. The MET procedure consisted of a CR protocol involving a 5 s resisted isometric contraction of unspecified strength, repeated for a total of 4 contraction cycles. Gross trunk rotation was the primary outcome measure. Results indicated a statistically significant ($p<0.0005$) mean (±SD) increase (10.7 degrees ± 9.8) in gross trunk range of motion in the direction of restriction equating to a "large" effect size ($d=1.09$) compared with the control (no treatment) group for which a non-significant ($p>0.1$) mean (±SD) increase of 1.2 degrees (±4.3; p>0.1) equating to a "small" ($d=0.19$) effect was reported. The authors noted that ROM towards the unrestricted direction was unaffected thus promoting a greater symmetry in movement. Lenehan et al., (2003) recommended further studies to examine the effects of MET on symptomatic participants to determine whether this technique is effective in alleviating pain associated with movement restriction. The authors also recommended investigation into the effect of a single application of MET over time to demonstrate the temporal effects of observed ROM changes.

3.2.3 Effect of MET on lumbar spine ROM

Schenk, MacDiarmid and Rousselle (1997) studied the effects of MET on lumbar extension range of motion on asymptomatic volunteers who exhibited a limitation in lumbar extension. Participants were randomly assigned to either a control group for which protocol was unspecified, or a treatment group who received MET twice a week for 4 weeks. The MET protocol consisted of isometric contractions of 5 s duration (of unspecified strength) followed by passive stretch repeated 4 times for each application. The authors found significant increases in lumbar extension ROM (6.9 degrees ±2.1; $p\leq0.001$) The authors recommended further studies to be conducted with regards to comparison of MET with other treatment modalities as well as examining the effect of MET on functional outcome measures.

3.2.4 Effect of MET on the TMJ

Changes in active mouth opening following MET has been studied in participants with temporo-mandibular joint (TMJ) dysfunction (Rajadurai, 2011) and in those with myofascial trigger points of the masseter muscle (Blanco, de las Penas, Xumet, Algaba, Rabadan, & de la Quintana, 2006). Blanco et al., (2006) applied a single application of a CR MET protocol utilizing 3 repetitions of sub-maximal isometric contraction for a duration of 6 s to increase mouth opening comparing it to a no treatment control group and a strain/counter-strain group. Blanco et al., (2006) reported significant increases for the MET group compared with the strain/counter-strain and control groups ($p<0.001$) and a “large” effect size (1.9mm ±1.3; d=1.42; $p<0.001$). The study by Rajadurai (2011) involved CR and ACR MET protocols with a 10 s contraction duration and 5 isometric contraction cycles applied 3 times a week for 5 weeks. Rajadurai (2011) found significant increases ($p\leq0.001$) with mean (±SD) differences in active mouth opening of 4.95mm (±1.26) at the end of the first week and a 22.45mm (±0.95) increase by the end of the 5 week trial. The findings of both these studies support the use of MET in treating restriction of the TMJ.

3.2.5 Effect of MET on hamstring extensibility

There are a large number of studies investigating the effect of CR stretch techniques on hamstring extensibility for both MET (Ballantyne, Fryer & McLaughlin, 2003; Shadmehr, Hadian, Naiemi, & Jallaie 2009; Smith & Fryer, 2008) and PNF (Bonnar et al 2004; Feland & Marin, 2004; Feland, Myrer, & Merrill, 2001; Ferber et al, 2002a; Ferber et al, 2002b;Magnusson et al, 1996c; Sheard & Paine, 2010; Schuback, Hooper & Salisbury, 2004; Spernoga, Uhl, Arnold, & Gansneder, 2001; Trampas, Kitsios, Sykaras, Symeonidis and Lazarou, 2010) all of which report statistically significant increases in ROM.

The MET studies all used CR protocols involving 3 repetitions of sub maximal contraction strength of between 5 and 10 s duration while PNF studies all used CR protocols involving 2 to 5 repetitions of maximal isometric contraction with duration times of between 3 and 15 s. Assessment of hamstring extensibility included measurement of either active or passive knee extension with the hip at 90˚ of flexion, or by measures of hip flexion with a straight leg raise.

Smith and Fryer (2008) and Spernoga et al., (2001) reported comparable results for immediate measures of mean (±SD) increase in active knee extension (AKE) from baseline of 7.2 degrees (±4.94; $p<0.01$), and 7.8 degrees (SD not reported; $p<0.01$) respectively. Although not reported, calculation of effect size was possible from data published by Spernoga et al., (2001) (but not Smith & Fryer 2008)which indicated a "moderate" (Hopkins, 2002) increase in ROM. The assessment of ROM utilizing AKE is dependent on participant effort (Fryer, 2006) and therefore variability of measure could be dependent on factors such as motivation or fatigue.

Immediate increases in passive knee extension (PKE) following a single application of CR stretch varies from 3.3˚ (SD not reported; $p<0.01$) for a group of mixed gender students of mean age 23.4 years (Ballantyne et al, 2003), to 33 degrees (±4) in a group of male recreational athletes, mean age 29.4 years. Significantly greater differences were reported ($p< 0.01$) from passive stretch (Magnusson et al, 1996c) and from baseline (Ballantyne et al, 2003). Shadmehr (2009) reported a mean increase of 22.1 degrees (±2.8˚) from baseline ($p<0.01$) for female students of mean age 22 years receiving 10 sessions of MET over 4 weeks. Shadmehr (2009), however, found no significant difference (*p* not reported) between the changes observed for the MET compared with the passive static stretch protocol (18.9 degrees ±3.4).

Ferber et al., (2002a; 2002b) and Feland et al., (2001) examined passive knee extension following PNF applied to older adults. Ferber et al., (2002a) compared competitive, masters level long distance runners ("trained adults") with "un-trained adults" and further divided participants into groups according to age (45 to 55 and 65 to 75 years). The authors reported the greatest mean increase in ROM of 14.6 degrees (±2.2) within the untrained adults aged between 45 and 55 years and the lowest increases in ROM of 8.6 degrees (±1.6) within the untrained adults aged 65 to 75 years. Smaller gains for the older untrained group may be due to factors of age related changes resulting in a reduced ability for older adults to recover from inactivity (Suetta et al., 2009). The mean increase in passive knee extension ROM for all groups in the Ferber et al., (2002a) study was 11.85 degrees (±2.1) which was consistent with findings for Ferber et al., (2002b) who reported mean increases of 12.1 degrees (±0.66) in a group of healthy, moderately active adults aged 50 to 75 years. Feland et al., (2001) reported a mean increase of 5 degrees (SD not reported) in a group of senior athletes aged 55 to 79 years. The number of contraction cycles (only 2) applied in the Feland et al., (2001) trial may have influenced the lower ROM outcome as age and level of fitness of the participants was similar the "trained adults" participating in the Ferber et al., (2002a) study who underwent 4 contraction cycles and achieved greater ranges. Mitchell et al., (2007) recommended at least 4 repetitions of the CR cycles should be performed due to progressive increases in stretch tolerance.

Feland and Marin, (2004) and Trampas et al., (2010) examined passive knee extension on groups of young men with a mean age of 22 and 20.8 years respectively. A mean (±SD) increase of 5.1 degrees (±5.1; $p \leq 0.0001$) was observed immediately following the maximal contraction PNF protocol by Feland and Marin (2004) while Trampas et al., (2010) reported an immediate mean increase of 6.9 degrees, (d=0.9; 95%CI=0.1 to1.8; $p < 0.01$) equating to a "moderate" effect size (Hopkins, 2002).

Hip flexion with a straight leg raise has also been used to assess changes in range of motion following application of CR PNF protocols with reported mean increases in ROM from 10.2 degrees representing a 9.2% increase (Bonnar et al, 2004) to 12.6 degrees (95%CI= 9.6 to 15.5; $p < 0.001$) (Schuback et al 2004), and 12.9 degrees (Sheard & Paine, 2010). Although the authors of these studies attributed the reported increases in ROM to hamstring extensibility they did not discuss the possible influence of restriction caused by other tissues. The straight leg raise is also a neurodynamic test to assess the mechanical movement of neurological tissues for which a painful restriction indicates pressure on neurological tissues. Tension on the sciatic nerve roots particularly occurs between 35 and 70 degrees of hip flexion (Magee, 2006).

Although methodological differences exist between the studies reviewed above, all reported that CR stretch techniques appear to be effective in increasing hamstring extensibility for both younger and older adults . Active knee extension and the straight leg raise methods of assessment may be influenced by factors other than hamstring extensibility and therefore passive knee extension is a superior mode of assessment.

3.2.6 Effect of MET on hip extension ROM

An extensive search of the literature revealed only one published study investigating the effect of a CR technique on hip extension ROM. Stodolny and Mazur (1989) examined the effect of "post-isometric relaxation" (PIR) in conjunction with "kinesitherapy" (a prescribed exercise regime) targeting the iliopsoas muscle. The authors associated a contracture of the iliopsoas with both a cause and consequence of intervertebral disc degeneration. Participants symptomatic with low back pain (LBP) diagnosed as "disc pathology" were allocated to one of two groups. Both groups undertook a prescribed exercise programme, and one group additionally received a CR stretch procedure while in the modified Thomas position. The CR protocol consisted of a 10 to 15 s isometric contraction of the hip flexor muscles followed by 15 to 30 s of relaxation and passive stretch, repeated for 3 to 5 contraction cycles. Both groups performed the exercise regime for 16 days although it is unclear if the PIR stretch was also applied for this period. The results indicated immediate positive gains in hip extension ROM for the PIR group; 11.9 degrees (±10.5; $p<0.001$) compared with 2.8 degrees (±7.4; $p<0.02$) in the non PIR group. Although effect sizes were not reported, using the information supplied in the report, the effect size was calculated to be "large" ($d=1.3$) for the participants receiving the PIR technique in conjunction with the exercise regime and "small" ($d=0.3$) for those who underwent the exercise regime alone. The participants in the Stodolny and Mazur (1989) study were all symptomatic with low back pain (LBP) and had all been diagnosed with disc pathology however no participant orientated outcome measures or assessments were made in relation to pain or disability.

An unpublished master's thesis investigating the immediate effect of MET on psoas major was conducted by Milliken (2003). The intervention consisted of a resisted sub maximal isometric contraction (approximately 50% of maximal effort) of the hip flexor muscles for a duration of 5 s and repeated for a total of 5 contraction cycles. The control group received no intervention and participants lay supine for the equivalent length of time taken for the intervention. The author reported a significant ($p<0.01$) increase in hip extension of 6.5 degrees in the intervention group as compared with a 2.8 degrees gain for the control group, however no standard deviations or effect sizes were reported. Using the raw data supplied in the appendix of the Milliken study, further analysis revealed a "very large" effect of MET (6.5 degrees, SD±3.7; 95% CI=4.4 to 8.6; p<0.01; d=2) and "small" effect in the control group (2.8 degrees; SD±2.5; p=0.0001; d=0.55). In recommendations for further study the author suggested an evaluation of the duration of the increased range in motion over time.

3.2.7 Duration of the effect of MET

Only two studies have investigated the temporal effects of CR technique (Spernoga et al., 2001; Trampas, Kitsios, Sykaras, Symeonidis and Lazarou, 2010). Spernoga, et al., (2001) measured the duration of a single application of CR PNF involving 5 repetitions of 7 s maximal isometric contractions on the hamstring muscles over a period of 32 minutes The authors reported an immediate significant (p<0.01) increase in active knee extension lasting only six minutes. By using data provided in the article the immediate effect size was calculated to be "moderate" (d=0.76). At 6 minutes, the effect size was "small" (d=0.24), and by 8 minutes "trivial" (d=0.16) according to Hopkins' (2002) descriptors. Spernoga et al., (2001) suggested that the temporary changes were probably due to viscoelastic properties of the tissue and that more lasting changes were not likely following a single stretching session and recommended further research into enhancing the lasting effect.

Trampas et al., (2010) measured passive knee extension immediately and at 10 and 30 minutes following a CR stretch protocol involving 3 repetitions of 6 s maximal isometric contractions. A "moderate" (d=0.60) effect size was maintained at 10 minutes which diminished to a "small" (d=0.2) effect size by 30 minutes post application of the CR stretch. The authors identified a lack of power (0.56) as a limitation of their study.

Although the examination of the temporal effects or duration of MET was not a primary aim of their study, Smith and Fryer (2008), noted a significant (p=0.04) increase of 2.49 degrees (±7.19) in active knee extension one week following application of an MET protocol. However, in view of the standard deviation, which was nearly 3 times larger than the mean increase reported, this is probably not clinically meaningful.

