Hip joint rotation range of movement: Improvement through stretching and an investigation of inter-tester reliability and agreement of the evaluative measurement method

Alan Chamberlain MA, PgDPE, Grad Dip Phys, RGN

This thesis is submitted for the degree of Master of Philosophy in Physiotherapy

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Declaration

This thesis has not been submitted in support of an application for another degree at this or any other university. It is the result of my own work and includes nothing that is the outcome of work done in collaboration except where specifically indicated. Many of the ideas in this thesis were the product of discussion with my supervisors.

Alan Chamberlain MA, PgDPE, Grad Dip Phys, RGN

Lancaster University, UK

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Alan Chamberlain MA, PgDPE, Grad Dip Phys, RGN

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Abstract

Full hip joint rotation is necessary for joint health and restriction is associated with pathology. Joint soft-tissue stretching is advocated, but there is no evidence to support this for improving hip joint rotation. Rotation measurement is fundamental to examination, diagnosis, determining severity and progression of disorders, evaluating intervention and rehabilitation decision-making.

The first study was a retrospective case series analysis with the primary purpose of investigating the effects of stretching on hip joint rotation. From a five-year period, thirty-two patients were identified where a stretch protocol was prescribed to improve rotation. Mean baseline medial rotation of affected joints was 26.38°±5.59° (*n*=26 hip joints) and lateral rotation was 37.18°±9.37° (*n*=43 hip joints). From baseline, there was a significant statistical (*p*<.001) mean 10.08°±4.63° increase of medial and 14.37°±6.00° lateral rotation after three-months of stretching with a large effect size (≥3.1) found.

The second study primary purpose was to examine inter-tester reliability and agreement of active hip joint rotation measurement in a prone position using a standard and new measurement method, the latter of which was used to measure rotation in the first study. Thirty-four participants (male, *n*=18; female *n*=18; age range 18-59 years) were recruited. Relative reliability for the measurement of hip joint rotation using the standard measurement method was excellent ($ICC_{2,1}$ range .93-.94) and good-excellent ($ICC_{2,1}$ range .89-.98) using the new measurement method. Absolute reliability (SE of Measurement) range was 3.0°-4.2° for the standard and 2.2°-3.9° for the new measurement method. Inter-tester MDC_{90} ranged from 7.0° to 9.7° for the standard and 5.2° to 9.0° for the new measurement method. Bland-Altman graphs indicated acceptable agreement for both measurement methods.

Results from the two studies suggest stretching may improve hip joint rotation and improvement would have been detected beyond measurement error had two testers conducted measurement.

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Contents

1. List of Tables

2. List of Figures

3. List of Abbreviations and Acronyms

AAOS	American Association of Orthopaedic Surgeons
ACSM	American College of Sports Medicine
AMA	American Medical Association
ANOVA	Analysis of Variance
AROM	Active Range of Movement
CI	Confidence Interval
DRIFT	Duration, Repetitions, Intensity, Frequency and Technique
DRIFTS	Duration, Repetitions, Intensity, Frequency, Technique and Sets
FAI	Femoro-acetabular Impingement
FITT	Frequency, Intensity, Time and Type
FITT-VP	Frequency, Intensity, Time, Type, Volume and Pattern
FITT-VPP	Frequency, Intensity, Time, Type, Volume, Pattern and Progression
ICC	Intraclass correlation coefficient
LLR	Left Lateral Rotation
LMR	Left Medial Rotation
LoA	Limits of Agreement
LR	Lateral Rotation
MCID	Minimal Clinically Important Difference
MDC	Minimal Detectable Change
MR	Medial Rotation
OA	Osteoarthritis
PROM	Passive Range of Movement
RCT	Randomised Control Trial
RLR	Right Lateral Rotation
RMR	Right Medial Rotation

ROM	Range of Movement
SAID	Specific Adaptation to Imposed Demand
SD	Standard Deviation
SE of M	Standard Error of Measurement
SP	Stretch Protocol
SPSS	Statistical Package for Social Sciences
UG	Universal Goniometer
UK	United Kingdom

4. List of Appendices

1. Introduction

Full hip joint rotation range of movement (ROM) is necessary to maintain joint health (Curwin, 2011; Reese and Bandy, 2010). A reduced joint ROM is considered to be hypomobile and pathological if it fails to reach normal anatomic limits of motion through capsular and ligamentous structures being unable to sufficiently elongate and can have undesirable effects on the affected joint and adjacent structures (Curwin, 2011). Indeed, Curwin (2011) further stresses that cartilage and bone nutrition and growth, depends on joint movement with articular cartilage specifically requiring a full ROM, in order to ensure the entirety of the structure receives the nutrients required for survival.

The notion of osteoarthritis (OA) being a disease of mechanical stress is asserted in the literature (Felson, 2013; Griffin and Guilak, 2005; Sims, 1999; Bland, 1993), with the concept of a reduced hip joint ROM (Lloyd-Roberts, 1953) and resultant migration of the femoral head as being associated with such pathology (Cameron and MacNab, 1975) being long-held. Evidence supports this view (Holla, Steultjens and van der Leeden *et al*., 2011; Dvořrák, Dvořrák, and Gilliar *et al*., 2008) and continues to be supported within the literature (Vogelgesang, 2015). The patterns of femoral head migration that have been proposed to be related to capsular restrictions in hip joint OA are those of central and medial with a proximal migration direction (Sims, 1999; Cameron and MacNab, 1975), but the chronology of events has not been established producing a causal link assumption. There is also recent systematic review evidence of superior and supero-lateral migration of the femoral head being a predictor of radiological progression of OA and an indication for total hip replacement (Teirlinck, Dorleijn and Bos *et al*., 2019).

Evidence suggests a correlation between reduced hip joint rotation and femoroacetabular impingement (Kapron, Anderson and Peters *et al*., 2012) and further research to determine how a reduced rotation ROM relates to the presence of femoroacetabular impingement has been recommended (Deneweth, Pomeroy, and Russell *et al*., 2014). A reduced hip joint rotation has also been suggested to be associated with other conditions such as low back pain (Ellison, Rose and Sahrmann, 1990).

From the above, hip joint ROM is required for joint health and loss of hip joint rotation appears to be associated with pathologies of the hip joint. In addition, Pisters, Veenhof and van Dijk *et al*. (2012) identified a reduced hip joint ROM as being a predictive factor in the development of further limitations and future decline in functional activities of those with hip joint OA. Pisters *et al*. therefore recommend to not only target the reduced ROM in treatment programmes to prevent the further functional decline and associated negative consequences such as co-morbidity development, but to investigate if this is so. Understanding of capsular and ligamentous anatomical contribution to this and function is important in developing accurate assessment and treatment strategies with more favourable outcomes (Martin, Savage and Braly *et al*., 2008).

There is no evidence of the restoration of hip joint ROM having any effect on the pathology or preventing further limitations and decline in functional activity that ROM loss is associated with, but there is a clear necessity to maintain hip ROM for joint health, which may help reduce the risk of mechanically induced pathological changes and the decline in functional activity that a loss of ROM is associated with. To increase hip joint ROM it would require soft-tissue adaptive lengthening of those that are shortened and this thesis will consider tissue adaptation theory that underpins techniques such as stretching that are designed to induce such effects.

Adaptive soft-tissue stretching is recommended to increase soft-tissue length and ROM by inducing a mechanical response of viscous deformation when taken to the limit of their available length (Glynn and Fidler, 2009), but using the Oxford Centre for Evidence-based Medicine classification of level 1 evidence (Portney, 2020), it has been concluded to only represent an immediate effect that is not sustained (Katalinic, Harvey and Herbert *et al*., 2010). Stretching remains recommended in national guidelines as an adjunct to core treatment despite having "…less well-proven efficacy…" (NCGC, 2014; NICE, 2008) and from systematic reviews (Harvey, Katalinic and Herbert *et al*., 2017; Katalinic *et al*., 2010), there is a dearth of evidence to support stretching as a technique to improve hip joint ROM. Stretching of hip joint soft-tissue structures to improve ROM is therefore restricted to a theoretical notion. The paucity of evidence supporting the stretching of soft-tissues and need for research in the field will be discussed in the literature review, together with relatively recent respective guidance on stretching prescription and the targeting of soft-tissues of the hip joint.

Diagnostic and intervention decisions frequently require reference to theory in the absence of evidence (Portney, 2020). A physiotherapist may see a series of cases with similar problems and outcomes and on finding something of interest, write it up as a case series study, which may not arise as a specific research question, but may suggest one (Bowers, 2020). A case series involves observations of several similar cases and as more are reported, a form of "…case law…" gradually develops where empirical findings are considered to be reasonably within the realm of accepted knowledge and professional experience and can focus on innovative approaches to treatment (Portney, 2020). Such studies highlight issues that require further enquiry and provide a rich source for generating research questions (Portney, 2020).

A series of cases that were prescribed a stretch technique, were observed to improve on their restricted hip joint rotation ROM, which is in need of further exploration. The first study in this thesis is therefore, a retrospective, descriptive case series (Portney, 2020) designed to investigate whether there is any evidence of a stretching technique improving medial and lateral rotation of the hip joint from physiotherapy clinical records. Much of clinical practice is quasi-experimental in nature where it is attempted to draw a causal link between interventions and outcomes and not due to extraneous variables (Carter and Lubinsky, 2016). Historical data access and analysis is recognised as a research method and as with all research, the data must be evaluated for authenticity as an accurate primary source record, extracted, synthesised and analysed within an objective frame of reference with a view to anticipate future events (Portney, 2020).

From the above, it can clearly be seen that accurate ROM measurement would be required to detect a change in hip joint rotation ROM. Hip joint rotation measurement is fundamental in physiotherapy to determine if there is a restriction, playing an important part of examining joints and surrounding soft-tissues (White and Norkin, 2016) and contributing to diagnoses (White and Norkin, 2016; Greene and Heckman, 1994) such as OA of the hip joint (Cibulka, Bloom and Enseki, *et al*., 2017; Clarkson, 2013; Poulsen, Christensen and Penny *et al*., 2012) or other injury (Ellenbecker, Ellenbecker and Roetert *et al*., 2007). ROM can indicate the severity and progression of such disorders and is a means of evaluating the results of treatment (White and Norkin, 2016; Prentice, 2011; Domb, Brooks and Byrd, 2009; Greene and Heckman, 1994); which is clearly very important (Bierma-Zeinstra, Bonen and Ramial *et al*., 1998). Joint ROM measurement is needed for decision-making in modifying rehabilitation (White and Norkin, 2016; Prentice, 2011) and it is also a parameter for determining a return to functional activity (Greene and Heckman, 1994). In sport, ROM deficiency identification and correction is argued to help in injury prevention and performance enhancement (Ellenbecker *et al*., 2007).

It is recommended that hip joint ROM measurement is standardised (Poulsen *et al*., 2012) and examples of this can be found in the literature (Hartigan and White, 2016; Clarkson, 2013; Reese and Bandy 2010; Green and Heckman, 1994), but there is currently no standard method for measuring hip joint rotation ROM (Gradoz, Bauer and Grindstaff *et al*. 2018; Cheatham, Hanney and Kolber, 2017) in research. The measurement technique used to evaluate the effect on rotation ROM of the hip joint was a new adaptation of a standard method and although it was developed to be more efficient, retain and improve measurement reliability, there is no evidence of reliability for the measurement method used. There is a need to investigate the reliability of the new measurement method with a view to not only determining whether the data from the first study is reliable, but also to consider whether the method could be used in future research. Concerns have been expressed of a need to potentially require more than one tester in research involving for example, a longitudinal or multi-centre study (Shultz, Nguyen and Windley *et al*., 2006). Establishing the inter-tester reliability of a measurement method would increase generalisability and it can be assumed that other examiners would obtain similar results (Portney, 2020), should one or more testers be called upon for hip joint rotation ROM measurement. The new measurement technique has never been investigated for inter-tester reliability and agreement and it is important to determine whether it can be demonstrated in comparison to the standard technique it was adapted from. It is also necessary to determine what change in hip joint rotation ROM would be required for two testers to detect beyond measurement error for both measurement techniques.

The aim of this thesis is therefore to explore the effect of a stretching prescription on hip joint rotation ROM and to investigate the reliability of the new measurement method used to obtain hip joint rotation ROM values compared to a standard method. The thesis will inform future research that will be designed and planned to further investigate not only methods for improving and evaluating hip joint rotation ROM, but also that of other joints and body segments of the musculoskeletal system.

2. Literature review

2.1. Introduction

The literature review is organised to contextualise and then justify the research interests of this thesis. In contextualising the research and reviewing the literature, the reader will understand the need to investigate improvement of hip joint rotation through the application of a stretch technique and evaluation through accurate measurement of range of movement.

2.2. Hip joint range of movement: A necessity for joint health

Full joint ROM is considered to be a fundamental requirement for efficient human movement and allows the joints to adapt to imposed stresses and reduce injurious risk (Reese and Bandy, 2010). Curwin (2011) summarises how normal joint ROM is required for joint health and function, highlighting how ROM of a joint is considered to be pathological if it fails to reach the normal anatomic limits of motion permitted by capsular and ligamentous structures, which can have undesirable effects on the affected joint and adjacent structures. Indeed, Curwin further stresses that cartilage and bone nutrition and growth, depends on joint movement with articular cartilage specifically requiring a full ROM, in order to ensure the entirety of the structure receives the nutrients required for survival. It is clearly necessary to not only maintain hip ROM for joint health, but to also reduce the risk of pathological changes that may be mechanically induced.

Mechanically, Lunn, Lamropoulos and Stewart (2016) explain how body weight in standing is shared between both hip joints, but stress how joint reaction forces can change from half in standing on both hips to three times body weight on a single leg stance. Lunn *et al*. therefore assert how knowledge and understanding of anatomy and mechanics is important for those disciplines involved in the diagnosis and treatment of the hip joint and as it is governed by mechanics like any other structure, they conclude that it is important to restore the hip joint to its normal state of ROM to prevent potential symptomatic changes in function. The effect of a reduced ROM in joint reaction forces is unknown, but it is a reasonable argument that a reduced ROM may generate increased mechanical forces sufficient to place the hip joint at a greater risk of pathology.

One such pathology to consider is osteoarthritis (OA), which can be developmental in nature and where it is argued that mechanical factors have a central role (Shipley, Rahman and O'Gradaigh *et al*., 2012). The association with altered and abnormal biomechanics is being increasingly implicated (Atkins, Kerr and Goodlad, 2016; NCGC, 2014; Robson and Syndercombe-Court, 2014; Ferguson, Bryant and Ganz *et al*., 2003). Joint overload is considered to be contributory in the development of OA (Felson, 2004; Bland, 1993) with excessive focal loading particularly driving OA processes (Felson and Hodgson, 2014). It is therefore argued that direct and indirect joint overload could result from increased mechanical stresses produced by shortening of the joint capsule and ligaments and reduced ROM.

An *in-vitro* study using cadavers suggests that anatomical centre displacement of the femoral head within the acetabulum occurs and increases with increasing removal of peri-articular structures; and ROM also increases in a lateral, posterior and distal direction on dissection and reduction of periarticular soft-tissues of the hip joint (Safran, Lopomo and Zaffagnini *et al*., 2013), resulting in an increased ROM (Safran *et al*., 2013; Martin *et al*., 2008). The converse can therefore be logically argued that if the same structures were to shorten and tighten, it could cause a migratory displacement in the opposing medial, anterior and superior direction and a loss of ROM. This could lead to overloading on some parts and insufficient loading in other parts of the articular cartilage, placing it at risk of pathological changes.

Features of early hip joint OA have been found to be associated with lower ROM (Holla *et al*., 2011) with medial rotation (MR) being considered to represent an early sign (Dvořrák *et al*., 2008) and lateral rotation (LR) is also noted to be restricted in some patients with hip joint OA (Holla *et al*., 2011). Loss of hip joint rotation is associated with many pathologies of the hip joint and understanding of ligamentous anatomical contribution to this and function as indicated above, is important in developing accurate assessment and treatment strategies with more favourable outcomes (Martin *et al*., 2008).

The association of a loss of ROM, biomechanical stress and pathology development is not new. Lloyd-Roberts (1953) described from cadaveric studies and observations in surgical practice almost seventy years ago, how the hip joint capsule shortens and becomes prematurely tense causing a progressive loss of ROM. Lloyd-Roberts goes on to suggest how this loss of ROM may have an important influence upon the progression of OA with resultant forces being increased and generated through a smaller surface area of the articular hyaline cartilage, which accelerates degenerative changes. Cameron and MacNab (1975) make similar observations and suggestions from a radiological and cadaveric correlation study, where they assert that articular cartilage degeneration and joint space narrowing is not random, varying in the hip joint between either, supero-lateral, superior, medial or in some cases, concentric cartilage degeneration with the majority resulting from a migratory pattern of the femoral head. This assertion of degenerative changes occurring in areas of maximal stress in weight-bearing joints where degenerative changes and joint space narrowing is non-uniform remains supported in the literature (Vogelgesang, 2015). The notion of OA being a disease of mechanical stress is supported by others in the literature (Felson, 2013; Griffin and Guilak, 2005; Sims, 1999; Bland, 1993).

Pisters *et al*. (2012) identified reduced hip joint ROM as a predictive factor in the development of further limitations and future decline in functional activities beyond that found at baseline over a five-year period in those with hip joint OA. Although the mechanism for this remains unclear and is subject to speculation at this time, Pisters *et al*. recommend to not only target this in treatment programmes to prevent the further functional decline and the associated negative consequences such as comorbidity development, but to investigate if this is so. Others make similar recommendations, which will be returned to shortly.

Contrary to the above regarding the association of ROM loss and OA, a systematic review found that limited MR and LR was not a predicting factor in the clinical progression of OA and that there was conflicting evidence of an association of the same restriction of ROM being a predictor of an indication for a total hip replacement in late stage OA (Teirlinck *et al*., 2019). However, this does not mean that rotation ROM loss does not contribute to the initiation of the development of OA as the structures that restrict this ROM may be the mechanical factors that produce the joint overload discussed by others. As indicated above, the theoretical causal link to the development of OA further justifies targeting the structures contributing to the loss and restoration of ROM. Furthermore, there is evidence that superior and supero-lateral migration of the femoral head being a predictor of radiological progression of OA and an indication for total hip replacement (Teirlinck *et al*., 2019). Such femoral head migration could be due to peri-articular soft-tissue shortening, which serves at this stage, to support the need to investigate rather than dismissing the targeting of structures producing any loss of MR and LR ROM. These patterns of femoral head migration have previously been proposed to be related to capsular restrictions and hip joint OA, together with those of central and medial with proximal migration (Sims, 1999; Cameron and MacNab, 1975), but the chronology of events has not been established producing a causal link assumption.

From the literature, it is accepted that the excessive or insufficient loading of joints or movement, could lead to articular cartilage degeneration. However, OA can also develop with normal loads if supporting capsules, ligaments and muscles are abnormal (Vogelgesang, 2015) and as it is recognised within the literature that joint capsules, ligaments and muscles that are too short are abnormal, it further supports the need to target such soft-tissues for intervention purposes.

Shortened musculo-tendonal units that can produce increased mechanical stress are the short hip joint rotators (Lloyd-Roberts, 1953) and hip abductors (Sims, 1999) in addition to that of joint capsule and ligaments. Consideration will be given to musculo-tendonal lengthening later, but in the meantime, Sims (1999) recommends the identification of all factors that create abnormal conditions, which implicitly includes a shortened joint capsule and ligaments that may assist in the development of OA for the purpose of improving the effectiveness of conservative management strategies for hip joint conditions. Griffin and Guilak (2005) also support the suggestion of targeting local and systemic biomechanical factors as a common modality for treating hip joint conditions such as OA and the hip joint capsule and ligaments are local factors.

Capsular and ligamentous shortening and femoral head migration may not be the only mechanism that could increase direct loading forces on the articular cartilage. The migrating femoral head could place the acetabular labrum at risk of impingement from the approximating femur, which is another pathological risk factor to consider that could indirectly cause further mechanical stresses on the articular cartilage. Migration of the femoral head is considered to be a predicting factor not only for OA, but also femoro-acetabular impingement (Teirlinck *et al*., 2019) and as argued earlier, if periarticular soft-tissue structures shorten, producing femoral head migration and subsequent impingement, it could place the acetabular labrum at risk of injury and failure. The acetabular labrum deepens the acetabulum and acts as a seal giving stability to the hip joint (Takechi, Nagashima and Ito, 1982) partly through a vacuum effect (Standring, 2005). Modelling (Ferguson, Bryant and Ganz *et al*., 2000) and *in-vitro* studies (Ferguson *et al*., 2003) support the suggestion of the acetabular labrum forming a seal contributing to increasing hip joint stability, maintenance of hyaline cartilage health and overall joint function and is therefore in integral need of protection to help prevent joint degeneration. In other words, if the acetabular labrum is compromised, reducing the joint seal with a loss of the negative pressure, it then produces a structural instability that increases translation forces of the femoral head (Martin *et al*., 2008) and it is argued that this may lead to early degenerative changes such as OA (Hudgins and Alleva, 2012). Conservative care asserted to avoid this includes recovering joint flexibility to address these biomechanical imbalances (Hudgins and Alleva, 2012). Although Hudgins and Alleva (2012) advocate the targeting of muscles to improve joint flexibility, they fail to acknowledge the need to address the passive non-contractile contributors to joint flexibility of the joint capsule and supporting ligaments.

Experimental studies have provided evidence of how sub-atmospheric pressure is a contributory component to hip joint stability (Prietzel, Hammer and Schleifenbaum *et al*., 2014) and animal studies infer that peri-articular soft-tissues such as joint capsules and ligaments contribute to alterations in intra-articular pressures, with increases in the latter as the former tighten during movement (Nade and Newbold, 1983). Nade and Newbold (1983) argue that consequences to adverse changes in intra-articular pressures include compromising of joint physiology and maintenance of joint tissues such as articular cartilage. Rutherford (2014) argues that interest in intra-articular joint pressures have been left aside in contemporary frameworks of joint function and is an important component to consider when attempting to understand it. Rutherford also observes how the passive structures of joint capsule and ligaments and corresponding intra-articular pressures have received little attention in the discussion of pathomechanics of other joints such as the knee joint. From the above, it is evident that the effects of intra-articular pressures have been considered in part within the literature when considering hip joint function, but Rutherford’s observations regarding the intra-articular pressures of the knee joint and the respective effects of the capsule and ligaments can equally apply to the hip joint. Whilst it is beyond the scope of the work within this thesis to measure intra-articular pressures relative to movement and peri-articular soft-tissue structure length, it can be theoretically argued from what is known within the literature, that if soft-tissue length were to be adversely affected, becoming too short and restricting ROM, the indirect effect that Nade and Newbold (1983) infer with a subsequent increase intra-articular pressure threatening the health of other joint tissue such as articular cartilage in the knee joints of dogs, could equally apply in the hip joints of humans. This further underpins justification for determining the most effective method of recovering ligamentous and capsular length and joint ROM restoration.

It is well documented within the literature how the joint capsule, ligaments and synovial membrane are innervated with mechanical nociceptors (Standring, 2005) and increased mechanical tension can occur due to ligamentous and capsular contracture or shortening, which would also cause mechanical pain earlier or prematurely in the range than what would be expected at the normal end of range of movement. This could affect functional ability and although evidence for physical function limitation and pain predicting an indication for late stage OA total hip replacement is conflicting, there is evidence both are predictors for radiological progression of OA (Teirlinck *et al*., 2019). If pain and function can be improved by recovering hip joint ROM, the radiological progression of OA may be prevented, which also theoretically supports targeting of structures contributing to the loss of ROM, but this is speculative at this time.

Irrespective of the above discussion regarding pain and function, pain is not present in many hip joints, including those with confirmed radiographic OA and even when hip joint pain is present, many do not show evidence of OA (Kim, Nevitt and Niu *et al*., 2015). The decision to address a restriction of ROM of hip joints may therefore need to be based purely on whether there is any restriction compared to normative values or the opposite hip joint, regardless of whether pain is being experienced or not. Although many with hip joint pain do not have evidence of radiographic OA, Kim *et al*. (2015) nevertheless recommend the pursuit of treatment and evaluation of the condition on the basis that it could suggest early OA and early intervention could reduce comorbidity, mortality and major public health care costs, which supports Pisters *et al*. (2012) who as indicated earlier, specify focusing on the predictive factor of a loss of hip joint ROM.

Proving causation is difficult for complex non-infectious human disease, particularly conditions such as OA, as it is ethically impossible to test causal agents (Felson, 2013), but identifying those at risk of the condition may offer the better opportunity to successfully intervene to lessen the burden on both patients and society (Felson and Hodgson, 2014). A reduced hip joint rotation is not only associated with hip joint pathology and functional decline, as it has also been suggested to be associated with other conditions such as low back pain (Ellison *et al*., 1990), which suggests an even greater need to improve it where present and evaluate the effects on lumbar spine related symptoms.

The case for targeting the hip joint capsule and ligaments and the maintenance or restoration of ROM where it is limited has therefore been made, not only in order to maintain joint health, but to also try and prevent hip joint pathology such as femoro-acetabular impingement (FAI) and OA. With OA, the ultimate goal may be to prevent or delay the development of the disease (Reginster and Cooper, 2016) and support for the notion of hip joint OA remaining stable or improving in some individuals is increasing (Vogelgesang, 2015; NCGC, 2014; Bland 1993; Perry, Smith and Whiteside, 1972). However, the evidence for the latter is limited to small-scale case studies (Bland 1993; Perry, *et al*., 1972) and the causal link for pathological improvement remains unknown. Irrespective, if targeting abnormal mechanics can alleviate OA related problems for many years (Felson, 2013) and if joint ROM improvement can reduce abnormal mechanical overload, adaptive lengthening of shortened capsular and ligamentous tissue may represent one of the most influential factors. What is known is that abnormal loading on normal cartilage is a risk factor to the development of pathological processes of joints (Surya, Srinivasan and Menon, 2018; Goldring and Goldring, 2010) and improving joint ROM may reduce abnormal loading. Unfortunately, whilst there is no evidence for the effects of improving ROM, there is no evidence on how to achieve it either.

In summary, a full hip joint ROM is necessary to maintain the health of the joint and related structures and as a reduced hip joint rotation ROM may be a possible predisposing factor, if the respective loss of ROM is improved, it could potentially reduce the risk of pathological changes. The importance of being able to restore ROM when reduced is therefore unequivocal.

Teirlinck *et al*. (2019) consider that targeting predictive factors that are potentially modifiable would be of special interest and recommend high-quality research to be conducted that focuses on these. Physiotherapists are best placed for identification and restoration of any loss of ROM that could maintain the desired joint health and reduce pathological risks through primarily targeting capsular and ligamentous structures and any other structures for lengthening that limit and allow hip joint rotation ROM.

Techniques to improve the loss of hip joint rotation will be considered later, which will be justified not only because of being the main movement loss, but also by considering normal movement limiting soft-tissue structure anatomy and related function. In other words, determine the most effective targeted tissue techniques that the literature recommends is needed to increase ROM.

2.3. Hip joint range of movement: Improvement and underpinning tissue-adaptation theory

A physical stress theory is presented describing the general principles of tissue adaptation from the literature, but these notions are not new (Mueller and Maluf, 2002). One theory from the literature is one of a '…General-Adaptation-Syndrome…' (Selye, 1950), later renamed by Selye as '…stress syndrome…' (Selye, 1978) or '…stress response…' where Selye describes how physical, chemical, biological and psychological stressors act on body systems producing adaptive effects (Szabo, Tache and Somogyi, 2012). However, Selye (1950) mainly discusses systemic stress such as hormonal, dietary and disease effects on body systems with little more than the effects of physical stress on muscle and a short acknowledgement that exercise will influence the development of bone, with no reference to physical stress on non-contractile tissues such as joint capsule and ligaments.

The SAID Principle, an acronym for specific adaptation to imposed demand was coined by Wallis and Logan (1964). According to Kegerreis (1983), the SAID Principle is where tissues have a capacity to adapt in response to load alterations and is adopted by many (Siff, 2005) in theoretical literature (Swain, 2014; Chamberlain, Munro and Rickard, 2013; Kisner and Colby, 2012; Curwin, 2011; Ellenbecker, De Carlo and DeRosa, 2009; Kegerreis, 1983). The SAID Principle is said to have been derived from the stress theory of Hans Selye (Chamberlain *et al*., 2013), or to be an extension of Wolff's Law (Bhave, Sodhi and Anis *et al*., 2019; Kisner and Colby, 2012), but both of these views are assumptions. Wolff's Law actually pertains to bone tissue alone (Curwin, 2011; Ellenbecker *et al*., 2009; Barker, 2005; Tippett and Voight, 1995; Frost, 1994; Riegger, 1985), which governs the remodelling of bone in response to physical stress (Ellenbecker *et al*., 2009; Turner, 1998) and not all body systems as asserted.

A true scientific law can predict reactions to given stimuli and mathematics can express it, with observation and experimentation testing it (Frost, 1994), but it may take some time before a tissue-specific theoretical law becomes scientifically proven. For example, Wolff's work was first published in the 1870s (Zippel, 1993), but it was over a century later that Turner (1998) converted theoretical rules derived from Wolff's law, into mathematical formulas and demonstrated utilisation of these with the most convincing evidence in support of Wolff's law for a large weight-bearing joint having arisen even later from animal studies (Teichtahl, Wluka and Wijethilake *et al*., 2015), such as bone adaptation in large mammals like sheep (Barak, Lieberman and Hublin, 2011). Prior to Wolff's work, Davis (1867) developed a theoretical law, which applies to soft-tissues responding to applied stresses (Ellenbecker *et al*., 2009; Tippet and Voight, 1995; Gould and Davies, 1985; Davis 1867). Davis (1867) discusses and provides observed examples of how soft-tissues such as joint capsules and ligaments can adaptively and gradually shorten and lengthen depending on the demand imposed according to a stated physical law he identifies. Unfortunately, the theoretical law of Davis, the apparent originator of soft-tissue adaptation theory, does not share the level of scientific development as that of Wolff's law. Indeed and despite Davis' observations, joint capsule and ligamentous structures were still considered to be biologically complex and were only just beginning to be understood during the turn of this last century according to Frank (1996), who asserted that a great deal of clinical work and experimental work remained to be undertaken before a scientific approach can be applied in physiotherapy. Underpinning theories continue to be developed that implicitly support Davis' law. For example, there is the stress-strain, load and plastic deformation theory, which is well documented within the literature (Özkaya, Leger and Goldsheyder, *et al*., 2018; Nordin and Frankel, 2012; Curwin, 2011; Frank, 1999; Özkaya and Nordin, 1999; and Butler, Grood and Noyes *et al*., 1978) where a tensile load will produce stress on soft connective tissue such as joint capsule and ligaments and produces a percentage change in the length, which is defined as strain where plastic deformation of tissues occur when loaded beyond their elastic or yield limits. Although strain cannot be measured directly, it can be mathematically expressed in percentage terms (Curwin, 2011; Grood and Noyes *et al*., 1978) with the following equation, where L2 equals the final length of a tissue in response to strain and L1 equals the original length.

$$\text{Strain} = \frac{L2-L1}{L1}$$

The stress-strain theoretical discussions do not appear to be directly related to Davis' law within the literature, which is in need of addressing. Irrespective, until the mathematical expression can be tested and responses predicted as asserted by Frost above, Davis' Law will remain theoretical.

It is Frost (2003) who analogously argues that studies of structure and function and respective responses at a micro-level can help explain those at a macro-level, but sometimes those at micro-level need to be conducted after those at a macro-level. Most of what was known up to the end of the last century about intervention on ligamentous structures was derived from *in-vitro* animal, human cadaver specimen and other non-human models (Frank, 1996; Butler *et al*., 1978). As human joint capsule and ligament structures are very complex in composition and biomechanical behaviour and as they never act in isolation, research in the field has been difficult and compounded further through a lack of quantitative evaluation tools (Frank, 1996). There is a paucity of information and research on *in-vivo* mechanical responses and behaviour of capsular and ligamentous tissue (Butler *et al*., 1978) and hence the ongoing call for *in-vivo* research in the field (Frank, 1996) including the effects of stretching to be evaluated (Harvey *et al*., 2017; Katalinic *et al*., 2010). The fibres of ligaments are not just parallel, as they are also oblique or spiral in nature (Siff, 2005; Butler *et al*., 1978) and so if they are non-linear and inconvenient to access anatomically, measuring adaptive changes in length is problematic. This perhaps along with the lack of research, best explains why Davis' law has still not yet been developed further. It is hoped that new emerging technology will be developed and become available to allow collagenous soft-tissues to be studied *in-vivo* at micro-level in the near future (Silver and Shah, 2017), but for the time-being and ahead of this, it is necessary to consider research on a tissue-structure macro-level, as Frost asserted above.

From the above, it is accepted that the passive structures of joint capsule and ligaments are difficult to quantitatively measure when and how they function (Lunn *et al*., 2016). However, it is possible to measure ROM of joints that joint capsules and ligaments structurally and functionally allow, but limit. Gajdosik and Bohannon (1987) assert that measuring ROM measures just that and not the length of specific structures. However, if a joint ROM is increased over time on account of intervention, it should be possible to conclude that structures that limit the ROM have adaptively changed their length and even if specified structures do not act in isolation, they are at least contributory.

In summary, adaptive soft-tissue theory and supporting law has existed for over one and half centuries, but Davis' law remains theoretical and has yet to be scientifically demonstrated for adaptive lengthening of hip joint capsular and ligamentous structures. It has been necessary to consider and make reference to soft-tissue adaptation theory, as intervention decisions frequently require reference to such theory in the absence of evidence (Portney, 2020).

2.4. Hip joint range of movement: Improvement through soft-tissue stretching

The importance of full hip joint ROM and the underpinning theory supporting adaptive lengthening of hip joint capsular and ligamentous structures has been discussed. If from physical examination the hip joint ROM is restricted due to these soft-tissue structures, it would be pertinent to consider a stretching technique for improving it.

There is a dearth of evidence supporting the stretching of capsular and ligamentous structures and there has been limited guidance on stretching prescription until more recently in the physiotherapy literature. What is theoretically known about capsular and ligamentous soft-tissue adaptation responses to stretching will be discussed ahead of stretching prescription before considering evidence for each component part of stretching prescription such as the duration and frequency.