4. CONCLUSION

A restriction of hip extension primarily effects posture and gait and may lead to low back and lower extremity pain as well as an increase energy cost of activity. Factors that affect hip extension ROM include the structural morphology of the joint, the muscles and connective tissues associated with the joint, as well as neurological factors. Hip extension ROM is primarily restricted as a result of inactivity or immobilization as well as pathological factors involved in central nervous system disorders and degenerative processes. Methods of treatment for restriction of hip extension ROM include surgical lengthening of the iliopsoas muscle and tendon, injection of Botulinum toxin A into the iliopsoas muscle, or stretch exercises of the hip flexor muscles and associated tissues anterior to the hip joint. MET is a form of manual therapy involving active stretch that has been demonstrated to be efficacious in increasing the short term ROM of the cervical, thoracic and lumbar spine, as well as the knee and hip joints. Studies examining the efficacy of MET have been predominantly focused on spinal movement and hamstring extensibility. Only one published study has investigated the effect of MET on hip extension ROM and little is known regarding the temporal effects of the technique. Therefore the aim of the experimental study reported in Section 2 of this thesis was to investigate the duration of the effect following a single application of MET on hip extension ROM.

REFERENCES

Alter, M. J. (1996). *Science of Flexibility* (3rd ed.). United states of America: Human Kinetics Publishers Inc.

Alter, M. J. (1998). *Sports Stretch.* United States of America: Human Kinetics Publishers Inc.

Baker, J. H., & Matsumoto, D. E. (1988). Adaptation of skeletal muscle to immobilization in a shortened position. *Muscle and Nerve, 11, 231-244.*

Ballantyne, F., Fryer, G., & McLaughlin, P. (2003). The effect of muscle energy technique on hamstring extensibility: the mechanism of altered flexibility. *Journal of Osteopathic Medicine,* 6(20), 59-63.

Blanco, C. R., de las Penas, C. F, Xumet, J. E., Algaba, C. P., Rabadan, M. F & de la Quintana, M. C. (2006). Changes in active mouth opening following a single treatment of latent myofascial trigger points in the masseter muscle involving post-isometric relaxation or strain/counterstrain. *Journal of Bodywork and Movement Therapies,* 10(3), 197-205.

Bogduk, N., Pearcy, M., & Hadfield, G. (1992). Anatomy and biomechanics of psoas major. *Clinical Biomechanics,* 7, 109-119*.*

Bonnar, B. P., Deivert, R. G., & Gould, T. E. (2004). The relationship between isometric contraction duration during hold-relax stretching and improvement of hamstring flexibility. *Journal of Sports Medicine and Physical Fitness,* 44(3), 258-261*.*

Burns, D. K., & Wells, M. R. (2006). Gross Range of Motion in the Cervical Spine: The Effects of Osteopathic Muscle Energy Technique in Asymptomatic Subjects. *The Journal of American Osteopathic Association,* 106(3), 137-142.

Byrd, J. W. T. (2005). Snapping hip. *Operative Techniques in Sports Medicine,* 13(1), 46-54.

Carter, A. M., Kinzey, S. J., Chitwood, L. F., & Cole, J. L. (2000). Proprioceptive Neuromuscular Facilitation Decreases Muscle Activity During the Stretch Reflex in Selected Posterior Thigh Muscles. *Journal of Sport Rehabilitation.* 9(4), 269-278.

Chaitow, L. (2006). *Muscle Energy Techniques*. (3rd ed.). London: Churchill Livingstone.

Christensen, B., Dyrberg, E., Aagaard, P., Enehjelm, S., Krogsgaard, M., Kjaer, M., Langberg, H. (2008a). Effects of long term immobilization and recovery on human triceps surae and collagen turnover in the Achilles tendon in patients with healing ankle fracture. *Journal of Applied Physiology,* 105, 420-426*.*

Christensen, B., Dyrberg, E., Aagaard, P., Kjaer, M., & Langberg, H. (2008b). Short term immobilization and recovery affect skeletal muscle but not collagen tissue turnover in humans. *Journal of Applied Physiology,* 105, 1845-1851.

Clapis, P. A., Davis, S. M. & Davis, R. O. (2008). Reliability of inclinometer and goniometer measurements of hip extension flexibility using the modified Thomas test. *Physiotherapy Theory and Practice,* 24(2): 135-141.

Cristopoliski, F., Barela, J. A., Leite, N., Fowler, N. E., & Rodaki, A. L. F. (2007). Stretching exercise programme improves gait in the elderly. *Gerontology,*55, 614-620*.*

Eland, D.C., Singleton, T.N., Conaster, R.R., Howell, J.N., Pheley, A.M., Karlene, M.M., & Robinson, J.M. (2002). The “iliacus test”: New information for the evaluation of hip extension dysfunction. *Journal of the American Osteopathic Association, 102 (3), 130-142*

Etnyre, B. R. & Abraham, L. D. (1986) H-reflex changes during static stretching and two variations of proprioceptive neuromuscular facilitation techniques. *Electroencephalography and Clinical Neurophysiology,* 63(2), 174-179*.*

Feland, J. B., & Marin, H. N. (2004). Effect of sub-maximal contraction intensity in contract-relax proprioceptive neuromuscular facilitation stretching. *British Journal of Sports Medicine,* 38(4) e18. doi: 10.1136/bjsm.2003.010967

Feland, J. B., Myrer, J.W., & Merrill, R. M. (2001). Acute changes in hamstring flexibility: PNF versus static stretch in senior athletes. *Physical Therapy in Sport,* 2, 186-193*.*

Ferber, R, Kendall, K.D., & McElroy, L. (2010). Normative and critical criteria for ilio-tibial band and iliopsoas muscle flexibility. *Journal of Athletic Training,* 45(4), 344-348.

Ferber, R., Gravelle, D. C., Osternig, L. R. (2002a). Effect of proprioceptive neuromuscular facilitation stretch techniques on trained and untrained older adults. *Journal of Aging and Physical Activity,* 10, 132-142*.*

Ferber, R., Osternig, L. R., & Gravelle, D. C. (2002b). Effect of PNF stretch techniques on Knee Flexor muscle EMG activity in older adults. *Journal of Electromyography and Kinesiology,* 12, 391-397.

Flanum, M. E., Keene, J. S., Blankenbaker, D. G., & De Smet, A. A. (2007). Arthroscopic treatment of the painful “internal” snapping hip. *American Journal of Sports Medicine,* 35(5), 770-779.

Fryer, G (2006) MET: Efficacy and Research. In: Chaitow, L. *Muscle Energy Techniques.* (3rd ed.). London: Churchill Livingstone.

Fryer, G. & Ruszkowski, W. (2004). The influence of contraction duration in muscle energy technique applied to the atlanto-axial joint. *Journal of Osteopathic Medicine,* 7(2), 79-84*.*

Gabbe, B. J., Bennell, K. L., Wajswelner, H., & Finch, C. F. (2004). Reliability of common lower extremity musculoskeletal screening tests. *Physical Therapy in Sport,* 5, 90-97.

Goodridge, J. P. (1997) Muscle Energy Procedures. In: Ward, R. C., (Ed) *Foundations of Osteopathic Medicine*. Philadelphia, United States, Lippincott Williams & Wilkins.

Gossman, M. R., Sahrmann, S. A., & Rose, S. J. (1982). Review of length associated changes in muscle: Experimental evidence and clinical implications. *Physical Therapy,* 62(12), 1799-1808*.*

Greenman, P. E. (1996). *Principles of manual medicine.* (2nd ed.). Maryland: Williams & Wilkins.

Guyton, A. C., & Hall, J. E. (2000). *Textbook of medical physiology* (10th ed.).Philadelphia: WB Saunders Company.

Hamill, J & Knutzen, K. M. (2003). *Biomechanical basis of human movement* (2nd ed.). Philadelphia: Lippincott Williams & Wilkins.

Harvey, D (1998). Assessment of the flexibility of elite athletes using the modified Thomas test. *British Journal of Sports Medicine,* 32(1), 68-70.

Hidaka, E., Aoki, M., Muraki, T., Izumi, T., Fujii, M., & Miyamoto, S. (2009). Evaluation of stretching position by measurement of strain on the ilio-femoral ligaments: An in vitro simulation using trans-lumbar cadaver specimens. *Manual Therapy,* 14: 427-432.

Hoge, K. M., Ryan, E. D., Costa, P. B., Herda, T. J., Walter, A. A., Stout, J. R., & Cramer, J. T. (2010). Gender differences in musculo-tendinous stiffness and range of motion after an acute bout of stretching. *Journal of Strength and Conditioning Research,* 24(10), 2618-2626.

Hopkins, W. G. (2002). A scale of magnitudes. In: A new view of statistics. Retrieved From http://www.sportssci.org/resource/stats/index.htm

Hoskins, J. S., Burd, T. A., &Allen, W. C. (2004). Surgical correction of internal coxa saltans. *The American Journal of Sports Medicine,* 32(4), 998-1001.

Hurwitz, D.E., Hulet, C.H., Andriacchi, T.P., Rosenberg, A.G. & Galante, J.O. (1997). Gait compensations in patients with osteoarthritis of the hip and their relationship to pain and passive hip motion. *Journal of Orthopaedic Research,* 15(4): 629-635

Ilizaliturri, V. M., & Camacho-Calindo, J. (2010). Endoscopic treatment of snapping hips, Iliotibial band, and iliopsoas tendon. *Sporsts Medicine and Arthroscopy,* 18(2), 120-127*.*

Ingber, R. S. (1989). Iliopsoas myofacsial dysfunction: A treatable case of “failed” low back syndrome. *Archives of Physical & Medical Rehabilitation,* 70(5), 382-386.

Johns, R. J., & Wright, V. (1962). Relative importance of various tissues in joint stiffness. *Journal of Applied Physiology,* 17, 824-828.

Kapandji, I. A. (2011). *The Physiology of the Joints: Volume 2; the lower limb* (6th ed.). Edinburgh: Churchill Livingstone.

Kato, E., Oda, T., Chino, K., Kurihara, T., Nagayoshi, T., Fukunaga, T., & Kawakami, Y. (2005). Musculotendinous factors influencing difference in ankle joint flexibility between women and men. *International Journal of Sport and Health Science*, 3, 218-225.

Konczak, C. R., & Ames, R. (2005) Relief of internal snapping hip syndrome in a marathon runner after chiropractic treatment. *Journal of Manipulative and Physiological Therapies,* 28(1), 67el. Doi: 10.1016/j.jmpt.2004.12.001

Kutchera, W. A. & Kutchera, M. L. (1994). *Osteopathic Principles in Practice* (2nd ed.). Columbus Ohio: Greyden Press.

Lederman, E. (2005). *The Science and Practice of Manual Therapy.* (2nd ed.). Edinburgh: Churchill Livingstone.

Lee, L. W., Kerrigan, D. C., & Della Croce, U. (1997). Dynamic implications of hip flexion contractures. *American Journal of Physical Medicine & Rehabilitation,* 18: 502-508.

Lenehan, K. L., Fryer, G., & McLaughlin, P. (2003). The effect of muscle energy technique on gross trunk range of motion. *Journal of Osteopathic Medicine, 6(1), 13-18.*

Levangie, P. K., & Norkin, C. C. (2005). *Joint structure and function: A comprehensive analysis.* Philadelphia: F.A. Davis Company.

Magee, D. J. (2006). *Orthopaedic Physical Assessment* (3rd ed.). Elsevier Sciences.

Magee, D.J., Zachazewski, J.E., & Quillen, W.S. (2007). *Scientific foundations and principles of practice in musculoskeletal rehabilitation*. St Louis, Saunders Elsevier.

Magnusson, S. P., Simonsen, E. B., Aagaard, P., Moritz, U., & Kjaer, M. (1995). Contraction specific changes in passive torque in human skeletal muscle. *Acta Physiologica Scandinavica,* 155, 377-386

Magnusson, S. P., Simonsen, E. B., Aagaard, P., Sorensen, H & Kjaer, M. (1996a). A Mechanism for altered flexibility in human skeletal muscle. *Journal of Physiology,* 479(1), 291-298.

Magnusson, S. P., Simonsen, E. B., Dyhre-Poulsen, P., Aagaard, P., Mohr, T., & Kjaer, M. (1996b). Viscoelastic stress relaxation during static stretch in human skeletal muscle in the absence of EMG activity. *Scandinavian Journal of Medicine & Science in Sports,* 6, 323-328.

Magnusson, S. P., Simonsen, E. B., Aagaard, P., Dyhre-Poulsen, P., McHugh, M. P., & Kjaer, M. (1996c). Mechanical and Physiological Responses to Stretching with and without pre-isometric contraction in Human Skeletal Muscle. *Archives of Physical Medicine and Rehabilitation,* 77, 373-378.

McHugh, M. P., Magnusson, S. P., Gleim, G. W., & Nicholas, J. A. (1992). Viscoelastic stress relaxation in Human Skeletal Muscle. *Medicine & Science in Sports & Exercise,* 24(12), 1375-1382.

Milliken, K. (2003). *The effects of muscle energy technique on psoas major length.* Unpublished MOst thesis. Unitec New Zealand, Auckland, New Zealand.

Mitchell, U. H., Myrer, J. W., Hopkins, J. T., Hunter, I., Feland, J. B., & Hilton, S. C. (2007). Acute stretch perception alteration contributes to the success of the PNF "contract-relax" stretch. *Journal of Sport Rehabilitation,* 16, 85-92.

Mitchell, U. H., Myrer, J. W., Hopkins, J. T., Hunter, I., Feland, J. B., & Hilton, S. C. (2009). Neurophysiological reflex mechanisms' lack of contribution to success of the PNF stretches. *Journal of Sport Rehabilitation,* 18, 343-357.

Molenaers, G., Eyssen, M., Desloovere, K., Jonkers, L., & De Cock, P. (1999). A multilevel approach to botulinum toxin type Atreatment of the (ilio)psoas in spasticity in cerebral palsy. *European Journal of Neurology,* 6(4), S59-S62.

Moore, K. L., & Dalley, A. F (1999). *Clinically oriented anatomy. 4th edition.* Maryland: Lippincott Williams & Wilkins.

Moore, M. A., & Kukulka, C. G. (1991). Depression of Hoffman reflexes following voluntary contraction and implications for proprioceptive neuromuscular facilitation therapy. *Physical Therapy,* 71(4), 321-329.

Nourbakhsh, M. R., & Arab, A. M. (2002). Relationship between mechanical factors and incidence of low back pain. *Journal of Orthopaedic Sports Physical Therapy, 32(9), 447-460.*

Novacheck, T. F., Trost, J. P., & Schwartz, M. H. (2002). Intramuscular psoas lengthening improves dynamic hip function in children with cerebral palsy. *Journal of Paediatric Orthopaedics,* 22, 158-164.

Osternig, L. R., Robertson, R. N., Troxel, R. K., & Hansen, P. (1987). Muscle activation during proprioceptive neuromuscular facilitation (PNF) stretching techniques. *American Journal of Physical medicine,* 66(5), 298-307.

Osternig, L. R., Robertson, R. N., Troxel, R. K., & Hansen, P. (1990). Differential responses to proprioceptive neuromuscular facilitation (PNF) stretch techniques. *Medicine & Science in Sports & Exercise,* 22(1), 106-111.

O'Sullivan, K., Murray, E., & Sainsbury, D. (2009). The effect of warm-up, static stretching and dynamic stretching on hamstring flexibility in previously injured subjects. *BioMed Central Musculoskeletal disorders.* 10:37. Doi: 10.1186/1471-2474-10-37

Peeler, J., & Anderson, J. E. (2006). Reliability of the Thomas test for assessing range of motion about the hip. *Physical Therapy in Sport,* 8, 14-21.

Porth, C. M. (2002). *Pathophysiology: Concepts of Altered Health States* (6th ed.). Philadelphia: Lippincott Williams & Wilkins.

Prentice, W. E., & Voight, M. L. (2001). *Techniques in musculoskeletal rehabilitation.* New York: McGraw-Hill Professional Publishing.

Rajadurai, V. (2011). The effect of muscle energy technique on temporo-mandibular joint dysfunction: A randomised clinical trial. *Asian Journal of Scientific Research, 4(1), 71-77.*

Schenk, R., Adelman, K. & Rousselle, J. (1994). The effects of Muscle Energy Technique on Cervical Range of Motion. *The Journal of Manual and Manipulative therapy.* 2(4), 179-183.

Schenk, R., MacDiamid, A., & Rousselle, J. (1997). The Effects of Muscle Energy Technique on Lumbar Range of Motion. *The Journal of Manual and Manipulative Therapy, 5(4), 179-183.*

Shedmehr, A., Hadian, M. R., Naiemi, S. S., & Jallaie, S. (2009) Hamsstring flexibility in young women following passive stretch and muscle energy technique. *Journal of Back and Musculoskeletal Rehabilitation* 22, 143-148.

Sheard, P. W., & Paine, T. J. (2010). Optimal contraction intensity during Proprioceptive neuromuscular facilitation for maximal increase in range of motion. *Journal of Strength and Conditioning Research,* 24(2), 416-421

Schache, A.G., Blanch, P.D. & Murphy, A.T. (2000). Relation of anterior pelvic tilt during running to clinical and kinematic measures of hip extension. *British Journal of Sports medicine,* 34: 279-283

Schuback, B., Hooper, J., & Salisbury, L. (2004). A comparison of a self stretch incorporating proprioceptive neuromuscular facilitation components and a therapist applied PNF technique on hamstring flexibility. *Physiotherapy,* 90, 151-157.

Shimada, T. (1996). Factors affecting appearance patterns of hip flexion contractures and their effects on postural and gait abnormalities. *Kobe Journal of Medical Sciences,* 42(4), 271-290.

Spernoga, S. G., Uhl, T. L., Arnold, B. L. & Gansneder, B. M. (2001). Duration of maintained hamstring flexibility after one time modified Hold-Relax stretching protocol*. Journal of Athletic Training,* 36(1), 44-48.

Smith, M. & Fryer, G. (2008). A comparison of two muscle energy techniques for increasing flexibility of the hamstring muscle group. *Journal of Bodywork and Movement Therapies,* 12, 312-317.

Spruit, M., & Fabry, G. (1997). Psoas and adductor release in children with cerebral palsey. *Acta Orthopaedica Belgica,* 63(2), 91-93*.*

Standring, S., Borley, N. R., Collins, P., Crossman, A. R., Gatzoulis, M. A., Healy, J. C., ... Wigley, C. B. (Eds). (2008) *Grey's anatomy: The anatomical basis of clinical practice*. (40th ed.). Edinburgh: Curchill Livingston.

Stodolny, J., & Mazur, T. (1989). Effect of post-isometric relaxation exercises on the ilio-psoas muscles in patients with lumbar discopathy. *Journal of Manual Medicine, 4(2), 52-54*

Suetta, C., Hvid, L.G., Justesen, L., Christensen, K., Neergaard, K., Simonsen, L., Ortenblad, N., Magnussen, S.P., Kjaer, M., & Aargaard, P. (2009). Effects of aging on human skeletal muscle after immobilization and retraining. *Journal of Applied Physiology.* 107, 1172-1180*.*

Taylor, D. C., Dalton, J. D., Seaber, A. V., & Garrett, W. E. (1990). Viscoelastic properties of muscle tendon units, the biomechanical effects of stretching. *The American Journal of Sport Medicine,* 18(3): 300-309.

Trampas, A., Kitsios, A., Sykaras, E., Symeonidis, S., and Lazarou, L. (2010). Clinical massage and modified proprioceptive neuromuscular facilitation stretching in males with latent myofascial trigger points. *Physical Therapy in Sport,*11, 91-98.

Trudel, G., Seki, M., & Uhthoff, H.K. (2008). Synovial adhesions are more important than pannus proliferation in the pathogenisis of knee joint contraction after immobilization: an experimental investigation in the rat. *Journal of Rheumatology,* 27(2), 351-357.

Trudel, G., Uhthoff, H.K. (2000). Contractures secondary to immobility: is the restriction articular or muscular? An experimental longitudinal study in the rat knee. *Archives of Physical Medicine & Rehabilitation* 81(1), 6-13.

Tyler, T. F., Nicholas, S. J., Mullaney, M. J., McHugh, M. P. (2006). The role of hip muscle function in the treatment of patellofemoral pain syndrome. *The American Journal of Sports Medicine,* 34(4): 630-636

Wang, K., McCarter, R., Wright, J., Beverly, J., & Raminez-Mitchell, R. (1991). Regulation of skeletal muscle stiffness and elasticity by titin isoforms: A test of the segmental extension model of resting tension. *Proceedings of the National Academy of Science,* 88(6): 7101-7105.

Ward, R. C., (2003) *Foundations of Osteopathic Medicine* (2nd ed.). Philadelphia, United States, Lippincott Williams & Wilkins.

Wert, D. M., Brach, J., Perera, S., & Van Swearingen, J. M. (2010). Gait biomechanics, spatial and temporal characteristics and energy cost of walking in older adults with impaired mobility. *Physical Therapy,* 90(7), 977-985.

Westhoff, B., Seller, K., Wild, A., Jaeger, M., & Krauspe, R. (2003). Ultrasound-guided botulinum toxin injection technique for the iliopsoas muscle. *Developmental Medicine & Child Neurology,* 45, 829-832.

Whysall, Z. (2008). Stress and MSDs: moving towards common ground? Occupational Health, 60(2), 27-29.

Williams, P .E. & Goldspink, G. (1973) The effect of immobilization on longitudinal growth of striated muscle fibres. *Journal of Anatomy,*116(1): 45-55.

Williams, J. G., Odley, J. L. & Callaghan, M. (2004). Motor Imagery Boosts Proprioceptive Neuromuscular Facilitation in the Attainment and Retention of Range of Motion at the Hip Joint. *Journal of Sports Science and Medicine*, 3, 160-166.

Winters, M. V., Blake, C. G., Trost, J. S., Marcello-Brinker, T. B., Lowe, L., Garber, M. B., & Wainner, R. S. (2004). Passive versus active stretching of hip flexor muscles in subjects with limited hip extension: A randomised clinical Trial. *Physical Therapy,* 84(9), 800-807.

Wright, P & Drysdale, I. (2008). A comparison of post-isometric relaxation (PIR) and reciprocal inhibition (RI) muscle energy techniques applied to piriformis.(Abstract). *International Journal of Osteopathic Medicine,* 11(4), 158-159.

Young, W., Clothier, P., Otago, L., Bruce, L., & Liddell, D. (2003). Relationship between a modified Thomas test and leg range of motion in Australian rules football kicking. *Journal of Sport Rehabilitation,* 12, 343-350.

-

Section 2: Manuscript

Note
This manuscript has been prepared in accordance with the Instructions for Authors for *Manual Therapy.*

The effect of a single application of Muscle Energy Technique on hip extension range of motion

Heather K Nicholls

Department of Osteopathy
Unitec New Zealand
Private Bag 92025, Auckland
New Zealand

Tel: + 64 9 815 4321 x8197
Fax: + 64 9 815 4573
Email: nichollsheather@hotmail.com

ABSRACT

The aim of this study was to examine the effect of a single application of muscle energy technique (MET) compared with passive stretch on hip extension range of motion (ROM) over a 30 minute follow-up period. In an experimental repeated measures controlled cross-over trial, 18 healthy males aged between 18 and 45 with a positive Thomas test indicating a restriction in hip extension, were allocated to one of two groups (*n*=9). Both groups received both the MET and a control procedure (passive stretch) interventions in reverse order to each other with a 7 day interval between sessions. Measurements of passive hip extension in the modified Thomas position were taken immediately prior to and following the intervention, and at 5 minute intervals up until 30 minutes post intervention. The MET intervention produced a “moderate” effect, and the passive stretch produced a “small” effect immediately following the interventions. A “small” effect remained for both groups 30 minutes following the interventions. Therefore both MET and passive stretch appear to be effective in increasing hip extension ROM for a duration of up to 30 minutes.

Key words: Muscle energy technique; hip extension; range of motion; osteopathy

1. INTRODUCTION

Hip extension range of motion (ROM) is an important component of independent mobility. Basic functions such as standing from sitting and walking, as well as more complex tasks are dependent on coordination between the trunk and lower extremity for which hip joint flexibility is necessary (Eland et al., 2002). A restriction of hip extension ROM is common (Magee 2006), can lead to altered biomechanical relationships and functional compromise (Shimada, 1996; Hurwitz et al., 1997; Lee et al., 1997; Schache et al., 2000; Cristopoliski et al., 2009), and may be associated with lower back and lower extremity pain (Winters et al., 2004; Tyler et al., 2006).