2.4.1. Hip joint range of movement: Improvement through stretching - Capsule and ligament adaptation responses

Stretching is maintained to increase soft-tissue extensibility and ROM where there is shortening, through the mechanical response of viscous deformation when taken to the limit of their available length (Glynn and Fidler, 2009), but this has been concluded to only represent an immediate effect that is not sustained (Katalinic *et al*., 2010). However, it is theoretically argued that if the mechanical loading of ligaments and capsules at cellular level is carefully studied, understood and applied, it is possible to deform these structures plastically (Siff, 2005) and will not return to its original state, which is either due to tissue fibres unravelling or local therapeutic inflammatory responses signalling a structural change (Anderson, 2014). What really occurs at microcellular level remains unclear. Tissue tension from stretching may well cause unravelling of tissue fibres, but there is no evidence of post-stretch symptoms being sustained and so if there are local inflammatory responses, they are believed here to be transient, low grade and the stretch may cause tissue tension induced ischaemia with the ischaemic effect possibly being the trigger for the localised inflammatory response and structural change that Anderson (2014) alludes to. However, this is pure conjecture in the absence of evidence of what occurs at micro-level through stretching-induced joint capsular and ligamentous tension.

Stretching techniques to increase ROM in hip joint OA for example, remain recommended in national guidelines, but only as an adjunct to core treatment, as they have less well-proven efficacy, produce less symptom relief, or place increased risks on patients (NCGC, 2014; NICE, 2008). The increased risks on hip joint OA patients from stretching are not made explicit and despite hip joint replacement being identically critiqued in the same guidelines, the rate and number of these procedures have paradoxically been increased from 43 thousand in 2003 (Bourn, 2003) to 66 thousand in 2013 per annum in England and Wales (NHS, 2014). Nevertheless, there is a need to obtain evidence to support the use of stretching techniques to improve hip joint ROM.

Prior to the Cochrane Systematic Review conducted by Katalinic *et al*. (2010), most evidence about stretching in the literature relates to musculotendonal units and these are mainly restricted to the hamstring muscle group, which can largely be disregarded because of fundamental anatomical structural differences, which will be considered shortly. In the meantime and to date, no studies have focused on restricted hip joint ROM and stretching that attempts to target the joint capsule and reinforcing ligaments. A lack of evidence for intervention techniques renders the physiotherapist dependent on clinical guidelines based on expert opinion (Bennell, 2013; Rannou and Poiraudeau, 2010) and theory as discussed earlier.

2.4.2. Hip joint range of movement: Improvement through stretching - Population targeting

Shortened soft-tissues around a joint causing joint hypomobility are known as contractures (Curwin, 2011). The nature of human tissue adaptation and the optimisation of load volume and the frequency required for it, is largely unknown and so there is a great deal to learn about connective tissue adaptation (Curwin, 2011) particularly in terms of what is required to stimulate the physiological process.

The Cochrane Systematic Review (Katalinic *et al*., 2010) concluded that stretching does not have clinically important effects on joint mobility in people with, or at risk of contractures and that they have little to no benefit over and above usual care if performed for less than seven months. However, Katalinic *et al*. (2010) included studies that had highly variable stretch dosages. Katalinic *et al*. also noted that most included studies that examined the added benefit of stretching on both control and experimental groups, were additionally exposed to undefined or variable normal care and whilst their systematic review included participants with non-neurological and neurological conditions, the meta-analysis was only conducted on studies that had participants with neurological conditions. Katalinic *et al*., judge that it will be difficult to obtain the definitive answer to the question of what the most effective stretch dosage should be, due to clinical and ethical research design problems that would require acceptance of a control group being "…immobilised without interruption…". However and contrary to the view of Katalinic *et al*., if research is conducted on participants where ROM restriction already exists, or is reduced in association with underlying pathology such as in hip joint OA, clinical research can be ethically designed to try and evaluate the effectiveness of stretching on improving ROM where immobilisation would not be required. Other population groups that could be targeted are those where a reduced ROM is associated with back pain (Ellison *et al*., 1990), those who participate in hip and spinal rotation sports (Sadeghisani, Manshadi and Kalantari *et al*., 2015) and other sports such as judo (Almeida, de Souza and Sano *et al*., 2012), cross-country running (Hogg, Schmitz and Nguyen, *et al*., 2018) recreational weight-training participants (Cheatham *et al*., 2017), football (Nguyen, Zuk, and Baellow *et al*., 2017; Tak, Glasgow and Langhout *et al*., 2015; de Castro, Machado and Scaramussa *et al*., 2013), American football (Deneweth *et al*., 2014) tennis and baseball (Ellenbecker *et al*., 2007), where such restrictions may place their hip joint health at risk as discussed earlier.

2.4.3. Hip joint range of movement: Improvement through stretching - Prescription

Clinical guidelines and organisations such as the Arthritis Research UK and Arthritis Care can only provide stretching information and guidance where there is research evidence and in the absence of such evidence, dependence is placed on expert opinion and consensus as highlighted earlier. The limited evidence for specific soft-tissue stretching prescription for the reduction of joint hypomobility remains thus far, unequivocal.

From recent North American published guidelines, the recommendation for flexibility recovery techniques is limited to a prescription dosage of 1-5 times per week over 6-12 weeks for those with ROM restriction associated with conditions such as mild to moderate hip joint OA, using techniques that are individualised to address patients' most relevant impairments in ROM (Cibulka *et al*., 2017). Such prescription is in need of greater specificity. Implicit within this guidance is the specificity of technique directing the targeting of ROM losses, but greater specificity is required.

The FITT Principle has been advocated for guiding rehabilitation intervention prescription, which is an acronym for frequency, intensity, time and type of technique being prescribed (Sanghvi, 2013). However, this is still insufficiently specific as the acronym does not include the number of repetitions and sets of techniques. Another acronym DRIFT, devised for prescription guidance in muscle rehabilitation, stands for duration, repetition, intensity and frequency of a technique (Chamberlain *et al*., 2013) and has since been extended to incorporate the letter 'S' and read as DRIFTS, in order to include the number of sets of repetitions to the prescription of techniques (Chamberlain, 2017). The prescription guidance can be applied to stretching that draws on Davis' law, extends the physical stress theory and the SAID Principle discussed earlier to refine and increase the specificity of physiotherapeutic intervention. As discussed earlier, human tissue adapts in response to imposing or removing a stress or demand and the reader is referred to an abundance of other literature concerning for example, where muscles can become stronger or weaker depending on stresses they either are or are not exposed to; or where joint ROM will be reduced if the joint is immobilised for a prolonged period of time and retained if mobility is maintained. The DRIFTS Model addresses the prescription guidance gap and renders it more specific. Namely through explicit reference to the duration (of time), repetition (number of repetitions), intensity (force applied), frequency (number of times per measurement of time), technique (type of technique related to targeted tissue structure and function) and sets (number of sets of repetitions).

As the DRIFTS Model was being recommended within the theoretical literature, it is worth noting that the FITT Principle was simultaneously being adapted to address the lack of specificity critique, to FITT-VP (adding Volume and Progression), which has now been further adapted to become FITT-VPP to include a further letter 'P' for 'Pattern' (Pescatello, 2014; Garber, Blissmer and Deschennes *et al*., 2011). The adaptation is a welcome increase in specificity for guiding prescription, but it appears that the FITT acronym has been developed to a point that the user may struggle to remember what each letter stands for now that it has become FITT-VPP and it may be possible to inadvertently overlook the second letter 'P'. The FITT-VPP acronym may be better suited to progressive resisted exercising for muscle tissue, but the DRIFTS Model is retained for stretch prescription guidance.

The acronym DRIFTS, has therefore been adopted to help structure the review of the paucity of stretching prescription literature and to guide stretching prescription as presented in Table 1. Whilst the acronym may serve well as an aide memoir for guiding stretch prescription, the order of the letters is inaccurate and needs adjustment to make prescription sense. For example, it is not usual to determine the duration before identifying the technique to be conducted as the acronym would suggest, just as a medication prescriber would not determine the dosage before identifying the drug to be prescribed. Prescription order for the stretch protocol should be adjusted as shown in Table 2.

Table 1: The experimental stretch protocol using the acronym DRIFTS

Duration	**R**epetitions	**I**ntensity	**F**requency	**T**echnique	**S**ets
60 seconds	One	To the point of tightness and highest tolerable level of discomfort	Once per day	Medial and lateral rotation of the hip joint	One

Table 2: The experimental stretch protocol following a more logical prescriptive order

Technique	**I**ntensity	**D**uration	**R**epetitions	**S**ets	**F**requency
Medial and lateral rotation of the hip joint	To the point of tightness and highest tolerable level of discomfort	60 seconds	One	One	Once per day

The lack of guidance on prescription for stretching is a criticism of the physiotherapy literature that has begun to be addressed by relatively recent publications, as discussed above. The lack of evidence for stretching as a technique to improve hip joint ROM is a criticism of the research that has not yet been conducted by the physiotherapy profession to determine the most effective stretch prescription for hip joint capsule and reinforcing ligaments that limit the ROM. The lack of supporting evidence for stretching techniques targeting capsular and ligamentous soft-tissues of the hip joint where they are found to be restricting ROM is clear, but it remains for the DRIFTS Model to be applied to elucidate the detail of the stretching protocol (SP) to be analysed and consider any evidence regarding the components of prescription.

The technique for stretching the hip joint will involve targeting the capsule and ligaments that restrict rotation ROM. These will be discussed in more detail shortly, but it is worth briefly considering muscle tissue and respective prescription for what will shortly be seen to be less dense anatomical structures. In terms of soft-tissue targeting, it is clear that the reinforcing ligaments of the joint capsule constrain hip joint rotation (Martin, Khoury and Schröder *et al*., 2017; Martin *et al*., 2008), but they are not the only structures that may limit medial and lateral rotation, as short rotator stabilising and other muscles (Williams, Newell and Davies *et al*., 2005) may also contribute to the restriction if they become shortened. However, hip joint rotation is largely dictated by inert capsular and ligament constraints (Hogg *et al*., 2018; Martin *et al*., 2008). Further research is needed to investigate the potential association between the function of stabilising and other hip muscles and hip pathology (Retchford, Crossley and Grimaldi *et al*., 2013) and whilst this is beyond the scope of this thesis, it is sufficient to accept that the short lateral rotator muscles of the hip joint would for example, be coincidently and unavoidably co-targeted in medial rotation stretching of the hip joint capsule and reinforcing ligaments.

If musculotendonal structures were to contribute to any restriction of ROM, the prescription advocated by the American College of Sports Medicine for lengthening musculo-tendonal units is stretching for up to 10-30 second stretches up to once per day at the point of tightness or slight discomfort (Riebe, 2018; Pescatello, 2014; Garber *et al*., 2011), which is based on a limited body of data from randomised control trials and some observational studies (Garber *et al*., 2011). Irrespective, controversy and lack of specificity exists within the literature regarding the effects of stretching and the prescription for stretching musculotendonal units and any stretching designed to increase range of movement through stretching muscles *per se*. There are those who claim regular stretching does not increase muscle extensibility (Ben and Harvey, 2010) and others such as Meira and Wagner, (2015) who advocate stretching as part of the rehabilitation of a stiff hip joint in an athlete with OA. The recommendation from Meira and Wagner (2015) however, is to target lumbo-pelvic muscles rather than the non-contractile structures of the hip joint capsule and ligaments for stretching purposes, but there are descriptions of movement techniques such as long traction of the hip joint with progressive increase in ROM in all directions as tolerated, together with gentle stretching into combined flexion, abduction and lateral rotation as tolerated, which may target some capsular and ligamentous fibres. However and although Meira and Wagner (2015) advocate that a full pain-free, range of movement is required for the athlete's particular sport, a full stretching prescription is not provided. In order to target the correct tissues and then identify the correct technique, anatomical structures, their related function involved in joint movement and biomechanics need to be understood and will be considered shortly, when it will be appreciated how the hip joint capsule and reinforcing ligaments differ in structure rendering them denser and less elastic than musculotendonal units. Hence, short rotator stabilising muscles should respond by adaptive lengthening if the capsules and ligaments do so, unless there are other issues which are also beyond the scope of this thesis such as soft-tissue adhesions for example. The limited evidence for musculotendonal stretching prescription can therefore be disregarded in favour of focusing on the literature for stretching joint capsules and ligaments.

It has been recognised in the literature that there is still no specific research to guide the dosage for articular mobility and suggestions can still only be based on what is found in clinical practice (Kennedy and Levesque, 2016). Bennell (2013) directed the physiotherapy profession to obtain evidence for key areas of physiotherapy management, including the roles, effects and dosages of techniques in managing conditions where there is a known restriction of ROM.

The interest in the first study in this thesis is to explore the effects of a more specific stretch technique designed to improve hip joint rotation ROM and the DRIFTS Model was adopted for guiding the stretch intervention. The rationale for each component part of the stretch prescription will now be considered.

2.4.4. Hip joint range of movement: Improvement through application of the DRIFTS Model for stretching

Siff (2005) describes connective tissue structure, which includes muscle, tendons, ligaments and joint capsules comprising of collagen, elastin and reticulin fibres. Reticulin gives some bulk to the structures, but it is collagen that provides the strength and stiffness, whilst elastin provides compliance and extensibility when it occurs in small concentrations. Elastin is thought to play a role in returning the shape of the crimped collagen fibre after stretching or muscle contraction. Siff goes on to explain how ligaments and capsules are mainly collagenous with very few elastin fibres that are mainly associated with intrinsic blood vessels and the mechanical stress-response of collagen fibres depends on the orientation, properties and relative proportions of collagen and elastin fibres. In addition, it is explained how fibre organisation of ligaments and joint capsules are generally parallel, but as indicted earlier, ligaments can be less uniform and often oblique or spiral, depending on their function. Siff rightly concludes that the stretching of ligaments requires a more extensive variety of techniques involving linear, rotational and spiral patterns of action and the pattern of stretching of hip joint capsular ligaments will be determined by their respective structure and function. As elastic fibre content is very rare in the iliofemoral and ischiofemoral ligaments (Sato, Uchiyama and Katayose *et al*., 2012) for example, their structure is likely to require greater stress applied to encourage adaptive lengthening.

Clearly, knowledge and understanding of the above is required in order to inform the selection of the stretching technique, which physiotherapists are well placed to determine. The reader is reminded that the DRIFTS Model is adjusted to a more logical order for application.

2.4.5. Hip joint range of movement: Technique of stretching for improvement

If it is recommended to target body structure and function changes where ROM restriction exists in pathology such as hip joint OA (Klässbo, Harms-Ringdahl and Larsson, 2003), the same should apply wherever such ROM restriction exists irrespective of the presence of OA as a reduced ROM has already been established earlier, as being abnormal or pathological in nature. Knowledge and understanding of hip joint capsular and ligamentous structure anatomy and their respective function is of value in defining accurate non-surgical treatment techniques of the hip joint (Martin *et al*., 2008). For example, it is necessary to know how to conduct a tensile load along their line of stress to determine their contribution to hip joint rotation, whether it is sufficient or restricted and subsequently produce elongation through stretching where it is found necessary. The techniques for stretching and measurement will have similar justification, but the former may need adapting for reasons which will be additionally explained shortly.

Despite some disagreement regarding the roles of hip joint reinforcing ligaments, there is consensus from cadaveric studies that these and the hip joint capsule are strong and tighten on hip joint extension (Martin and Kivlan, 2011), which contributes to the close-packed position where articular surface congruence and compression is increased (Martin and Kivlan, 2011; Standring, 2005). The reinforcing pubofemoral and the medial band of the iliofemoral ligament contribute to limiting abduction; and the lateral band of the iliofemoral ligament and ligamentum teres (ligament of the head of femur) contribute to limiting adduction, but it is the ischiofemoral ligament and posterior capsule that limits medial rotation and was thought that the lateral band of the iliofemoral ligament that limits lateral rotation (Standring, 2005) in contrast to the counter-claim that the latter resists medial rotation in extension (Martin and Kivlan, 2011; Martin *et al*. 2008). In short, it is therefore now accepted that the iliofemoral ligament limits lateral rotation together with the pubofemoral ligament and anterior capsule, but limits medial rotation together with the posterior capsule and ischiofemoral ligament (Martin and Kivlan, 2011). However and irrespective, if the joint capsule and the main reinforcing ligaments of the pubofemoral, ischiofemoral and iliofemoral ligaments are placed on tension when the joint is in extension, adding medial and lateral rotation in this position would further load these reinforcing ligaments and indicate their contribution to limiting ROM. There are some positions in various degrees of hip flexion that some ligaments or branches of ligaments may also be placed on tension more than others (Martin *et al*., 2017; Martin *et al*., 2008), but targeting the reinforcing ligaments collectively in the same manner for stretching would be more economical and accurate than stretching in various angles of flexion, which can be conducted by the patient and save physiotherapy time. Additionally, other than hip joint extension, the greatest proportionate amount of difference in the mean range of movement available when comparing hip joints with and without pathology such as OA, was medial and lateral rotation (Klässbo *et al*., 2003), which further justifies the stretching technique of medial and lateral rotation.

The technique of medial and lateral rotation stretches in hip joint extension to place the capsule and ligaments on tension to plastically adapt their length has been justified. However, position and mode control may require adaptation to meet idiosyncratic patient ability, need and preferences. For example, some would find it preferable to conduct a lateral rotation stretch passively using the external force of their own hands in sitting with the hip joint flexed at a point of around 90° and in slight abduction, rather than actively stretching into lateral rotation by contracting the lateral rotator muscles of the hip joint whilst lying on their front in prone with the hip joint in a neutral position. As it is advocated that physiotherapists involve patients in shared and reasoned decision-making (Roberts and Langridge, 2018), the more convenient and preferred seated passive LR stretch is acceptable provided structures contributing to a reduced ROM remain targeted. When conducting a LR stretch in sitting with the hip joint in flexion and abduction, it is argued that flexion allows the capsule and supporting ligaments to relax (Kapandji, 2019; Agarwal, Kaur and Ganesh, 2013; Simoneau, Hoenig, Lepley *et al*., 1998; Greene and Heckman, 1994; Fuss and Baccher, 1991) and may therefore require the hip joint to be taken through a greater LR ROM, in order to ensure the end of range tension of soft-tissues is achieved. The same applies to the MR stretch where it was conducted in sitting close to 90° flexion.

The focus of the first study in this thesis is to explore the effects of hip joint rotation stretches on rotation ROM when measured in prone.

2.4.6. Hip joint range of movement: Stretching intensity for improvement

There is inconsistency in the intensity of stretch recommendations. It is not possible to give a minimum intensity of stretching, as this may not produce the desired effect of an increase in joint ROM. In order to induce adaptation through the application of capsular and ligament tension, encourage tissue to plastically respond through micro-failure of collagen fibres leading to subsequent collagen synthesis and reorganisation of new tissue components, it is necessary according to Irani, Vennix and Jain (1995), to slowly apply and maintain a tensile load past the point of pain. However, Curwin (2011) recommends the maximum tolerable level of discomfort and Anderson (2014) recommends stretching intensity to the point of mild to moderate discomfort, but the problem here is that tolerance to discomfort and pain is subjective and again, Anderson's recommendation is based on targeting muscle tissue.

There is an absence of evidence of stretch intensity requirements for hip joint capsule and ligament structures in the literature, demonstrating a clear need for research to determine specific objectively measured intensity required for producing soft-tissue adaptation of length. Objectively quantifiable intensity remains unknown due to technological constraints and so the intensity is subjectively dependent. However, it can be objectively demonstrated by the physiotherapist taking the hip joint through to the end of ROM to a point of a firm end-feel that will be felt sooner in the range than usual if ROM is abnormal (White and Norkin, 2016) and pressure can be applied until the most tolerable level of discomfort can be subjectively felt. The first study in this thesis is interested in the effects of stretching with intensity equal to at least the maximum tolerable level of discomfort as advised by Curwin (2011).

2.4.7. Hip joint range of movement: Stretching duration for improvement

Krivickas (2006; 1999) summarises the scientific literature on flexibility where flexibility is the ROM of a joint and discusses the conflict of research findings. Krivickas (2006) recommends a stretch duration of 30 seconds, conducted on a five times per day minimum basis for a greater and faster gain. However and whilst

Krivickas asserts that flexibility is influenced by muscles, tendons, ligaments, bones and bony structures, the recommendation of Krivickas is based on musculo-tendonal unit stretching rather than joint capsule and ligamentous structures, which may be because the author further asserts that musculo-tendonal units are the greatest contributor to flexibility. The latter assertion is not supported from earlier discussions above and in essence, is challenged on account of tissue structure differences if a hierarchy of contributors to flexibility were to be considered. However, Krivickas (2006) does recommend limiting the number of different stretches, in order to increase patient compliance, but on the contrary, recommends five stretches per day of up to 30 seconds duration, which equates to 2.5 minutes per stretch technique in total.

The stretching prescription recommended by Krivickas can be disregarded as capsule and ligamentous structures have as considered earlier, a higher density of collagenous bundles that do not have the same elastic properties as musculo-tendonal units and are therefore more resistant to tension. However, Krivickas does recognise that the recommendations are based on a very limited number of studies, recommends more research to be conducted on flexibility techniques and the assertion of limiting the number of stretches to one technique for each tight soft-tissue structure is a welcome recommendation for addressing the compliance issue Krivickas is concerned with. A single stretch would be efficient on patient time and may possibly help improve compliance. If more than one structure needs stretching, or if more stretch techniques are required to address each tissue structure contributing to the loss of ROM, efficiency to improve compliance becomes even more important. The problem remains the varied recommended timescales for stretching, that ranges from thirty seconds from Krivickas based on limited research, or a prolonged stretch of twenty minutes based on opinion (Irani *et al*., 1995) on one end of the scale, through to a prolonged stretch of thirty minutes based on some studies over the last twelve years at the other end of the scale.

Thirty minute stretches have been advocated through the application of an expensive single-use knee brace, but author acknowledged lack of a matched control group, short-follow-up time for half the participants, mixed pathologies and small numbers of participants in each group precluding statistical evaluation of the different groups (Bonutti, McGrath and Ulrich *et al*., 2008), prevents the findings of improved knee movement being generalised. The imposition of a daily thirty-minute stretch may be quite difficult and such a brace is not available that would place the hip joint in sufficient rotation to improve it. Author acknowledged short falls of no control group and a small sample limiting the power of statistical analysis apply in another similar study using the same knee brace (Bonutti *et al*., 2008), which also prevents the findings of improved knee movement being generalised. The same brace and stretch duration was applied on the forearm to improve supination and pronation ROM (McGrath, Ulrich and Bonutti *et al*., 2009), but author acknowledged methodological issues such as multiple ROM testers and an absence of a matched control group prevented being able to generalise the improved ROM. One study used the same brace applied to the shoulder for the same duration up to three times per day (Ibrahim, Donatelli and Hellman *et al*., 2014), which is not a practicable option for the hip joint. Hussein, Ibrahim and Hellman *et al*. (2015) report on an extension of the Ibrahim *et al*. (2014) study, but it is argued that the 100% follow-up rate at two-years, together with the extreme results and large treatment effects favouring the experimental condition, renders the study implausible (Harvey *et al*. 2017). Harvey, Glinsky and Katalinic *et al*. (2011) with an interest in restricted joint ROM conclude from reviewing the literature, to expect no change in joint mobility from stretches that are less than 30-minutes per day over a time period of less than 3-months, but this was for those who had developed complications of contractures following a spinal cord injury.

Finally on stretch duration, Light, Nuzik, and Personius *et al*. (1984) concluded that a one-minute low load was preferable to a brief high-load passive stretch to reduce knee flexion contractures, but unfortunately, as one stretch intervention was compared to another it was not possible to isolate the effects of the stretch duration (Harvey *et al*., 2017; Katalinic *et al*., 2010).

In summary, there is no definitive evidence for the optimum duration of a stretch technique to improve hip joint rotation ROM and the first study in this thesis is interested in the effects of a sixty-second stretch on hip joint rotation ROM measured in a prone position.

2.4.8. Hip joint range of movement: Stretching repetition, sets and frequency for improvement

Without research in the prescription of stretching, patients with a pathological restriction of ROM and associated conditions such as hip joint OA and FAI, will need to continue to follow opinion-based advice on how to increase and maintain joint ROM that may be inadequate. Typically, organisations such as the Arthritis Care Organisation (2015) try to encourage patients with OA to take their joints through their comfortable ROM, but also try to "…ease them just a little further…twice per day…between three and 10 times each session, building up the number of repetitions...". No limit of repetitions is set and those with OA are warned not to "…push it further as this can result in overstretching…". There is an assumption that those with such a condition know what stretch technique, joint plane and axis of movement the joint is to be moved through too. It is likely that interest groups and organisations not only have to be mindful of the lack of research findings, but understandably may also have to take care not to enter a potentially litigious arena and give poor advice in public information leaflets. Research in the area of stretching prescription would allow more definitive advice to be given.

As with the duration of a stretch technique, the optimum number of repetitions, sets and frequency of stretching for the hip joint capsule and reinforcing ligaments is unknown. Thus far, it appears that stretch prescription recommendations remain based on variable opinion-based and theoretical literature and none yet adequately focus on hip joint capsular and ligamentous structures with most focusing on the more elastic connective tissue of muscles.

2.4.9. Hip joint range of movement: Improvement through stretching - Summary

In summary, stretching techniques to improve joint ROM are supported in the theoretical literature, but there remains no evidence to support such interventions (Harvey *et al*., 2017; Katalinic *et al*., 2010). Stretching remains recommended in national guidelines as an adjunct to core treatment, despite such an intervention being recognised as having less well-proven efficacy (NCGC, 2014; NICE, 2008). Intervention decisions frequently require reference to theory in the absence of evidence (Portney, 2020) and underpinning tissue adaptation theory has therefore been applied. Prescription guidance has emerged in the literature and the DRIFTS theoretical Model has been applied for a stretching technique designed to target a restriction of hip joint rotation ROM using one repetition conducted with a frequency of once per day and an intensity of maximum tolerable discomfort for a duration of sixty seconds.

Descriptive exploratory research such as case series studies (Portney, 2020) do not always generate a specific research question in advance of being conducted, but may suggest such a question (Bowers, 2020). Research is highly recommended on the effectiveness of stretching as an intervention for increasing hip joint rotation ROM (Harvey *et al*., 2017; Katalinic *et al*., 2010) and the question generated for the first study in this thesis is therefore as follows:

Is there evidence from retrospective case series data to demonstrate that a stretch protocol increases medial and lateral hip joint ROM over a three-month time period?

Chapter 3 will focus on retrospective data, collection, analysis, results and respective inferences in an attempt to answer the above research question and recommendations will be made for future research in the subject area. However, evidence for the data collection measurement instrumentation and method is in need of being considered (Portney, 2020), which now follows.

2.5. Hip joint medial and lateral rotation range of movement: Introduction

The measurement and recording of joint mobility is an important part of examining joints and surrounding soft-tissues (White and Norkin, 2016); contributing to correct diagnosis (White and Norkin, 2016; Greene and Heckman, 1994) such as OA of the hip joint (Cibulka *et al*., 2017; Clarkson, 2013; Poulsen *et al*., 2012) or other injury (Ellenbecker *et al*., 2007); an indicator of the severity and progression of such disorders and also a means of evaluating the results of treatment (White and Norkin, 2016; Prentice, 2011; Domb *et al*., 2009; Greene and Heckman, 1994); which is clearly very important (Bierma-Zeinstra *et al*., 1998). Joint ROM measurement is needed for decision-making in modifying rehabilitation (White and Norkin, 2016; Prentice, 2011) and it is also a parameter for determining a return to functional activity (Greene and Heckman, 1994). In sport, ROM deficiency identification and correction is argued to help in injury prevention and performance enhancement (Ellenbecker *et al*., 2007).

Simoneau *et al*. (1998) rightly asserted that properly developed normative values for active and passive joint ROM can provide population-specific references to which patients can be compared and in research, it is also necessary to know normal ROM of joints in order to judge the status of ROM in the population under study (Dijkstra, de Bont and van der Weele *et al*., 1994). However without relative knowledge and understanding of normative ROM values, judgement and decision-making regarding each of the above factors is not possible.

Having reviewed four guidelines published between 1920 and 1960, the American Academy of Orthopaedic Surgeons (AAOS) concluded it was difficult to accurately determine the average hip joint ROM due to the wide variability amongst the population (AAOS, 1965). Irrespective, it is suggested that ROM may be compared with published average normal ROM values such as those published by the AAOS (White and Norkin, 2016; Clarkson, 2013; Klässbo *et al*., 2003) and other standard texts (White and Norkin, 2016; Clarkson, 2013). The values published by the AAOS remain suggested despite the source populations (White and Norkin, 2016) and methodologies such as the body position for measurement and mode of movement (White and Norkin, 2016; Simoneau *et al*., 1998) being unknown (White and Norkin, 2016).

Where there is unilateral hip joint involvement, a comparison can be made with the contralateral side or unaffected hip joint (Macedo and Magee, 2008; Ellenbecker *et al*., 2007; Klässbo *et al*., 2003; Bierma-Zeinstra *et al*., 1998; Roaas and Andersson, 1982; AAOS, 1965), but this is not possible if there is bilateral impairment (White and Norkin, 2016) and it is therefore necessary to compare ROM values with population-specific ROM values in the research literature (White and Norkin, 2016; Ellenbecker *et al*., 2007), provided comparisons are made using the same measurement method (White and Norkin, 2016; Roaas and Andersson, 1982). Comparison with published guidelines can be problematic however, as normative values may not have been established for all population groups (White and Norkin, 2016). Clarkson (2013) recommends text-based values derived from evaluation of the research literature suggested by Reese and Bandy (2010), which demonstrates disparate values that will be considered as hip joint MR and LR ROM is discussed further below. It may therefore currently, only be possible to use published values as a general guide to identify normal versus impaired ROM as there are considerable differences in mean ROM values noted across the literature (White and Norkin, 2016).

Normative hip joint rotation ROM values will be discussed, prior to considering measurement of change of ROM using minimal detectable change and minimal clinically important difference values.

2.5.1. Hip Joint medial and lateral rotation range of movement: Predominance

The traditional assumption is that there is a predominance of LR over MR (Cannon, Finn and Yan, 2010). Reese and Bandy (2010) assert however, that traditional values for normal hip joint MR and LR ROM are 45°-50° and 40°-45° respectively, based on published values by the AAOS (1965) and the AMA (1984), or 35°-40° for both MR and LR based analysis of existing data. Whilst Reese and Bandy appear to assert that there is a traditional predominance of MR or an equal MR and LR ROM from their data-based analysis, there is inaccuracy and conflict in their assertion from the historical literature they refer to. The AAOS (1965) suggest that MR and LR are of an equal value of 45° if measured with the hip joint flexed and that average values for MR and LR should be 35° and 48° respectively when measured in extension. Unfortunately and as indicated above, the AAOS did not fully stipulate body position for measurement and it was not disclosed whether the values were measures of active or passive ROM (Simoneau *et al*., 1998). The AMA (1984) advocate an active MR and LR ROM of 40° and 50° respectively with the hip joint in extension, so when considering these values along with earlier values published by the AAOS, it is difficult to see why Reese and Bandy declare a predominance of MR ROM and it can only be assumed that the disparity is the result of typographical errors in the Reese and Bandy (2010) text. Although referring to a passive mode of movement, it is therefore noted that normative MR and LR values in theoretical literature are quite consistent in that MR is equal or less than LR across all populations with LR values historically believed to be in the range of 45°-50° (Cannon *et al*., 2018), if the above Reese and Bandy (2010) typographical errors are accepted.

It has to be noted that the AMA (1984) values were advocated based on measurement with the hip in extension, but in a supine position. However, the values do not appear to have been adjusted as the AMA changed their recommended measurement method to that of the hip joint remaining in extension, but in the prone position (Rondinelli, Genovese and Katz *et al*., 2008; AMA, 1993).

Thus far from traditional and historical literature, there appears to be either symmetry of MR and LR, or asymmetry of rotation with a predominance of LR. Very few have specifically studied normal hip rotation ROM in adults (Kouyoumdjian, Coulomb and Sanchez *et al*., 2012) until the most recent decade, but further inconsistency has emerged as more populations are studied. For example, Cannon *et al*., (2018) found a predominance of MR in a convenience sample of distance runners, whilst Kouyoumdjian *et al*. (2012) mostly found the converse in healthy adults. There not only appears to be discrepancy in normal MR and LR ROM values, but also regarding LR or MR predominance versus equivalence, or in other words, directional symmetry versus asymmetry.

2.5.1.1. Hip Joint medial and lateral rotation range of movement: Lateral rotation predominance

Kouyoumdjian *et al*. (2012) found from a random sample of healthy Caucasian adults (*n*=120; mean age, 39.1 years; age range 22-60 years), a MR and LR ROM of 35.3° ±

(11.9°) and 41.8° (± 10.2°) respectively in their study, demonstrating a slight mean predominance of LR present in 47.5% of their cases, but 13% had a predominance of MR leaving 39.5% with MR and LR being equivalent in value. Kouyoumdjian *et al*. (2012) discuss how other factors such as age, gender and body mass index seem to have contributed to the lower values found relative to previous literature, but still conclude that a LR predominance or LR and MR symmetry is usually found.

Roach, San Juan and Suprak *et al*. (2013) found MR and LR to be 37.45° (±2.15°) and 50.55° (±1.7°) respectively in their convenience sample of thirty healthy subjects and report that their MR ROM values appear to be consistent with others in the literature such as Kouyoumdjian *et al*. (2012). Roach *et al*. recognise however, how their LR values are greater than those reported elsewhere in the literature, hypothesising a range of explanations for the differences from population sample, measurement technique protocol and accuracy, through to whether an active or passive ROM was measured. Both Roach *et al*. and Kouyoumdjian *et al*. conducted analysis on PROM values and whilst PROM is greater than AROM in most joints (White and Norkin, 2016; Clarkson, 2013; James and Parker, 1989; Haley, 1953) due to the stretch properties of soft-tissues surrounding the joint (White and Norkin, 2016), a higher passive than active ROM does not explain the differences between the LR values in the two studies of Roach *et al*. (2013) and Kouyoumdjian *et al*. (2012). If measurement technique produced the differences in LR ROM between the two studies, the same differences do not appear to be evident with MR. This suggests sample differences may have produced the lower LR values in the Kouyoumdjian *et al*. (2012) study and as these authors report that 43% of the sample included sport participants, the reported LR value differences could be due to sporting effects.