Hip extension ROM has been investigated in relation to gait function in the elderly (Cristopoliski et al., 2008), and persons with central nervous system disorders such as cerebral palsy (Lee et al., 1997), athletic performance (Schache et al., 2000; Young et al., 2003;), sufferers of low back pain (Stodolny & Mazur, 1989;Winters et al., 2004), patella-femoral pain (Tyler et al., 2006; Winters et al., 2004) and osteoarthritis of the hip joint (Hurwitz et al., 1997).

A restriction of joint range of motion and a loss of flexibility may be attributed to a number of different causes including inactivity and immobilization (Alter, 1996; Trudel & Uhthoff, 2000; Prentice & Voight, 2001; Lederman, 2005; Magee et al., 2007), myoelectric hyperactivity related to central nervous system disorders (Shimada, 1996; Lee et al., 1997; Spruit & Fabry, 1997; Novacheck et al., 2002; Westhoff et al., 2003) and degenerative joint disorders (Shimada, 1996; Hurwitz et al., 1997; Porth, 2002).

Sedentary lifestyles and a habitual seated posture are likely contributing factors in reduction of hip extension ROM.

A range of treatment options for hip flexion contracture have been reported in the literature. Surgical lengthening of iliopsoas muscle and tendon has been performed in cases of spastic contraction associated with cerebral palsy (Hoffer 1986; Spruit & Fabry 1997 Novacheck et al., 2002), and for "internal snapping hip syndrome" (Hoskins et al., 2004; Byrd, 2005; Flanum et al., 2007). Injection of Botulinum toxin A into the psoas muscle has also been reported (Molenaers et al., 1999; Westhoff et al., 2003) as well as self stretch of the hip flexors and exercise (Winters et al., 2004; Tyler et al., 2006; Cristopoliski et al., 2007).

Muscle energy technique (MET) and its variants of contract-relax (CR) stretch techniques such as proprioceptive neuromuscular facilitation (PNF) are commonly employed by osteopaths and other manual therapists in order to improve musculoskeletal function (Chaitow, 2006), effect fluid dynamics, stretch muscles perceived to be "tight", and increase ROM (Kuchera & Kuchera, 1994; Greenman, 1996; Goodridge, 1997). Potentially MET could be employed as a treatment option for a restriction in extension ROM in the hip joint.

The immediate effect of MET on ROM has been studied in a range of different joints by a number of researchers who have found immediate positive effects on cervical spine ROM (Schenk et al., 1994; Fryer & Ruszkowski, 2004; Burns & Wells 2006), thoracic spine ROM (Lenehan et al., 2003), lumbar spine ROM (Schenk et al., 1997) and hamstring extensibility (Ballantyne et al., 2003; Smith & Fryer, 2008; Shadmehr et al., 2009).To date there appears to be only one published study investigating the effect of MET on hip extension range of motion. Stodolny and Mazur (1989) examined the effect of post-isometric relaxation in conjunction with kinesitherapy (a prescribed exercise regime) compared with kinesitherapy alone over a 16-day period on participants with low back pain (LBP) diagnosed as disc pathology. One other study, an unpublished master's thesis (Milliken, 2003) investigated the effect of a single application of MET targeting the psoas major muscle on asymptomatic participants. Both these studies indicated an immediate positive effect on hip extension ROM. Neither study included a longer term follow-up.

There is also a lack of research investigating the longer term effects of MET targeting muscle groups other than hip flexors. Spernoga et al., (2001) investigated the effect of a single application of PNF on hamstring extensibility over a 30 minute period and results indicated that a significant ($p<0.05$) effect lasted a maximum of six minutes. Trampas et al., (2010) measured passive knee extension immediately, and at 10 and 30 minutes following a CR PNF stretch on the hamstring muscles. A "moderate" effect size was maintained at 10 minutes which diminished to a "small" effect size by 30 minutes post application of the CR stretch. Smith and Fryer (2008) reported a mean (±SD) increase of 2.49 degrees (±7.19; p=0.04) in active knee extension one week following application of an MET protocol and the authors suggested lasting effects of the technique. There appear to be few investigations into the duration of the effect of MET on hip extension ROM.

The aim of this study was to investigate the effect of a single application of MET on hip extension ROM compared passive stretch over a 30 minute follow-up period.

2. METHODS

2.1 Study design

This study was a repeated measures experimental trial using a controlled crossover design (Hopkins, 1997). Figure 1 illustrates the flow of the experimental design and testing procedures.

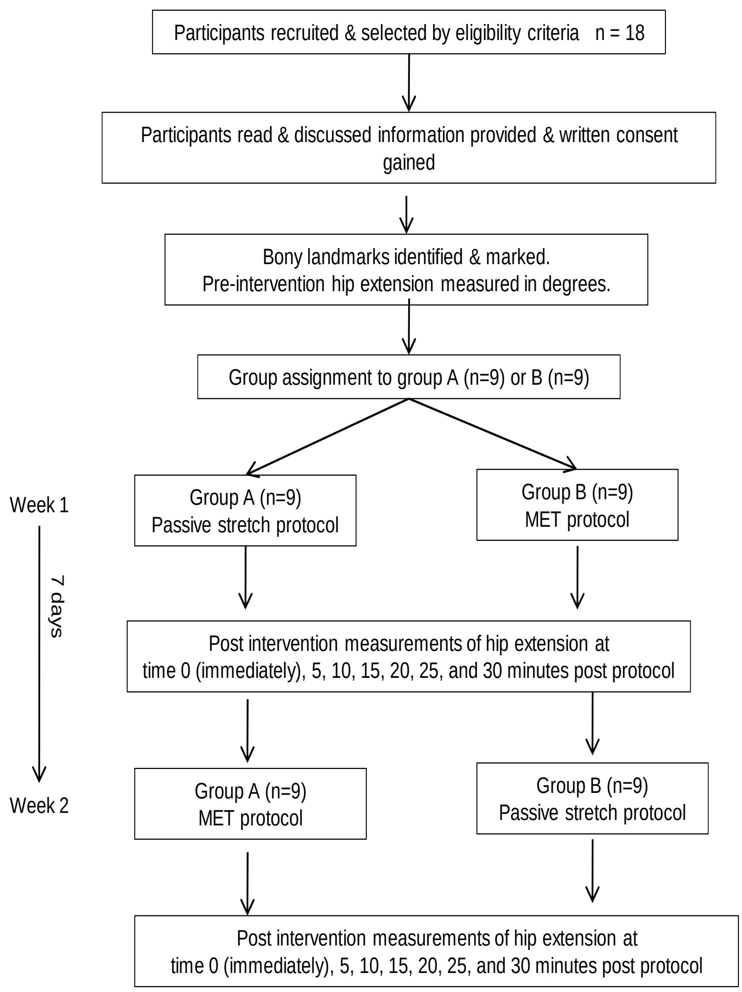


Figure 1: Flow diagram of experimental design.

2.2 Participants

Participants were recruited on a voluntary basis from the Unitec New Zealand campus by way of poster advertising on notice boards, group announcement and by word of mouth. Inclusion criteria were healthy adult males aged between 18-45 years who exhibited a "positive" Thomas test. The Thomas test was conducted according to guidelines described by Magee (2006) whereby the participant lay supine on a treatment table. The examiner flexed the participant's left hip and knee to their chest and if the extended (right) leg lifted off the table this was interpreted as a restriction in hip extension (a "positive" test). Participants were excluded if they had a) history of hip, pelvic or lower back pain, congenital hip joint dysplasia, pathology or trauma; b) were currently receiving manual therapy treatment or undertaking a flexibility training regime; c) had a known musculoskeletal or neurological disorder; or d) were taking medications that affect the musculoskeletal system (e.g. muscle relaxants).

Participants who met the criteria were provided with a written information sheet outlining the requirements of participation and were provided with the opportunity to discuss all procedures with the primary researcher. Written informed consent was obtained before commencement of the study and all participants were aware that they had the opportunity to withdraw from the study prior to data analysis. Ethical approval for this study was granted by the Unitec Research Ethics Committee.

2.3 Procedures

Data collection took place within a laboratory at Unitec New Zealand and was undertaken by the principal researcher and an assistant researcher who was a registered osteopath with more than 5 years of experience, and was instructed in the specific experimental protocol for the MET intervention.

All participants completed both an MET and a passive stretch protocol as described in sections 2.3.3 and 2.3.4. Group allocation was determined by logistical factors primarily on the basis of the availability of the practitioner performing the MET procedure. Testing took place at the same time of day, with 7 days between sessions. Participants were asked to refrain from vigorous exercise and stretching their hip flexors during the 7-day interval between both intervention trials.

2.3.1 Room and camera set-up

The room was arranged with two height adjustable treatment tables and a video camera secured to a tripod. The first table (table-1) was placed in a static position with the brakes on and a second table (table-2) was used with the brakes off so it could be freely moved end-on to table 1 as required. The camera (a Sony digital model DCR-HC40E) was set at a right angle to the treatment tables and positioned for a clear view of the right side of the participant's lower body centred in the frame in both the supine and the extended hip position required for intervention and measurement. The tripod was fixed at a set height and a spirit level was used to ensure the camera position was level. The tripod and treatment table positions were measured and semi-permanent reference markers were placed on the floor to ensure consistency in the room set up between sessions.

2.3.2 Pre-intervention

All participants undertook a warm-up exercise consisting of walking for 5 minutes at moderate speed immediately prior to commencement of the intervention. Following the warm-up, table-1 was adjusted to the height of each participant's gluteal fold. The participant was asked to sit with their sacrum at the very edge of the end of the table, they were then instructed to draw up their left knee and holding it with both hands, slowly roll back into a lying position while the researcher assisted with guiding the right leg up, simultaneously pulling the second (mobile) treatment table into place so that the participant was able to lie fully supine. The height of the second table was adjusted to be level with the first so that the participant could lie comfortably.

The greater trochanter of the proximal femur and the lateral epicondyle of the distal femur of the right limb were palpated and marked with an indelible marker and overlaid with adhesive markers that enabled clear identification on the video recording (refer figure 2).

The participant was then asked to bend their left hip and knee and hold the leg in the fully flexed position to maintain a flat lumbar spine and prevent pelvic tilt which was checked by the principal researcher. The principal researcher then removed the mobile treatment table while supporting the participant's right leg by cupping their heel, and slowly lowering it, allowing the leg to extend at the hip and hang in a relaxed manner (refer figure 2).

2.3.3 Passive stretch protocol

The participant maintained the extended hip position described above for 60 s which was equivalent to the length of time spent in this position during the MET protocol. The principal researcher then lifted the extended leg up by supporting the participant's heel, while drawing the mobile treatment table back into place, enabling the participant to return to the supine position.

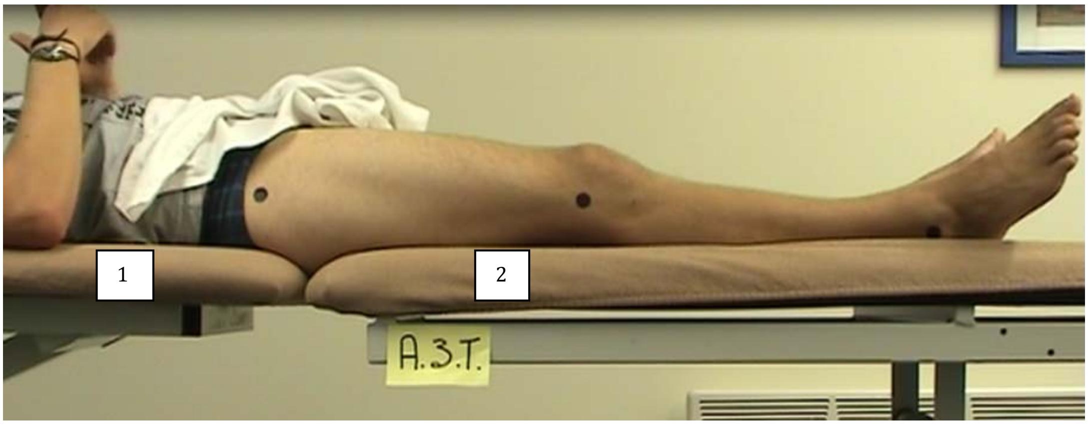
2.3.4 MET protocol

The MET intervention used for this study was based on the description by Chaitow (2006) and was clearly explained in plain language to each participant immediately prior to commencement. The participants were instructed to follow the prompts given by the practitioner, and during the contraction phase of the stretch to "push their right leg up to meet the practitioners resistance with approximately half of their perceived strength". The participant was also asked not to allow their lumbar spine to lift off the table, and to indicate if at any time during the procedure they experienced pain or discomfort.

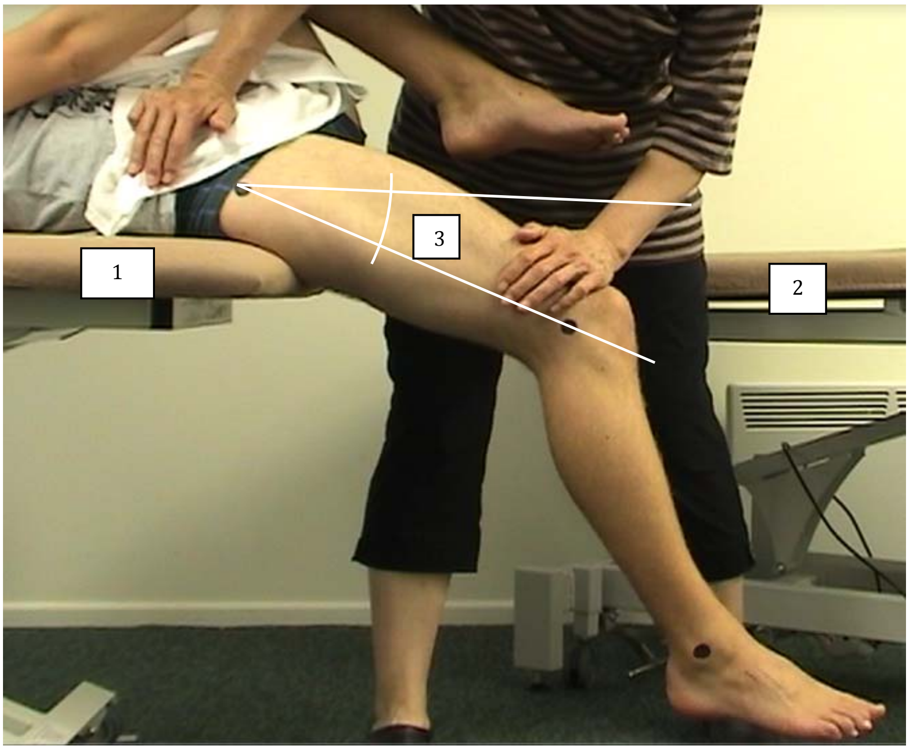
The MET intervention proceeded as follows:

1. The participant was assisted into the extended hip position as previously described in the pre-intervention protocol(refer figure 2).
2. The practitioner stood adjacent to the participant at the end of the table facing the participant's right leg (and camera).

3. The practitioner then placed their left hand over the participant's distal thigh just above the right knee and their right hand over the participant's right iliac crest to stabilise the pelvis as illustrated in Figure 2.
4. The practitioner then gently pushed down on the thigh to stretch the hip joint to the first stretch barrier as perceived by the practitioner.
5. The participant was then requested to "gently push up".
6. The contraction phase was maintained for the duration of 5 seconds as recommended by Fryer and Ruszkowski (2004).
7. The participant was then instructed to "relax" (duration 3 seconds).
8. The practitioner then gently pushed down on the thigh to stretch the hip joint to the next stretch barrier as perceived by the practitioner.
9. This process was repeated for a total of five contraction phases (Greenman, 1996).
10. The principal researcher then lifted the extended leg up by supporting the participant's heel, while drawing the mobile treatment table back into place, enabling the participant to return to the supine position.



A



B

Figure 2*: (A) resting position, (B) intervention and measurement position*.
1 =Table 1 (static)
2=Table 2 (mobile) ;
3 = angle of hip extension measured.

2.3.5 Post intervention

Following the intervention, measures of hip extension were recorded immediately, and at intervals of 5 minutes and up to 30 minutes post intervention (*t*= 0, 5, 10, 15, 20, 25, 30 min). For the repeated measurements, the principal researcher assisted the participant into the extended leg position (as previously described) and instructed the participant to "relax". This position was maintained for 2 s, then the leg was lifted back onto the second treatment table by the principal researcher and the participant returned to the supine position for the time interval between each measurement.

Following the first session the participants were each given an indelible ink pen and asked to maintain the markings on the anatomical reference points for the subsequent session.

2.3.6 Data Extraction

The experimental trials were recorded by video which was then captured onto an IBM "ThinkPad" using a Sony digital video cassette recorder (model GV-D1000) and Silicon Coach software (SiliconCOACH, Dunedin, NZ). Angles of hip extension were measured using SiliconCOACH measurement tools while the participant was in the extended hip position immediately prior to intervention, and at *t*= 0, 5, 10, 15, 20, 25, and 30 minutes post intervention. Three measurements were taken at each time interval and measurement was repeated on three separate occasions one week apart while the researcher was blinded to the previously recorded measurements. The mean value of these measures was rounded to the nearest whole number and used for data analysis.

2.3.7. Reliability of data extraction

In order to assess potential measurement error associated with the operator use of SiliconCOACH for measuring angles of hip extension, the three measurements taken (as described above) for 144 of the slides measured where assessed by calculating the intraclass correlation coefficient (ICC) using SPSSv17 (SPSS Inc, Chicago, IL). The ICC was calculated to be=0.99 (95% CI= 0.994 to 0.997; $p<0.001$) which when interpreted using Hopkins (2002) descriptors is “almost perfect”.

2.4. Data analysis

The raw data was tabulated using the Microsoft Office Excel 2007, was then explored and descriptive statistics were calculated. Inspection of the descriptive statistics for the raw data indicated a narrow range for the primary outcome measure (degrees of hip extension) which was interpreted to indicate that the sample was reasonably homogenous and therefore appropriate to undertake analysis using the actual measurement of degrees rather than the calculation of a percent change measurement. Normality of the raw data was assessed using Q-Q and stem-and-leaf plots as well as calculation of the Shapiro-Wilk statistic and parametric statistics were used for all normally distributed variables. The Intra-class correlation coefficient (ICC) was calculated using a customized spreadsheet devised by Hopkins (2002) and was used to assess the stability of the trait (hip extension) across the 7-day measurement interval and thus the consistency or reliability of the measure. Pre-intervention (baseline) measures of degrees of hip extension ROM were compared with post- intervention measures for both passive stretch and MET using paired t-tests which were performed to calculate *p* values. 95% confidence intervals were constructed for the mean differences and effect sizes were examined by calculating Cohen's *d* and interpreted using the descriptors for magnitudes of effect (Hopkins, 2002). The standard error of measurement (SEM) and smallest detectable difference (SDD) were calculated to assess the relative strength of the findings, using the equations; $SEM=SD\bullet\sqrt{(1-ICC)}$; $SDD=1.96\bullet\sqrt{2}\bullet SEM$. SPSS v17 (SPSS Inc, Chicago, IL) was used for the descriptive and inferential data analysis. Throughout the text all data is reported as mean (±SD).

3. RESULTS

3.1 Participants

The sample consisted of 18 male participants who were allocated to group A (*n*=9) or group B (*n*=9). The mean age of participants was 27.2 years (±7.2); the mean weight 80kg (±10.4); mean height 181.1cm (±5.5) and the mean hip extension at baseline was 19.2 degrees (±5.5). Paired *t*-tests indicated there were no significant differences between the group characteristics of mean age (*p*=0.52), weight (*p*=0.50), height (*p*=0.82) and hip extension (*p*=0.77) at baseline.

3.2 Immediate effect of intervention

Immediately following the MET intervention a mean increase of 5.3 degrees (±3.2) of hip extension was observed (95% CI=3.6 to 6.9; $p \le 0.001$) which represented a "moderate" effect (*d*=0.97). This was compared with the passive stretch (control) procedure for which a mean increase of 2.1 degrees (±2.7; 95%CI=0.7 to 3.4; *p*=0.006) was measured representing a "small" (*d*=0.46) effect size. The mean values for hip extension range of motion for both the MET and passive stretch interventions for each time interval are displayed in figure 3.

3.3 Five minutes post intervention

At five minutes post intervention the mean increase in hip extension from baseline following the MET procedure was 2.5 degrees (±2.6; 95% CI=1.2 to 3.8; $p \le 0.001$; *d*=0.45). The passive stretch procedure maintained a mean increase of 1.8 degrees

(±1.9; 95% CI=0.9 to 2.8; $p \leq 0.001$; d=0.40). These results represented a "small" effect for both procedures.

3.4 Thirty minutes post intervention

A comparison of hip extension immediately prior to, and at 30 minutes following the intervention showed mean differences very similar to those at 5 minutes post intervention. For MET this was an increase of 2.6 degrees (±3.9; 95%CI=0.7 to 4.6; p=0.01; d=0.46), for the passive stretch procedure an increase of 1.7 degrees (±3.1; 95%CI= 0.2 to 3.3; p=0.03; d=0.36) and thus a "small" effect was maintained over thirty minutes for both procedures.

A "small" (d=0.49) decrease in the effect of the MET intervention on hip extension occurred between the immediate measurement (t= 0 min) and 30 minutes following the MET procedure with a mean difference of 2.7 degrees (±2.2; 95%CI=1.6 to 3.8; $p \leq 0.001$). The mean difference in the effect of the passive stretch procedure for the same time interval was calculated to be "trivial" (d=0.07) (mean difference 0.3 degrees (±2.5); 95%CI=-0.9 to 1.6; p=0.58).These findings indicated that although the effect was "small" there was some deterioration over this time interval observed for the MET procedure and no significant reduction of the effect of the passive stretch procedure.

The effect of both the MET and the control procedures appeared to level out and to remain stable for each 5 minute time interval from 5 minutes until 30 minutes post intervention.

The difference between the effect of the two interventions at thirty minutes post procedure was "trivial" (mean difference 1.6 degrees (±3.9); 95% CI=0.3 to 3.6; *d*=0.15) and did not reach statistical significance (*p*=0.1).

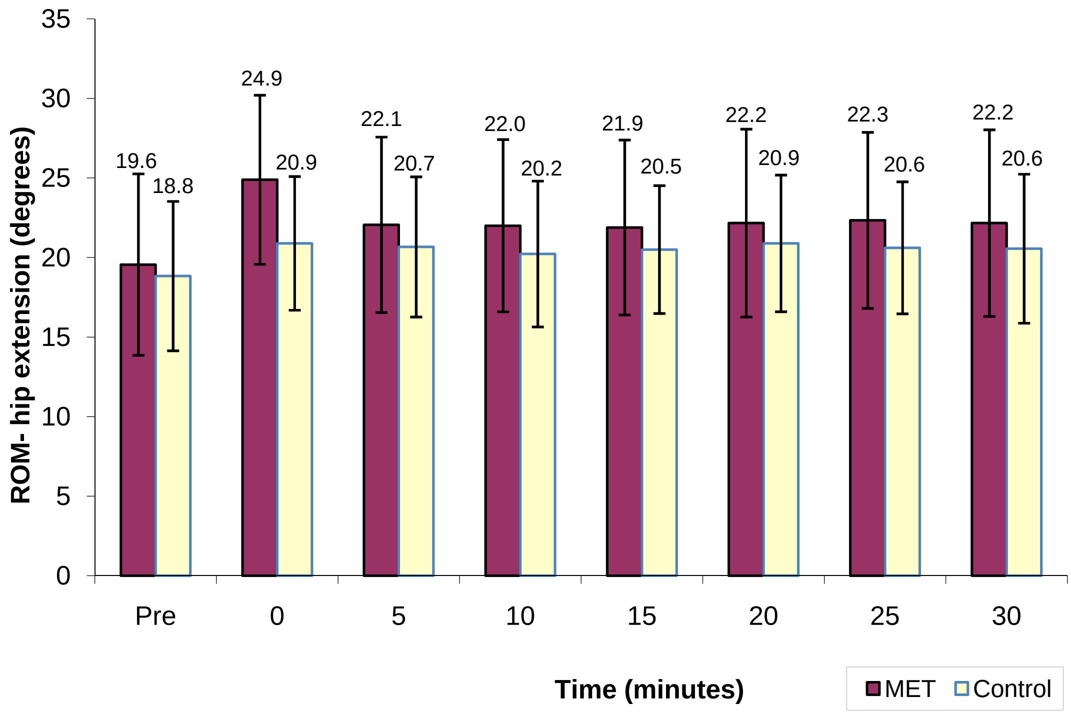


Figure 3: Mean hip extension ROM over time for MET and passive stretch (control)

3.5 Seven days post intervention

There was no evidence of a maintained effect one week following either technique. Analysis showed a "small", non-significant reduction in pre-intervention hip extension 7 days following both passive stretch (mean difference -1.4 degrees (±2.55; 95% CI=0.5 to 3.40; *d*=0.26; *p*=0.128) and MET (mean difference -2.9 degrees (±5.0); 95% CI=0.9 to 6.7; *d=0.59; p*=0.121).