A little over a decade ago, a mean greater hip joint LR ROM than MR value was reported by Malliaras, Hogan and Nawrocki *et al*., (2009) in both the asymptomatic control and symptomatic groin pain groups of young, male, elite Australian Rules football and soccer players in their reliability study using a fluid-filled inclinometer with the hip joint in an extended position. Interestingly, Malliaras *et al*. do not discuss the mean higher left-sided LR (46.2°±13.4° groin pain group; 48.3°±9.6° asymptomatic group) compared to the right (39.4°±8.7° groin pain group; 40.8°±7.1° asymptomatic group), which may be a sport-related difference. Despite the potential sport effect on rotation ROM, Malliaras *et al*. demonstrated a mean LR ROM predominance (MR inter-group range 32.7°-34.4°), which supports Simoneau *et al*. (1998), who reported the same from their study of healthy young adults (*n* = 60), with an active MR and LR ROM of 36° and 45° respectively when measured in prone using a goniometer. It is worth noting however that LR predominance can be found in other sports such as former elite handball players, but near MR and LR symmetry was found in their matched control group (L'Hermette, Polle and Tourny-Chollet *et al*., 2006) suggesting not only a sporting effect influence, but also provides evidence of an expectation of MR and LR symmetry in non-sporting groups.

Pua, Wrigley and Cowan *et al*. (2008) found a 12° higher mean value of LR than MR, but data was obtained from a sample of those with OA and MR and LR difference in values may be due to a relative loss of MR, which reflects the capsular pattern of loss of ROM (Saunders and Longworth, 2006). Features of early hip joint OA have been found to be associated with lower ROM (Holla *et al*., 2011) and medial rotation is considered to represent an early sign (Dvořrák *et al*., 2008). The capsular pattern of loss of ROM has been disputed within the literature (Klässbo *et al*., 2003) where for example, LR has been noted to be restricted with hip joint OA (Holla *et al*., 2011). Irrespective, the association of movement loss and pathology is consistent within the literature and Pua *et al*. (2008) determined their values from subjects who were seated when evidence from the literature appears to favour MR and LR symmetry when measurements are obtained in this position.

2.5.1.2. Hip Joint medial and lateral rotation range of movement: Lateral and medial rotation symmetry

Boone and Azen (1979) by and large, found MR and LR ROM symmetry with an active MR of 44.4° and LR of 44.2° when their healthy male adult sample was measured in a seated position using a goniometer. Later as indicated above, whilst Simoneau *et al*. (1998) reported LR predominance of ROM when measured in a prone position, they reported a lesser difference when measurements were obtained seated, where MR and LR values of 33° and 36° were respectively found.

Bierma-Zeinstra *et al*. (1998) found mean active MR and LR to be 46.3° and 47.0° and passive MR and LR to be 53.2° and 51.9° respectively in prone, which again demonstrates that passive ROM is greater than AROM, but there appears to be little difference in the mean values of MR and LR whether conducted actively or passively. The same applies where little difference was found when Bierma-Zeinstra *et al*. obtained active and passive MR and LR values when measured in sitting, where active MR was 33.6° and LR was 33.9° and passive MR was 38.8° and LR was 37.6°. The Bierma-Zeinstra *et al*. sample was unfortunately small (n = 9 healthy subjects) and the age range was younger (21-43 years-old), but the LR values are similar to what Roach *et al*. (2013) found in their later study as indicated above, albeit that Bierma-Zeinstra *et al*. obtained greater MR values in prone than found in other studies. Bierma-Zeinstra *et al*. did find similar MR and LR values in sitting however, to those that Roach and Miles (1991) found in their large sample ROM study (n = 1683), which were 33.0° and 34.0° respectively and symmetry was largely found across all age-groups.

Influences on MR and LR ROM values such as measurement position effects will be considered later. In the meantime from a study conducted by Cibulka, Strube and Meier *et al*. (2010), an important finding that was not part of their original hypothesis is that asymmetry in hip rotation is much more prevalent than previously expected in a normal population. Cibulka *et al*. (2010) studied the relationship between symmetrical and asymmetrical hip rotation and hip rotator muscle strength in a healthy convenience sample (n = 64; mean age, 27.1 years, SD 10.6 years, range 18-60 years) and 42 of 64 subjects had LR exceeding MR on their left side and 49 of 64 subjects had the same asymmetry on their right side. Cibulka *et al*. (2010) did not report the hip joint rotation ROM values that they obtained in the prone position and rather than accepting the LR predominance as normal, Cibulka *et al*. (2010) advocated the restoration of MR and LR symmetry before targeting rotator muscle weakness and also when treating patients with low back, hip, or knee pain. The evidence for symmetry of MR and LR may be equivocal however, which may influence the rehabilitation intervention and respective chronology of decision-making.

L'Hermette *et al*. (2006) found near symmetrical rotation ROM in a matched control group in a study of former elite handball players and the values were 23°±4.0° and 20°±3.0° for left and right hip joint MR respectively, whilst values of 23°±3.0° and 21°±3.0° were found for the same respective LR ROM. The MR and LR values reported by L'Hermette *et al*. (2006) are clearly lower than those reported elsewhere in the literature suggesting other influencing factors. Such influencing factors on ROM values will be considered further later.

Van Dillen, Bloom and Gombatto *et al*. (2008) compared hip joint MR and LR ROM measured in a prone position between those with and without low back pain. Van Dillen *et al*. (2008) reported from their study, little mean difference between MR (left MR 26.92°; right MR 28.55°) and LR (left LR 24.63°; right LR 28.29°) for those with low back pain or for those without low back pain (left MR 31.01°; right MR 29.83°; left LR 31.15°; right LR 30.43°). Considering Van Dillen *et al*. measured passive ROM there appears to be less available ROM in those healthy individuals without low back pain than what others report in the literature. Van Dillen *et al*. (2008) used a hand-held inclinometer, which could explain the lower MR values as Roach *et al*. (2013) found in their validity study comparing a digital inclinometer with a UG and therefore suggests instrumentation differences. However, instrument differences are unlikely to explain the much lower LR values when Roach *et al*. found 20° more LR than Van Dillen *et al*. Roach *et al*. discuss in their study how their LR values were greater than reported by others using an inclinometer, but the values were not too dissimilar as those determined by the UG. Conversely, Bierma-Zeinstra *et al*. (1998) found a mean greater passive MR than LR using a digital inclinometer and goniometer in a prone position, but this was not replicated when active ROM was measured. Although Bierma-Zeinstra *et al*. (1998) report a systematic difference between the two instruments and warn against them being used interchangeably, they conclude that the inclinometer is no more reliable than the goniometer when conducting active rotation ROM measurements. The difference in passive ROM measurements between the two instruments was greater for LR where it was found to be 8.9°, whilst a 2.8° difference was reported for MR. The systematic difference reported by Bierma-Zeinstra *et al*. (1998) falls short of explaining the 20° difference in LR values found by Van Dillen *et al*. (2008) compared with Roach *et al*. (2013) in healthy subjects.

Irrespective and as indicated earlier, Bierma-Zeinstra *et al*. (1998) reported very little mean difference between active LR and MR ROM which were 47.0° and 46.3° respectively when measured using a goniometer in the prone position, suggesting almost symmetrical values rather than MR predominance when using a goniometer to measure active ROM.

To return to the study conducted by Van Dillen *et al*. (2008), both the low back pain and non-low back pain groups were a sample of those who regularly participated in rotation-related recreational sport, which may explain the lower rotation ROM values of both groups.

2.5.1.3. Hip Joint medial and lateral rotation range of movement: Medial rotation predominance

Moromizato, Kimura and Fukase *et al*., 2016 report near symmetrical mean MR and LR ROM, which were respectively 42.1°±9.6° and 43.9°±8.4° in young, healthy, Japanese adults, but a LR predominance in males and MR predominance in females. MR predominance is considered to be rare (Kouyoumdjian *et al*., 2012), but there is evidence of the incidence of this in healthy subjects as well as in those with low back pain where Ellison *et al*. (1990) suggest that subjects with this pattern of movement may have short medial rotator muscles, tight joint capsules, or femoral neck anteversion, which could limit the amount of lateral rotation ROM. There is evidence of MR predominance in other populations such as sport and it also appears that gender may be an influencing factor. Influences on ROM values are complex with gender, activity, skeletal morphology, pathology and others being implicated within the literature and although recognition of such influences will be considered later when ROM measurement is discussed, the focus of this thesis is the soft-tissue effects on ROM.

2.5.2. Hip joint medial and lateral rotation range of movement: Normative values summary

From traditional and historical literature, there appears to be either symmetry of MR and LR, or asymmetry of rotation with a predominance of LR, but where there is symmetry, positional effects appear to be the greater influence of this, which will be considered shortly. From the research literature, there is inconsistency in MR and LR symmetry and asymmetry expectation with the latter being argued to be pathological. However, there is increasing evidence of LR predominance being found where pathology is not associated, but the MR to LR value ratio is unknown due to the degree of variability in reported values.

The AAOS (1965) suggest that MR and LR are of an equal value of 45° if measured with the hip joint flexed and that average values for MR and LR should be 35° and 48° respectively when measured in extension. Unfortunately and as indicated above, the AAOS did not fully stipulate body position for measurement and it was not disclosed whether the values were measures of active or passive ROM (Simoneau *et al*., 1998). The AMA (1984) advocate an active MR and LR ROM of 40° and 50° respectively with the hip joint in extension, so when considering these values along with earlier values published by the AAOS, it is difficult to see why Reese and Bandy declare a predominance of MR ROM and it can only be assumed that the disparity is the result of typographical error. Although referring to a passive mode of movement, it is therefore noted that normative MR and LR values in theoretical literature are quite consistent in that MR is equal or less than LR across all populations with LR values historically believed to be in the range of 45°-50° (Cannon *et al*., 2018), if the above typographical errors are accepted.

It remains necessary to know and understand normal MR and LR ROM, not only to determine whether ROM is abnormally reduced, but also to be able to evaluate any intervention designed to improve such abnormality. It has been recognised that up to a decade ago, that there was still very little published normative joint ROM data for healthy men and women across a wide span of ages and whilst many joint ROM values have been published on a publicly available database for comparative study purposes including hip joint flexion and extension (Soucie, Wang and Forsyth, *et al*., 2011), MR and LR still do not appear to have been precisely determined to be included on the database (Centers for Disease Control and Prevention, 2020). Furthermore, the inconsistency of MR and LR ROM across the literature renders it necessary to defer to the most recent normative values published and recommended by the AMA (1984) for the purpose of the studies within this thesis. The variability in reported MR and LR values appears to be due to other influencing factors, which will be further considered later as ROM measurement is discussed. Whilst it is important to know normal ROM values for comparison purposes, it is also important to know whether any change in ROM is beyond measurement error, which will now be considered.

2.6. Hip joint medial and lateral rotation range of movement: Minimal detectable change and minimal clinically important difference

To show improvement following an intervention, a change score is required by measuring the difference between a pre- and post-test and confidence in instrument reliability is required to be able to assume observed difference represents true change and not just measurement error (Portney, 2020).

In health care, an improvement of the ROM of a joint due to an intervention and not due to chance is one that has statistical significant difference (Copay, Subach and Glassman *et al*., 2007). In measurement theory, it is suggested that when pre-test scores are subtracted from post-test scores, the true value will cancel out and measurement error will remain (Portney, 2020), so any change in ROM will contain measurement error. Therefore, minimal detectable change (MDC) and minimal clinically important difference (MCID) are two measures that are increasingly being reported in rehabilitation research (Carter and Lubinsky, 2016). The MDC being the amount of change in ROM that is necessary to be confident that a true difference has occurred and is not due to measurement error that accounts for the entire measured difference (Portney and Gross, 2020a, Beaton, 2000). The more reliable an instrument or measurement method is, the smaller the MDC value (Portney, 2020; Portney and Gross, 2020a). Statistically significant differences in ROM may at the same time be of little importance to the health of joints of patients and so the MCID evolved, which is a threshold value that represents a change that would be considered worthwhile (Copay *et al*., 2007), is meaningful in the care of a patient (Carter and Lubinsky, 2016) and distinctly separates clinical importance from statistical significance (Copay *et al*., 2007). The MCID is criterion-based that establishes when sufficient change has taken place to be considered important, which can be subjective (Portney and Gross, 2020a) and the criterion of a normative

ROM value would need to be applied pending knowing what healthy hip joint ROM is. To use the criterion-based normative ROM value would be considered an anchor-based approach to determining a MCID, which is more objective (Haley and Fragola-Pinkham, 2006), but if a distribution-based approach is used, the MCID should for example, be at least as large as the MDC (Copay *et al*., 2007).

Research suggests that a change of 3°-4° is required when a single tester measures the same movement in upper and lower limb joints and should be 6° when more than one tester conducts the same goniometric measurements in the lower limb (Clarkson, 2013; Boone, Azen, and Lin *et al*., 1978). Generally, clinicians consider 5° of error for ROM measurements as acceptable, but it is questioned in terms of generalising from one joint to another in this regard (Portney and Gross, 2020a).

Bohlin, Sandstrom and Angstrom *et al*. (2005) concluded that a change of more than 20-25% and 12-13% is required for MR and LR respectively, in order to state an actual change of in hip ROM has occurred. Percentage changes in ROM may be useful where movement restriction is greater, but the usefulness reduces where ROM loss is less severe. For example, to improve hip joint MR ROM that is restricted to 15° by 20-25% would require movement to be increased to 18°-19°, which is a difference of 3°-4°. However, to increase a ROM from 30° by the same percentage, a ROM 36-38° would be required, which is a difference of 6°-8°. In other words, Bohlin *et al*. conclude that the greater value a ROM is, the greater the ROM increase is required in order to demonstrate an improvement has occurred.

Bohlin *et al*. believed that the lower reliability and the need for a higher percentage of improvement being required for hip joint MR ROM measurement in their study, was due to patient variability with differing degenerative joint problems and go on to suggest that the results of hip joint ROM measurement should be interpreted with caution. This demonstrates how the reliability and MDC of one ROM measurement cannot be generalised to another. Prior to the study by Bohlin *et al*., Gajdosik and Bohannon (1987) warned physiotherapists to exercise caution in accepting generalisations about the reliability of one ROM measurement and applying it to another because of variations that exist among different ROM measurements. It is therefore necessary to consider the MDC for each hip joint ROM independently.

A change of 6° hip joint abduction has been reported to be beyond measurement error when more than one tester is involved in measurement and investigation of other motions was therefore recommended (Boone *et al*, 1978). Although Cliborne, Wainner and Rhon *et al*. (2004) did not calculate the MDC for flexion, Cibulka, White and Woehrle *et al*. (2009) have done so from the intra-tester reliability results of Cliborne *et al*., publishing a MDC value of 5° in their guidelines. Pua *et al*. (2008) report a MDC value of 8.2° for flexion, but 7.3°, 7.8° and 7.1° respectively for abduction, MR and LR in their intra-tester reliability study. It can therefore be seen how the MDC values for abduction reported by Boone *et al*. and flexion reported by Cibulka *et al*. (2009) are identical, but Pua *et al*. obtain marginally higher values for the same respective direction of movement as well as rotation. Bennell, Egerton and Martin *et al*. (2014) set the MCID at 5° for hip joint abduction, flexion, extension and rotation for their study of the effect of physiotherapy in patients with hip joint OA, citing the guideline MDC value determined by Cibulka *et al*. (2009). The setting of the MCID of 5° by Bennell *et al*. (2014) is understandable if as indicated above, it should be at least as large as the MDC using a distribution-based approach according to Copay *et al*. (2007), who cite Beaton (2000) and Hägg, Fritzell and Nordwall (2003), which is implicit in Beaton's discussions of responsiveness studies and the report by Hägg *et al*. on their study aimed at estimating the MCID of outcome measures used in the evaluation of treatment of patients with chronic low back pain. However, Bennell *et al*. (2014) have applied the MDC value found for hip joint flexion for all their ROM measurements when Pua *et al*. (2008) have found higher and differing MDC values. The warning from Gajdosik and Bohannon (1987) does appear to be well-founded, as it is beginning to appear dubious to generalise the MDC of one movement to another. Bennell *et al*. do not report their ROM measurement methods, but the MDC values found by Pua *et al*. were despite controlling for body segment movement potentially contributing to measurement error, through the application of body segment stabilisers in the measurement of MR and LR in a seated position and achieving excellent reliability. More needs to be known regarding the MDC values of hip joint rotation ROM relative to measurement methods.

Poulsen *et al*. (2012) identified an inter-tester MDC value of 20° for medial rotation and 17° for lateral rotation of the hip joint and although the poor results were possibly attributable to measurement precision being affected by measurement being conducted in supine, the resultant recommendation was for standardisation of the measurement procedure and training of those conducting ROM measurement, in order to improve reliability when more than one tester is involved. Standardisation of the measurement technique and training of testers will be returned to later, but the minimal detectable change identified by Poulsen *et al* is too large, as it may exceed the ROM improvement required in a hip joint.

Gradoz *et al*. (2018) identify the need to investigate reliability of ROM measurement in those with hip joint pathology and should include MR and LR in the prone position. As future research may require more than one tester, it is necessary to explore and improve hip joint rotation inter-tester reliability and respective MDC.

2.7. Hip joint medial and lateral rotation range of movement: Measurement

There are several influencing factors on MR and LR ROM values which include the following examples:

1. Age (White and Norkin, 2016; Roach *et al*., 2013; Kouyoumdjian *et al*., 2012; Gilleard and Smith, 2007; Roach and Miles, 1991; Svenningsen, Terjesen and Auflem *et al*., 1989; Ahlberg, Moussa and Al-Nahdi, 1988; AAOS, 1965)
2. Sex (Moromizato *et al*., 2016; White and Norkin, 2016; Roach *et al*., 2013; Kouyoumdjian *et al*., 2012; Gilleard and Smith, 2007; Roach and Miles, 1991; Svenningsen *et al*., 1989)
3. Body mass (White and Norkin, 2016; Roach *et al*., 2013; Kouyoumdjian *et al*., 2012; Gilleard and Smith, 2007; Roach and Miles, 1991; Svenningsen *et al*., 1989) and physical build (Moromizato *et al*., 2016; AAOS, 1965).

4. Daily activities (Moromizato *et al*., 2016; Chung and Wang, 2009; Macedo and Magee, 2009), such as occupational (White and Norkin, 2016; Chung and Wang, 2009; Felson, 2004), recreational (White and Norkin, 2016) and postural activities (Moromizato *et al*., 2016)
5. Culture (Felson, 2004; Greene and Heckman, 1994)
6. Ethnicity (Chung and Wang, 2009; Ahlberg *et al*., 1988)
7. Skeletal morphology (Moromizato *et al*., 2016)
8. Status of soft-tissue structures (Hogg *et al*., 2018; Martin *et al*., 2008; Felson, 2004; Lloyd-Roberts, 1953).

Many factors influencing ROM values such as body mass, occupational and recreational activities have not been the subject of research as much as age and sex (White and Norkin, 2016) and from the above list of influencing factors and their possible respective interactions, a great deal of research is required to know and understand their combined complexity.

As the studies within this thesis are focused on soft-tissue stretching effects to improve MR and LR ROM of the hip joint and respective measurement, the influencing factors on ROM values will not be considered any further at this point. There are however, several influencing factors that can affect the accuracy of MR and LR ROM measurement of the hip joint and the sources of measurement error that have been identified and classified are the examination, the examiner and the examinee (Stratford, Agostino and Brazeau *et al*., 1984). A protocol should be specified to maximise reliability that details procedures and instructions for the use of the instrument and conduction of the examination technique and as such, researchers should anticipate and identify sources of error that can often be controlled for (Portney, 2020, Poulsen *et al*., 2012). The examination effects on ROM measurement will now be considered and those of the examiner and those being examined will be discussed later.

The influencing factors or sources of error for MR and LR ROM measurement examination are the measurement instrument (White and Norkin, 2016; Bierma-Zeinstra *et al*., 1998); measurement position (White and Norkin, 2016; Roach *et al*., 2013; Bierma-Zeinstra *et al*., 1998) and mode of movement measured (Moromizato *et al*., 2016; Roach *et al*., 2013; Bierma-Zeinstra *et al*., 1998).

The intention of the second study in this thesis was designed to replicate the examination technique adopted to obtain the hip joint ROM data of the first study, where the same measurement technique was used throughout. The measurement of joint ROM of the lower limbs using a goniometer have generally been found to have good-to-excellent reliability and are more reliable if measurements are taken by the same examiner using the same examination methods than those obtained by different examiners (Scalzitti and White, 2016). However, the aim of the second study was to investigate the inter-tester reliability and agreement of the measurement examination technique. Irrespective, it is still worth reviewing the literature in regard to the examination rather than making assumptions and the exercise may also contribute future research decision-making.

2.7.1. Measurement instrument

Instrument choice is largely driven by the degree of accuracy required, availability of time and resources, as well as the comfort and well-being of those whose joints are being measured (Clarkson, 2013).

The standard UG is a transparent plastic 360-degree protractor, 25.0cm in length with moveable arms and a measurement scale marked in 1-degree increments (see Figure 1), which was used for obtaining MR and LR ROM measurement data from the first study in this thesis. In their text focusing on the measurement of joint ROM, Greene and Heckman (1994) assert that the use of a UG enhances the accuracy of measurement over that of visual estimation based on a study comparing the two methods of measurement of knee ROM by Watkins Riddle and Lamb *et al*. (1991). Clarkson (2013) equally asserts the UG to be more reliable than visual estimation and is considered to be the most widely used valid method of joint ROM measurement (Clarkson, 2013; Prentice, 2011, Reese and Bandy, 2010).

Generally, the accurate application of anatomical knowledge, palpation of bony landmarks, visual inspection skills and alignment of the UG, combined with interpretation of the results of ROM measurement, provides sufficient evidence to ensure content validity (Scalzitti and White, 2016; Gajdosik and Bohannon, 1987). Indeed, the reliability and validity of the UG has been established in the literature since before the turn of the last century (Simoneau *et al*., 1998). Having reviewed the literature, Clarkson (2013) stresses that there is greater intra-tester than inter-tester reliability of ROM measurement using a Universal Goniometer. However, the instrument can introduce measurement error. Small measurement errors due to play in the articulation of the UG may exist, but testers can be confident that ROM measurements are clinically valid (Gajdosik and Bohannon, 1987) and can be used with confidence for longitudinal purposes in a clinic (Nussbaumer, Leung and Glatthorn *et al*., 2010). Play in the articulation of the UG can be controlled for and will be considered later.

Reliability of measurement of joints and ROM may be affected by the complexity of a joint (Scalzitti and White, 2016; Gajdosik and Bohannon, 1987). Indeed, there are methodological issues with establishing the centre of rotation of the hip joint because it is situated deeply beneath soft-tissues and thus, affects reliability (Greene and Heckman, 1994). Alignment of centre of rotation through soft-tissues overlying the hip joint is not the only threat to reliability however and includes other factors such as segment movement control, which will also be considered later when the measurement protocols are discussed.

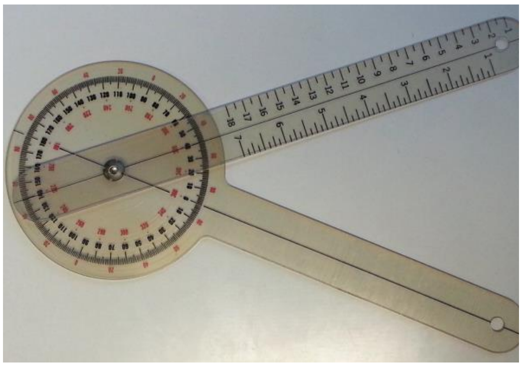

Figure 1: A standard Universal Goniometer for measuring joint ROM in degrees

Future research may require more than one tester for ROM data collection and it is therefore important to try and overcome the inter-tester reliability problem by examining the possibility of obtaining a more reliable form of measurement, which would reduce the necessity of having the same person record hip joint ROM on all occasions. Shultz *et al*. (2006) express similar concerns of the potential for more than one tester being required in the event of loss and replacement of a tester during a longitudinal study, or for a multi-centre study. Establishing the inter-tester reliability of a measurement method would increase generalisability and it can be assumed that other examiners would obtain similar results (Portney, 2020).

The use of other instrumentation has been explored, which included radiographs, digital imaging, photographs, electrogoniometer, flexometer and inclinometer, XSens 3-D motion tracking technology, an isokinetic dynamometer, Smartphone goniometer application technology and DorsaVi motion technology. Radiographs were considered impractical, non-accessible and would expose participants to unnecessary radiation risks. To obtain an X-ray of a hip joint, a suitably qualified practitioner would have to make a referral and in doing so according to the Ionising Radiation (Medical Exposure) Regulations 2017, be able to justify sufficient net benefit. Given that a hip X-ray gives a radiation exposure equivalent to seven weeks of natural background radiation (Public Health England, 2008) and would require several monitoring X-rays to measure ROM, the net benefit is considered to be dubious here. If a privately obtained plain hip X-ray costs £99.00 (Senior, 2013), the cost of serial X-ray imaging for ROM measurement would be too great and so even if clinical justification could be provided, the cost would render the method of measurement financially infeasible.

Digital imaging and the use of specialist angle measurement software has been found to have satisfactory inter-tester reliability (Lin's CCC >0.7) for the measurement of hip joint rotation (Kouyoumdjian *et al*., 2012). Digital imaging may also have comparable reliability to the UG, but this is in the measurement of knee joint ROM and the method is considered to be time consuming, requiring a digital camera and computer with angle measurement software, which are drawbacks when compared to the low cost and simplicity of the UG (Bennett, Hanratty, and Thompson, *et al*., 2009).

An electrogoniometer is similar to a Universal Goniometer with electronic readings, but is more expensive and the flexometer does not overcome hip joint ROM measurement problems experienced with a Universal Goniometer when measuring hip joint rotation, which will be discussed later. The XSens 3-D motion tracking technology (Xsens Technologies, 2012) was too expensive with a cost of over £12 thousand. The shaft encoder of an isokinetic dynamometer is an option, but is costly, impractical in terms of access and is limited to a seated measurement position, as well as being time consuming to set up and operate. Smartphone goniometer application technology is not only in need of further research to demonstrate inter-tester reliability, but again it does not address problems involved in the measurement of hip joint rotation ROM measurement in prone, which as indicated above, will be discussed later. DorsaVi motion technology remains in development and is presently time consuming through protracted calibration procedures. From observation of a demonstration, there is a measurement error risk with DorsaVi motion technology through the method of application of a single sensor and the need to control for body segment movement when measuring hip joint range of movement in a sitting position.

To date and from the above brief summary of earlier exploration of instrumentation, it would appear that the higher level technology that Clarkson (2013) recommends is either inaccessible from a safety, financial or practical perspective, or is not yet suitable for the conduction of research involving measurement of MR and LR of the hip joint in prone. In an attempt to obtain more suitable higher level technology instrumentation, protracted partnership work with the University and two local engineering companies led to a grant funded, patent application and the production of prototype hard and software designed to overcome the problem of sources of error with a view to improving inter-tester reliability. Unfortunately, the prototype device never reached a usable form.

It is argued that the best tool and method for measuring hip joint ROM still therefore remains unclear (Roach *et al*., 2013). The UG was concluded to be the preferred instrument for measuring ROM up to 1987 (Gajdosik and Bohannon, 1987) and there is no evidence of sufficiently superior instrumentation being found that is affordable, available, accessible and practicable in terms of ease and efficiency of usage with inter-tester as well as intra-tester reliability. Despite the variety of instrumentation options, the UG remains the instrument of choice for ROM measurement and concurrent validity and reliability studies in the shoulder (Kolber and Hanney, 2012) and the hip joint (Roach *et al*., 2013; Bierma-Zeinstra *et al*., 1998), as well as joint range of motion studies for multiple joints (Moromizato *et al*., 2016). The UG remains the recommended instrument of choice in international guidelines for measuring medial and lateral rotation ROM in prone of non-arthritic hip joints (Enseki, Harris-Hayes and White *et al*., 2014) and osteoarthritic hip joints (Cibulka, *et al*., 2017; Cibulka *et al*., 2009). In the absence of evidence of the UG being superseded by other valid and reliable instrumentation for hip joint ROM measurement and the presence of its continued use in international guidelines and concurrent validity and reliability studies, the UG continues to be used in research and unless an electronic device is demonstrated to be at least equivalent, if not superior, it will be retained for the purpose of any future studies. Given the above and that measurement data was obtained using the UG for the retrospective case series stretch study, the UG is unequivocally justified for reliability investigation. However, the inclinometer may be as affordable, available, accessible and practicable in terms of ease and efficiency of usage.

Unfortunately, the inclinometer is considered by the American College of Sports Medicine (ACSM) to be more difficult to stabilise than the UG because of its shape and size and whilst mounting devices may have been developed for the inclinometer to reduce measurement error, it may still require repeated adjustment of the device position to overcome the challenge posed to testers when measuring joints with pathology and pain (Swain, 2014). The inefficiency of the inclinometer and the need for repeated device adjustment therefore renders the inclinometer as inferior to the UG as an instrument for measuring MR and LR of the hip joint in prone. The continued ACSM support for the UG for more precise measurement following strict procedures (Pescatello, 2014) is therefore understandable.

As indicated earlier, mechanical instruments can be a source of measurement error through fluctuating performance (Portney, 2020). The goniometer may perish (Stratford *et al*., 1984), become damaged with the pivot point becoming loose (Carter and Lubinsky, 2016; Gajdosik and Bohannon, 1987; Stratford *et al*., 1984), which can produce small measurement errors (Gajdosik and Bohannon (1987). This necessitates continuous checking and a contingency plan would be required with the use of a clamping cylindrical spring clip being applied to hold the goniometer in place on obtaining the measurement until the obtained value is read.

In summary, the instrument used for obtaining data in the first study was the UG and as the intention was to investigate the inter-tester reliability and agreement of the measurement examination method used, the instrument choice is justified. However and from the above discussions, the use of a UG remains justifiable until such time there is evidence of sufficiently superior instrumentation being found that is affordable, available, accessible and practicable in terms of ease and efficiency of use with inter-tester as well as intra-tester reliability. Having considered the UG as an instrument, it is now necessary to consider other potential sources of measurement error when measuring hip joint rotation.

2.7.2. Measurement position

As identified earlier, measurement position appears to influence MR and LR ROM values and predominance. In theoretical literature, it is recommended for hip joint rotation to be measured either seated in 90° flexion (Kapandji, 2019; Hartigan and White, 2016; Clarkson, 2013); with the hip joint in the anatomical position of 0° flexion lying prone or supine (Kapandji, 2019; Hartigan and White, 2016; Clarkson, 2013; Green and Heckman, 1994), or supine in 90° hip and knee joint flexion (Greene and Heckman, 1994). The two most common measurement positions for measuring rotation ROM in clinical settings are prone where the subject lays face down and the hip joint in extension with the knee flexed at 90°, or in a seated position with both the hip and knee joint in 90° flexion (Simoneau *et al*., 1998), but the prone position is argued to be the most widely used (Svenningsen *et al*., 1989), preferred by most on account that the position approximates that found in most upright functional activity (Greene and Heckman, 1994). In more recent research literature, Aefsky, Fleet and Myers *et al*. (2016) and Gulgin, Remski and Sugg *et al*. (2019) have used the same argument for measuring in 0° flexion in a weight-bearing position.

Hip joint MR and LR ROM measurement techniques are standardised within the theoretical literature (Hartigan and White, 2016; Clarkson, 2013; Reese and Bandy 2010; Green and Heckman, 1994), but in essence, there is currently no standard method for measuring hip joint rotation ROM (Gradoz *et al*, 2018; Cheatham *et al*., 2017) in research with researchers measuring both AROM and PROM using the full range of positions including a supine position with the hip joint in 90° or 0° flexion, seated in 90° flexion, prone in 0° flexion (Cheatham *et al*., 2017) and weight-bearing in either a kneeling (Aefsky *et al*., 2016), or standing position in 0° flexion (Gulgin *et al*., 2019). Roach *et al*. (2013) therefore warns prospective researchers to be aware of subject and hip joint positional influences on measured ROM variability when measuring MR and LR, as it was found for example, that there was a statistically significant greater ROM in prone than in sitting (Simoneau *et al*., 1998). In addition, measuring hip joint rotation weight-bearing in a standing position, does not isolate rotation of the hip joint and may include rotation occurring at other joints of the leg such as the knee and ankle.

In the absence of bony apposition hip joint ROM can be influenced by active, or muscular, restraints, but it is largely dictated by inert capsular constraints (Hogg, 2018; Martin *et al*., 2008) and it is important to differentiate between osseous, musculotendonal and capsule-ligamentous causes of ROM restriction (Martin *et al*., 2008). Whilst soft-tissues clearly constrain MR and LR ROM, there is some inconsistency in regard to whether ROM is lesser or greater with the hip joint in 0° or 90° of hip flexion and the respective mechanism of movement restriction.

Kapandji (2019) argues that hip LR can be greater in a seated position because the ilio-femoral and pubo-femoral ligaments, the main structures limiting this ROM, are relaxed with the hip joint in 90° flexion. Indeed, Greene and Heckman (1994) also assert that the capsular structures are more relaxed when the hip joint is in 90° flexion producing a much greater rotation ROM. Agarwal *et al*. (2013) and Simoneau *et al*. (1998) both cite Fuss and Baccher (1991) and equally assert that ligamentous structures are under less tension when the hip joint is flexed such as when seated. With capsular and ligamentous structures being relaxed in a seated position, a greater rotation ROM could be expected. However, Kouyoumdjian *et al*. (2012) found no significant difference between seated and prone rotation ROM measurement. There is not only conflict within the literature on position-related differences in ROM measurement, but there is some confusion in regard to explanation of why the differences exist, which is in need of consideration.

Whilst acknowledging that ligamentous structures are under less tension when the hip joint is in a flexed position, Agarwal *et al*. (2013) and Simoneau *et al*. (1998)

identically cite Fuss and Baccher (1991) and go on to counter-argue and explain why MR and LR is more limited with the hip joint in flexion than in extension in terms of how an inferior and superior glide of the femoral head respectively limit medial and lateral rotation in sitting, where the former places tension on the inferior capsule and superior ischial ligament and the latter places tension on the superior capsule and iliofemoral ligament. Agarwal *et al*. and Simoneau *et al*. equally identically, offer how the relative tension of the capsule and ligaments when moving from prone to the seated position is unknown and go on to explain how passive tension of muscles, active insufficiency of muscle (where a muscle cannot shorten any further on contraction) and the effect of gravity may influence MR and LR ROM measurement in these positions. It would require an in-depth application of knowledge and understanding of the length/tension relationship, orientation and respective action for each muscle surrounding the hip joint in both prone and sitting to fully consider the issue of muscle tension (Agarwal, *et al*., 2013; Simoneau *et al*., 1998), which is beyond the scope of this thesis.

Standring (2005) recognises and describes spin, slide and roll movement that occurs between a concave and convex or convex and concave articular surface, such as that of the hip joint during physiological movement. It is worth noting that the terms roll and spin are used universally across the literature, but slide and glide have begun to be used interchangeably within some texts (White and Norkin, 2016), which needs to be understood when Agarwal *et al*. (2013) and Simoneau *et al*. (1998) explain femoral head gliding affecting capsular and ligamentous tension. Fuss and Baccher (1991) do identify the parts of the capsule and ligaments that are placed on tension on MR and LR, but make no such reference to the gliding of the femoral head contributing to this, as asserted by Agarwal *et al*. and Simoneau *et al*. It may be that Agarwal *et al*. and Simoneau *et al*. are actually describing a sliding and rolling movement of the femoral head in the acetabulum, which may expose the articular surface of the femoral head at the end of range of MR and LR and it is therefore perhaps the bulbous shape of the femoral head that approximates up against the corresponding portion of the capsule and respective reinforcing ligament that creates the additional tension, but this is theoretical conjecture at this point. The capsule and ligaments that allow and limit joint MR and LR were considered earlier when rotation ROM improvement stretching techniques were discussed. In the meanwhile, it is postulated that as a result of the change in position of the femoral head and subsequent change in rolling and gliding kinematics, the femoral head does not undergo a normal translator movement during medial and lateral rotation when the hip is in the flexed position and so the greater trochanter may impinge on the oblique posterior pelvic wall preventing further motion (Hollman, Burgess and Bokermann, 2003). If the greater trochanter does impinge on the oblique posterior pelvic wall on rotation of the hip joint in a flexed position, it is at least in part, bony apposition that is being measured rather than wholly soft-tissue tension. Such bony apposition is not evident in hip joint rotation when conducted in 0° flexion such as when lying prone, explaining why rotation ROM values are greater when measured in prone rather than a seated position.

Unfortunately, there is evidence of inconsistency in positional effect values when measured in the two most common positions of prone and seated position and respective values *per se*. Boone and Azen (1979) for example, found respective values of MR and LR of 44.4°±4.3° and 44.2°±4.8° to be greater in seated male adults (age range 19-54 years-old) than Roach and Miles (1991) found in younger adults, which were 33.0°±8.2° and 34.0°±6.8° respectively. Bierma-Zeinstra *et al*. (1998) found mean active MR and LR to be 46.3°±4.4° and 47.0°±4.1° and passive MR and LR to be 53.2° and 51.9° respectively in prone, whilst mean active MR and LR were found to be 33.6°±4.4° and 33.9°±3.0° and passive MR and LR to be 38.8°±4.4° and 37.6°±3.2° respectively in the seated position. The seated active MR and LR values found by Bierma-Zeinstra *et al*. are not too dissimilar to those found by Simoneau *et al*. (1998), who having determined that normative values for hip joint rotation had not been established, found MR and LR to be 33.0°±7.0° and 36.0°±9.0° respectively in young, healthy, college students (*n*=60). Both Bierma-Zeinstra *et al*. (1998) and Simoneau *et al*. (1998) by and large, support the values found by Roach and Miles (1991), where they obtained MR and LR values of 33.0°±8.2° and 34.0°±6.8° respectively in their larger sample of younger healthy adults (*n*=433). Roach and Miles 1991 found MR and LR values of 32.0°±8.0° and 32.0°±9.0° respectively in the same seated position across a larger range of ages (*n*=1683; age range 25-74 years-old).

The prone LR values of Bierma-Zeinstra *et al*. and Simoneau *et al*. are not too dissimilar either, where they respectively obtained values of 47.0°±4.1° and 45.0°±10.0°. The prone MR values were contradictory however, where Bierma-Zeinstra *et al*. and Simoneau *et al*. respectively obtained values of 46.3°±4.4° and 36.0°±9.0°. In the meantime and as indicated above, Kouyoumdjian *et al*. (2012) reported a mean greater MR ROM (37.9°±8.4°) seated with the hip joint in flexion than when lying prone with the hip joint in extension (35.3°±11.9°) and a mean greater LR ROM (41.8°±10.2°) with the hip joint extended lying prone, than when seated with it in flexion (40.7°±7.6°), but the differences were not significant.

In summary of ROM values, the majority of research findings demonstrate higher values for hip joint rotation in prone, but this is not consistent across the literature. MR values are inconsistent in both the common measurement positions with a range of 32.0° through to 44.4° when measured seated and 35.3° through to 46.3° when prone. LR values are also inconsistent with a range of 32.0° through to 44.2° when measured seated and 41.8° through to 47.0° when prone.

In summary with regard to measurement position, the inconsistency of values found in both measurement positions thus far, renders reasoned choice difficult. The prone position has been preferred by others in the research literature for a better control of the pelvis (Kouyoumdjian *et al*., 2012). Pelvic stabilisation effects and control will be considered further later, but in the meantime, it is worth noting that pelvic stabilisation can be obtained in the seated position (Pua *et al*., 2008), where subjects are seated in an isokinetic dynamometer with stabilisation belts applied across the waist, chest and the ipsilateral upper leg to stabilise the body segments above and below the hip joint, but such apparatus is not freely available. Without such apparatus the preferred alternative advocated by Kouyoumdjian *et al*. (2012) of lying prone for measurement purposes is understandable on account of simplicity and a negligibly higher correlation coefficient reliability value.

Cannon *et al*. (2018) obtained hip joint rotation values through measuring in the seated and prone positions, in order to determine if they differed between runners and non-runners. No significant difference was found between the two groups when seated, but there was when measured in the prone position. As established earlier, hip joint rotation measurement techniques are standardised, but there is no standard position for research (Cheatham *et al*., 2017). Cannon *et al*. (2018) also discuss how the measurement position is not standardised and warn that a statistical and clinical significant difference in hip rotation may be missed if measurement is conducted with the hip joint in 90° flexion, arguing that measurement in prone was more sensitive and conclude the latter should be adopted for measurement across populations.

In contrast, Hollman *et al*. (2003) were able to differentiate a significant greater rotation ROM in non-runners compared with runners when participants were seated, but not in a prone position. Cheatham *et al*. (2017) were also able to identify a significant gender difference in MR and LR in a large convenience sample of male and female weight-training participants in the seated position and Hogg *et al*. (2018) were able to detect significant gender; between sport group; and between side differences when measured lying in prone. There are clear inconsistencies in which position would detect significant group differences.

There is inconsistency of findings with a variability of ROM values found when using the two most common measurement positions of prone and seated when measuring hip joint rotation. Given this; that the two positions for rotation measurement are not interchangeable (Bierma-Zeinstra *et al*. 1998); that the two positions may be measuring two very different causes of restriction with the suggestion that bony apposition occurs when conducting rotation measurement in a seated position (Hollman *et al*., 2003), justifying avoiding measurement in flexion; that data was obtained in prone in the first study, and that research is recommended to investigate pathology affected hip joint rotation ROM in this position (Gradoz *et al*., 2018), it remains the position of choice with a view to adding to the body of knowledge on what is known in this subject area.

Measurement instrumentation and position have been considered, but mode of movement and control of body segments can be a source ROM measurement error, which will now be considered.

2.7.3. Measurement mode of movement

Joint ROM can be measured as active or passive (AAOS, 1965) with active ROM (AROM) resulting from the voluntary muscle contraction of the individual being measured and with passive ROM (PROM) being attained when an external force is applied by the examiner to move the limb (White and Norkin, 2016; Reese and Bandy, 2010; Green and Heckman, 1994).

To return to the Reese and Bandy (2010) recommendation of a ROM value of 35°-40° for both MR and LR based on analysis of pre-2010 data from across population groups with ranges for active medial rotation being from 22° (SD ±6°) for older adults aged 60-84 years-old, through to 50° (SD ±6°) for younger adults and active lateral rotation being from 32° (SD. ±6°) through to 45° (SD ±11°) for the same population groups. It would therefore be reasonable to expect the majority of expected values across a wider adult population to range from 16°-56° for active medial rotation and 24°-56° for lateral rotation. The lower values would be considered abnormal or pathological as discussed earlier, but the higher ranges of ROM remains a reasonable expectation given that the mean passive medial and lateral rotation ROM can be found to be 42.1° (SD ± 9.6°) and 43.9° (SD ± 8.4°) respectively, in a study of the available passive hip joint range of movement values in younger adults (Moromizato *et al*., 2016). The mean values found by Moromizato *et al*. (2016) only just fall within the higher range value suggested by Reese and Bandy (2010), but this would be expected given that the higher range value represents a passive ROM, which is usually as indicated earlier, greater than what can be achieved actively (White and Norkin, 2016; Clarkson, 2013; James and Parker, 1989; Haley, 1953), due to the stretch properties of soft-tissues surrounding the joint (White and Norkin, 2016). Unfortunately, Moromizato *et al*. (2016) do not report their ROM measurement technique methodology beyond the use of a goniometer in the main text of their study report, but it is made explicit within their abstract, as it is important to acknowledge the mode of motion as it influences ROM values measured (Roach *et al*., 2013).

Single-tester passive ROM measurement is difficult to perform because of the body segment fixation, moving the limb and reading the results at the same time (Bohlin *et al*., 2005; Bierma-Zeinstra *et al*., 1998). Non-uniformity in the amount of passive force is most likely the reason for greater variability in passive movement measurement between observers (Bierma-Zeinstra *et al*., 1998) and van Trijffel *et al*. (2010) concluded from their systematic review, that inter-tester reliability of passive hip joint ROM measurement remains low, which is not surprising when error can be introduced without being able to objectively measure the force applied when conducting PROM (Ellenbecker *et al*., 2007).

Keating, Matyas and Bach (1993) demonstrated how they were able to train physiotherapists to apply quantifiable forces through the use of bathroom weighing scales in order to evaluate lumbar spine joint behaviour and although Klässbo *et al*. (2003) used a similar method in an attempt to improve PROM measurement reliability using a manual force of approximately 50 newtons, test–retest intra-tester reliability was found to be high for MR, but moderate for LR. Klässbo *et al*. (2003) considered that the examiner would have required an assistant to improve the reliability of the measurement. It is recommended that the same amount of force is used to move the body part during successive PROM measurement and that the individual being measured is encouraged to exert the same effort to perform a motion during successive AROM measurement (Scalzitti and White, 2016), which presently appears to remain subjective pending the development of higher level technology that may overcome the problem of objectively controlling for the end of range pressure applied in PROM and the force applied during AROM measurement. The above suggestion by Klässbo *et al*. (2003) of using an assistant to allow the examiner to obtain a more reliable PROM measurement is presumably through the assistant controlling for and conducting body segment movement, whilst the examiner is free to focus on obtaining the measurement rather than control of body segment movement and force of passive movement. The ability to control force while stabilising the pelvis and aligning the goniometer can be difficult and may have contributed to the relatively low intra-rater reliability coefficients found in the investigatory study of MR and LR ROM in runners compared to non-runners conducted by Hollman *et al*. (2003). Controlling for body segment stability and movement will be considered further shortly. However and in the meantime, it is worth briefly reconsidering instrumentation and how it may overcome the problem of PROM measurement reliability.

Bohlin *et al*. (2005) cite Bierma-Zeinstra *et al*. (1998) in their justification for the use of an inclinometer in their inter-tester reliability study measuring hip joint ROM on the basis that the inclinometer was found by Bierma-Zeinstra *et al*. to be more reliable than the UG when measuring hip joint rotation. However, this was only for intra-tester reliability in measuring passive rotation and inter-tester reliability measuring active MR with the differences between the two instruments being small for the latter (Bierma-Zeinstra *et al*., 1998). Bierma-Zeinstra *et al*. (1998) did not report how they controlled for body segment movement, but if as they describe the zero starting position was the longitudinal axis made by the perpendicular line from the flat surface of the examination bench, the differences in reliability could have occurred because of difficulty in controlling body segment movement, rather than instrument differences, but this is speculation. Body segment movement control affecting inter-tester reliability is recognised within the literature and as indicated above, will be considered shortly, when a new control method in the measurement of hip joint MR and LR ROM is discussed. Despite Nussbaumer *et al*. (2010) concluding that the UG-based hip joint ROM measurement was over-estimated with the likely cause being uncontrolled pelvic rotation, they also conclude the UG remains the first choice tool for hip joint ROM measurement, but with the recommendation that work be conducted to improve ROM measurement accuracy.

An examiner needs to determine whether measurement of active or passive ROM is most appropriate (Reese and Bandy, 2010). Ordinarily, AROM may be measured as a screening technique to determine if the individual is willing and able to perform movement easily and painlessly and if so, PROM measurement is not needed (White and Norkin, 2016). Both modes may be used to examine ROM where PROM is first conducted to allow the individual being examined to be aware of the movement to perform, gain their co-operation (Reese and Bandy, 2010) and to give an estimate of available ROM with the examiner able to ascertain reasons for the limitation (White and Norkin, 2016) such as pain or soft-tissue tightness (Reese and Bandy, 2010). In other words, gain information on extensibility of the joint capsule, ligaments, muscle, fascia and skin (Hartigan and White, 2016; White and Norkin, 2016) through applying overpressure at the end of available range to determine the end-feel (White and Norkin, 2016; Reese and Bandy, 2010), which should be firm, leathery and not hard, largely occurring when the joint capsule and surrounding non-contractile tissue limit ROM (Reese and Bandy, 2010) and quintessentially, felt sooner in the range than usual if ROM is abnormal (White and Norkin, 2016).

As indicated above, both modes may be used to examine ROM and data from the stretch study was obtained by measuring AROM followed by examination of PROM and the end feel through the application of overpressure for comparison and tissue discriminatory purposes without measuring the quantity of PROM, which was more efficient. However and again for efficiency purposes during subsequent ROM evaluation sessions, PROM may have been conducted with the individual then being requested to hold the position actively having previously established ROM was not limited due to muscle weakness.

In summary, AROM rather than PROM may be used to prevent error introduction inherent in PROM measures without objective measures of end-point overpressure (Ellenbecker *et al*., 2007) and arguably appears to be a more reliable mode of movement, pending such technology becoming available where PROM can be measured and controlled for. Controlling for AROM in terms of the effort produced by those being measured may present reliability challenges too, but as the mode of movement for data collection in the stretch study was AROM, it remains the mode of movement choice for further investigation. From the above, both active and passive modes of movement are used to efficiently obtain an AROM measurement where a PROM is therefore first conducted to allow the individual being examined to be aware of the movement to be performed and to gain their co-operation (Reese and Bandy, 2010) in conducting an AROM on instruction to do so. On being satisfied that the end of AROM has been achieved giving an estimate of available ROM, the examiner is then able to ascertain limiting factors (White and Norkin, 2016) by then conducting a further passive force checking that any further movement is only slightly greater than what can be achieved actively (White and Norkin, 2016; Clarkson, 2013; James and Parker, 1989) to a point overpressure is applied at the end of available range to determine the end feel (White and Norkin, 2016; Reese and Bandy, 2010), which can also be detected when compensatory motion from the pelvis would be necessary to achieve additional movement (Hollman *et al*., 2003). The individual being examined is instructed at this point to hold the position actively whilst a measurement is obtained. The above method was utilised for obtaining the data from the stretch study, which further justifies the method of obtaining an AROM measurement.

The measurement instrument, position and mode of movement have been considered that can contribute to variability of measurement value and error, but there are other influencing factors that will be considered as the measurement protocols being evaluated are discussed.

2.7.4. Measurement protocols for evaluation

As identified earlier, one of the contributing factors to introducing the risk of error in the measurement of MR and LR ROM of the hip joint in prone is that the joint is situated deep to soft-tissues overlying it (Greene and Heckman, 1994). Reliability of hip joint rotation ROM measurement in prone is not just problematic due to soft-tissues overlying the hip joint however, as the trunk and pelvis may rotate with the femur when rotation is measured (see Figure 2). Segmental control of the pelvis and trunk is recognised within the literature (Nussbaumer *et al*., 2010; Bohlin *et al*., 2005;

Klässbo *et al*., 2003; Bierma-Zeinstra *et al*., 1998) and it is recommended that work be conducted to more accurately measure hip joint ROM (Nussbaumer *et al*., 2010).

Figure 2: Medial rotation of the right hip joint showing additional trunk/pelvic rotation in prone

Figure 3: Medial and lateral rotation of the right hip joint respectively, in prone showing a horizontal pelvis

One method is for both hip joints to be simultaneously measured, counter-balancing each other to maintain a neutral pelvic alignment during medial rotation and by keeping one hand on the pelvis to detect when the pelvis starts to tilt to determine when maximum lateral rotation has been achieved for measurement (Greene and Heckman, 1994). Reese and Bandy (2010) assert that when measuring medial and lateral rotation of the hip joint with the patient lying prone, there is no need for stabilising the pelvis and thigh, as the patient's weight stabilises these segments, but the physiotherapist must instruct the patient to not allow the pelvis to come off the supporting surface and then ensure this does not occur, in order to avoid inaccurate measurement (see Figure 3). Ensuring the pelvis and trunk does not rotate may be possible, but it may be inefficient through time-consumption of repeatedly controlling for segmental rotation and stabilisation of the pelvis.

One suggested method of stabilisation is to manually stabilise the pelvis (Enseki *et al*., 2014; Cibulka *et al*., 2009) or use strapping to anchor the pelvis (Clarkson, 2013). Manual stabilisation would produce resource inefficiency through the need for an assistant to undertake this and strapping application would also be inefficient or inadequately stabilise the pelvis. Cibulka *et al*. (2017) recommend the use of strapping to stabilise the pelvis citing Pua *et al*. (2008), but Pua *et al*. report intra-tester reliability in the measurement of MR and LR of the hip joint in sitting rather than in prone, where participants were required to be seated in an isokinetic dynamometer with stabilisation belts applied to the waist and chest to ensure stabilisation of the trunk. As discussed earlier, such instrumentation is not always available and practicable and the measuring method is clearly more time-consuming.

From the above, it can be seen that any standard procedure requiring control of pelvic rotation is less efficient on resources and the intention is to try and emulate the more efficient ROM measurement technique used for obtaining data in the stretch study, where only one examiner was available with time constraints within a busy clinical environment.

Failure to control the pelvis leads to problems accurately aligning the stationary or reference arm of the goniometer and thus inducing measurement error. The problem in the standard measurement protocol is clearly control of the pelvis and the need of resources to be deployed to control for it. The pelvis has to be controlled to remain in the horizontal plane to allow alignment of the moving goniometer arm with a prominent bony landmark or an imaginary line through the long axis of the lower segment of the lower limb and the static reference arm with the line of gravity (Stratford *et al*., 1984), or perpendicular to the horizontal surface of the examination couch (Bierma-Zeinstra *et al*., 1998) and floor (Hollman *et al*., 2003), which is perpendicular to the horizontal alignment of the pelvis if maintained. When prominent landmarks are not available, an imaginary line through the long axis of each limb segment should be used for alignment reference (Stratford *et al*., 1984). However, a long axis is not available for the static reference arm of the goniometer, but it can be placed parallel to an imaginary line perpendicular to the tangent of the sacrum and glutei. To increase reliability and efficiency, a new method of measurement was devised to allow the pelvis to rotate or tilt and to place the stationary arm parallel to the perpendicular (see line X-Y in Figure 4) to the tangent (see line A-B in Figure 4) of the sacrum and glutei and with the fulcrum of movement and centre of the goniometer being placed level with the centre of the apex of the patella (see point Y in Figure 4) and the moving arm to be aligned with the mid-line of the tibia, as in Figure 4. As considered earlier, provided the measurement was taken by the same examiner using the same method on each occasion of measurement, the method was assumed to be as valid and reliable as other goniometry measuring methods.

There is a need to investigate whether the new measurement protocol would retain or improve inter-tester reliability, but there are additional aspects to consider however, in terms of body segment control in active and passive movement of the hip joint and instrumentation.

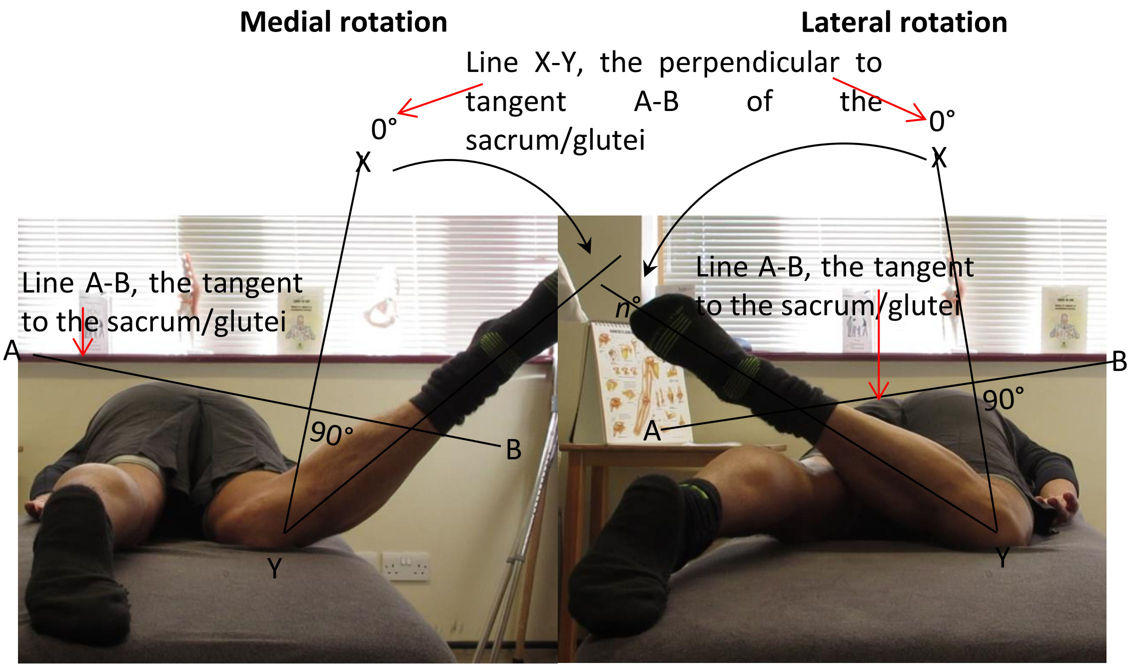

Figure 4: Medial and lateral rotation of the right hip joint respectively, in prone

In short, the new hip joint rotation measurement protocol is basically similar to the standard and the main difference is that the pelvis is stabilised in the horizontal plane using the standard measurement protocol, whereas the pelvis is free to move without stabilisation in the new. The standard measurement protocol recommended in published guidelines is in essence, where the pelvis is stabilised by an external force to ensure a valid hip joint rotation range of movement measurement is obtained (Clarkson, 2013) through detecting and preventing the pelvis tilting as maximum rotation is achieved for measurement (Greene and Heckman, 1994), which is time consuming, but unless pelvic stabilisation is undertaken the risk of measurement error is clear. Pelvic stabilisation can be achieved through the use of a belt around the examination couch and the pelvis (Norkin and White, 2016), which is again time consuming. If measurement error can be controlled for by a more efficient technique, it would be advantageous to adopt it. The new measurement protocol has never been investigated to the knowledge of the author. Therefore and in summary of the examining positions, medial and lateral rotation measurements of the left and right hip joint for both the standard and new measurement protocol are conducted with participants in prone on an examination couch, with the hip joint extended into neutral or the anatomical position, with the upper leg aligned with the mid-line and the knee flexed at 90° for the hip joint being measured. The contralateral lower limb would need to be placed in sufficient abduction to prevent the lower leg of the hip joint being measured approximating onto the opposite lower limb during LR and in neutral for MR, as illustrated in published guidelines (Reese and Bandy, 2010; Greene and Heckman, 1994).

Knowledge and understanding of hip joint capsular and ligamentous structure anatomy and their respective function is of value in defining accurate examination techniques of the hip joint (Martin *et al*., 2008). As discussed more fully earlier when considering positional effects on ROM and hip joint rotation stretching techniques, the position of measurement of the hip joint is argued from the literature, to be closer to the close-packed position of the hip joint, producing greater joint articular surface congruence and measures ROM that is mainly restricted by capsular and ligamentous structures and the closely related rotator muscles, but not bony apposition. In summary, relating anatomy to function has justified the position for measurement of MR and LR of hip joint, which is prone, the position where body segment movement can be better controlled to reduce the risk of measurement error whilst obtaining a measurement. It is possible to measure MR and LR in sitting, but not to control for body segment movement at the same time when using a UG. Irrespective of the measurement position, body segment movement control can still be challenging and whilst a standard measurement protocol from the literature describes how to control for body segment movement, it is not efficient and this places greater demand on resources such as time, equipment and the number of people involved in obtaining a measurement. The new measurement protocol has been devised that is more efficient on resources, but still controls for body segment movement. However, there is a need to evaluate the inter-tester reliability of the new measurement method in comparison with the standard to determine whether inter-tester reliability can be demonstrated.

2.7.5. Measurement examiner

The examiner can be a source of measurement error and Stratford *et al*. (1984) identified three aspects as being responsible for this, which are the method of recording the angle, the end-digit preference and expectation. The end-digit preference is a potential source of error for the reader of a measurement value and will be considered later. The examiner expectation (Stratford *et al*., 1984) and unconscious examiner bias, which can influence measurement (Portney, 2020) will be considered shortly. Whilst the method of recording the angle may be a source of examiner error (Stratford *et al*., 1984), examiner experience (White and Norkin, 2016) or a lack of skill (Portney, 2020), not following a protocol, or being distracted can influence measurement (Portney, 2020) and measurement data can be inaccurately recorded or transcribed. Therefore, a rigid and standardised measurement protocol should be used for ROM measurement (Portney, 2020; Heyward and Gibson, 2014; Clarkson, 2013; Poulsen *et al*., 2012; Prentice, 2011; van Trijffel *et al*., 2010; Bohlin *et al*., 2005; Dijkstra, *et al*., 1994) and rigorous training of testers (Portney, 2020; Poulsen *et al*., 2012) are recommended in hip joint range of movement measurement and inter-rater reliability research to improve reproducibility. Indeed, Poulsen *et al*. (2012) made their recommendation after concluding inter-rater reliability was poor using a UG in the measurement of ROM in those with OA of the hip joint.

A standardised measurement procedure protocol coupled with respective training designed to reduce disparity of examiner experience or lack of skill; and enable examiners to focus on measurement will therefore be required to be written and evaluated to determine if inter-tester reliability and agreement can be achieved using both the standard and new measurement protocol.

Having established from the literature that no previous studies had investigated experienced and novice examiner reliability and recognised that there was no standardised position for measuring hip joint rotation, Gradoz *et al*. (2018) were able to demonstrate novice and experienced tester inter-tester reliability with training and the use of a standardised measurement protocol for measurement with the hip joint in flexion obtained in a seated and supine position. Gradoz *et al*. also acknowledged that hip joint flexion influences rotation ROM values with higher values expected in prone on account for example as discussed earlier, a decreased potential for bony abutment. Gradoz *et al*. went on to recommend that future research should investigate reliability in those with hip joint pathology and should include measurement in prone. This recommendation is understandable given that measurement in prone is one of two most common positions for measuring hip joint rotation (Simoneau *et al*., 1998). Gradoz *et al*. have therefore demonstrated that examiner experience can be controlled for by standardisation of the measurement method and training as recommended (Poulsen *et al*., 2012). If it was possible to demonstrate inter-tester reliability between a novice and experienced tester when measuring hip rotation in prone following standardisation of measurement and training, it could be deduced that tester experience does not affect measurement, provided other control measures are in place to reduce measurement error.

Whilst examiner performance of hip joint rotation measurement in prone can be controlled for through the use of training and a standardised measurement protocol, as indicated above, examiner expectation (Stratford *et al*., (1984) and unconscious examiner bias (Portney, 2020) is in need of being controlled for through covering one side of the goniometer in order to blind the examiner from the measurement value scale (Portney, 2020; Han, Kubo, and Kurosawa *et al*., 2015; Stratford *et al*., 1984).

2.7.6. Measurement examinee

It is argued that the results of intra-tester and inter-tester reliability studies with patients generally support the findings reported for healthy subjects (Gajdosik and Bohannon, 1987) and if the reliability of a new instrument to measure ROM should always be tested on healthy participants first (Bierma-Zeinstra *et al*., 1998), the same could be argued for the testing of a new measurement protocol. Conversely, Carter and Lubinsky (2016) assert that the results of reliability studies can only be generalised to the participants studied and the reliability of an instrument should therefore be determined using individuals on whom the instrument is intended for use.

If a population sample with healthy unaffected hip joints were to be selected, it may not produce ROM data that is as low as would be found in those with a pathology related reduction of ROM, which is a population of interest for future research and so the assertion of Lubinsky and Carter is understandable. Equally, if a population sample with unhealthy hip joints were to be selected, it may not produce ROM data that is within the normal or higher range. It is therefore important in reliability studies to ensure the sample has some variance where examinees have a range of scores across the continuum to show reliability; demonstrate sufficient specificity to detect a normal ROM and sensitive enough to detect a low ROM (Portney, 2020) and using a mixed group of participants may be the ideal for establishing the reliability of a measurement instrument and technique (Carter and Lubinsky, 2016).

Many factors influence ROM values, such as age, sex, occupational and recreational activities (White and Norkin, 2016) and as previously discussed, a reduced ROM is associated with other population groups such as those with OA of the hip joint (Hartigan and White, 2016) and back pain (Ellison *et al*., 1990). Lower hip joint ROM as considered earlier, is also associated with those who participate in hip and spinal rotation sporting activity (Sadeghisani *et al*., 2015) and other sports such as judo (Almeida *et al*., 2012), runners (Hogg *et al*., 2018; Hartigan and White, 2016) recreational weight-training participants (Cheatham *et al*., 2017), football (Nguyen *et al*., 2017; Tak *et al*., 2015; de Castro *et al*., 2013), American football (Deneweth *et al*., 2014) tennis and baseball (Ellenbecker *et al*., 2007). To obtain a mixed group of participants with a variance of ROM values, it would be pertinent to include those who participate in recreational physical activities recreational exercise, sport and physical activity and provided those with any history of hip joint or spinal problems were not being investigated or treated at the time, they could be included within such a study. Such a participant recruitment strategy should ensure variance in ROM values within a sample.

2.7.7. Measurement readings

Inter-tester reliability is best assessed when both examiners are able to measure simultaneously independently of one another, but this is not possible with ROM testing (Portney, 2020) as there would be an inherent delay between examiners being able to conduct the measurement.

As identified above, end-digit preference can be a source of error and is more of an issue when the instrument is calibrated in 2.5° or 5.0° increments, but less so when 1.0° increments (Stratford *et al*., 1984). Nevertheless, it is possible that an examiner may obtain a readable value between one of two degree increments when blinded from the reading obtained and end-digit preference still therefore needs to be made explicit.

Using the mean of two or more readings, tests or trials may be effective in reducing overall error, especially for less stable measurements (Portney, 2020). The terms of readings, measurements, trials and tests are each used within the literature and for the purpose of this thesis, the term readings will be used to reduce ambiguity when considering the number of measurements obtained by one examiner. There is inconsistency in the literature regarding the number of readings required with goniometry ROM measurements (Scalzitti and White, 2016) where it is recommended that the mean of several readings are required to increase reliability

(Scalzitti and White, 2020; Low, 1976), but it is equally argued that one reading is as reliable as the mean of repeated readings (Scalzitti and White, 2020; Boone *et al*. 1978). It is advised by Scalzitti and White (2016) that inexperienced examiners may wish to take several readings and record the mean to improve reliability, but one measurement is usually sufficient for more experienced examiners using a good technique. This suggests that if a standardised measurement protocol and training were available as indicated above, an inexperienced examiner may be as equally reliable as one who is experienced.

Mosler, Crossley and Thorborg *et al*. (2017) conducted two readings for each measurement when investigating the normal hip joint ROM in football players using a goniometer as did Kolber and Hanney (2012) in their reliability and concurrent validity study measuring shoulder ROM using an inclinometer and goniometer. Gulgin *et al*. (2019) reported using the mean of three readings of hip joint MR and LR ROM values in their investigation of normal ROM in a weight-bearing position. Muscle fatigue can be a source of measurement error (Portney, 2020) and if active ROM were to be maintained for the duration of two, or three readings for the first examiner, fatigue risk may affect the readings of the second examiner.

Conversely, Roaas and Andersson (1982) reported the use of a single reading in their study designed to determine normal ROM in the hip, knee and ankle in their sample of male subjects using a goniometer, but a supporting rationale was not reported. Simoneau *et al*. (1998) conducted a single reading in their investigation of measurement position and gender effects on hip joint rotation, but reported no rationale and neither did Ellison *et al*. (1990) in their investigation involving the evaluation of patterns of available hip joint ROM. Klässbo *et al*. (2003) report using a single reading to avoid treatment effect in their investigatory study of PROM and capsular patterns in the hip joint. Macedo and Magee (2009; 2008) also obtained a single reading for each movement measured to reflect what is normally undertaken in clinical practice for their multi-joint ROM studies where one study investigated dominant side effects and the other investigated age-effects. However, the single reading was also undertaken with a view to minimising any carryover effect and to control for any viscoelastic changes that may be induced in the tissues with repeated readings (Macedo and Magee, 2009; Macedo and Magee, 2008; Nigg, Nigg, and Reinschmidt, 1995).

From the above, a single reading measurement is therefore understandable if the mean value of two or more readings are recorded from one examiner in a reliability study, which could go on to affect the values obtained by a second examiner.

Cheatham *et al*. (2017) selected to use a single measurement reading of the right and left hip joint and the mean of the two values were used for the reliability analysis aspect of their study reporting the PROM values of hip joints in weight-training participants, to develop reference data for future research on injury patterns and prevention strategies for this population. Boone and Azen (1979) used a single reading of AROM in their study investigating the normal ROM of multiple joints in male subjects and indeed report that repeated readings from an earlier study produced nonsignificant variation and therefore concluded that one measurement per measurement session is as reliable as taking the average of repeated measurement readings in one session (Boone *et al*., 1978). On this basis, Cannon *et al*. (2018) also selected to use a single reading measurement for their comparison study of hip joint rotation ROM of runners and non-runners. Whilst Cannon *et al*. (2018) express how a single reading may have been a limitation of their study they justified it as an additional part of their investigation as it was consistent with clinical practice. This supports the earlier study conducted by Hollman *et al*. (2003), who investigated positioning effects on hip joint rotation ROM in runners and non-runners and equally used a single reading measurement asserting that their measurement methods were representative of those used clinically.