3.6 Reliability of hip extension

The test-re-test reliability the of hip extension measurement across the 7 day trial interval was assessed by calculating the intra-class correlation coefficient (ICC) of the pre-intervention ROM measurement (ICC=0.66; 95%CI=0.29 to 0.86) which indicated a "high" degree of reliability (Hopkins 2002) and that hip extension ROM is a reasonably stable measurement.

In order to give context to the size of the change observed the SEM and SDD were calculated and found to be 3.0 degrees and 8.32 degrees respectively.

3.7 Power

A post hoc power analysis was calculated for the non-significant comparisons, namely, the difference between the MET and passive stretch procedures at 30 minutes. This revealed a power of 0.22, and that a sample of 88 participants would be required to adequately power this contrast at 0.8.

4. DISCUSSION

The aim of this study was to evaluate the effect of a single application of MET compared with passive stretch on hip extension range of motion over a 30 minute period on asymptomatic participants with a restriction in hip extension. The results indicated that MET produced a "moderate" increase and that passive stretch produced a "small" increase on hip extension flexibility immediately following intervention. A "small" effect was maintained up to thirty minutes following both interventions.

4.1 Changes in Range of motion

The immediate effect observed in this present study was similar to effects observed by both Stodolny and Mazur (1989), and Milliken (2003). Stodolny and Mazur (1989) described an investigation in which post–isometric relaxation (PIR) was either self performed or applied to the hip flexors in the modified Thomas position as was used in this current study. The PIR stretch was performed in addition to unspecified "kinesitherapy" (a prescribed exercise programme), and was compared to a group who performed kinesitherapy alone over a 16 day period. Stodolny and Mazur (1989) reported immediate positive gains in hip extension ROM for the PIR group of 11.9 degrees (±10.5) compared with 2.8 degrees (±7.4) in the non PIR group. Although the effect size was not reported, however, using the data supplied, it was calculated to be "large". The participants in the Stodolny and Mazur (1989) study were all symptomatic with low back pain (LBP) and had all been diagnosed with disc pathology, however, no outcome measures or assessments were made in relation to their pain or functional abilities which would have been useful information in assessing clinically relevant outcomes of the technique.

Milliken's unpublished thesis investigating hip extension ROM following a single application of MET to hip flexor muscles in asymptomatic participants reported an immediate increase of 6.5 degrees following intervention and 2.8 degrees for the control group (Milliken, 2003). These results appear to be consistent with the immediate findings in the present study, however, no standard deviations or effect sizes were reported. Using the raw data supplied in the appendix of the Milliken study, further analysis revealed a "very large" effect of MET (6.5 degrees, ±3.7; 95% CI=4.4 to 8.6; p<0.01; d=2) and "small" effect in the control (no treatment) group (2.8 degrees; ±2.5; p=0.0001; d=0.55).

Both the Stodolny and Mazur (1989) and the Milliken (2003) studies achieved greater immediate increases of hip extension ROM than in the current study. Reasons for this are most likely to be due to greater restriction of hip extension ROM of the participants of these two studies at baseline than in this current study. Another explanation may relate to methodological differences, namely contraction duration and the duration of the post-isometric stretch phase. However this is a less likely explanation as these factors were consistent between this current study and that of Milliken (2003) and although longer duration times were employed for both these phases in the Stodolny and Mazur (1989) investigation neither contraction duration (Fryer & Ruszkowski, 2004) nor the duration of the post isometric stretch phase (Smith & Fryer, 2008) appear to influence the efficacy of MET.

4.2 Temporal effect of MET

There appear to be no other studies investigating the effect of MET, PNF or other related CR stretch techniques on hip extension ROM either with immediate or longer term follow-up. Only two studies were found investigating the effect of CR PNF over time, however, neither investigated hip extension ROM; in these studies the hamstring muscle was targeted and assessment was made measuring knee extension ROM with the hip joint in 90˚ of flexion. Spernoga et al., (2001) measured the duration of a single application of PNF (using maximal isometric contraction) on the hamstring muscles over a period of 32 minutes and found that a significant increase in active knee extension only lasted 6 minutes. Although this finding may appear to contrast with the present study in which a “small” but significant effect of intervention was still evident at 30 minutes, the reduction in the effect size was evident at the 5 minute interval following the intervention. Trampas et al., (2010) measured passive knee extension immediately, and at 10 and 30 minutes following a CR stretch protocol. A “moderate” (d=0.6) effect size was maintained at 10 minutes which diminished to a “small” (d=0.2) effect size by 30 minutes post application of the CR stretch, findings that are more consistent with the present study.

In this present study a “small” but non-significant reduction of hip extension ROM was observed 7 days following both the MET (mean difference -2.9 degrees, ±5.0; 95%CI= 0.9 to 6.7; p=0.121; d=0.59) and passive stretch (mean difference -1.4 degrees (±2.55; 95% CI=0.5 to 3.40; d=0.26; p=0.128) procedures prior to the second intervention. Smith and Fryer (2008) noted a significant (p=0.04) increase of 2.49 degrees (±7.19) in active knee extension one week following application of an MET protocol. Differences in the findings between Smith and Fryer (2008) and the present study may be due to differences in the characteristics of the target tissues (hamstrings compared with hip flexors). However, in view of the standard deviation reported in Smith and Fryer's (2008) study, which was nearly 3 times greater than the mean increase reported, the small increase is probably not clinically meaningful. Furthermore, although Smith and Fryer (2008) reported "very high" reliability of repeated measures of active knee extension (ICC=0.99), the authors derived the ICC from two measures within the same session and not across the same interval (7 days) as used for the main experiment. In the present study the ICC was derived across the 7-day interval over which the experiment was conducted.

4.3 Physiological mechanism of MET

The changes in ROM observed in the present study appear to be consistent with a viscoelastic tissue response within the elastic range where the stretched tissue does not immediately return to its original length (Lederman 2005; Magee et al., 2007). Ballantyne et al., (2003) suggest that if increases in ROM following MET were due to changes in viscoelastic properties alone, allowing greater muscle extensibility, this would be achieved using a constant torque or force of stretch. In this current study, the passive hip extension ROM measured pre and post interventions was "assisted" by gravity, a constant force. Therefore the immediate increases in ROM measured for the MET stretch compared with the passive stretch protocol were assessed with a constant force of stretch, thus supporting Lederman's (2005) theory that increased gains in ROM for CR stretch techniques may be due to the focus of the stretch being directed onto the stiffer in-series connective tissue elements of the muscle tissue, as well as the more elastic parallel connective tissues primarily targeted during passive stretch. A more favoured explanation however, is that an increase in stretch tolerance occurs as a result of CR procedures (Magnusson et al., 1996; Ballantyne et al., 2003). It is possible that an increase in stretch tolerance may have allowed for greater relaxation of the participants in the modified Thomas test position used for intervention and assessment and thus achieve a greater degree of hip extension.

4.4 Limitations of the study

The maximum range of hip extension has been reported to be up to 15 degrees of active extension (Magee, 2006), up to 20 degrees for passive extension and 30 degrees with assisted stretch (Kapandji, 2011). Harvey (1998) and Ferber et al., (2010) measured the hip extension ROM of athletes in the modified Thomas test position and found the mean hip extension ROM to be 11.9 degrees (±5.6) and 10.6 degrees (±9.6; 95% CI=9.5 to 11.7) respectively. Although Schache et al., (2000) measured a mean hip ROM of 17.4 degrees (range 7.5° to 25°), the mean baseline ROM in this current study was 19.2 degrees (±5.1), which was larger than expected, particularly as the participants tested "positive" for the Thomas test. Two primary explanations are suggested:

Firstly, some of the participants in this present study may have tested falsely 'positive' to the Thomas test. Kendall et al., (2005) suggests a 'false-positive' result for the Thomas test may occur if the non-test leg is flexed excessively, flexing the lumbar spine and sacrum, posteriorly rotating the pelvis and lifting the tested limb off the table and therefore giving the appearance of a restriction in hip extension. To increase reliability, Peeler and Anderson (2006) suggest more specific criteria, particularly regarding the amount of flexion of the non tested leg, are required for the Thomas test.

Secondly, Harvey (1998) noted that if the contra-lateral hip (non-test leg) is not held maximally to the chest, the angle of extension in the test leg appears greater. Although in the present study the non-test leg was flexed and held so that the lumbar spine remained flat on the treatment table to prevent lumbar spine extension and an anterior rotation of the pelvis exaggerating hip extension range, the participants were not instructed to hold the leg maximally to their chest. This may have allowed anterior rotation of the pelvis to occur and falsely increasing the recorded range.

Although the current study indicated a "moderate" effect in mean increase in hip extension ROM of 5.3 degrees (95% CI = 3.6 to 6.9) for MET immediately following this intervention, in light of the calculated SEM (3.0 degrees) and the SDD (8.32 degrees) the results of the present study do not represent a convincing positive benefit. The size of the SDD appears to be due to the level of variability of the outcome measure which is reflected in the ICC (0.66) for repeated measures and therefore an improvement in experimental reliability in the repeated measure of hip extension ROM would be desirable. Gabbe et al., (2004) also reported similar ICC scores (0.63- 0.75; 95% CI =0.20 to 0.95) for test-retest reliability, however, Harvey (1998) reported 'extremely high' reliability (ICC= 0.91-0.94) although both these studies instructed their participants to hold their contra-lateral leg in maximal flexion while measuring hip extension ROM.

There are two primary sources of measurement variability or error, namely technical error in measurement, and biological variability. Biological factors leading to a variation in ROM include the participants' recent physical activity and muscle temperature. These factors were controlled for by requesting the participants refrain from vigorous exercise and stretching activities prior to and between sessions, a warm-up procedure prior to the intervention, and conducting the trial at the same time of day (7 days apart) in a warm room for both intervention sessions for each participant.

Possible sources of technical error for the experimental trial include; consistency of room set-up; positioning of the markers on the participant's skin; the position of the participant's sacrum at the edge of the table; the degree of flexion in which the non-test hip was held; and the operators ability to accurately extract data. Reliability of data extraction from raw video footage was "almost perfect" (ICC=0.99; 95%CI=0.99 to 1.0). The most likely source of technical error is a variation in the range of flexion in which the participant held their non-test hip which would have affected the consistency of the angle measured across all the time intervals as it may have differed each time the participant assumed the test position. A strap (adjustable for each individual) to hold the non-test hip and leg in a constant position that maintains a neutral lumbar spine and pelvis should be considered in future investigations. It is clear that meticulous attention in controlling variables involved in ROM measurement is required when conducting a experimental trial such as this.

In randomized controlled experimental designs participants are typically allocated to groups in a random fashion, with the aim of making each group sample representative of the population and minimising group bias (Hopkins, 2010). Randomised controlled designs are considered to be optimal in investigation of cause and effect relationships (Hicks, 2004; Hopkins, 2010). Random selection, however, does not guarantee equality of characteristics in a population at baseline and non-random allocation aimed at minimising differences in group means may be a superior method particularly when the effect of a treatment depends on a group characteristic (Scott et al., 2002). A potential limitation of this study is that random allocation was not used, participants were allocated to groups as they were recruited, depending on availability of the practitioner performing the technique, and in order to achieve even group numbers. Pre-post controlled cross-over experiments, however, have the smallest errors arising from group mean participant characteristics (Hopkins, 2010) due to groups receiving both intervention and control procedures. In this study no differences were observed between group characteristics and therefore it is less likely a lack of randomisation impacted on the outcome in any way.

A suitably powered study enables the detection of a real difference and that the findings are not merely a result of chance. More specifically, adequate power is required to avoid the statistical error of concluding there is no difference when a difference may actually exist (Thomas et al., 2005). A post-hoc power analysis between passive stretch and MET at 30 minutes post application of the intervention, demonstrated the present study was under powered (power = 0.22) to determine the difference for this (non-significant) comparison, and that a larger number of participants (n=88) would be required. Therefore, there is insufficient evidence to conclusively determine that no difference exits between the effect of MET and passive stretch at 30 minutes.

4.5 External validity

The technique protocol used in this study was consistent with how MET may be applied in a clinical situation and the technical approach to delivery was intended to be similar to how the technique may be delivered in clinical practise (e.g. no constraints). The participants in this study , males between the age of 18 and 45 years who exhibited a restriction in hip extension ROM, were asymptomatic, and therefore less representative of patients presenting at an osteopathic clinic, however, findings of this study will be relevant to patients who present with a similar profile.