In summary, there is inconsistency within the literature on the number of measurement readings that should be obtained by an examiner in one measurement session. The mean of two or more readings may improve reliability and is suggested for those with lesser experience. There is evidence of reliability studies being conducted where the advice from research methodology has been followed using the mean of two or more readings. However, there is also evidence within the literature of reliability studies being undertaken where only one reading was obtained, especially where clinical practice was being replicated. This procedure is supported by others who were interested in investigating the inter-tester reliability of hip joint ROM measurement results reflecting current clinical practice (Poulsen *et al*., 2012).

The measurement instrumentation and technique has been identified for testing and the following research question is therefore in need of answering.

Can inter-tester reliability and agreement be demonstrated in a new measurement protocol and how does it compare to that of a standard measurement protocol when measuring medial and lateral hip joint ROM in prone using a Universal Goniometer?

3. Retrospective case series analysis: The effects of a stretch protocol on hip joint rotation range of movement

3.1. Introduction

Normal joint ROM is required for joint health, movement and function, which is necessary for the nutrition and growth of articular cartilage and bone (Curwin, 2011). A reduced ROM is considered to be pathological if the joint fails to reach normal anatomic limits of motion permitted by capsular and ligamentous structures, producing undesirable effects on the affected joint and adjacent structures (Curwin, 2011). Full joint ROM is not only a fundamental requirement for efficient human movement, but it allows the joint to adapt to imposed stresses and reduce injurious risk (Reese and Bandy, 2010).

Features of early hip joint OA have been found to be associated with lower ROM (Holla *et al*., 2011). Whilst a reduction in MR is considered to represent an early sign (Dvořrák *et al*., 2008), LR is also noted to be restricted in some patients with hip joint OA (Holla *et al*., 2011). Pisters, Veenhof and van Dijk *et al*. (2012) identified reduced hip joint ROM as being a predictive factor in the development of further limitations and future decline in functional activities of those with hip joint OA and recommend targeting this predictive factor in treatment programmes to prevent the further functional decline and the associated negative consequences such as co-morbidity development.

The acetabular labrum is a ring of fibrocartilage that deepens the acetabulum and acts as a seal giving stability to the hip joint (Takechi *et al*., 1982) through a vacuum effect (Standring, 2005). Modelling (Ferguson *et al*., 2000) and *in-vitro* studies (Ferguson *et al*., 2003) support the suggestion of the structure forming a seal contributing to increasing hip joint stability, maintenance of hyaline cartilage health and overall joint function and is therefore in integral need of protection to help prevent joint degeneration. If the acetabular labrum is compromised, the joint seal is reduced with a loss of the negative pressure, producing a structural instability that increases translation forces of the femoral head (Martin *et al*., 2008), which may lead to early degenerative changes such as OA (Hudgins and Alleva, 2012). Evidence suggests a correlation between reduced hip joint rotation and femoroacetabular impingement (Kapron *et al*., 2012). A reduced hip joint rotation has also been suggested to be associated with other conditions such as low back pain (Ellison *et al*., 1990).

There is a clear need to improve hip joint rotation ROM where it is determined to be restricted to maintain joint health and potentially reduce the risk of associated pathological and other related conditions, but there is no definitive evidence of how this may be achieved. Stretching techniques are supported in the theoretical literature to increase hip joint rotation ROM. However from systematic reviews, there remains insufficient evidence to support such an intervention (Harvey *et al.*, 2017; Katalinic *et al.*, 2010). Nevertheless, stretching remains recommended in national guidelines as an adjunct to core treatment such as muscle strengthening, despite such an intervention being recognised as having less well-proven efficacy (NCGC, 2014; NICE, 2008). There is clearly a need to investigate therapeutic interventions such as stretching techniques designed to improve hip joint rotation ROM. Indeed, research is highly recommended on the effectiveness of stretching as an intervention for increasing joint ROM *per se* (Harvey *et al.*, 2017; Katalinic *et al.*, 2010).

Intervention decisions frequently require reference to theory in the absence of evidence (Portney, 2020) and the underpinning tissue adaptation theory discussed in the literature review of this thesis has therefore been applied. Theoretical prescription guidance for physiotherapy intervention has emerged in the literature and the DRIFTS Model has been applied to increase the specificity of the stretch technique designed to target a restriction of hip joint rotation ROM. This study is interested in exploring the effects of this stretch protocol on hip joint rotation ROM measured in a prone position.

This chapter therefore presents a retrospective descriptive case series study (Bowers, 2020; Portney, 2020) exploring the behaviour of hip joint ROM where patients were exposed to a specified stretch protocol. A case series involving observations in several similar cases gradually develops a form of "…case law…" whereby empirical findings are considered reasonable and a conceptual framework forms providing a basis for generating hypotheses and using more formal experimental methods (Portney, 2020). Historical data access and analysis is recognised as a research method and as with all research, the data must be evaluated for authenticity as an accurate primary source record, extracted, synthesised and analysed within an objective frame of reference with a view to anticipate future events (Portney, 2020). The format for case series research reporting differs from that of formal experimental studies and is presented as recommended by Portney (2020).

Descriptive exploratory research such as case series studies (Portney, 2020) do not always generate a specific research question in advance of being conducted, but may suggest such a question (Bowers, 2020). The question generated for the first study in this thesis is therefore as follows:

Is there evidence from retrospective case series data to demonstrate that a stretch protocol increases medial and lateral hip joint ROM over a three-month time period?

3.2. Purpose

The primary purpose of this study was to determine whether there was any significant statistical and clinically important evidence to support the effectiveness of a stretch protocol improving hip joint ROM and if so, the secondary purpose was to determine the effect size and whether the three-month timescale was sufficient to obtain a statistically and clinically important change. The study and subsequent results will inform future research design and planning.

3.3. Case description

Published guidelines advocate that normal active hip joint MR and LR is 40° and 50° respectively when measured in a neutral position (AMA, 1984) with the recommended measurement being conducted in prone (Rondinelli *et al*., 2008; AMA, 1993).

All cases had their hip joint rotation ROM measured and examined to determine the reasons for any limitation ascertained (White and Norkin, 2016) such as pain or soft-tissue tightness (Reese and Bandy, 2010). Information was gained on the extensibility of hip joint soft-tissue structures (Hartigan and White, 2016; White and Norkin, 2016) through applying passive overpressure at the end of available measured active ROM to determine the end-feel (White and Norkin, 2016; Reese and Bandy, 2010), which should be firm, leathery and not hard, when the joint capsule and surrounding non-contractile tissue limit ROM (Reese and Bandy, 2010). A firm end-feel will be felt sooner in the range than usual if ROM is abnormal (White and Norkin, 2016).

3.4. Intervention

Following a review of clinical trials involving joint contractures on those with spinal cord injury, Harvey *et al*. (2011) with an interest in restricted joint ROM conclude from reviewing the literature, to expect no change in joint mobility from stretches that are less than 30-minutes per day using devices, splints and orthoses over a time period of less than 3-months. The stretch technique and duration would be impractical for those with a restricted rotation ROM in the hip joint, but the three-month advocated timescale seemed to be consistent with observed improvement of ROM findings from those exposed to the stretch protocol in this study. Baseline measurements of active hip joint MR and LR ROM were obtained prior to intervention and repeat measures were obtained at varied time-intervals, as evaluation session frequency was determined by various factors such as clinical need, personal availability, appointment availability and affordability. Importantly however, ROM values were obtained at the three-month time point.

The stretching prescription of hip joint rotation was applied in the direction of identified restriction of ROM measurement as discussed in the literature review and was conducted with an intensity of most tolerable subjective discomfort for an objective duration of sixty-seconds, on a once per day basis (independent variable) as taught, at a time and place most convenient to the patient using their preferred position and mode, as considered in the literature review. The effectiveness was evaluated through an active hip joint rotation measurement (dependent variable) conducted at baseline and at the three-month time period in a prone position using a standardised measurement protocol, as discussed in the literature review. The stretch intervention was continued on a daily basis until a more normal ROM was achieved in line with published guidelines where a normal active hip joint is respectively considered to be 40° and 50° for MR and LR, when measured with the hip joint in a neutral position (AMA, 1984) and as recommended with the patient in a prone position (Rondinelli *et al*., 2008; AMA, 1993). The timescale for the stretch intervention and repeated measurement may in some cases have extended beyond the three-month timescale if ROM was in need of further improvement.

It is not usual to continue to collect data of the unaffected hip joint after baseline measurements are obtained, as the focus of clinical attention is placed on the affected joint and so the data for the unaffected joint was not available beyond baseline measurements for comparison. From the historical clinical records, ROM was monitored along with associated symptoms and function, but hip joint medial and lateral rotation range of movement measurement was the only outcome measure of interest for the purpose of this study, in order to determine whether there was evidence of improvement of hip joint rotation.

3.5. Outcomes

3.5.1. Measurement procedures

All hip joint rotation ROM measurements were conducted on a standard physiotherapy examination couch using a standard Universal Goniometer, a transparent plastic 360-degree protractor which is 25.0cm in length with moveable arms and a measurement scale marked in 1-degree increments, as discussed in the literature review (see Figure 1). The reliability and validity of the UG has been established in the literature (Simoneau *et al*., 1998) and it has greater intra-tester than inter-tester reliability (Clarkson, 2013). Indeed, the UG is the most widely used valid instrument used for joint ROM measurement (Clarkson, 2013; Prentice, 2011, Reese and Bandy, 2010). All ROM measurement data was obtained by the same tester.

The influencing factors and sources of error that can affect the accuracy of MR and LR ROM measurement have been discussed in justification of the use of a standardised protocol in the literature review. Typically, physiotherapists usually conduct measurements on their own (Bohlin *et al*., 2005) and stabilisation of the pelvis is not common practice in the clinical setting, due to time-constraints and it is therefore recommended that clinicians pay attention to the possibility of substitution techniques that may reduce measurement error (Simoneau *et al*., 1998). If the pelvis is not stabilised the static reference arm can be aligned parallel to an imaginary line perpendicular to the tangent of the sacrum and glutei. The measurement method for obtaining ROM data was therefore an adaptation of a standard method designed to be more efficient, but retain reliability, also as discussed in the literature review.

3.5.2. Data handling and statistical analysis methods

The hand-written demographic and raw ROM data was anonymised and analysed using *MS Excel* (Microsoft, 2010) and *IBM SPSS Statistics 24.0* (IBM Corp., 2016). Descriptive statistics of raw data including measures of central tendency and dispersion such as the mean and median for the former and range and standard deviation (SD) for the latter, were calculated for affected joints at the baseline and three-month point for comparison analysis and clinical interpretation purposes.

The conventional alpha or significance levels were set at $p = \leq .05$ (Petrie and Sabin, 2020; Portney 2020; Carter and Lubinsky, 2016; Pallant 2016; Pituch and Stevens, 2016). Preliminary analysis of the ROM data between baseline and three-month measurement point was conducted to determine whether the assumption of normality had objectively been met using the frequency distribution Shapiro-Wilk statistical test, required to determine whether parametric or non-parametric tests were to be used for inferential statistical analysis (Petrie and Sabin, 2020; Portney, 2020; Pallant, 2016). Where the assumption of normality was met the paired-samples *t*-test was conducted comparing the mean differences (Petrie and Sabin, 2020; Portney, 2020; Carter and Lubinsky, 2016).

Effect sizes were calculated to quantify the size or magnitude of the differences (Carter and Lubinsky, 2016; DePoy and Gitlin, 2016) where an effect size of 0.20, 0.50 and 0.80 are considered small, medium and large respectively using Cohen criteria (Pallant, 2020; Portney, 2020; Carter and Lubinsky, 2016; Cohen, 1988) for the paired *t*-test.

3.5.3. Ethics

It is important that clinicians and researchers take precautions to protect patient privacy in case series reports (Portney, 2020). All patient data collected during research is confidential, must be protected and unidentifiable by anyone outside the research project by law through the Data Protection Act (Hicks, 2009). All patient-related personal and clinical information and data was treated as highly confidential with paper-based information being stored in a lockable storage cabinet/container. All transcribed data including case names, demographic data and raw hip joint ROM values were therefore electronically saved and encrypted to preserve and confidentially safeguard the data, which was then anonymised for statistical analysis.

Patients must always give consent for the use of any identifiable information (Portney, 2020), but no identifiable information was to be used for analysis. Nevertheless, such retrospective studies may undergo an expedited ethical review if it is clear that all patient information is anonymised and no potentially sensitive information is involved and it is therefore advisable to check (Portney, 2020). Ethical approval was therefore requested and obtained from the University of Cumbria's Research Ethics Panel (see Appendix 1).

3.5.4. Results

Preliminary analysis revealed the assumption of normality for the ROM differences between baseline and month three data was met for both MR and LR using the Shapiro-Wilk test (MR, $p = .874$; LR, $p = .318$).

A paired-samples *t*-test was conducted to evaluate the impact of the stretch protocol and there was a mean increase of hip joint medial rotation range of movement from baseline (mean = 26.38°, *SD* = 5.49°) to month three (mean = 36.46°, *SD* = 5.25°). This was found to be statistically significant; *t* = (25) = -11.099, *p* = <.001, two-tailed. The mean increase of MR ROM was 10.08° (±4.63°) with a 95% confidence interval ranging from 8.21° to 11.95°. The effect size (3.078) indicated a large effect.

There was also a mean increase of hip joint lateral rotation range of movement from baseline (mean = 37.18°, *SD* = 9.37°) to month three (mean = 51.56°, *SD* = 9.33°), which was also found to be statistically significant; *t* = (42) = -15.707, *p* <.001, two-tailed. The mean increase of LR ROM was 14.37° (±6.00°) with a 95% confidence interval ranging from 12.53° to 16.22°. The effect size (3.387) indicated a large effect.

The Baseline ROM for hip joints that were exposed to the stretch protocol is presented in Table 3, where the results can be compared with the Month 3 measurement point.

Table 3: Baseline hip joint rotation ROM compared with the Month 3 measurement point following intervention with the stretch protocol

Measure	Baseline ROM ±SD	Month 3 ROM ±SD
Medial Rotation (*n* = 26 hip joints)		
Mean Median	26.38° ±5.49° 26.0°	36.46° ±5.25° 37.5°
Lateral Rotation (*n* = 43 hip joints)		
Mean Median	37.18° ±9.37° 37.0°	51.56° ±9.33° 52.0°

3.6. Discussion

The primary aim of this retrospective case series data analysis study was to determine if a prescribed stretch protocol increased medial and lateral rotation of the hip joint.

The secondary aims of this study were as follows:

To determine the effect size to contribute to *a priori* sample size calculations for future research (Portney, 2020) and whether the three-month time-scale was sufficient to obtain a statistically and clinically important change, which would assist in anticipating the time-scale required for future research (Portney, 2020).

To the knowledge of the researcher, no research has been conducted to evaluate the effectiveness of such a specific stretch protocol designed to improve restricted medial and lateral rotation ROM of the hip joint.

There was a statistically significant increase of mean hip joint MR ROM from a baseline value of 26.38° (± 5.49°) to 36.46° (± 5.25°) in month three. The mean increase of MR ROM was 10.08° bringing the month three MR ROM value close to what is considered to be within the normal limits as recommended by the AMA (1984) in their published guidelines and discussed in the literature review, which is reported as 40.00°. The same applies with LR where there was a statistically significant increase of mean ROM from a baseline value of 37.18° (±9.37°) to 51.56° (±9.33°) in month three. The mean increase of LR ROM was 14.37° bringing the month three LR ROM value close to what is considered to be within the normal limits as recommended by the AMA (1984) in their published guidelines and discussed in the literature review, which is reported as 50.00°. The resultant increase in MR and LR ROM is therefore also considered to represent a clinically important change.

As considered in the introduction of this chapter and more fully discussed in the literature review, a full hip joint ROM is required for joint health with a reduction being considered pathological and associated with further pathology, pain and a loss of function. Preserving and improving hip joint ROM may have implications beyond joint health and may contribute to improved general health, if for example, it allows exercise activity that may reduce the risk of comorbidity such as cardiovascular disease and it may also help reduce healthcare provision costs. Hip joint replacement surgery is reported to be substantial with an increasing excessive rate (Kim, 2008) and if healthy joint ROM can be preserved and improved, the burden of joint replacement surgery rates and costs could be reduced.

Whilst it may be biologically plausible (Jewell, 2015) that the stretch protocol may be effective in reducing hip joint hypomobility, this study represents one of the first steps for the researcher to begin to address the gap in research, knowledge and understanding of such soft-tissue adaptation on a macro-level. However, this study does not contribute to what occurs at micro-physiological, anatomical and pathological levels which would need to be investigated through micro-cellular studies to support and develop theoretical notions to a point of knowing and understanding tissue-adaptation further. As discussed in the literature review, the effects of stretching at a micro-level are unknown. Theoretical literature supports the notion that soft-tissue plastically deforms (Glynn and Fidler, 2009; Siff, 2005) through the stress-strain, load and plastic deformation theory (Özkaya, Leger and Goldsheyder, *et al*., 2018; Nordin and Frankel, 2012; Curwin, 2011; Frank, 1999; Özkaya and Nordin, 1999; Butler, Grood and Noyes *et al*., 1978), occurring when such tissue is loaded beyond their elastic or yield limits. It is asserted that the soft-tissues will not return to their original state due to tissue fibres unravelling or local therapeutic inflammatory responses signalling a structural change (Anderson, 2014). It is also suggested that plastic deformation responses include micro-failure of collagen fibres leading to subsequent collagen synthesis and reorganisation of new tissue components (Irani, Vennix and Jain (1995). It has been concluded from a systematic review however, that deformation represents an immediate effect that is not sustained (Katalinic *et al*., 2010), that stretching does not have a clinically worthwhile short-term effect on joint mobility and that stretching administered for many months or years is unknown (Harvey *et al*., 2017). It is hypothesised here from the theoretical literature and results of this study, that there may well be unravelling of tissue fibres which may not be sustained, but it is believed that transient, low grade, local inflammatory responses may occur, produced by soft-tissue tension induced ischaemia with the ischaemic effect possibly being the trigger or catalyst that leads to adaptive lengthening of tissue, through fibroblast cell proliferation and collagen synthesis. However, this is pure conjecture in the absence of evidence of what occurs at micro-level through stretching-induced joint capsular and ligamentous tension. In addition, inflammatory responses at a micro-level are highly complex and beyond the scope of this thesis. However, if adaptive soft-tissue lengthening requires the above hypothesised micro-level effects, it is little wonder that short-term effects of stretching are not sustained and a greater period of time is required for such changes as this study suggests. As considered in the literature review, sometimes studies of structure, function and responses need to be conducted at macro- ahead of a micro-level (Frost, 2003), as this study has with ROM behaviours. Also as considered in the literature review, it is hoped that new emerging technology will be developed and become available to allow collagenous soft-tissues to be studied *in-vivo* at micro-level in the near future (Silver and Shah, 2017), which would present further research opportunity if a stretch protocol can be demonstrated to be effective at a macro-level. At this juncture, it may become possible to advance the work of Davis (1867), mathematically test for increased lengthening of soft-tissue using the stress-strain theory calculation where the pre-stretch measured value of a soft-tissue is deducted from that of a post-stretch length value, with the resultant value then being divided by the pre-stretch value to provide a percentage increase (Curwin, 2011). This would contribute to progressing Davis' Law from being theoretical to becoming scientific, if improvement could be tested, demonstrated and then become predictable (Frost, 2003). From the current study, angles of ROM are being used and if that is what is being measured rather than the length of specific tissues (Gajdosik and Bohannon, 1987), it may need technology that can measure tissue length of a linear ligament such as a collateral ligament of a knee to prove Davis' Law. Unfortunately, a new generation of clinically viable technologies are still needed for *in-vivo* soft-tissue length measurement and to facilitate data driven progression of rehabilitation intervention (Zhang, Adam and Nasab *et al*., 2021). In the meantime and pending being able to measure linear change, it may be possible to apply the linear equation to that of angles of ROM by deducting the pre-stretch ROM value from the post-stretch ROM value and dividing the result by the pre-stretch ROM value to give a percentage increase in ROM. If it is accepted that a combination of soft-tissues permit and restrict joint ROM, which is subsequently increased having been confirmed that restriction was due to soft-tissue constraints, the soft-tissues could be said to have adapted in length. This would include the inert capsular and ligamentous structures of the hip joint that largely dictate and constrain rotation (Hogg *et al*., 2018; Martin *et al*., 2008). As discussed within the literature review and above however, what is thought to be occurring at a soft-tissue cellular level remains theoretical.

From the literature review, the philosophical origins of soft-tissue adaptation theory being specifically applied to joint capsules and ligaments can be traced back to Davis (1867). However, evidence for the specificity of intervention to adaptively lengthen such soft-tissues to increase hip joint rotation ROM remains to be discussed relative to the results of this study. The DRIFTS Model (Chamberlain, 2017; Chamberlain *et al*., 2013) has been successfully operationalised to evaluate and guide stretch prescription specificity and although the theoretical model requires a logical order adjustment, it is recommended for use in physiotherapy research and practice. The logical prescription order and an example summary of current stretching prescription guidance from within the literature, can be seen in Table 4, where the gaps in stretching prescription are made clear, together with how the plausibly effective stretch protocol from this study, initiates the process of increasing stretch prescription specificity to improve hip joint rotation ROM.

Clinical guidelines and organisations such as the Arthritis Research UK and Arthritis Care can only provide stretching information and guidance where there is research evidence to support it and in the absence of such evidence, there is dependence on guidelines from consensus and expert opinion (Bennell, 2013; Rannou and Poiraudeau, 2010). Clearly from the literature and the Table 4 comparison, more research is required in this field and as indicated above, this study represents the first step toward increasing stretching prescription specificity, which could be transformational for clinical and organisation guidelines, physiotherapy effectiveness and patient health outcomes in the fullness of time, if future research were to unequivocally demonstrate the effectiveness of the stretch protocol.

This current study suggests a single daily stretch may increase hip joint rotation ROM, but it is not known whether the frequency of the stretch is to be continued to maintain ROM, or whether the frequency can be reduced to a weekly maintenance technique for example. More research is required to determine what is required to maintain and prevent a recurrence of any loss of ROM.

The reason for the improvement in ROM may extend beyond physiological effects however. Researchers should try to ensure participant adherence as this could influence the results (Portney, 2020). The minimising of dosing frequency and the tailoring of techniques so that they can be integrated into the lives of patients and participants coupled with the setting of goals can enhance adherence (Robiner, 2005) and private funding may encourage the same. The minimising of the stretch prescription and conduction of ROM measurement is believed to encourage adherence and although the results of an improved ROM suggest this, other strategies may be necessary in other milieus. It is therefore recommended that adherence enhancement strategies are adopted in future research in addition to goal setting, such as providing social support, encouraging reminders and monitoring through a self-reporting journal or log (Robiner, 2005).

Table 4: Literature-based prescription guidance for hip joint stretching

Reference source	Technique	Intensity	Duration	Repetitions	Sets	Frequency
Cibulka *et al*. (2017)	Individualised to address the most relevant impairment of hip joint ROM	Not specified	Not specified	Not specified	Not specified	1-5/week for 6-12 weeks
Meira & Wagner (2015)	Longitudinal traction with progressive increase in ROM in all directions as tolerated, together with gentle stretching into combined flexion, abduction and lateral rotation as tolerated	Not specified	Not specified	Not specified	Not specified	Not specified
Arthritis Research UK (2014)	Lateral rotation Flexion	As far as they safely and comfortably can be, feeling a stretch in the muscles around the joint	5-10 secs	5-10	Not specified	Not specified
Arthritis Care (2015)	Flexion Abduction Lateral rotation	Through comfortable range, feel a soft pull & ease a little further	Not specified	3-10 & build-up repetitions slowly	X 1	X 2/day
This study	Medial rotation Lateral rotation	To the point of tightness and highest level of tolerable discomfort	60 secs	X 1	X 1	X1/ day

Whilst this study provided the opportunity to apply the theoretical DRIFTS Model as indicated above, the stretch prescription requires further discussion. This study suggests a daily single rotation stretch for the duration of sixty seconds may plausibly improve respective hip joint ROM, but participants were free to choose their preferred or most convenient position and mode to conduct the stretch technique. For example, some used a sitting, whilst others used a prone position, as it is important for physiotherapists to involve patients in shared and reasoned decision-making (Roberts and Langridge, 2018). Knowledge and understanding of capsule and ligamentous structure and function is important in determining treatment strategies to attain favourable outcomes (Martin *et al*., 2008), which is the clinical expertise required to enable the above shared and reasoned decision-making and providing the informed choice. The end of range rotation of the hip joint was still obtained however, regardless of the stretch position and mode and duly evaluated through ROM measurement. Thus, bringing together the best available evidence and clinical expertise for the evidence-based practice discussed above (Jewell, 2015). Although the direction accuracy and end of range rotation was attained in this study, placing restraining soft-tissues on tension, the position adopted and mode for stretching could be considered to be a control issue that would be required to be addressed in future research. Future research could for example, control for the variable of position where participants would either be randomised to an experiment specified stretch position or control group of no stretch, or if necessary, randomised to one of two stretch position groups and a control group of no stretch, in order to determine the most effective stretch position.

This study successfully demonstrates how the adopted intensity of a subjective maximum tolerable level of discomfort (Curwin, 2011) can be applied and how when participants were uncertain of what they should feel on stretching, or in the event of a plateau of improvement, could be passively taken through to a point of the maximum tolerable level of discomfort to increase their awareness of how much intensity of tension was to be applied to improve ROM, whether conducted actively or passively. As considered above, the preferred stretching position and method meant that the highest tolerable level of discomfort would either be achieved either earlier or later in the range of movement. For example, the maximum tolerable level of discomfort may be felt sooner in the range of MR in sitting than in prone. Whilst most may have conducted a passive stretch, some may have preferred an active stretch and as considered above with the position for stretching, it is not known which mode would be most beneficial. However, whilst it is the intensity of stretch rather than mode that is believed to have contributed to the results of this study, the mode of stretch technique remains along with the position as indicated above, a variable in need of control for future research.

The applied maximum tolerable level of discomfort was of greater intensity than the tightness or slight discomfort espoused by some in the literature such as the ACSM (Riebe, 2018; Pescatello, 2014; Garber *et al*., 2011) and possibly less than going past the point of pain, as advocated by Irani, Vennix and Jain (1995). Either way, the intensity remains subjective and the most presently objective measure is one of an end-feel being firm and leathery when soft-tissues are sufficiently placed on tension (Reese and Bandy, 2010) rather than one that is measurably quantifiable, which is in need of being investigated through further research.

This study successfully demonstrates how a stretch duration of sixty seconds can be applied to improve ROM. The ACSM (Riebe, 2018; Pescatello, 2014; Garber *et al*., 2011) based on a limited body of data from RCTs and some observational studies (Garber *et al*., 2011), advocate up to 10-30 second stretches up to once per day and as indicated above, at the point of tightness or slight discomfort. However, these recommendations are as discussed in the literature review, based on targeting major musculo-tendon units as a technique to increase joint ROM, rather than joint capsules and ligaments that differ in their anatomy and properties. Although the same authors assert that there seems to be little benefit from holding the stretch for a longer duration, they further advocate that greater benefit may be gained in flexibility for older adults who hold a stretch up to 60 seconds. The above duration and frequency recommendation may appear to be equal to those applied in this study, but the same authors express how the 60 second duration may be divided into 15 or 30 second repeat stretches, in order to achieve the total stretch duration. This current study therefore supports a single stretch sustained for sixty-seconds rather than repeated stretches, which is clearly more efficient.

As discussed in the literature review, the anatomical structure of joint capsule and ligaments differ from muscle tissue where capsules and ligaments are mainly dense collagenous structures in nature (Siff, 2005) and elastic fibre content is very rare in the hip joint ligaments (Sato *et al*., 2012). Although this renders the hip joint capsule and ligaments more resistant to adaptive lengthening, this study supports the argument that it is possible to adaptively lengthen these structures plastically (Siff, 2005). From the theoretical literature, it is argued that the optimisation of load volume or intensity and the frequency required for adaptive lengthening has largely remained unknown (Curwin, 2011) and it is further asserted that there has remained no specific research to guide the dosage for articular mobility (Kennedy and Levesque, 2016). This study therefore contributes to guiding the dosage to increase hip joint rotation ROM and needs to be investigated further.

The paucity of studies within the field of stretch prescription to improve hip joint rotation ROM renders it difficult to compare this study with others. However, this study does demonstrate the symbiotic relationship of clinical practice and research where evidence-based practice involves integrating best available evidence and clinical expertise (Jewell, 2015) with the prescribed stretch protocol being evaluated through a quasi-experimental approach to practice and where it is attempted to draw a causal link between interventions and outcomes, rather than extraneous variables (Carter and Lubinsky, 2016). Thus, suggesting evidence of biological plausibility (Jewell, 2015) of how to adaptively lengthen soft-tissues contributing to a restriction of hip joint rotation.

This study has successfully determined the minimal operational time duration for future research, which is 3-4 months based on the rate of recovery of the clinical important MR ROM. The operational time duration for research recommended in systematic reviews is seven months identified by Harvey *et al*. (2017) and Katalinic *et al*. (2010), but this study suggests that this could be reduced by 50%. Harvey *et al*. (2017) recommend such longer studies to only be conducted on neurological clinical populations however, where stretches may routinely be performed over long time periods. This is understandable as the effects of continued daily stretching of joints of those without a neurological condition could be detrimental to joint health if hypermobility were to be produced for example. The total duration of a study designed to investigate the effects of the stretch protocol on hip joints with restricted rotation would need to be at least 6-9 months in order to sufficiently recruit and complete data collection if for example, the final participant were to be recruited three months after the commencement of a longitudinal study. In other words, a future study would need to be continued for a further 3-4 months beyond the recruitment of the last participants. However in order to establish if an improved ROM can be sustained, a longitudinal study of a greater timescale would be required.

If there were two interventions, a cross-over design could be applied where half the subjects are exposed to one intervention and the other half are exposed to the other intervention with the two groups then being exposed to the alternative intervention at a future point (Portney, 2020). However, a partial cross-over study could be undertaken whereby a control group could be exposed to the same stretch protocol on establishing the experiment group had completed and benefitted from the study and if it were demonstrated that the control group had retained a restriction of ROM (Portney, 2020). Such a study would need to be 12-18 months in duration in the event of a partial cross-over study design being selected to not only evaluate the effectiveness of the stretch prescription, but also whether improvement is sustained or not. A cross-over design would be more ethical, in order to give each participant an opportunity to benefit from the SP if it is found to be effective. However, such a study is more resource demanding in terms of cost and time and risks a threat of attrition (Portney and Gross, 2020b). Whilst attrition can be minimised by regular contact with participants (Portney and Gross, 2020b), an experiment group may remain motivated by the stretch effects and the control group may remain motivated knowing the potential to cross-over to a second experiment group.

The clear limitation of this study is that it is a retrospective analysis where the researcher is unable to exert control on variables (Portney and Gross, 2020b) with no control group being available for comparison (Portney, 2020). It is therefore not possible to extrapolate from the results, whether improvement in hip joint rotation is due to the stretch protocol, or some other variable effect such as time. If the retrospective historical case notes had included unaffected hip joint repeated measurement data collection at the same time as the affected, it could have been possible for the unaffected joint to be a form of inactive control (Portney, 2020) if it was not exposed to the stretch protocol for comparison purposes, where it could have been demonstrated whether the affected joint had changed compared to the unaffected over the same time-scale. Unfortunately, the data of the unaffected joints were not available at the three-month data collection point with the focus remaining on the affected joint through a treatment episode. This demonstrates the weakness of retrospective studies where data can be missing (Portney and Gross, 2020b) and further demonstrates the need to expose the stretch protocol to a randomised control trial (RCT), where two groups are formed having been randomly allocated to either an experiment or control group to determine if there is a significant difference between them from before and after intervention (Portney, 2020; DePoy and Gitlin, 2016).

Irrespective of the above, this study provides confidence to accurately hypothesise that the SP would improve ROM and it succeeds in obtaining data for use in supporting future research applications such as predicted study timescales and participant sample sizes as required for example, when completing the integrated research application system process for permission and approval for healthcare research in the UK (IRAS, 2021). Due to the dearth of research in the field, this process would be difficult without this study.

This study did not take account of time of day fluctuations where data collection points were mutually agreed at variable times of day. As the time of day can affect ROM values (White and Norkin, 2016), it is recommended that data collection points are controlled to off-set this variable in future research. The absence of controlling for time of day fluctuations on ROM values further demonstrates the weakness of a retrospective case series study design compared to a prospective RCT where the time of day for ROM data collection was not controlled for in the former, but can be in the latter.

This study did not consider other effects of the stretch protocol on domains such as pain and function and future research would need to include such variables using for example, patient-reported outcome measures for pain and functional health and well-being (de Groot, Reijman and Terwee *et al*., 2007). The quasi-experimental approach includes evaluating the effect of the stretch protocol on symptoms and function, in order to justify continuity of the intervention and had improvements not appeared to affect the subjective, objective and functional domains, the stretch protocol would not have been the sustained intervention of choice, or additional interventions may have been included. It is nevertheless a clear weakness of the study with a need to gain evidence for the efficacy of the stretch protocol in regard to the variables of pain, ROM and function or quality of life through experimental research that includes formal valid and reliable patient-reported outcome measures.

This current study successfully demonstrates how a retrospective study is cheaper, faster and more efficient than prospective clinical studies (Portney and Gross, 2020b) as well as other advantages of case series studies discussed earlier in the Introduction and in part, the literature review. For example, case series studies in the absence of evidence, are especially beneficial in demonstrating how clinical theories can be applied to focus on new treatment methods (Portney, 2020) and such studies often reveal a need to investigate interventions further (Bowers, 2020; Portney, 2020), as they are a rich source for generating research questions and inducing hypotheses (Portney, 2020). The results of this study are encouraging and do support the need for the SP effects to be investigated and evaluated through further research given the dearth of evidence to support stretching to improve hip joint rotation, or any other joint movement (Harvey *et al*., 2017; Katalinic *et al*., 2010). This study will contribute to the generation of further research questions regarding the effects of stretching not only on the metric of ROM, but also as discussed above, others such as pain and function. Research findings designed to develop reference data for future research has been found to be useful to others in physiotherapy (Cheatham, *et al*., 2017) and retrospective case series analysis of clinical data in an *ex post facto* approach is designed to fulfil the purpose of directing future research (Carter and Lubinsky, 2016). The effect size calculations would for example, contribute towards sample size calculations in further research designed to explore the effects of stretching on joint ROM.