4.6 Recommendations for further study

Prolonged effects of treatment are clinically desirable, therefore studies investigating how best to achieve longer term outcomes of treatment would be of clinical interest. Investigations into the prolonged effect of repeated applications of MET (e.g. multiple sessions over 4 weeks), are recommended as well as the efficacy of "self applied" (Chaitow, 2006) versus practitioner applied MET, aimed to improve hip extension ROM is also advisable if repeated applications are required for long term changes to occur. Comparison of MET with other manual techniques designed to improve biomechanical function and joint movement, as well as the use of functional and pain related assessments on symptomatic subjects pre and post application of MET would also contribute to an informed approach to the use of MET within clinical practise. How to best obtain immediate *and* lasting improvements in joint range of motion are desirable.

5. CONCLUSION

The findings of this study indicate a “moderate” effect for increasing hip extension range of motion immediately following a single application of muscle energy technique to improve hip extension, and a “small” effect following passive stretch. Five minutes following the intervention the observed increase was “small” for both groups and was maintained at 30 minutes. There was no evidence that an effect of either intervention was maintained following the 7-day interval. Therefore both MET and passive stretch appear to have a small effect in increasing hip extension ROM for a duration of up to 30 minutes.

REFERENCES

Alter MJ. Science of Flexibility (3rd ed.). United states of America: Human Kinetics Publishers Inc; 1996. p. 32-35, 54-55.

Ballantyne F, Fryer G, McLaughlin P. The effect of muscle energy technique on hamstring extensibility: the mechanism of altered flexibility. Journal of Osteopathic Medicine 2003; 6(20): 59-63

Burns DK, Wells MR. Gross Range of Motion in the Cervical Spine: The Effects of Osteopathic Muscle Energy Technique in Asymptomatic Subjects. The Journal of American Osteopathic Association 2006; 106(3): 137-142.

Byrd JWT. Snapping hip. Operative Techniques in Sports Medicine 2005; 13(1): 46-54.

Chaitow L. Muscle Energy Techniques. 3rd edition. London: Churchill Livingstone; 2006. p. 1, 152-153.

Cristopoliski F, Barela JA, Leite N, Fowler NE, Rodacki ALF. Stretching exercise program improves gait in the elderly. Gerontology 2009; 55: 614-620.

Eland DC, Singleton TN, Conaster RR, Howell JN, Pheley AM, Karlene MM, Robinson JM. The "iliacus test": New information for the evaluation of hip extension dysfunction. Journal of the American Osteopathic Association 2002; 102(3): 130-142.

Ferber R, Kendall KD, McElroy L. Normative and critical criteria for iliotibial band and iliopsoas muscle flexibility. Journal of Athletic Training 2010; 45(4): 344-348.

Flanum ME, Keene JS, Blankenbaker DG, De Smet AA. Arthroscopic treatment of the painful "internal" snapping hip. American Journal of Sports Medicine 2007; 35(5): 770-779

Fryer G, Ruszkowski W. The influence of contraction duration inmuscle energy technique applied to the atlanto-axial joint. Journal of Osteopathic Medicine 2004; 7(2): 79-84.

Gabbe BJ, Bennell KL, Wajswelner H, Finch CF. Reliability of common lower extremity musculoskeletal screening tests. Physical Therapy in Sport 2004; 5: 90-97.

Goodridge JP. Muscle Energy Procedures. In: Ward RC. (Ed) Foundations of Osteopathic Medicine. Philadelphia: Lippincott Williams & Wilkins; 1997. p. 692.

Greenman PE. Principles of manual medicine (2nd ed.). Maryland: Williams & Wilkins; 1996. p. 93, 96.

Harvey D. Assessment of the flexibility of elite athletes using the modified Thomas test. British Journal of Sports Medicine 1998; 32: 68-70.

Hicks C. Research Methods for Clinical Therapists (4th ed.). Edenburgh: Churchill Livingston 2004. p. 93.

Hoffer MM. Management of the hip in cerebral palsey. The Journal of Bone and Joint surgery 1986; 68: 629-631.

Hopkins WG. 1997 A New View of Statistics: Generalizing to a population: Repeated measures Model. Retrieved from: http://www.sportsci.org/resource/stats/index.html (last accessed 15 March 2011)

Hopkins WG. 2002 A scale of magnitudes. In: A new view of statistics. Retrieved From: http://www.sportsci.org/resource/stats/index.htm (last accessed 15 March 2011)

Hopkins WG. Assigning subjects to group in a controlled trial. Sporstscience 2010; 14: 7-12. Retrieved from: http://spostsci.org/2010/wghminim.htm (last accessed 14 March 2011).

Hoskins JS, Burd TA, Allen WC. Surgical correction of internal coxa saltans. The American Journal of Sports Medicine 2004; 32(4): 998-1001.

Hurwitz DE, Hulet CH, Andriacchi TP, Rosenberg AG, Galante JO. Gait compensations in patients with osteoarthritis of the hip and their relationship to pain and passive hip motion. Journal of Orthopaedic Research 1997; 15(4): 629-635.

Kapandji IA. The Physiology of the Joints: Volume 2; The lower limb (6th ed.). Edinburgh: Churchill Livingstone; 2011. p. 8.

Kendall FP, McCreary EK, Provance PG, Rodgers MM, Romani WA. Muscles testing and function with posture and pain. Philadelphia: Lippincott Williams & Wilkins; 2005. p. 377.

Kuchera WA, Kuchera M. L. Osteopathic Principles in Practice: revised 2nd edition. Columbus Ohio: Greyden Press; 1994. p. 292

Lederman E. The Science and Practice of Manual Therapy (2nd ed.). Edinburgh: Churchill Livingstone; 2005. p. 18, 23, 51, 61-63.

Lee LW, Kerrigan DC, Della Croce U. Dynamic implications of hip flexion contractures. American Journal of Physical Medicine and Rehabilitation 1997; 76: 502-508.

Lenehan KL, Fryer G, McLaughlin P. The effect of muscle energy technique on gross trunk range of motion. Journal of Osteopathic Medicine 2003; 6(1): 13-18.

Magee DJ. Orthopaedic Physical Assessment (3rd ed.). Elsevier Sciences; 2006. p. 631, 610.

Magee DJ, Zachazewski JE, Quillen WS. Scientific foundations and principles of practice in musculoskeletal rehabilitation. St Louis, Saunders Elsevier; 2007. p. 540, 536.

Magnusson SP, Simonsen EB, Aagaard P, Dyhre-Poulsen P, McHugh MP, Kjaer M. Mechanical and Physiological Responses to Stretching with and without pre-isometric contraction in Human Skeletal Muscle. Archives of Physical Medicine and Rehabilitation 1996; 77: 373-378

Milliken K. The effects of muscle energy technique on psoas major length. A research project submitted in partial requirement for the degree of Master of Osteopathy, Unitec Institute of Technology, Auckland: New Zealand, 2003.

Molenaers G, Eyssen M, Desloovere K, Jonkers L, De Cock P. (1999). A multilevel approach to botulinum toxin type A treatment of the iliopsoas in spasticity in cerebral palsy. European Journal of Neurology 1999; 6(4): S59-S62

Novacheck TF, Trost JP, Schwartz MH. Intramuscular psoas lengthening improves dynamic hip function in children with cerebral palsy. Journal of Paediatric Orthopaedics 2002; 22: 158-164.

Peeler J, Anderson JE. Reliability of the Thomas test for assessing range of motion about the hip. Physical Therapy in Sport, 2006; 8: 14-21.

Prentice WE, Voight ML. Techniques in musculoskeletal rehabilitation. New York: McGraw-Hill Professional Publishing; 2001. p. 83.

Porth CM. Pathophysiology: Concepts of Altered Health States (6th ed.). Philadelphia: Lippincott Williams & Wilkins; 2002. p. 1382.

Schache AG, Blanch PD, Murphy AT. Relation of anterior pelvic tilt during running to clinical and kinematic measures of hip extension. British Journal of Sports medicine 2000; 34: 279-283.

Schenk R, Adelman K, Rousselle J. The effects of Muscle Energy Technique on Cervical Range of Motion. The Journal of Manual and Manipulative therapy 1994; 2(4): 179-183.

Schenk R, MacDiarmid A, Rousselle J. The Effects of Muscle Energy Technique on Lumbar Range of Motion. The Journal of Manual and Manipulative Therapy 1997; 5(4): 179-183.

Scott NW, McPherson GC, Ramsay CR, Campbell MK. (2002). The method of minimization for allocation to clinical trials. a review. Controlled Clinical Trials 2002; 23: 662-674.

Shedmehr, A., Hadian, M. R., Naiemi, S. S., & Jallaie, S. (2009) Hamstring flexibility in young women following passive stretch and muscle energy technique. Journal of Back and Musculoskeletal Rehabilitation 2009; 22: 143-148.

Shimada T. Factors affecting appearance patterns of hip flexion contractures and their effects on postural and gait abnormalities. Kobe Journal of Medical Sciences 1996; 42(4): 271-290.

Smith M, Fryer G. A comparison of two muscle energy techniques for increasing flexibility of the hamstring muscle group. Journal of Bodywork and Movement Therapies 2008;12(4): 312-317.

Spernoga SG, Uhl TL, Arnold BL, Gansneder BM. Duration of maintained hamstring flexibility after one time modified Hold-Relax stretching protocol. Journal of Athletic Training 2001; 36(1): 44-48.

Spruit M, Fabry G. Psoas and adductor release in children with cerebral palsy. Acta Orthopaedica Belgica 1997; 63(2): 91-93.

Stodolny J, Mazur T. Effect of post-isometric relaxation exercises on the iliopsoas muscles in patients with lumbar discopathy. Journal of Manual Medicine 1989; 4(2): 52-54.

Thomas JR, Nelson JK, Silverman SJ. Research Methods in Physical Activity (5th ed.). Auckland: Human Kinetics; 2005. p. 116

Trampas A, Kitsios A, Sykaras E, Symeonidis S, Lazarou L. Clinical massage and modified proprioceptive neuromuscular facilitation stretching in males with latent myofascial trigger points. Physical Therapy in Sport 2010; 11: 91-98.

Trudel G, Uhthoff HK. Contractures secondary to immobility: is the restriction articular or muscular? An experimental longitudinal study in the rat knee. Archives of Physical Medicine & Rehabilitation 2000; 81(1): 6-13.

Tyler TF, Nicholas SJ, Mullaney MJ, McHugh MP. The role of hip muscle function in the treatment of patellofemoral pain syndrome. The American Journal of Sports Medicine 2006; 34(4): 630-636.

Westhoff B, Seller K, Wild A, Jaeger M, Krauspe R. Ultrasound-guided botulinum toxin injection technique for the iliopsoas muscle. Developmental Medicine and Child neurology 2003; 45: 829-832.

Winters MV, Blake CG, Trost JS, Marcello-Brinker TB, Lowe L, Garber MB, Wainner RS. Passive versus active stretching of hip flexor muscles in subjects with limited hip extension: a randomized clinical trial. Physical Therapy (2004); 84(9): 800-807.

Young W, Clothier P, Otago L, Bruce L, Liddell D. Relationship between a modified Thomas test and leg range of motion in Australian rules football kicking. Journal of Sport Rehabilitation 2003; 12: 343-350.

Section 3: Appendices

Appendix A: Measures of hip extension (degrees) at each time interval, for passive stretch and MET.

Table 1a. Raw data for passive stretch procedure group A

Subject	Group	AC pre	AC 0min	AC 5min	AC 10min	AC 15min	AC 20min	AC 25min	AC 30min
1	A	20	20	20	16	16	18	16	18
2	A	27	28	27	27	27	27	27	28
3	A	27	26	28	27	27	29	25	27
4	A	18	20	23	21	22	22	23	21
5	A	25	25	23	26	21	24	21	20
6	A	12	10	11	12	12	13	13	13
7	A	19	20	21	20	20	21	20	19
8	A	15	19	17	16	16	16	17	17
18	A	23	25	26	27	26	26	28	28

Notes: AC = Group A Control (Passive Stretch)

Table 1b. Raw data for passive stretch procedure group B

Subject	Group	BC pre	BC 0min	BC 5min	BC 10min	BC 15min	BC 20min	BC 25min	BC 30min
9	B	24	25	26	25	24	25	26	28
10	B	19	18	20	19	19	20	20	20
11	B	16	22	21	20	22	22	22	21
12	B	15	16	17	15	17	15	17	18
13	B	19	23	22	22	22	22	23	23
14	B	12	21	16	17	18	20	19	19
15	B	16	20	18	18	22	21	19	20
16	B	15	20	17	19	19	18	19	17
17	B	17	18	19	17	19	17	16	13

Notes: BC = Group B Control (Passive Stretch)

2a. Raw data for MET procedure group A

Subject	Group	AT pre	AT 0min	AT 5min	AT 10min	AT 15min	AT 20min	AT 25min	AT 30min
1	A	17	20	16	17	16	17	16	16
2	A	27	35	31	30	31	31	31	31
3	A	25	30	28	30	29	30	30	31
4	A	15	26	23	20	22	23	24	23
5	A	19	29	24	27	25	26	25	23
6	A	11	20	15	18	19	16	17	18
7	A	21	25	23	23	23	23	22	22
8	A	13	22	19	17	15	18	21	22
18	A	25	28	27	27	28	28	28	28

Notes: AT = Group A Treatment (MET)

2b. Raw data for MET procedure group B

Subject	Group	BT pre	BT 0min	BT 5min	BT 10min	BT 15min	BT 20min	BT 25min	BT 30min
9	B	29	32	31	31	31	32	31	33
10	B	18	20	20	20	21	20	19	17
11	B	15	17	15	16	16	16	17	16
12	B	14	18	16	16	15	15	16	14
13	B	16	24	21	22	22	23	23	22
14	B	15	20	18	16	17	15	17	17
15	B	26	32	26	26	26	27	29	28
16	B	18	23	16	16	16	15	16	17
17	B	28	27	28	24	22	24	20	21

Notes: AT = Group A Treatment (MET)

Appendix B: Confirmation letter for ethical approval of this study was granted by the Unitec Research Ethics Commitee.

Unitec
NEW ZEALAND
Te Whare Wānanga o Wairaka

phone +64 9 849 4180 fax +64 9 815 2901 web www.unitec.ac.nz
address Private Bag 92025, Auckland Mail Centre, Auckland 1142, New Zealand
Mt Albert campus Carrington Rd, Mt Albert, Auckland, New Zealand
Waitakere campus Ratanui St, Henderson, Auckland, New Zealand

Heather Nicholls
49 Renfrew Avenue
Sandringham
Auckland

10 December 2009

Dear Heather

Your file number for this application: 2009-1026
Title: The effect of a single application of muscle energy technique on hip extension range of motion

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

Start date: 23 November 2009
Finish date: 23 November 2010

Please note that:

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

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

Yours sincerely

pp Frances Ward
Deputy Chair, UREC

cc: Derek Nash
Cynthia Almeida

Appendix C: Guidelines for submission to Manual Therapy.

Guide for Authors

Submission to this journal proceeds totally online at ⇒http://ees.elsevier.com/math.
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.

Word Count

Manuscripts should not exceed the following word counts
Original articles and review articles 3500 words
Technical and measurement notes 2000 words
Case reports and professional issues 2000 words
Masterclass 3500 words
Letters to the Editors 500 words
These word counts do not include references or figures/tables

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 line numbers to their manuscript in word prior to submission.

Authors are encouraged to submit electronic artwork files. Please refer to ⇒http://www.elsevier.com/authors for guidelines for the preparation of electronic artwork files. To facilitate anonymity, the author's names and any reference to their addresses should only appear on the title page. Please check your typescript carefully before you send it off, both for correct content and typographic errors. It is not possible to change the content of accepted typescripts during production.

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
• 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) wherever 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 letter 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 'he', 'his' etc. where the sex of the person is unknown; say 'the patient' etc. Avoid inelegant alternatives such as 'he/she'. Avoid sexist language.

References
The accuracy of references is the responsibility of the author.

Text: In the text your reference should state the author's surname and the year of publication (Smith 1989).If there are two authors you should give both surnames (Smith & Black 1989). When a source has more than two authors, give the name of the first author followed by 'et al'.

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

Examples:
"...sensitivity and variable specificity (Kerry and Rushton, 2003; Gross et al., 2005; Ritcher and Reinking, 2005)"
"Yaxley and Jull (1991) reported that no significant variation..."

List: References should be arranged first alphabetically and then sorted chronologically if necessary. Each reference to a paper needs to include the author's surname and initials, full title of the paper, full name of the journal, year of publication, volume and issue number and first and last page numbers. 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:
Lee M, Svensson NL. Effects of loading frequency on response of the spine to lumbar postero - anterior forces. Journal of Manipulative and Physiological Therapeutics 1993; 16(7): 439-466

References to a book should be in a slightly different format:
Kendall HO, Kendal FP, Boynton DA. Posture and pain. Baltimore: Williams and Wilkins; 1970. p. 135-8.

Reference to a chapter in an edited book:
Toupet M, Gage P, Heuschen S. Vestibular patients and aging subjects lost use of visual input and expend more energy in static postural control. In: Vellas B, Toupet M, Rubenstein L, et al., editors. Balance and gait disorders in the elderly. Paris: Elsevier; 1988. p. 183-98.

For more than 6 authors, the first three should be listed followed by 'et al.'

Citing and listing of Web references.
As a minimum, the full URL should be given. Any further information, if known (Author names, dates, reference to a source publication, etc.), should also be given. The date on which the website was last accessed should also be included. Web references can be listed separately (e.g., after the reference list) under a different heading if desired, or can be included in the reference list. When citing a Churchill Livingstone journal, the digital object identifier (DOI) may also be included, if noted, from the article's title page. Please note the following example: Joos U, Kleinheinz J 2000 Reconstruction of the severely resorbed (class VI) jaws: routing or exception? Journal of Craniomaxillofacial Surgery 28: 1-4. doi:10.1054/jcms.2000.0102 (last accessed 7 February 2006)

Figures and Illustrations
A detailed guide on electronic artwork is available on our website: http://www.elsevier.com/authors

Tables
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.

Preparation of supplementary data. Elsevier now accepts electronic supplementary material (e-components) to support and enhance your scientific research. Supplementary files offer the Author additional possibilities to publish supporting applications, movies, animation sequences, high-resolution images, background datasets, sound clips and more. Supplementary files supplied will be published online alongside the electronic version of your article in Elsevier Web products, including ScienceDirect: http://www.sciencedirect.com
In order to ensure that your submitted material is directly usable, please ensure that data is provided in one of our recommended file formats. Authors should submit the material in electronic format together with the article and supply a concise and descriptive caption for each file.
For more detailed instructions please visit our artwork instruction pages at http://www.elsevier.com/wps/find/authors.authors/authorartworkinstructions

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 unexpected 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/math

For further details on the Case Report section please contact: Jeffrey D. Boyling, Jeffrey Boyling Associates, Broadway Chambers, Hammersmith Broadway, LONDON, W6 7AF, UK. Tel: +44 (0) 7814 880 370 E-mail: jeffboyling@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/math.
For further details and full instructions for authors for the Masterclass section please contact: Karen Beeton, Department of Physiotherapy, University of Hertfordshire, College Lane, HATFIELD, Herts, AL10 9AB, UK. Tel: +44 (0)1707 284114 Fax: +44 (0)1707 284977 E-mail: k.s.beeton@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.
• The main body 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/math

For further details on the Professional Issue section please contact: Jeffrey D. Boyling, Jeffrey Boyling Associates, Broadway Chambers, Hammersmith Broadway, LONDON, W6 7AF, UK. Tel: +44 (0) 7814 880 370. E-mail: jeffboyling@yahoo.co.uk

Copyright Information
A "Transfer of Copyright" agreement will be sent to authors following acceptance of a paper for publication. A paper is accepted for publication on the understanding that it has not been submitted simultaneously to another journal in the English language. All authors must sign the "Transfer of Copyright" agreement before the article can be published. This transfer agreement enables Elsevier Science Ltd to protect the copyrighted material for the authors, without the author relinquishing his/her proprietary rights. The copyright transfer covers the exclusive rights to reproduce and distribute the article, including reprints, photographic reproductions, microfilm or any other reproductions of a similar nature, and translations. It also includes the right to adapt the article for use in conjunction with computer systems and programs, including reproduction or publication in machine-readable form and incorporation in retrieval systems. Authors are responsible for obtaining from the copyright holder permission to reproduce any material for which copyright already exists.

Funding body agreements and policies
Elsevier has established agreements and developed policies to allow authors whose articles appear in journals published by Elsevier, to comply with potential manuscript archiving requirements as specified as conditions of their grant awards. To learn more about existing agreements and policies please visit http://www.elsevier.com/fundingbodies

Patient Anonymity
Studies on patients or volunteers require ethics committee approval and informed consent which should be documented in your paper. Patients have a right to privacy. Therefore identifying information, including patients? images, names, initials, or hospital numbers, should not be included in videos, recordings, written descriptions, photographs, and pedigrees unless the information is essential for scientific purposes and you have obtained written informed consent for publication in print and electronic form from the patient (or parent, guardian

or next of kin where applicable). If such consent is made subject to any conditions, Elsevier must be made aware of all such conditions. Written consents must be provided to Elsevier on request. Even where consent has been given, identifying details should be omitted if they are not essential. If identifying characteristics are altered to protect anonymity, such as in genetic pedigrees, authors should provide assurance that alterations do not distort scientific meaning and editors should so note. If such consent has not been obtained, personal details of patients included in any part of the paper and in any supplementary materials (including all illustrations and videos) must be removed before submission

English Language Service
Please write your text in good English. Authors who require information about language editing and copyediting services pre- and post-submission please visit http://www.elsevier.com/languagepolishing or our customer support site at http://epsupport.elsevier.com for more information. Please note Elsevier neither endorses nor takes responsibility for any products, goods or services offered by outside vendors through our services or in any advertising. For more information please refer to our Terms & Conditions: http://www.elsevier.com/termsandconditions

Permissions Information
Written permission to produce borrowed materials (quotations in excess of 100 words, illustrations and tables) must be obtained from the original copyright holders and the author(s), and submitted with the manuscript. Borrowed materials should be acknowledged in the captions as follows: 'Reproduced by kind permission of (publishers) from (reference)'.

Page Proofs
When your manuscript is received by the Publisher it is considered to be in its final form. Proofs are not to be regarded as "drafts".
One set of page proofs in PDF format will be sent by e-mail to the corresponding Author, to be checked for typesetting/editing. No changes in, or additions to, the accepted (and subsequently edited) manuscript will be allowed at this stage. Proofreading is solely your responsibility.
A form with queries from the copyeditor may accompany your proofs. Please answer all queries and make any corrections or additions required. The Publisher reserves the right to proceed with publication if corrections are not communicated Return corrections within 48 hours of receipt of the proofs. Should there be no corrections, please confirm this.
Elsevier will do everything possible to get your article corrected and published as quickly and accurately as possible. In order to do this we need your help. When you receive the (PDF) proof of your article for correction, it is important to ensure that all of your corrections are sent back to us in one communication. Subsequent corrections will not be possible, so please ensure your first sending is complete. Note that this does not mean you have any less time to make your corrections, just that only one set of corrections will be accepted.

Author Enquiries
For enquiries relating to the submission of articles (including electronic submission where available) please visit http://www.elsevier.com/authors There is also the facility to track accepted articles and set up e-mail alerts to inform you of when an article's status has changed, as well as detailed artwork guidelines, copyright information, frequently asked questions and more at: http://authors.elsevier.com/TrackPaper.html. Contact details for questions arising after acceptance of an article, especially those relating to proofs, are provided when an article is accepted for publication.

Changes to authorship
This policy concerns the addition, deletion, or rearrangement of author names in the authorship of accepted manuscripts:

Before the accepted manuscript is published in an online issue: Requests to add or remove an author, or to rearrange the author names, must be sent to the Journal Manager from the corresponding author of the accepted manuscript and must include: (a) the reason the name should be added or removed, or the author names rearranged and (b) written confirmation (e-mail, fax, letter) from all authors that they agree with the addition, removal or rearrangement. In the case of addition or removal of authors, this includes confirmation from the author being added or removed. Requests that are not sent by the corresponding author will be forwarded by the Journal Manager to the corresponding author, who must follow the procedure as described above. Note that: (1) Journal Managers will inform the Journal Editors of any such requests and (2) publication of the accepted manuscript in an online issue is suspended until authorship has been agreed.

After the accepted manuscript is published in an online issue: Any requests to add, delete, or rearrange author names in an article published in an online issue will follow the same policies as noted above and result in a corrigendum.

Checklist
Before submitting your paper, please check that:
• All files are uploaded.
• The reference list is complete and in correct style.
• Written permission from original publishers and authors to reproduce any borrowed material has been obtained

http://www.elsevier.com/wps/find/journaldescription.cws_home/623058/authorinstructions