This current study successfully demonstrated how a non-neurological population can be targeted who has a pre-existing restriction of joint ROM. From the literature review, it was asserted that it would be difficult to obtain the definitive answer to the question of what the most effective stretch dosage should be, which according to Katalinic, *et al*. (2010), would be due to dubious clinical and ethical research design problems such as acceptance of a control group being immobilised without interruption. As indicated above, neurological clinical populations are recommended to be targeted on the basis of their condition requiring longer-term stretching (Harvey *et al*., 2017). However, other clinical populations could be targeted such as those with hip joint OA who have restricted ROM (Vogelgesang, 2015; Holla *et al*., 2011; Dvořrák *et al*., 2008; Lloyd-Roberts, 1953), where a pre-test-post-test design could be utilised (Portney, 2020).

3.7. Conclusions

The stretch protocol in this study has never previously been investigated and the findings from this study suggest it could be an efficient and effective method of improving hip joint rotation over a three-month period. However, whilst retrospective, historical physiotherapy case records may be a valuable source for producing case series data for analysis, it is not possible to extrapolate from the results, whether the improvement in hip joint rotation is due to stretch protocol effects or some other variable such as time, which is due to the methodological flaw of not having a control group for comparison. The results of this study are however, highly encouraging and in view of the dearth of evidence on the effectiveness of stretching, it is recommended that randomised control trials are conducted to ascertain whether hip joint rotation ROM can be improved using the stretch protocol. It is also recommended that such research be conducted targeting those populations where there is a known reduction in hip joint rotation ROM such as those with OA and other associated pathology. The additional value of the results of this study is that they can contribute to timescale duration and samples size calculations in future research.

This study successfully demonstrates the need to investigate the effects of the stretch protocol further, as it may have implications for hip joint health and function and reduce the predisposition to the development of associated hip joint pathology by recovering or preventing the loss of hip joint rotation ROM. Further investigation of the effects of the stretch protocol is also warranted to contribute to what is known and understood in the field of soft-tissue adaptation.

This study demonstrates the need to not only conduct more research to determine if the sixty-second stretch duration conducted on a daily basis is effective in improving

ROM, but also to investigate which position to conduct a rotation stretch is the most effective technique. In addition, the optimum intensity of the stretch is in need of quantifiably being determined too, when technology has been sufficiently developed to measure it. This study represents an early contribution, but clearly supports the literature, which asserts the need for research to be conducted in the field of capsular and ligamentous tissue adaptive lengthening through stretching. Research is not only indicated to investigate whether stretching can improve ROM, joint health, pain and function, but also to determine what is required to maintain any improvement that may be gained.

The study supports the application of a theoretical prescription model designed to increase the specificity of stretching prescription to improve hip joint ROM, which apart from the technique, also includes the duration, intensity, number of repetitions, number of sets and the frequency of administration. The application of a theoretical prescription model such as the DRIFTS Model or FITT-VPP is therefore recommended to physiotherapists to assist in increasing therapeutic intervention prescription specificity and to contribute to the identification of therapeutic intervention variables for research.

4. Hip joint range of movement: Inter-tester reliability and agreement – A comparison of a new and standard measurement technique for measurement of active medial and lateral rotation in prone

4.1. Introduction

Range of movement deficiency is considered to be pathological with a risk of producing undesirable effects on the affected joint and adjacent structures (Curwin, 2011). The measurement and recording of joint mobility is therefore an important part of examining joints and surrounding soft-tissues (White and Norkin, 2016); contributing to the correct diagnosis (White and Norkin, 2016; Greene and Heckman, 1994) of conditions such as OA of the hip joint (Cibulka, *et al*., 2017; Clarkson, 2013; Poulsen *et al*., 2012) or other injury and identification can help in injury prevention (Ellenbecker *et al*., 2007). Joint ROM measurement can also be an indicator of the severity and progression of disorders and a means of evaluating the results of treatment (White and Norkin, 2016; Prentice, 2011; Domb *et al*., 2009; Greene and Heckman, 1994); which is clearly very important (Bierma-Zeinstra *et al*., 1998) and is needed for decision-making in modifying rehabilitation (White and Norkin, 2016; Prentice, 2011) and for determining a return to functional activity (Greene and Heckman, 1994).

Reliability is an indicator of the ability of a measurement instrument to produce similar scores as for example, on repeated testing occasions that occur under similar conditions (DePoy and Gitlin, 2016) and the same applies for measurement techniques. The sources of measurement error that have been identified and classified are the examination, the examiner and the examinee (Stratford *et al*., 1984), which are independent variables that researchers should anticipate and that can often be controlled for (Portney, 2020). The influencing factors or sources of error for MR and LR ROM measurement examination are the measurement instrument (White and Norkin, 2016; Bierma-Zeinstra *et al*., 1998); measurement position (White and Norkin, 2016; Roach *et al*., 2013; Bierma-Zeinstra *et al*., 1998) and mode of movement measured (Moromizato *et al*., 2016; Roach *et al*., 2013; Bierma-Zeinstra *et al*., 1998), which have been discussed and justified in the literature review, together with the measurement protocols for evaluation that have been designed to control for the sources of error. The new measurement protocol was also used in the first study of this thesis and further discussed in Chapter 3.

Whilst instrumentation, position and mode of movement are controlled for, another source for error in the measurement of hip joint rotation ROM is segmental control as discussed in the literature review. Failure to control the pelvis leads to problems accurately aligning the stationary or reference arm of the goniometer and thus inducing measurement error. As discussed in the literature review, the need for segmental control of the pelvis and trunk for accurate ROM measurement is recognised within the literature (Nussbaumer *et al*., 2010; Bohlin *et al*., 2005; Klässbo *et al*., 2003; Bierma-Zeinstra *et al*., 1998) and it is recommended that work be conducted to reduce this source of error (Nussbaumer *et al*., 2010; Simoneau *et al*., 1998) as for example, uncontrolled pelvic rotation has been identified to contribute to over-estimation of ROM values (Nussbaumer *et al*., 2010). Physiotherapists usually conduct measurements on their own (Bohlin *et al*., 2005) where resource constraints render it unlikely that the pelvis is stabilised and it is therefore recommended that close attention should be paid to possible substitution techniques that may affect their measurements (Simoneau *et al*., 1998).

The new measurement protocol has never previously been investigated to the knowledge of the author and there is a need to evaluate the reliability and agreement of this in comparison with the standard measurement protocol. Macedo and Magee (2009; 2008) have argued data collection methodological decision-making on the basis of intending to replicate data collection in clinical practice in their multi-joint ROM studies and the intention of the second study in this thesis is designed to replicate the examination technique adopted to obtain the hip joint ROM data of the first study, where the same examiner used the same measurement technique throughout.

Whilst the measurement of joint ROM of the lower limbs using a goniometer have generally been found to have good-to-excellent reliability and are more reliable if measurements are taken by the same examiner using the same examination methods than those obtained by different examiners (Scalzitti and White, 2016; Clarkson, 2013), there is a need to investigate the inter-tester reliability and agreement of the new measurement examination technique, as future research that may involve more than one examiner obtaining ROM data. Shultz *et al*. (2006) express similar concerns of the potential need for more than one tester being required in the event of loss and replacement of a tester. Establishing the inter-tester reliability of a measurement method would increase generalisability and it can be assumed that other examiners would obtain similar results (Portney, 2020).

The results of the study will contribute to determining whether the new measurement method can replace the standard for future research. It has also previously been reported how the purpose of a study can be to develop reference data for future research (Cheatham *et al*., 2017), which this study will aim to do. It is additionally necessary to determine the inter-tester minimal detectable change for both measurement techniques not only for future research purposes, but also to establish whether two examiners would have detected improvement in ROM values found in the first study of this thesis.

The development and testing of measurement instruments for use in research and clinical practice involves methodological research such as this second study (Portney, 2020) and to maximise reliability, it requires standardisation of measurement protocols and examiner training (Portney, 2020; Poulsen *et al*., 2012), where a lack of such control has been shown to reduce reliability and increase minimal detectable change values for hip joint rotation (Poulsen *et al*., 2012).

4.2. Purpose

The primary purpose of this study is to investigate whether inter-tester reliability and agreement can be demonstrated for a new measurement method for obtaining hip joint rotation ROM values. In order to evaluate the new method further, it will be compared with the inter-tester reliability and agreement of a standard method of measurement.

The secondary aim is to determine the minimal detectable change, which is required to assist in further evaluation of the findings of the first study in this thesis where the minimal detectable change will be compared with the mean improvement of ROM values and establish whether two testers would have detected change.

4.3. Methodology

4.3.1. Study design

A test-retest design (Portney, 2020) was utilised in this study to determine inter-tester reliability and agreement of a new and standard measurement protocol for obtaining active hip joint medial and lateral rotation ROM data obtained from subjects in a prone position using a Universal Goniometer.

4.3.2. Subjects

The subjects recruited in this study were all volunteers and included the following.

4.3.2.1. Study participants

From the literature as discussed in the literature review, the ideal of a mixed-group of participants (Carter and Lubinsky, 2016) were recruited who were generally healthy, but did not necessarily have a healthy hip joint rotation ROM, as it is important to recruit a sample with some variance where examinees have a range of scores across the continuum to show reliability (Portney, 2020).

Participant inclusion criteria

Participants were aged eighteen years-old or above, available for designated data collection times and dates and they must have completed the screening questionnaire and provided informed, signed consent.

Participant exclusion criteria

Any participants reporting they were currently being investigated or receiving treatment for pathology affecting the spine and/or lower limb were excluded.

Permission was sought through direct contact and discussion with respective proprietors, commercial, recreational club and physical activity group leads to approach prospective participants for recruitment to the study.

It is necessary to look after the subjects, ensuring they are fully informed of the purpose and importance of the study, what is required of them and the duration of time they will be required to volunteer (Hicks, 2009). Written and verbal explanations and instructions were therefore provided in order to encourage recruitment, motivation, cooperation and performance. Prospective participants were provided with a study participation invitation letter (see Appendix 2). Volunteer participants were provided with detailed written information about the study and invited to complete the screening questionnaire and informed consent form, which was approved by the University Ethics Committee (see Appendix 3).

Participant recruitment and data collection were timetabled to coincide with times either side and during their respective physical activity sessions to increase recruitment and data collection efficiency and reduce attrition rates. The members of an additional off-site recreational sport club were invited to attend at the same sessions, as there was no guarantee of on-site group attendance and data collection sessions were thus made more efficient.

Most reliability studies involving the UG or a comparison of other instruments in joint ROM measurement chose a sample size of 9-34 (Dos Santos, Derhon and Brandalize *et al*., 2017; Norris, Wright and Sims *et al*., 2016; Park, Kim and Bae *et al*., 2015; Roach *et al*., 2013; Nussbaumer *et al*., 2010; Chevillotte, Mir and Trousdale *et al*., 2009; Pua *et al*., 2008; Bohlin *et al*., 2005; Bierma-Zeinstra *et al*., 1998; Boone *et al*., 1978). Poulsen *et al*. (2012) had a larger sample size of 48-61, but the participants were already recruited to another larger randomised control trial making a larger sample accessible.

Forty participants were recruited and whilst one participant had to withdraw a further five were lost through attrition. A convenience sample of thirty-four were therefore recruited from local recreational exercise, sport and physical activity groups who were either healthy, or were not being investigated or treated for pathology or conditions affected the lower limbs and spine (n = 34; mean age, 36.91 ±13.56 years; age range, 41 years) of mixed sex (females, n = 18; mean age, 38.39 ±13.59; age range, 41 years; males, n = 16; mean age, 35.25 ±13.77 years; age range, 39 years), producing 136 and 134 measurements per tester for the standard and new measurement protocol respectively.

4.3.2.2. Study testers

Two volunteer testers were recruited with one of the testers being a complete novice with no experience and the other tester was a Chartered Physiotherapist with more than twenty years of experience and expertise in obtaining joint ROM measurements using a Universal Goniometer.

Prospective testers were approached directly via e-mail or direct contact, requesting to consider volunteering and to attend a face-to-face meeting to explain the study. It is necessary to look after all subjects including volunteer testers, ensuring they were fully informed of the purpose and importance of the study, what is required of them and the duration of time they will be required to volunteer (Hicks, 2009). Graphic supported written and verbal explanations and instructions were therefore provided in order to encourage recruitment, motivation, cooperation and performance.

On agreement of a meeting, prospective testers were provided with a formal study participation invitation letter (see Appendix 4) and on meeting, study information documentation, screening questionnaire and an informed consent form approved by the University Ethics Committee (see Appendix 5) were provided and the study was discussed. Graphic supported written materials instructing on measurement procedures for the standard and new measurement protocol were provided and explained, including the nature of their role (see Appendix 6 and 7). The prospective testers were assured that the written materials would be supplemented with formal face-to-face measurement training and practise sessions, which was again to encourage recruitment and retention. The practise session were continued until there was expressed and observed competence.

4.3.2.3. Research assistant

A volunteer research assistant was recruited who was a junior graduate with verbal and written communication skills and data handling experience. Procedures for recruitment, training, practise sessions and rationale were similar to those applied for the testers using the same materials with additional role instructions being provided (see Appendix 8).

4.3.3. Apparatus

4.3.3.1. Data collection location

Data collection sessions were held and conducted within a dedicated room with floor space sufficient enough to hold an examination plinth, a participant, researcher, research assistant, two testers and a table surface for documentation and data recording.

4.3.3.2. Examination couch

One of two examination and treatment plinths were used for participants to lie on for data collection purposes and the choice was determined by the data collection venue. One was a standard plinth with a static height of 74.0cm and the other had the same height controlled by a hydraulic system. The latter was set at the same height as the former for continuity purposes and to avoid height variation potentially contributing to measurement error. Both had a purposeful breathing hole with a fresh, disposable, paper towel sheet provided to place their face on.

A blanket was provided for participants who attended in clothing that was removed to adequately reveal their lower legs and knees for ROM measurement purposes and to preserve participant dignity.

4.3.3.3. Instrument

A standard Universal Goniometer was used for range of movement measurement (see Figure. 1), as discussed in the literature review in regard to validity and reliability (see 2.7.1.).

The same UG was used for each data collection session and was covered on one side to blind the tester from the measurement value scale to control for tester bias (Portney, 2020; Han *et al*., 2015; Stratford *et al*., 1984).

4.3.4. Procedures

4.3.4.1. Data collection

Participant completed documentation was screened, checked for eligibility, accuracy and legibility, followed by checking of their understanding of the study requirements to maintain motivation and cooperation (Portney, 2020) and continuity of keeping them informed (Hicks, 2009) such as the reminding of how tests will be conducted involving manual handling and positioning by the research assistant. On confirmation of eligibility, the participant was prepared for data collection by exposing their knee joint and lower leg. The participant was reminded they may feel discomfort as the end of available ROM was achieved and to make it known if and when the sensation of discomfort was felt.

Inter-tester reliability would better be assessed if both examiners were able to simultaneously and independently obtain a ROM measurement reading to reduce measurement error, but this is not possible for ROM data collection because of the interaction required between the examiner and examinee for the purpose of measurement (Portney, 2020). Repeat testing of ROM can have a stretching effect, increase ROM and produce a systematic error, but if tests are conducted close enough, genuine changes in ROM can be avoided (Portney, 2020). Consecutive single measurements were obtained by each tester of one direction of hip joint rotation ROM with the minimum interval time during which the research assistant read the value obtained by the novice tester and reset the UG before handing it to the expert for their measurement. Interval time efficiency also avoided participant fatigue. A single measurement reading was obtained to replicate the ROM data collection method in the first study of this thesis. This ROM measurement process was repeated until all movement measurements were obtained for each hip joint of each participant and in summary, using the standard measurement protocol first, each tester measured a participant's left hip medial rotation (LMR), then right hip medial rotation (RMR), followed by left hip lateral rotation (LLR) and then right hip lateral rotation (RLR). This was repeated using the new measurement protocol. The measurement method protocol, tester, joint and ROM measurement order was repeated for each participant to ease administering the number of tests (Pua *et al*., 2008). Tester order was also to ensure the novice tester followed the measurement protocol as directed and trained, rather than try to imitate the experienced tester and therefore reduce the risk of novice tester measurement familiarity learning effects (Portney, 2020) through observation of the expert tester.

A protocol should be specified to maximise reliability that details procedures and instructions for the use of the instrument and conduction of the examination technique and as such, researchers should anticipate and identify sources of error that can often be controlled for (Portney, 2020; Poulsen *et al*., 2012). The protocol for the standard and new method of measuring hip joint rotation in a prone position is more fully described in Appendix 6 and 7 respectively, with both in Appendix 8 and are discussed in the literature review. Alternative versions of the same measurement method can be used to compare and see if they have similar scores where they can be considered reliable alternatives based on their statistical equivalence (Portney, 2020).

The hip joint being measured was moved by the research assistant to the end of available ROM where no further rotation movement could be passively obtained at a point that a tight end-feel could be felt and began to place sufficient tension that the pelvis started to move, detected by the placement of the research assistant's other hand on the contralateral and ipsilateral pelvis when measuring MR and LR respectively. The measured hip joint was actively held by the participant in position for the duration of measurement and requested by the research assistant not to relax until asked to do so. The research assistant stabilised the pelvis when using the standard, but this was not required when using the new measurement protocol when pelvic rotation was to be ensured. Participants were reminded by the research assistant, to maintain the position and ROM until both testers had obtained measurements and informed when to relax to ensure participants did not unwittingly contribute to between-tester variability by moving and thus ensuring comparable measurements were obtained. The research assistant observed and ensured that the participant maintained the measurement position.

When the tester was satisfied that a measurement had been made, the blanked UG was presented to the research assistant to read the non-blanked side of the UG for data recording, but if the UG was disturbed after obtaining a measurement, the measurement was repeated. If this occurred at the point the second tester obtained their measurement, both testers repeated their measurements to ensure a valid measurement was obtained and recorded. Participant names and raw ROM measurement data was recorded on previously prepared documentation on obtaining measurement values of both testers to reduce interval time between testers, ensure efficient and accurate data recording and thus reduce participant attendance time.

4.3.4.2. Data analysis

The hand-written demographic and raw ROM data was anonymised and analysed using *MS Excel* (Microsoft, 2010) and *IBM SPSS Statistics 24.0* (IBM Corp., 2016). Descriptive statistics including measures of central tendency such as the mean and median, measures of dispersion such as the ranges and standard deviations (SD) were calculated for each hip joint ROM and the between-tester differences of ROM for both the standard and new measurement protocol for comparison analysis.

The conventional alpha or significance levels were set at p = ≤.05 (Petrie and Sabin, 2020; Portney 2020; Carter and Lubinsky, 2016; Pallant 2016; Pituch and Stevens, 2016). Preliminary analysis of data was conducted to determine whether the assumption of normality was objectively met using the frequency distribution Shapiro-Wilk test, required to determine whether parametric or non-parametric tests were to be used for inferential statistical analysis (Petrie and Sabin, 2020; Portney, 2020; Pallant, 2016).

Establishing reliability often requires multiple approaches, looking at differing elements with a number of indices to understand the accuracy of a measurement method (Portney, 2020, Bruton, Conway and Holgate, 2000), but it is recommended that evaluation tools intended for future longitudinal studies should have their agreement determined in addition to reliability (Berchtold, 2016). Inter-tester reliability and agreement will therefore be estimated for both the standard and new measurement protocol for comparison purposes.

One of the most commonly used relative reliability indices is the Intraclass correlation coefficient (ICC) with values ranging from 0.00 to 1.00 where the higher values indicate greater reliability and it is permissible to compare the ICCs of alternative testing methods to determine the most reliable test (Portney and Gross, 2020a). The advantage of the ICC from other correlation coefficients such as Pearson's CC, is that it can register correlation and agreement between two sets of scores, whereas Pearson's CC can only determine correlation (Petrie and Sabin; Portney, 2020) and the ICC should be used when inter-tester reliability is to be evaluated (Portney, 2020).

The ICC ($_{2,\ 1}$) will be applied where model 2 has been selected as two examiners measure the ROM of each examinee. As it is not possible to have access to all prospective examiners to truly randomly select two, it is contextually permissible to consider the two examiners as theoretically selected at "…random…" with the essential point of being able to generalise the outcome to other similar examiners (Portney and Gross, 2020a) and in this case, one complete novice and one experienced examiner. Reliability studies are commonly designed so that a single rating or a single measurement is obtained from each subject using form 1 (Portney and Gross, 2020a). Koo and Li (2016) assert that if it is planned to use measurement from a single tester as the basis of the ROM measurement, "…single rater…" type or form "…should be selected even though the reliability…" investigation "…involves 2 or more raters…", which is supported by Portney and Gross (2020a). The Intraclass correlation coefficient 2, 1 (ICC $_{2,\ 1}$) with 95% confidence intervals (CIs) were therefore used (Portney and Gross, 2020a; Koo and Li, 2016; Shrout and Fleiss, 1979). For interpretation of the ICC there is agreement within the literature that for most clinical purposes, .70 is considered to be the minimum standard for a test to be useful (Portney and Gross, 2020a). However, reliability is considered to be excellent when >.90; good when >.75 and <.90; but moderate when between .50 and .75; and poor when below.50 (Portney and Gross, 2020a; Koo and Li 2016).

Absolute reliability will be estimated using the standard error of measurement (SE of M), which is the most common statistic to assess absolute reliability with the added advantage of being measured in degrees of ROM, providing direct clinical application (Portney and Gross, 2020a), a more useful estimate for interpreting how much error has occurred that is likely to be present in a single measure (Portney, 2020) and thus provides a threshold where a statistically significant change can be deduced to have occurred in a repeated measure (Pua *et al.*, 2008). Standard error of measurement was calculated by dividing the standard deviation of the differences by the square root of two (Portney and Gross, 2020a; Scalzitti and White, 2016).

Bland-Altman graphs were to be plotted for each measurement with the respective calculated means of the differences and their 95% limits of agreement (LoA) superimposed on them to be visually inspected to ensure there was no heteroscedasticity and for comparison and clinical interpretation of inter-tester agreement of the two methods of measurement (Bland and Altman, 1999; 1986).

Where the mean difference (systematic error) line is or very near zero, it would seem that there is no systematic deviation between the measured values of the two testers (Kwiecien, Kopp-Schneider and Biettner (2011) and so half the range of the LoA could be considered to be the smallest or minimal detectable change (within 95% confidence) required to indicate an effect following intervention (Poulsen *et al.*, 2012). However and as discussed in the literature review, the Minimal Detectable Change will be calculated where a threshold value can be linked to either a 95% or 90% confidence level (Portney and Gross, 2020a). There is inconsistency in MDC threshold value application with Gradoz *et al*. (2018) for example, reporting use of the 95% and Pua *et al*. (2008) reporting use of the 90% confidence level, with the latter authors judging it to have provided an acceptable level for clinical interpretation of a change in ROM score. The MDC_{95} threshold value will be larger than the MDC_{90} value (Scalzitti and White, 2016) and so both will be calculated for comparison purposes. The MDC_{95} is calculated multiplying the standard deviation of the differences value by 1.96 and the MDC_{90} is calculated by multiplying the standard deviation of the differences value by 1.65 (Portney and Gross, 2020a; Scalzitti and White, 2016).

All the results were prepared to allow accurate interpretation and presentation through tabulated and figure supported text.

4.3.5. Ethics

Ethical approval for the study was requested and obtained prior to data collection in accordance with the Declaration of Helsinki, which was most recently amended and reaffirmed in 2013 (Portney, 2020). Ethical approval was obtained from the University of Cumbria's Research Ethics Panel (see Appendix 9). Informed, signed consent was obtained prior to data collection.

4.4. Results

There were two testers and thirty-four participants producing 136 and 134 measurements per tester for the standard and new measurement protocol respectively.

Differences in measurement data were found to have a normal distribution using the Shapiro-Wilk test for LMR (n = 34; p = .471); RMR (n = 34; p = .196); LLR (n = 34; p = .463); and RLR (n = 34; p = .827) using the standard measurement protocol and for LMR (n = 34; p = .168); RMR (n = 34; p = .580); LLR (n = 32; p = .152); and RLR (n = 34; p = .057) using the new measurement protocol. The inter-tester reliability results can be seen in Table 5.

Table 5: Inter-tester reliability for new and standard measurement protocols measuring hip joint rotation range of movement

Measurement	**Mean Diff ± SD**	**$ICC_{2,1}$ (95% CI)**	**SE of M**	**MDC_{95}**	**MDC_{90}**
Standard measurement method (pelvis stabilised)					
LMR (n=34)	0.53°±4.24°	.93 (.86-.96)	3.0°	8.3°	7.0°
RMR (n=34)	0.74°±4.39°	.93 (.86-.96)	3.1°	8.6°	7.3°
LLR (n=34)	0.21°±5.45°	.94 (.88-.97)	3.9°	10.7°	9.0°
RLR (n=34)	2.38°±5.88°	.94 (.87-.97)	4.2°	11.5°	9.7°
New measurement method (pelvis non-stabilised)					
LMR (n=34)	-1.09°±4.29°	.93 (.87-.97)	3.0°	8.4°	7.1°
RMR (n=34)	-0.24°±5.29°	.89 (.80-.95)	3.7°	10.4°	8.7°
LLR (n=32)	-1.22°±3.17°	.98 (.95-.98)	2.2°	6.2°	5.2°
RLR (n=34)	0.12°±5.47°	.95 (.89-.97)	3.9°	10.7°	9.0°

The ICC ($_{2,\,1}$) for measurements using the standard measurement protocol showed excellent inter-tester reliability ranging from .93 to .94. The ICC ($_{2,\,1}$) for measurements using the new measurement protocol showed good-excellent inter-tester reliability ranging from .89 to .98.

Absolute reliability was measured using the Standard Error of Measurement and the point estimate value range was 3.0°-4.2° for the standard and 2.2°-3.9° for the new measurement method.

MDC_{95} point estimate value range was 8.3°-11.5° for the standard and 6.2°-10.7° for the new measurement method, but the MDC_{90} point estimate value range was 7.0°-9.7° for the standard and 5.2°-9.0° for the new measurement method.

Visual inspection of the Bland-Altman plots (see Figures 5-8) did not indicate heteroscedasticity. The mean differences (systematic errors) and mean difference standard deviations are presented in Table 6, together with respective limits of agreement and limits of agreement ranges. The systematic error for all measurements between tester 1 and 2 using either the standard or new measurement protocol can mostly be considered as minimal. The mean difference range was from 0.21° to 2.38° for the standard measurement protocol and from −1.22° to 0.12° for the new measurement protocol.

Table 6: Standard and a new measurement protocol for measuring medial and lateral rotation range of movement of the hip joint: Mean differences and agreement

	Tester 1 and 2 ROM differences and agreement				
Measurement Protocol		LMR	RMR	LLR	RLR
Standard Measurement Protocol	Mean difference	0.53°	0.74°	0.21°	2.38°
	Mean difference SD	4.24°	4.39°	5.45°	5.88°
	LoA	−7.79° to 8.85°	−7.87° to 9.34°	−10.48° to 10.90°	−9.14° to 13.90°
	LoA range	16.64°	17.21°	21.38°	23.04°
New Measurement Protocol	Mean difference	−1.09°	−0.24°	−1.22°	0.12°
	Mean difference SD	4.29°	5.29°	3.17°	5.47°
	LoA	−9.49° to 7.31°	−10.60° to 10.13°	−7.43° to 4.99°	−10.59° to 10.83°
	LoA range	16.80°	20.73°	12.42°	21.42°
LMR = Left medial rotation; RMR = Right medial rotation; LLR = Left lateral rotation; RLR = Right lateral rotation; LoA = Limits of Agreement					

Further standard and new measurement method Bland-Altman LoA analysis was conducted, once the differences in the standard and new measurement data were found to have normal distribution using the Shapiro-Wilk test for LMR (n = 34; p = .288); RMR (n = 33; p = .095); LLR (n = 34; p = .939); and RLR (n = 34; p = .905). Bland-Altman LoA analysis (see Figures 9-12) was conducted where the mean value of both examiners was determined for each movement using the standard and again for the new method of measurement and subsequently, the mean of the two methods was then plotted against their differences. There was no indication of heteroscedasticity and whilst the mean differences were minimal and close to zero for MR, there was a systematic error of almost 6° for LR.

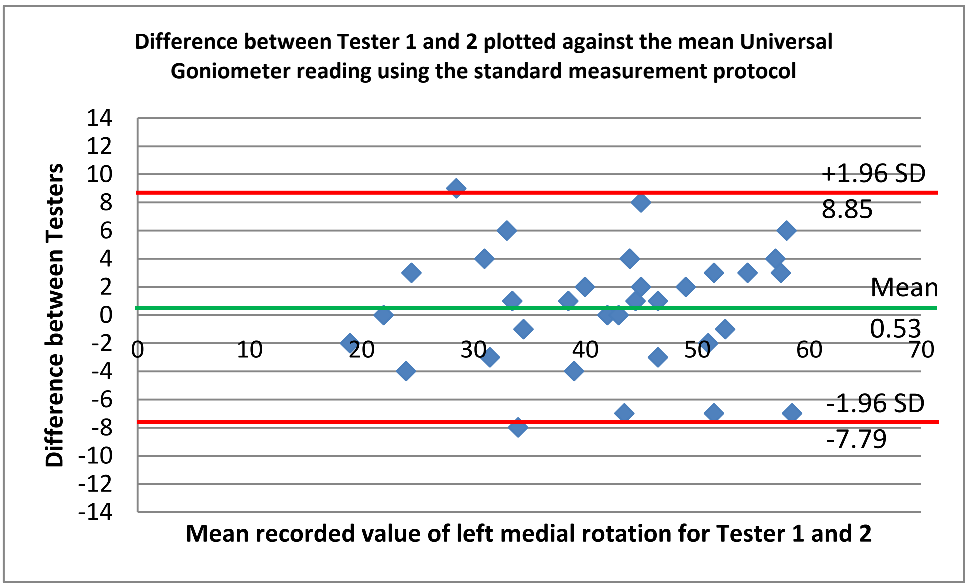

Figure 5a:

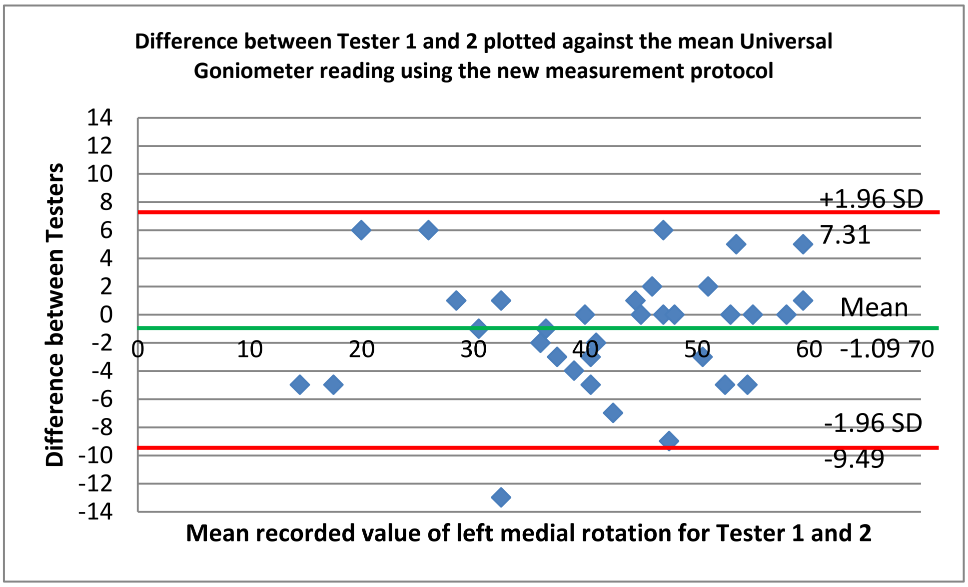

Figure 5b:

Figure 5: Limits of agreement between two measurement methods for left hip joint medial rotation range of movement (in degrees). 5a: Limits of agreement between two testers for left hip joint medial rotation range of movement (in degrees) using a Standard Measurement Protocol. 5b: Limits of agreement between two testers for left hip joint medial rotation range of movement (in degrees) using a New Measurement Protocol

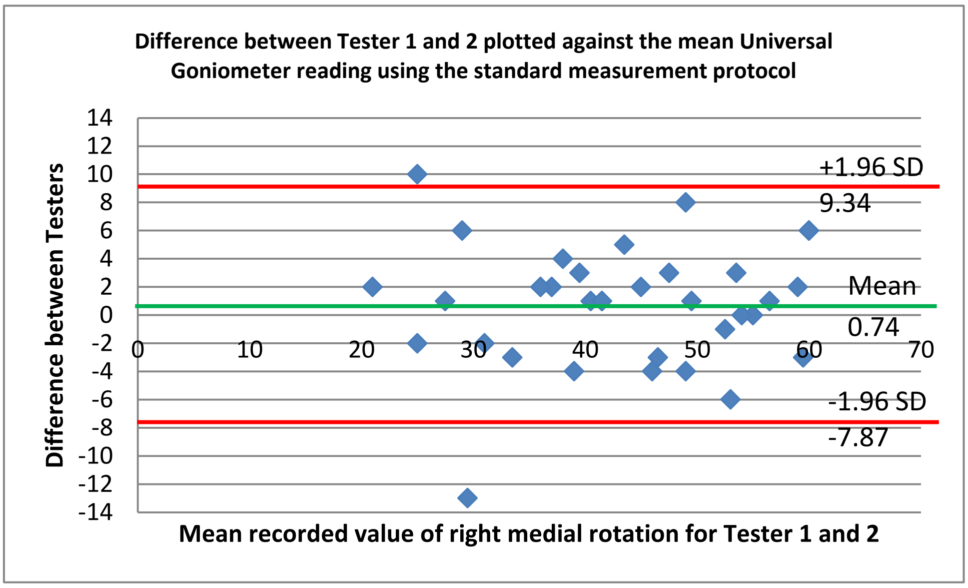

Figure 6a:

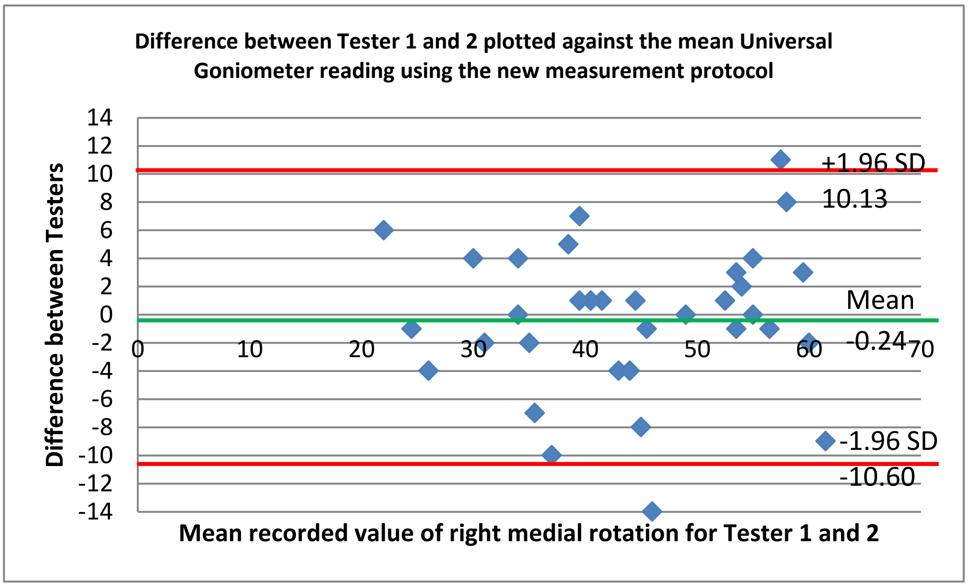

Figure 6b:

Figure 6: Limits of agreement between two measurement methods for right hip joint medial rotation range of movement (in degrees). 6a: Limits of agreement between two testers for right hip joint medial rotation range of movement (in degrees) using a Standard Measurement Protocol. 6b: Limits of agreement between two testers for right hip joint medial rotation range of movement (in degrees) using a New Measurement Protocol

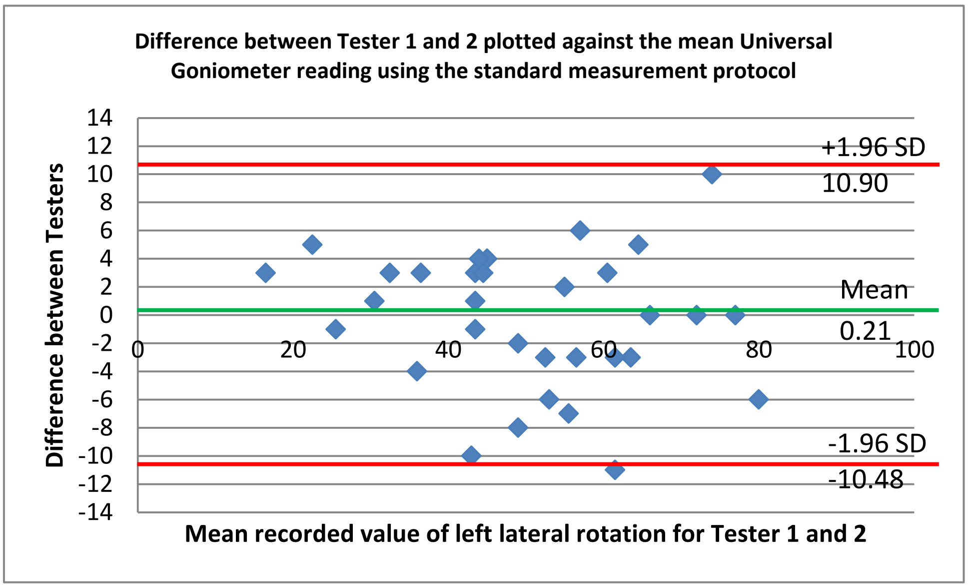

Figure 7a:

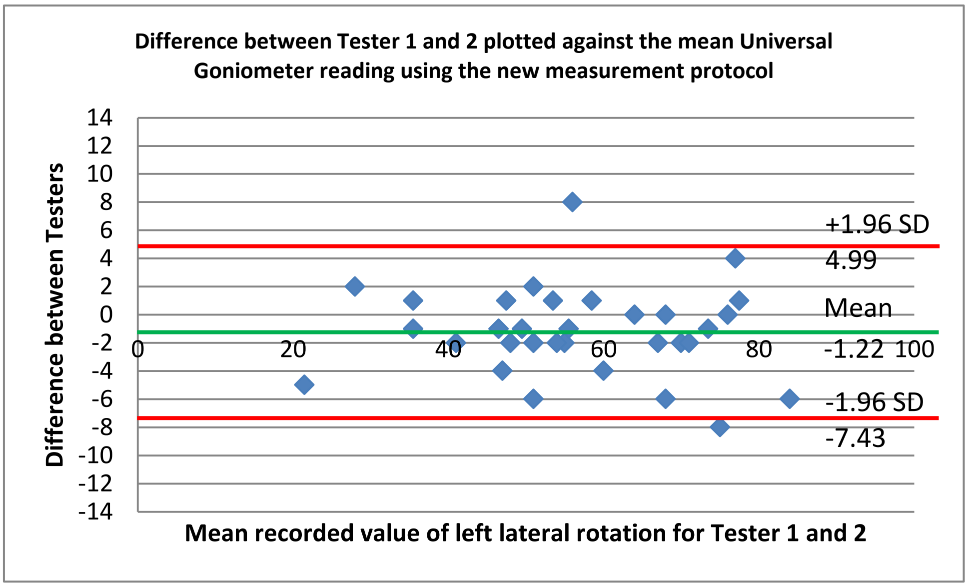

Figure 7b:

Figure 7: Limits of agreement between two measurement methods for left hip joint lateral rotation range of movement (in degrees). 7a: Limits of agreement between two testers for left hip joint lateral rotation range of movement (in degrees) using a Standard Measurement Protocol. 7b: Limits of agreement between two testers for left hip joint lateral rotation range of movement (in degrees) using a New Measurement Protocol

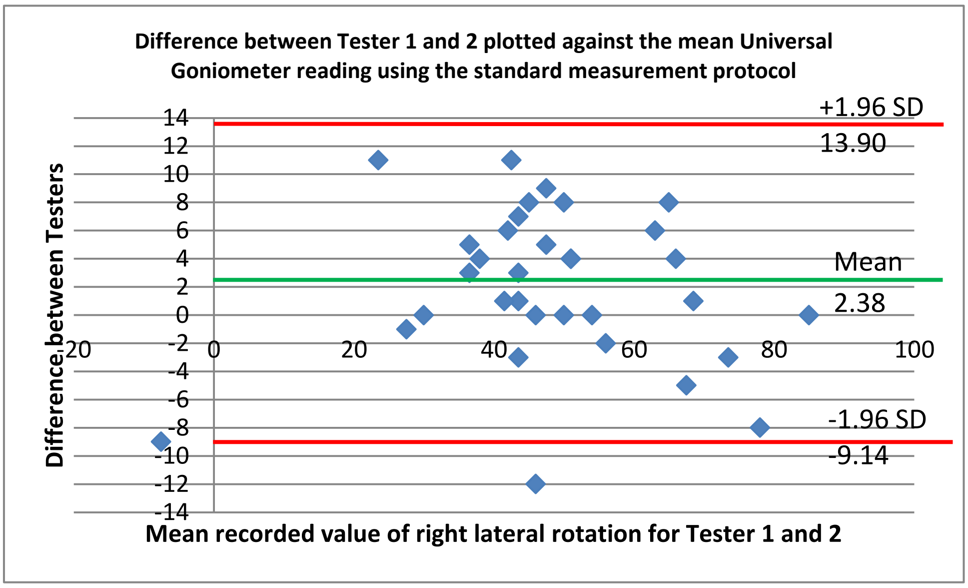

Figure 8a:

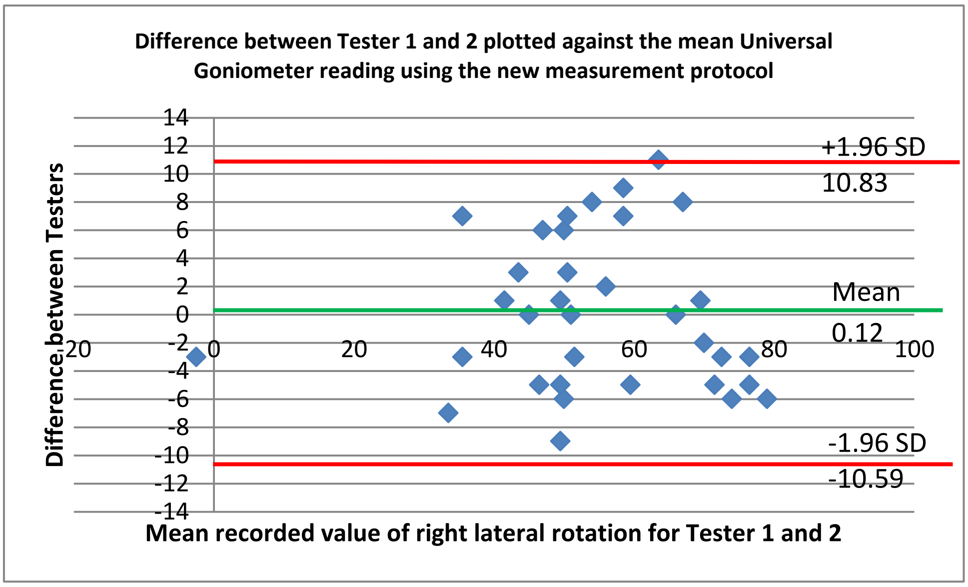

Figure 8b:

Figure 8: Limits of agreement between two measurement methods for right hip joint lateral rotation range of movement (in degrees). 8a: Limits of agreement between two testers for right hip joint lateral rotation range of movement (in degrees) using a Standard Measurement Protocol. 8b: Limits of agreement between two testers for right hip joint lateral rotation range of movement (in degrees) using a New Measurement Protocol

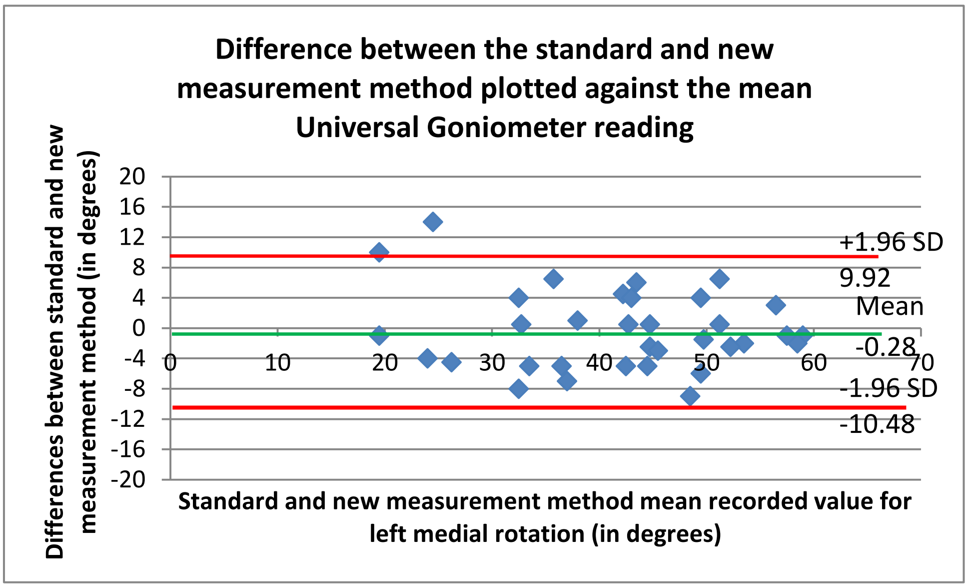

Figure 9: Limits of agreement between two measurement methods for left hip joint medial rotation range of movement (in degrees). Where the inter-tester mean has been obtained for the standard and new measurement method and the mean of the two values have been plotted against their differences.

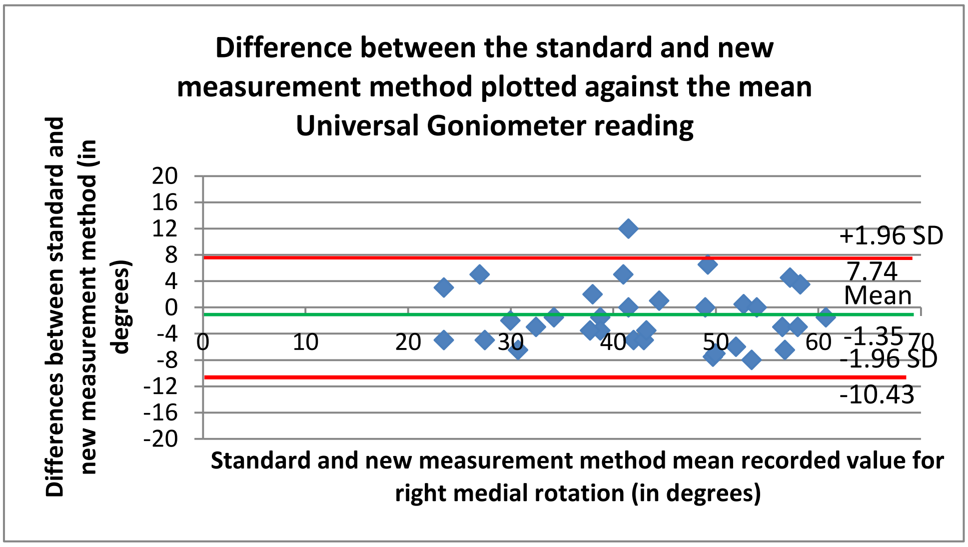

Figure 10: Limits of agreement between two measurement methods for right hip joint medial rotation range of movement (in degrees). Where the inter-tester mean has been obtained for the standard and new measurement method and the mean of the two values have been plotted against their differences.

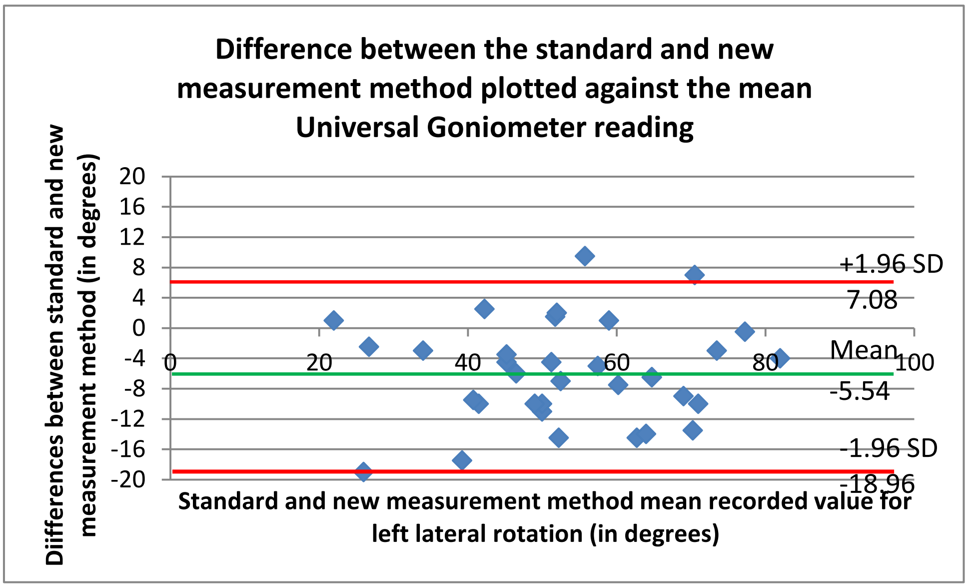

Figure 11: Limits of agreement between two measurement methods for left hip joint lateral rotation range of movement (in degrees). Where the inter-tester mean has been obtained for the standard and new measurement method and the mean of the two values have been plotted against their differences.

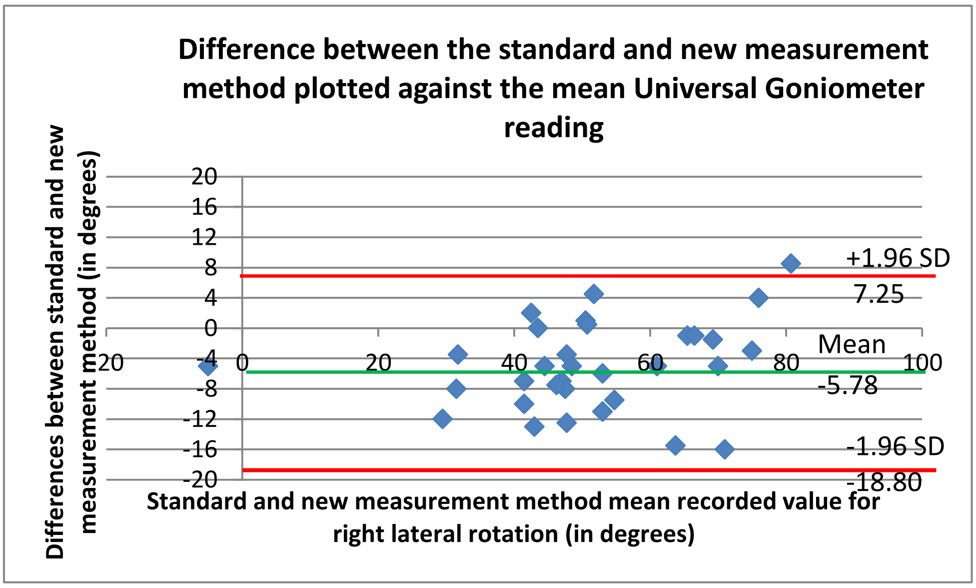

Figure 12: Limits of agreement between two measurement methods for right hip joint lateral rotation range of movement (in degrees). Where the inter-tester mean has been obtained for the standard and new measurement method and the mean of the two values have been plotted against their differences.

4.5. Discussion

The primary purpose of this study was to investigate and compare the inter-tester reliability and agreement of a new and standard measurement method for obtaining active hip joint rotation ROM values in a prone position, measured by a novice and expert tester using a Universal Goniometer. The new method is an adaptation of the standard to control for pelvic rotation without the need to stabilise the pelvis manually through the use of the additional resources of a second person or belt application.

It is recognised how research can produce reference data for future research (Cheatham, *et al*., 2017) and by replicating the data collection method from the first study in this thesis, this second study would assist not only in further evaluation of the method used, but contribute to further research design, planning and interpretation.

The secondary aim was to determine the minimal detectable change, also required to assist in further evaluation of the findings of the first study in this thesis, where it will be compared with the mean improvement of hip joint ROM values and establish whether two testers would have detected such change.

The new measurement protocol for the measurement of hip joint rotation in prone has never previously been investigated to the knowledge of the researcher.

Applying the ICC point estimate value interpretation classification where reliability is considered to be excellent when >.90, good when >.75, moderate when between .50 and .75 and poor when below.50 (Portney and Gross, 2020a; Koo and Li 2016) this study indicates inter-tester reliability was excellent for LMR, RMR, LLR and RLR (ICC = .93-.94) using the standard measurement method and LMR, LLR and RLR (ICC = .93-.98) using the new with RMR being good (ICC = .89) for the latter method. If the lower bounds of the 95% confidence intervals were presumed to be point estimates, it would indicate good inter-tester reliability for LMR, RMR, LLR and RLR (.86-.88), using the standard and also for LMR, RMR and RLR (.80-.89) using the new measurement method with LLR (.95) remaining excellent for the latter. The point estimate values clearly exceed .70, which is the value considered to be the minimum standard for a test to be useful (Portney and Gross, 2020a).

Visual inspection of the Bland Altman plots suggest a negligible systematic bias or mean difference between the novice and expert tester for both measurement protocols (mean difference range for standard method, 0.21° to 2.38°; new method range, -1.22° to 0.12°) with most mean difference ROM values lying between the 95% LoA and there was no evidence of heteroscedasticity. The difference of measurement between the two testers using the new measurement method is not enough to cause clinical interpretation problems and appears to be comparable to the standard method of measurement, so the new method can therefore replace the standard method of measurement (Bland and Altman, 1999; 1986).

From the further standard and new measurement method Bland-Altman LoA analysis, where the mean value of both examiners was determined for each movement using the standard and again for the new measurement method and subsequently, the mean of the two methods was then plotted against their differences, there was no indication of heteroscedasticity on inspection of the Bland-Altman plots. Whilst the mean differences were minimal and close to zero for MR, there was a systematic error of almost 6° for LR, indicating that the new consistently measured a larger ROM than the standard method of measurement (Bland and Altman, 1999). The MR and LR LoA ranges are also larger and these together with the systematic error, necessitates further discussion, which will be considered shortly.

The standard error of measurement (SE of M) values for the new and standard measurement methods were also similar (SE of M for standard method range, 3.0°-4.2°; new method range, 2.2°-3.9°). Whilst the SE of M may be a useful estimate for interpreting how much error has occurred that is likely to be present in a single measure (Portney, 2020), it provides a threshold where a statistically significant change can be deduced to have occurred in a repeated measure (Pua *et al*., 2008). As discussed in the literature review, the MDC represents a clinical significant value, which is definitively more useful for interpreting any change in ROM. However, determining a statistical significant improvement in ROM can still be useful for physiotherapists who are trying to determine the direction of change in ROM. Any ROM improvement is likely to be a gradual process and if a statistically significant change of improvement is detected, it can provide confidence in a trend of improvement over time until such time a MDC value has been achieved.

The findings of this study, suggest both measurement methods demonstrate acceptable inter-tester relative and absolute reliability, as well as agreement and that the new measurement protocol could replace the standard, where manual stabilisation of the pelvis is not undertaken through the use of an additional person or belt application.

An additional aim was to establish and compare the inter-tester minimal detectable change for hip joint MR and LR ROM of the hip joint when measured in prone by a novice and expert tester for both measurement protocols. The MDC_{95} for both the measurement protocols were found to be comparable (standard method range, 6.2°-11.5°; new method, 8.0°-10.7°), but as in the calculation of the SE of M, the MDC is based on the standard deviation of the differences (Portney and Gross, 2020a; Scalzitti and White, 2016), this is not surprising given the similar standard deviation of the differences values for the standard and new measurement protocol (mean difference SD range 4.24°-5.88°, standard; and 3.17°-5.47°, new measurement method). If the MDC_{95} values are applied to the ROM improvement values in the first study, two testers would have detected a change in all AROM values using the new measurement protocol, albeit that for right MR using the new measurement method MDC_{95} value (10.4°) negligibly exceeds the mean MR improvement value (10.01°). Pua *et al*. (2008) judge that the application of a 90% level provides an acceptable level for clinical interpretation of change score. The MDC_{90} for both measurement protocols were also found to be similar (standard method range, 7.0°-9.7°; new method, 5.2°-9.0°) and if these values are applied to the ROM improvement values in the first study, two testers would have detected a change in all AROM values using the new measurement protocol, where a mean improvement of MR in the first study was 10.01° (*n* = 26) as indicated above and 14.4° for LR (*n* = 43). As therapists usually conduct measurements on their own (Bohlin *et al*., 2005), the suggested advantage of the new measurement protocol in this respect is evident and is recommended, unless they have the ability and time to stabilise the pelvis manually through the use of another person or straps. The new measurement method and this study contribute to addressing this need. The findings of the two studies within this thesis suggest both measurement protocols could be considered for future research and clinical practice, but in view of the differences in controlling for pelvic rotation, the two methods are not considered interchangeable.

Some interpret an ICC of .75-1.0 as being excellent (Gradoz *et al*., 2018; Blonna, Zarkadas and Fitzsimmons *et al*., 2012; Cicchetti, 1994) and if applied to the results of this study, the inter-tester reliability would be considered as excellent for all rotation measurements using the standard and new measurement method, which demonstrates how the reporting of results can be inflated depending on the interpretation classification used and hence the need to also report point estimate values for interpretation purposes.

Comparison analysis with those in the literature is restricted due to differing methodologies and populations studied (Kouyoumdjian *et al*. 2012; Pua *et al*. 2008). The study that was most similar in method to this study was conducted by Simoneau *et al*. (1998), who evaluated inter-tester reliability using a goniometer as part of their investigation of the influence of hip position and gender on MR and LR AROM. Inter-tester reliability was evaluated as part of the study conducted by Simoneau *et al*. where one test reading of active MR and LR was taken per tester in both prone and seated positions, but both manual and belt stabilisation was applied for the conduction of measurements in the prone position. There were three teams of testers where two testers per team conducted measurements on the dominant leg of twenty subjects per team. ICC values were found to range from .82 to .97 for MR and from .79 to .98 for LR when contrasted across the teams, but when the data of all sixty subjects were pooled, the point estimate coefficients raised to a range of .93 to .94. A sample of healthy, college-aged students were recruited for the study conducted by Simoneau *et al.*, who may have had a lack of variability when grouped in their sub-set of twenty. A lack of variability in ROM values can reduce ICC values (Portney and Gross, 2020a) and when Simoneau *et al*. pooled the values of the three sub-sets of testers, it may have increased the variability and hence the ICC values.

Bierma-Zeinstra *et al*. (1998) evaluated the inter-tester reliability of a half-circled, long-armed goniometer as part of a comparison study with an inclinometer for measuring active and passive hip joint rotation in a prone, supine and seated position. Ten testers obtained ten consecutive measurements of nine subjects. Significance tests were conducted, but not ICCs. However, the inter-tester variability standard deviation of the ten testers, were reported as 4.8° and 4.1° for MR and LR respectively. The mean difference standard deviation in this study were not too dissimilar (MR mean difference SD left 4.24° and right 4.39° using standard, but 4.29° and 5.29° using new method; LR mean difference SD left 5.45° and right 5.88° using standard, but 4.08° and 5.47° using new method).

Kouyoumdjian *et al*. (2012) evaluated the inter-tester agreement of the hip joint rotation ROM as part of a study investigating ROM values and position effects of three positions, including prone with the pelvis stabilised using a belt. A sample of healthy adults were recruited (n = 120), but passive ROM was measured using a digital photographic method and inter-tester agreement was evaluated with Lin's Concordance Correlation Coefficient. Kouyoumdjian *et al*. reported a point estimate value of .83 for MR and .67 for LR (confidence intervals unreported) considered as satisfactory by the authors. As Lin's concordance correlation coefficient is an index of reliability which is almost identical to the ICC and the maximum value of Lin's CCC is 1 when there is perfect concordance (Petrie and Sabin, 2020), it would appear that the inter-tester relative reliability of the standard and new measurement protocol using a UG in this study is comparable to that found by Kouyoumdjian *et al*. (2012) when measuring hip joint rotation in a prone position, a position reported by the authors to have higher agreement than what was found in a seated position with the hip joint in 90° flexion and supine position in 0° flexion. Digital imaging has previously been reported to have comparable reliability to a UG in the measurement of knee joint ROM, but as considered in the literature review, it is time consuming, requires a digital camera and computer with angle measurement software, which are drawbacks when compared to the low cost and simplicity of the UG (Bennett *et al*., 2009).

Pua *et al*. (2008) reported excellent intra-tester relative reliability for MR [ICC $_{(2,2)}$ = .93; 95% CI .83-.97] and LR [ICC $_{(2,2)}$ = .96; 95% CI .91-.99], but this was for a sample of subjects with OA of the hip joint (n = 22) and the mean of two readings of passive hip joint rotation were measured using an electronic inclinometer in a seated position, with body segments stabilised by straps in the seat of an Isokinetic Dynamometer. It is not possible to compare the study conducted by Pua *et al*. (2008) with this study due to the differences in methodology and population, but it is interesting to note how the inter-tester relative reliability of this study was found to be not too dissimilar to the intra-tester reliability found by Pua *et al*. (2008). The inclinometer and goniometer are reported to have a similar reliability (Bierma-Zeinstra *et al*., 1998) and the goniometer has been found to have greater intra-tester than inter-tester reliability in the literature (Clarkson, 2013). It could therefore be suggested that the inter-tester findings of this study is comparable to the intra-tester relative reliability found by Pua *et al*. (2008). However and as indicated earlier, variance affects reliability and as already established within this thesis, those with OA of the hip joint will have a reduced rotation ROM, which will affect the variance. It is therefore not possible to suggest that the relative reliability in this study is comparable to that found by Pua *et al*., who have found excellent reliability in a population with a likely low variance having measured the ROM of the symptomatic hip joints.

It is interesting to note how a similar absolute reliability estimate of SE of M is reported by Pua *et al*. for MR and LR, which was 3.4° and 3.1° respectively compared with 3.0°-3.1° for MR (standard measurement method) and 3.0°-3.7° (new measurement method), or 3.9°-4.2° for LR (standard measurement method) and 2.2°-3.9° (new measurement method). Again, not really comparable due to the differences in methodology and population sample beyond acknowledgement of similar inter-tester compared to intra-tester SE of M values.

The intra-tester MDC_{90} values reported by Pua *et al*. were 7.1°-7.8° for hip joint rotation compared to inter-tester MDC_{90} values of 7.0°-9.7° using the standard and 5.2°-9.0° using the new measurement protocol in this study. Gradoz *et al*. (2018) investigated intra-tester and inter-tester reliability of hip joint passive MR and LR in a seated and supine position with the hip joint in 90° flexion. One experienced and two novice testers were involved in measurement and inter-tester point estimate ICC values ranged from .64-.79 with MDC_{95} values reported as ranging from 6.1°-8.6°, which are not too dissimilar to the intra-tester MDC_{90} values found by Pua *et al*. (2008). Whilst it is not possible to directly compare the MDC values of this study with those of Pua *et al*. (2008) and Gradoz *et al*. (2018) due to the differing methodologies and population samples, it is worth considering positional effects that could contribute to differences in MDC_{95} values between this study and those reported by Gradoz *et al*. Gradoz *et al*. do report an improvement of MDC_{95} values compared to those found in this study, which may be due to seated positional effects. For example, when the hip joint is in the flexed position, bony impingement may restrict rotation in addition to tension of soft-tissues (Hollman *et al*., 2003), whereas in extension there is no bony impingement. Restriction of ROM through bony impingement may reduce measurement error compared to that restricted by soft-tissue tension as they can extend further at the end of ROM producing soft-tissue effects on measurement reliability, but measurement in the flexed position would be measuring where in the range bony impingement restricts ROM rather than soft-tissue constraints. Gradoz *et al*. do not report the SE of M and therefore prevents any further comparison on measurement error. However, Gradoz *et al*. (2018) do report how more research is required to investigate hip joint rotation measurement reliability in a prone position, due to the inconsistency of findings within the paucity of related studies and this study therefore contributes to what needs to be known about rotation measurement in a prone position.

Poulsen *et al*. (2012) investigated the inter-tester reliability of a senior orthopaedic surgeon, a junior doctor and two senior chiropractic practitioners where all but one of the latter practitioners had experience in the orthopaedic examination of hip joints of those with hip joint OA. Again, methodology differs from this study preventing direct comparison, but the authors asserted that the MDC (within 95% confidence) can if the systematic tester error is zero, be established by calculating the half value of the LoA range. As the systematic bias in this study is close to zero (range 0.53°-2.53° standard measurement method; -1.22°-0.12° new measurement method), it produces a MDC of 8° for left MR using both measurement methods, 8°-9° (using standard method) and 10° (using new method) for right MR; 11° (using standard method) and 6° (using the new method) for left LR and 10°-11° using both measurement methods for right LR. These values are comparable to those calculated and presented earlier suggesting the technique asserted by Poulsen *et al*. (2012) is effective for estimating the MDC, provided the systematic error is close to zero.

Poulsen *et al*. (2012) reported poor-moderate inter-tester reliability and an inter-tester MDC value of 20° and 17° for MR and LR respectively. The authors were interested in reflecting current clinical practice and reported that their findings indicated that their poor results were attributable to a lack of standardisation of measurement method and rigorous training. Others who have found improved inter-tester reliability reported standardisation of measurement and tester training measures to achieve this including for example, Bierma-Zeinstra *et al*. (1998) and Simoneau *et al*. (1998). Gradoz *et al*. (2018) attribute their good-excellent novice versus experienced inter-tester reliability to stabilisation of the pelvis in the supine position rather than the provision of tester training and others have equally reported segmental control of pelvic rotation to improve inter-tester reliability such as Pua *et al*. (2008) and Simoneau *et al*. (1998). The inter-tester reliability and agreement findings in this study are consistent with those studies where the measurement method was standardised and training was provided and in this current study, it is more evident considering there was a complete novice and an experienced tester. The current study is also consistent with those where control measures were applied to prevent pelvic or trunk rotation movement. However, the difference is that other studies use either or both straps and manual stabilisation of the pelvis and this is the first study to the knowledge of the researcher, of a study being conducted with an alternative method of controlling for pelvic or trunk rotation in prone by allowing movement, but changing the reference point for the reference arm of the UG from one that is either aligned with the line of gravity (Simoneau *et al*., 1998) or the perpendicular to the horizontal plane (Bierma-Zeinstra *et al*., 1998) and floor (Hollman *et al*., 2003) to one that is aligned with the perpendicular to the tangent of the sacrum and glutei instead. Simoneau *et al*. (1998) assert that stabilisation of the pelvis is unlikely to be common practice in the clinical setting due to time-constraints and recommend that clinicians should pay attention to the possibility of substitution techniques that may affect measurement. This study has successfully investigated such a substitution technique to retain reliability of measurement.

Irrespective of measures within this study to improve inter-tester reliability and agreement, the MDC_{90} and MDC_{95} values in this study could be considered as being in need of improvement to detect change beyond measurement error in research and clinical practice and to improve consistency. This may require the use of higher level technology as suggested by Clarkson (2016), when such instrumentation for the measurement of hip joint rotation ROM in a prone position becomes available, that adequately controls for pelvic rotation. However, if a population group such as those with hip joint OA who present with either <24° MR or 15° less than what is found in their unaffected hip joint (Cibulka *et al*., 2017) were targeted to measure and improve their ROM, the MDC_{90} values of this study would be adequate to detect such loss and any resultant improvement from intervention designed to do so.

Previously, research has suggested that an intra-tester and inter-tester change value of 3°-4° and 6° (Clarkson, 2013; Boone *et al*., 1978) should be respectively applied for lower limb joints including the hip joint, but this is questioned in terms of generalising from one joint to another in this regard (Portney and Gross, 2020a; Gajdosik and Bohannon, 1987). This study supports the latter assertion and contributes to what is known about the MDC for the hip joint. More research would be required to demonstrate consistency, but this study suggests that the inter-tester MDC for active hip joint rotation measured in prone may be larger than what has previously been recommended. The joint and reliability of measurement clearly influences MDC values, but this study suggests that it is also questionable to generalise from one direction of movement to another.

As discussed in the literature review, it is important in reliability studies to ensure the sample has some variance where examinees have a range of scores across the continuum to show reliability (Portney, 2020) and using a mixed group of participants may be the ideal for establishing the reliability of a measurement instrument and technique (Carter and Lubinsky, 2016). As discussed, if a population sample with healthy unaffected hip joints were to be selected, it may not produce ROM data that is as low as would be found in those with a pathology related reduction of ROM. Equally, if a population sample with unhealthy hip joints were to be selected, it may not produce ROM data that is within the normal or higher range. Populations that are expected to have an associated lower hip joint rotation ROM are those with pathology such as OA and lower limb injuries; conditions such as low-back pain; and those who participate in exercise such as running activity (Hartigan and White, 2016) and hip and spinal rotation sports (Sadeghisani *et al*., 2015). Inclusion and exclusion criteria were therefore designed to recruit subjects with variability in ROM values. So, if prospective participants reporting a history of pathology involving the lower limb or spine volunteer for the study, they were recruited provided they were not currently being investigated or treated. Many of those targeted and recruited however, were those who participated in recreational exercise, sport and physical activity groups. If the inter-tester mean and range in ROM values are calculated, it can be seen from Table 7 how the recruitment strategy successfully produced a mixed-group sample with variance of ROM values, as recommended in the literature for reliability studies. For example, an inter-tester mean range of 14.5° to 59.5° was found using the new measurement protocol when measuring LMR. However, more research is recommended to determine if reliability can be demonstrated using the new measurement protocol to measure hip joint rotation in a population with a lower variance of ROM values such as those with OA, as demonstrated by Pua *et al*. (2008) who measured affected joints using a digital inclinometer where participants were seated in the chair of an isokinetic dynamometer with belt stabilisation of the trunk.

Table 7: The mean range of movement and range for Tester 1 & 2 using the standard and new measurement protocol

Descriptive statistic	LMR Std (*n*=34)	LMR New (*n*=34)	RMR Std (*n*=34)	RMR New (*n*=34)	LLR Std (*n*=34)	LLR New (*n*=32)	RLR Std (*n*=34)	RLR New (*n*=34)
Tester 1 & 2 mean ROM	41.7°	42.0°	43.3°	44.2°	50.6°	56.8°	48.6°	54.4°
Tester 1 & 2 mean range	39.5° (19.0° to 58.5°)	45.0° (14.5° to 59.5°)	39.0° (21.0° to 60.0°)	39.5° (22.0° to 61.5°)	63.5° (16.5° to 80.0°)	62.5° (21.5° to 84.0°)	92.50° (−7.5° to 85.0°)	81.5° (−2.5° to 79.0°)

LMR = lateral medial rotation; RMR = right medial rotation;
LLR = left lateral rotation; RLR = right lateral rotation
Std = Standard measurement protocol; New = New measurement protocol

The assumption of normality was not met for all variables, producing a necessity to present the results of an inconsistent sample size, which was thirty-four for all but one of the variables, where the sample size for LLR using the new measurement protocol was marginally lower at thirty-two. The mean differences data for LLR using the new measurement method (*n*=34) was found not to have a normal distribution using the Shapiro-Wilk test (p = .008). Visual inspection of boxplots revealed two outliers and it could be seen from the distribution curve that the respective ROM difference values were responsible for producing the non-normal distribution and a positive skew. The Pearson's CC equivalent non-parametric Spearman's rank correlation coefficient (Spearman rank CC) was undertaken (Petrie and Sabin, 2020; Portney, 2020; Carter and Lubinsky, 2016) and for interpretation, it is large when r = >.50, medium when between .30 and .49 and small when below .29 (Portney, 2020, Pallant 2016, Cohen, 1998). A strong inter-tester correlation was found (r = .957, n = 34, p < .01) and in view of this despite the inclusion of the two outlier differences in ROM values, it was considered pertinent to conduct further analysis with the respective outlier values removed. This produced a normal distribution and parametric statistical analysis was therefore conducted on the reduced sample size (*n*=32) as non-parametric tend to be less powerful than parametric tests (Portney, 2020) and it is recommended that the most powerful test be conducted that the type of data will allow (Bowers, 2020). For the purpose of consistency, the two outliers were removed from the Bland-Altman plot analysis for LLR using the new measurement method.

The retention and removal of the above outliers requires further consideration in respect of LoA analysis, however. It is noted how much of between subject variation has been removed with using differences data leaving measurement error, which is likely to follow a normal distribution, but a non-normal distribution of the differences data may not be as serious in calculating the 95% LoA as in other statistical contexts and will therefore not have a great deal of impact on LoA (Bland and Altman, 1999). When the outliers for measuring LLR using the new measurement protocol were retained for the LoA analysis (n = 34), the mean difference value became −0.56°, with the mean difference SD value becoming 4.08° and the LoA range value becoming 16.01° (−8.56° to 7.45°) rather than −1.22°, 3.17° and 12.42° (−7.43° to 4.99°) for the same respective value when the outliers were removed. With the outliers retained, these respective values are not too dissimilar to those of LMR and RMR using the standard and LMR using the new measurement protocol. Furthermore however, the same respective values differ to those when measuring lateral rotation for both protocols and RMR using the new measurement protocol where wider LoA values were found, which warrants further analytical discussion.

From Table 6, medial rotation have large, but similar LoA range values (left 16.64°; right 17.21°) when using the standard measurement protocol and whilst the LoA range values are large using the new measurement protocol with the LMR LoA range value (16.8°) being similar to those using the standard, the RMR LoA range value (20.73°) exceeds the LMR value using the new measurement protocol. From the raw data, the following observations were made where an examiner obtained a difference of ≥10°. Using the standard measurement protocol for measuring LMR neither examiner obtained a difference value of ≥10°. Both examiners obtained one difference value of ≥10° than the other when using the standard measurement protocol measuring RMR, which was 10° and 13° respectively for the novice and experienced examiner. Using the new measurement protocol for measuring LMR, the experienced examiner obtained one difference value of ≥10°, which was 13° higher than that obtained by the novice. When measuring RMR using the new measurement protocol, there were three difference values ≥10° with the experienced examiner obtaining two of these, which were 14° and 10° respectively and consecutively obtained higher than the novice examiner. The novice examiner obtained the other higher difference value, which was 11° and was obtained immediately preceding the higher values obtained by the experienced examiner. It is not known why three consecutive values ≥10° were obtained by the two examiners, but it may be due to random error or noise such as examiner inattention through distraction as described by (Portney, 2020), whilst conducting the RMR measurements using the new measurement protocol. Irrespective of the causation of these higher value differences, they appear to have affected and widened the LoA range value for RMR.

From Table 6, the LoA range values for LLR and RLR using the standard measurement protocol are even larger, but are similar to each other (21.38° and 23.04° respectively) and are equally similar to RLR (21.42°) using the new measurement protocol. There is a clear lower LoA range value for LLR (12.42°) using the new measurement protocol however. From the raw data, the following observations were made where an examiner obtained a difference of ≥10°. Using the standard measurement protocol for measuring LLR, both examiners obtained two difference values of ≥10° each. The experienced examiner obtained two higher difference values of 10° and 11° than the novice, whilst the novice obtained two higher difference values of 10° and 15° than the experienced examiner. Measuring RLR using the standard measurement protocol four difference values were found to be ≥10° with the experienced examiner obtaining one higher difference value of 12°, whilst the novice obtained three of the higher difference values, which were 11°, 15°

and 11° respectively with the former two novice values being obtained consecutively. When measuring RLR using the new measurement protocol, the novice obtained one higher difference value of ≥10°, which was 11°, whereas when measuring LLR, neither examiner obtained a higher difference value of ≥10°. The absence of difference values of ≥10° for LLR when using the new measurement protocol is due to having removed one outlier value of 11° and another of 9° for sample size consistency purposes with those of the reliability analysis.

The above raw data analysis would appear to support Bland and Altman (1999) in non-removal of outliers for LoA analysis, irrespective of outlier retention producing a non-normal distribution. Had the outliers not been removed, the LoA range for LLR would have been 16.01° rather than 12.42°, which would have been more consistent with the LoA range values for MR where less frequent higher inter-tester difference values were obtained. It is not known whether the larger LoA range values for lateral rotation is an intrinsic anomaly of this measurement of the hip joint irrespective of the measurement protocol used, or whether there was a higher frequency of noise such as examiner distraction and more research would be required to determine this, where more highly stringent control measures for noise would be recommended to reduce this risk such as preventing inter-participant conversation.

Whilst it is not known whether examiner inattention or distraction noise led to larger LLR and RLR LoA range values using the standard; and RLR LoA range value using the new measurement protocol, or not, the removal of outliers has clearly led to a narrower LoA range value and without these being removed this value is increased to 16.01°. Bland and Altman (1999) assert that a lack of agreement is inevitable and as indicated by Bland and Altman above, difference value data does not always have a normal distribution and is not as serious on LoA analysis as other statistical context. The sample size for LLR using the new measurement method was reduced to thirty-two when outliers were removed to produce a normal distribution for reliability analysis and the sample size was maintained at thirty-two rather than thirty-four for sample size consistency purposes for agreement analysis. In view of the assertion of Bland and Altman regarding a non-normal distribution not generally impacting on LoA, the sample size for LLR using the new measurement protocol could have remained at thirty-four, on reflection. Had the outliers not been removed, the larger respective LoA range value of 16.01° for LLR using the new measurement protocol still remains lower than the other lateral rotation LoA range values using the standard and new measurement protocols. However, this is likely due to only one examiner obtaining only one value ≥10°. This suggests after all, that noise such as examiner inattention or distraction may have been the more likely cause of larger LoA range values for LLR and RLR using the standard and RLR using the new measurement protocol rather than an intrinsic anomaly of lateral rotation measurement of the hip joint and supports the recommendation of more stringent control of the measurement environment such as the reduction of examiner distraction risk to reduce the frequency of larger inter-tester ROM difference values further.

Prior to the conduction of the further standard and new measurement method Bland-Altman LoA analysis, where the mean value of both examiners was determined for each movement using the standard and again for the new measurement method and subsequently, the mean of the two methods was then plotted against their differences, it was found that the assumption of normality was not met for all variables. It was therefore necessary to present the results of an inconsistent sample size, which was thirty-four for LMR, LLR and RLR, but it was marginally lower at thirty-three for RMR, as the mean differences data for RMR (n=34) was found not to have a normal distribution using the Shapiro-Wilk test (p= .008). Visual inspection of boxplots revealed one outlier and it could be seen from the distribution curve that the respective ROM difference value was responsible for producing the non-normal distribution and a positive skew. It was considered pertinent to conduct further analysis with the respective outlier value removed. This produced a normal distribution using the Shapiro-Wilk test (p= .095) and LoA analysis was therefore conducted on the reduced sample size (n=33).

It was explained earlier in regard to the retention and removal of outliers in respect of LoA analysis and how a non-normal distribution of the differences data may not be as serious in calculating the 95% LoA as in other statistical contexts and that it would therefore not have a great deal of impact on LoA (Bland and Altman, 1999). So when the outlier for measuring RMR was retained for the LoA analysis (n= 34), the mean difference value became −0.84°, with the mean difference SD value becoming 5.45° and the LoA range value became 21.36° (−11.52° to 9.84°) rather than −1.35°, 4.63° and 18.17° (−10.43° to 7.74°) for the same respective values when the outlier was removed. With the outlier retained, the respective values are not too dissimilar to those for LMR. Furthermore however, the same respective values differ to those when measuring lateral rotation where wider LoA values were found, which warrants further analytical discussion.

From the above and Figures 9, 11 and 12 the LoA range values were all larger than the inter-tester respective values discussed earlier. These larger LoA range values are again related to a greater frequency of difference values ≥10°. There were two difference values ≥10° for LMR and RMR, but there were eleven and nine respectively for LLR and RLR. An examinee was measured for MR and LR of both hip joints using the standard measurement protocol and the same process was repeated using the new measurement protocol before then proceeding to repeat the same process with the next examinee. In other words, those measurements obtained using the new method could be considered as repeat readings, which can result in a carry-over effect and induce visco-elastic changes (Macedo and Magee, 2009; Macedo and Magee 2008, Nigg et al., 1995), a treatment effect (Klässbo et al., 2003), producing an immediate soft-tissue stretch effect (Katalinic, Harvey and Herbert et al., 2010) and such a stretch effect can increase ROM (Portney, 2020). Whilst such an effect may not be sustained (Katalinic, Harvey and Herbert et al., 2010), it may have been sustained for the duration of the interval time between the two methods of measurement and explain why there was a greater frequency of difference values ≥10° and larger LoA ranges on conduction of the further standard and new measurement method Bland-Altman LoA analysis. To reduce the above effects, a data collection adjustment where the new could be conducted immediately after the standard method of measurement for each movement using a single tester with a minimal interval time would be possible if the key interest was direct inter-method analysis. This would be recommended if this was so, but great care would be required to control for position change of the examinee pelvis whilst they maintain an active ROM for measurement using both measurement methods. If tests are conducted close enough, genuine changes in ROM from repeat testing stretching effects can be avoided (Portney, 2020), but there is an inherent delay of conducting a measurement using the standard measurement method, releasing the manual stabilisation of the examinee pelvis and conducting an examinee position change before a measurement can be obtained using the new measurement protocol. Even if ROM measurements were able to be efficiently obtained using the two methods consecutively with the examinee maintaining an active ROM avoiding the need for a repeat movement measurement, it may unfortunately be sufficient enough to produce other effects that may cause measurement error. For example, muscle fatigue can be a source of measurement error (Portney, 2020) and if active ROM were to be maintained for the duration of the above described process, fatigue may affect the ROM measurement readings. As discussed in the literature review and methodology of this Chapter, inter-tester reliability and agreement would better be assessed if both examiners were able to simultaneously and independently obtain a ROM measurement reading to reduce measurement error, but this is not possible for ROM data collection because of the interaction required between the examiner and examinee for the purpose of measurement (Portney, 2020). The same argument would apply when using two methods of measurement, where it would be better for the two methods to be used simultaneously, and independently obtain ROM values, but it is not possible where two different measurement positions are used, however similar they may be.

The carry-over effects of a repetition of movement by conducting all the measurements using the standard followed on completion, by the new measurement method considered above such as the inducement of visco-elastic changes, the stretch and treatment effects may explain the larger LoA range values, but it does not explain the systematic bias differences between MR and LR, where there was a negligible mean difference between the two methods for the former and almost 6° for the latter. Neither does it explain the much higher frequency of difference values found in LR than MR. This very much suggests a more fundamental difference between the two measurement methods beyond the above repeated movement effects and one that is most likely positional.

When measuring LR using the new method of measurement where the pelvis is not manually stabilised in the horizontal plane, the suggested positional effect may be due to the hip joint being allowed a small amount of flexion as the pelvis rises on the side of the hip joint that is being measured. In other words, ipsilateral hip joint flexion occurs on measuring LR using the new method, which does not occur when using the standard. When measuring MR, the ipsilateral pelvis does not rise using either method of measurement, but the contralateral or opposite pelvis does; preventing the ipsilateral hip joint being measured from rising and further prevents the joint from flexing. This suggests why there is a negligible systematic bias being evident between the two methods of measurement when measuring MR, but almost a 6° systematic error when using the new measurement method when measuring LR. In other words, the new appears to consistently measure almost 6° more ROM than the standard measurement method when measuring LR. This represents a positional effect and serves to demonstrate that the standard and new method of measuring LR is not interchangeable.

There are some limitations and additional recommendations.

An independent research assistant was recruited to remove potential researcher bias, where bias control is necessary to ensure an appropriate data collection procedure (DePoy and Gitlin, 2016) that cannot be influenced by the researcher. The research assistant completed training to fulfil their intended role including management of the data collection environment, subjects, apparatus and materials for data collection, as well as assisting in the data collection method and reading, interpreting and recording the data. Unfortunately, the research assistant had to withdraw at short-notice as data collection sessions commenced and the researcher had to assume the role. This is one of the weaknesses of the study and any future research would require a contingency plan of for example, recruiting an additional assistant to control for researcher bias during data collection sessions in the event of loss of the recruited research assistant. Concerns have been reported in the literature expressing a need to potentially require more than one tester in research involving for example, a longitudinal or multi-centre study (Shultz *et al*., 2006) and the same can evidently apply for other personnel involved in such research.

For relative inter-tester reliability data analysis where the ICC ($_{2,1}$) is used, random selection of testers is assumed and affords generalisability to all raters (Ellison *et al*., 1990). The ICC ($_{2,1}$) was applied in this study and whilst it is not possible to have access to all prospective examiners to truly randomly select two, it is contextually permissible to consider the two examiners are theoretically selected at random with the essential point of being able to generalise the outcome to other similar examiners (Portney and Gross, 2020a), which was a novice and experienced examiner. This study failed to continue the randomisation process throughout all data collection procedures such as participant and test order. To be able to fully generalise that other testers would equally demonstrate reliability, randomisation is a crucial feature of research and central to inferential statistics (Hicks, 2009). However, there is inconsistency in the literature in regard to randomisation of participants and ROM testing order. There are those who did not randomise to ease administrative data recording procedures of multiple tests and to reduce position changing (Pua *et al*., 2008), whilst others did not report on sequencing (Gradoz *et al*., 2018; Kouyoumdjian *et al*., 2012; Hollman *et al*., 2003; Holm, Bolstad and Lütken *et al*., 2000; Bierma-Zeinstra *et al*., 1998; Simoneau *et al*., 1998; Ellison *et al*., 1990). Poulsen *et al*. (2012) randomised the order of four testers to control for learning effects. In this study, there was no randomisation of the tester order to prevent learning effects of the novice observing the experienced tester ahead of them conducting their measurement. The intention was for each tester to turn away whilst the other conducted measurement, but the loss of research assistant and the researcher assuming the vacant role contributed to loss of this control measure. In addition, the non-randomisation of test order to ease administering of data collection (Pua *et al*., 2008) is understandable and as this study included eight measurements by each tester on each participant, the ROM measurement order was not randomised, which is a weakness of this study. Gabbe *et al*. (2004) randomised participant order, but not the ROM measurement tests. This study did not formally randomise participant order who self-randomised by attending data collection sessions convenient to them. Whilst it is not believed that participant, tester and measurement test order in this study adversely affected the results, from the above discussion, randomisation of all data collection procedures such as participant, tester and measurement test order would improve generalisability and would be recommended for future research.

There is evidence within the literature of reflecting clinical practice for inter-tester reliability studies such as reported by Poulsen *et al*. (2012) in the use of a single reading for the measurement of hip joint rotation ROM. This study was interested in reflecting the measurement and data collection method of the first study in this thesis. It was also considered that muscle fatigue would be induced with repeated tests and be a source of inter-tester error. There is inconsistency in the literature regarding the number of readings required with goniometry ROM measurements (Scalzitti and White, 2016) where it is recommended that the mean of several readings are required to increase reliability (Scalzitti and White, 2020; Low, 1976), but it has equally been argued in the literature that one reading is as reliable as the mean of repeated readings (Scalzitti and White, 2020; Boone *et al*. 1978). The findings of this study can therefore only be applied where a single reading has been conducted as in the first study of this thesis. However, as the arithmetic mean of two or more measurement tests would be effective in reducing overall error and improving reliability (Portney, 2020), it is recommended to investigate this in future research. Such research can be conducted as part of a larger investigative study (Petrie and Sabin, 2020), or as an independent study.

As considered above, this is the first study conducted to investigate a substitution technique for stabilisation of the pelvis in the measurement of rotation of the hip joint in a prone position, required on account of pelvic stabilisation being unlikely in clinical practice due to resource constraints (Simoneau *et al*., 1998). Measurement is often conducted by a therapist on their own (Bohlin *et al*., 2005), as in the first study, where the new measurement method was used to substitute for pelvic stabilisation. It is possible that the same problem applies in measurement of LR of the glenohumeral joint when lying supine and a substitution technique is adopted for upper trunk rotation. This presents scope for further methodological research to investigate whether it is possible to control for trunk rotation by placing the static arm of the UG in line with an imaginary line that is perpendicular to the tangent of the sternum and chest, which is similar to that in the new measurement method of hip joint rotation, where the static arm is placed in line with an imaginary line perpendicular to the sacrum and glutei.

4.6. Conclusions

Inter-tester reliability and agreement for both the new and standard measurement protocol has been demonstrated by the results of this study. This study addresses the identified need to investigate a substitution technique for stabilising the pelvis and contributes to what needs to be known about hip joint rotation measurement in prone *per se*, but particularly when using a UG. The new measurement method is an adaptation of the standard where a substitution technique is adopted to retain reliability of measurements obtained by a single tester without stabilising the pelvis, which is more efficient on time and other resources by reducing the need for stabilisation through the use of belts or an additional person. Findings from this study suggests that either measurement protocol can be used for active hip joint rotation ROM measurement, but not interchangeably as they represent two differing methods of controlling for pelvic rotation. The need for measurement standardisation and tester training is supported by this study, in order to demonstrate inter-tester reliability and agreement between a novice and experienced tester.

The new measurement protocol produced an inter-tester minimal detectable change value that would enable the detection of change if two testers were involved in the measurement of active hip joint rotation in the first study in this thesis that investigated a stretch protocol for improving the same ROM, whether the MDC_{95} or MDC_{90} is applied. The results from this study suggest either the new or standard measurement protocol could be adopted for research provided a change of ROM exceeds the minimal detectable change of 9°-10° when two testers are involved in obtaining ROM data and the MDC_{90} is applied. The standard measurement protocol is recommended in clinical practice should manual stabilisation of the pelvis be possible, but the new measurement method is recommended where it is not.

This study supports that acceptance of minimal detectable change values universally across all joints for all ROM appears to be an assumption and it is therefore recommended that the ROM of all joints continues to be investigated to be known and understood for examination interpretation, intervention evaluation, supporting evidence-based practice and research purposes, as values may be dependent on the direction of movement as well as measurement position and mode of movement when measuring using a UG.

Intra-tester reliability is considered to be greater than inter-tester reliability, which may produce a lower MDC value. Research is recommended to demonstrate intra-tester reliability and determine the respective MDC value for both measurement protocols. The inter-tester MDC found in this study can only be applied where a single ROM measurement reading has been obtained. The inter-tester MDC from this study could be considered to be too large unless differences of ROM are greater. If the inter-tester MDC found in this study is considered too large, research is recommended to determine if inter-tester reliability can be improved to reduce it through for example, the use of the mean value of two or more ROM measurement readings. If greater inter-tester reliability is required with a reduced MDC value and is found that it cannot be improved using a UG when measuring hip rotation in prone, it may require higher level technology.

Further research is required to determine if the results of the study can be replicated, including other population groups with known lower variance of ROM values, such as those with OA of the hip joint. This may contribute to determining whether measures need to be taken to improve reliability further.

5. General discussion and conclusions

The aim of this thesis was to investigate hip joint rotation ROM improvement through soft-tissue stretching and the evaluative measurement method. The purpose of this chapter is to integrate and summarise findings from the two studies inclusive of the main limitations and recommendations for future research.

Having established from the literature that full hip joint ROM is required for joint health and function (Curwin, 2011; Reese and Bandy, 2010), that ROM loss can have undesirable effects not only on the joint, but also adjacent structures (Curwin, 2011), that rotation loss is considered pathological and associated with pathology (Curwin, 2011) such as OA (Vogelgesang, 2015; Holla *et al*., 2011; Dvořrák *et al*., 2008), it was considered important to investigate how to improve such loss through adaptive lengthening of soft-tissue structures. There are inconsistencies and inaccuracies within the literature regarding the origins of soft-tissue adaptation theory, but it can be traced back to Davis' theoretical law from the mid-late 19th Century (Ellenbecker *et al*., 2009; Tippet and Voight, 1995; Gould and Davies, 1985; Davis 1867). From observed examples, Davis (1867) discusses how soft-tissues such as joint capsules and ligaments can adaptively and gradually shorten and lengthen depending on the demand imposed. Implicit from more recent literature, this is referred to as the stress-strain, load and plastic deformation theory (Özkaya *et al*., 2018; Nordin and Frankel, 2012; Curwin, 2011; Frank, 1999; Özkaya and Nordin, 1999; Butler *et al*., 1978) where a tensile load will produce stress on soft connective tissue, producing a percentage change in the length, which is defined as strain where the plastic deformation of tissues occurs when loaded beyond their elastic or yield limits. Although strain cannot be measured directly, it can be mathematically expressed in percentage terms by calculating the difference in tissue length by subtracting the original length from the resultant length value of a tissue and then dividing this difference in length by the original tissue length value (Curwin, 2011; Grood and Noyes *et al*., 1978). However, the fibres of hip joint ligaments are not just parallel, as they are also oblique or spiral in nature (Siff, 2005; Butler *et al*., 1978) and so if they are non-linear and inconvenient to access anatomically, measuring adaptive changes in length is problematic. However, as hip joint rotation is largely dictated by inert capsular and ligament constraints (Hogg *et al*., 2018; Martin *et al*., 2008), it is reasonable to assume that any adaptive change in their length must produce a change in same respective ROM. Irrespective, Davis' law remains theoretical and experimental research needs to be continued until a scientific law can be applied. *In-vitro* soft-tissue engineering may assist in obtaining evidence to support scientific law development, but the timescale for such advances may be indefinite.

It is hoped that new emerging technology will be developed and become available to allow collagenous soft-tissues to be studied *in-vivo* at micro-level in the near future (Silver and Shah, 2017) and unfortunately, a new generation of clinically viable technologies are still needed for *in-vivo* soft-tissue length measurement (Zhang *et al*., 2021). Until evaluative soft-tissue length measurement instrumentation becomes available, research is recommended to continue to measure the effects of soft-tissue stretching on joint ROM improvement.

Stretching is argued to increase soft-tissue extensibility and joint ROM (Glynn and Fidler, 2009) through plastic deformation (Siff, 2005), ensuring they do not return to their original state (Anderson, 2014). Stretch techniques are therefore a theorised common intervention in physiotherapy. Indeed, such an intervention is recommended as an adjunct intervention to increase joint ROM in those with hip joint OA in national guidelines (NCGC, 2014 and NICE, 2008). Specificity of prescription guidance exists within the literature (Chamberlain, 2017; Pescatello, 2014; Chamberlain *et al*., 2013; Sanghvi, 2013; Garber *et al*., 2011), but stretch prescription is largely unknown (Curwin, 2011) and theoretical recommendations are inconsistent and insufficiently specific with research pertaining to muscle tissue within the literature. As there is no evidence of the effectiveness of stretching (Harvey *et al*., 2017; NCGC, 2014; Katalinic *et al*., 2010; NICE, 2008) and systematic reviews recommended the need for research (Harvey *et al*., 2017; Katalinic *et al*., 2010), it was considered important to initiate exploration through the first study in this thesis. The first study in Chapter 3 of this thesis, was a descriptive retrospective case series data study designed to enquire whether a stretch protocol increased medial and lateral hip joint ROM over a three-month time period.

The first study suggests that stretching to a point of feeling a firm end-feel (White and Norkin, 2016; Reese and Bandy, 2010), tightness and an intensity of the highest tolerable level of discomfort (Curwin, 2011) may have produced a significant statistical and clinically important improvement in hip joint rotation ROM with a large effect size over a three-month period, if conducted for sixty-seconds on a daily basis. There was a statistically significant increase of mean MR ROM of 10.08° (±4.63°) producing a final mean value of 36.46° (± 5.25°) from a baseline mean value of 26.38° (± 5.49°); and a mean increase of LR ROM of 14.37° (±6.00°) producing a final mean value of 51.56° (±9.33°) from a baseline mean value of 37.18° (±9.37°). The clear limitation of such a study is the lack of a control group for comparison analysis, but the results of the study successfully supports and demonstrates the clear need to investigate the stretch protocol further through a randomised control trial with the study and respective results informing future research design and planning. The study contributes to increasing stretch prescription specificity, but more research is required to improve this further. Research is required to determine the most effective position to conduct the stretch technique, as it is not possible to discriminate whether stretching with the hip joint in flexion or extension is more effective from the first study. It is recommended for this to be investigated through further research where participants would be randomly allocated to one of three groups and namely, either one of two stretch techniques or a control group. The most effective intensity of the stretch is in need of investigation to determine if it can be measurably quantified and identified, as the intensity of the stretch technique in the first study could be considered to be too subjective. Determining the quantifiable intensity of stretching could be considered to be a priority and is recommended, but this could delay further investigation of the stretch protocol effects and could be considered ethically dubious to do so. It is therefore recommended that the quantifiable stretch intensity should be explored in terms of acquisition or development of apparatus to measure stretch intensity and then determine the quantifiable intensity required to induce improved hip joint ROM, or adaptively lengthen soft-tissues, but should not necessarily delay further investigation of the stretch protocol within this thesis.

Whilst the reliability and validity of joint ROM measurement using a Universal Goniometer is well established in the literature (Simoneau *et al*., 1998), there is no evidence of reliability for the measurement method used to evaluate the effect of hip joint rotation stretching on ROM improvement in the first study. In addition, further investigation of the effect of the stretch protocol on ROM may require data collection by more than one tester and so it was important to not only investigate inter-tester reliability, but also determine whether improvement of ROM from stretching would have been detected had two testers been involved in the ROM data collection of the first study. The literature warns of potential attrition of those involved in data collection procedures (Shultz *et al*., 2006), which was experienced during the course of the second study in this thesis and supports the need for contingency planning that includes the recruitment and training of more than one tester and research assistant for future research. The demonstration of inter-tester reliability and agreement is therefore necessary to be confident that measurement accuracy is sufficient to detect a true change through loss or improvement of ROM resulting beyond measurement error (Petrie and Sabin 2020; Portney and Gross, 2020a).

The primary purpose of the hip joint rotation measurement study in Chapter 4 was to compare two measurement protocols for measuring active medial and lateral rotation of the hip joint in prone. One was a standardised measurement protocol recommended within the literature where measurement error will occur unless pelvic rotation is not recognised and controlled through physical stabilisation (Greene and Heckman, 1994). The other was a new measurement protocol, which included a substitution technique to control for pelvic rotation without physical stabilisation, the method that had been used for ROM data collection in the first study. Physiotherapists usually conduct measurements on their own (Bohlin *et al*., 2005) where resource constraints render it unlikely that the pelvis is stabilised and it is therefore recommended that close attention should be paid to possible substitution techniques that may affect their measurements (Simoneau *et al*., 1998). If the pelvis is not stabilised the substitution technique involves the static reference arm of the goniometer being aligned parallel to an imaginary line perpendicular to the tangent of the sacrum and glutei. This new measurement method for obtaining ROM data was therefore an adaptation of a standard method designed to be more efficient, but retain reliability as recommended in the literature. The second study successfully investigated the substitution technique to improve reliability of measurement with inter-tester reliability and agreement being demonstrated. The new can therefore replace the standard method of hip joint rotation measurement, which is more efficient on resources and is recommended where physical stabilisation of the pelvis is not undertaken. The results of the second study suggest that an improvement of ROM would have been detected had two testers been involved in ROM measurement in the first study and as intra-tester reliability is found to be greater than inter-tester reliability in joint ROM measurement using a UG in the literature (Clarkson, 2013), it further suggests that a single tester would also have detected improvement.

Gradoz *et al*. (2018) recommend investigation of the reliability of rotation ROM measurement in prone in those with hip joint pathology. As a reduced hip joint ROM is considered to be pathological (Curwin, 2011), the two studies within this thesis contribute to the research need identified within the literature. However, the intra-tester reliability, agreement and minimal detectable change remains in need of being established for both measurement protocols through further research, in order for physiotherapists to be able to accurately measure and evaluate hip joint rotation ROM change when only one tester is involved in ROM measurement. More research is required to determine if the results of the second study can be replicated, but also to demonstrate intra- and inter-tester reliability, agreement and respective minimal detectable change in populations with a known low variance of ROM. For example, Pua *et al*. (2008) measured the affected hip joints of those with OA who have a known low variance of ROM in their intra-tester reliability study of an electronic inclinometer where participants were seated and stabilised with belts applied across the waist, chest and the ipsilateral upper leg to stabilise the body segments above and below the hip joint. Intra- and inter-tester reliability and agreement research could be conducted as part of a larger future study designed to evaluate the stretch protocol effects.

From the above, more research is clearly required and both studies within this thesis serve to inform research planning, design and methodology decision-making for future research. As indicated above, the results of the first study may for example, help predict the duration of a study for obtaining a significant statistical and clinically important improvement in hip joint rotation ROM, which is 3-4 months of data collection beyond the recruitment of the final participant. This is inconsistent with the seven-month duration recommended by systematic reviews (Harvey *et al*., 2017; Katalinic *et al*., 2010), but this recommendation is understandable given the context of having found no evidence to support stretching as a technique to improve joint ROM and that the reviewed evidence included studies of shorter durations when the variable of time could influence results. The results of the stretch study will also contribute to *a priori* sample size calculations for future research.

The results of the measurement study support the literature in the need for standardisation of the measurement method (Hartigan and White, 2016; Clarkson, 2013; Poulsen *et al*., 2012; Reese and Bandy 2010; Green and Heckman, 1994) and training (Portney, 2020; Poulsen *et al*., 2012) of those conducting the ROM measurement to improve inter-tester reliability, agreement and respective minimal detectable change. More research is recommended to determine if this can be improved any further however. For example, it may be possible to improve reliability and agreement through calculating the mean of two or more readings conducted by those obtaining ROM measurement data (Portney, 2020), which is in need of being ascertained with both measurement protocols. It is necessary to conduct such research to help determine whether the greater contributor to measurement error in measuring MR and LR in prone is indeed, related more to anatomy with the hip joint being situated deep to soft-tissue bulk (Greene and Heckman, 1994) and if so, may support the need for higher level technology (Clarkson, 2016) to be acquired or developed that may address this.

From discussions within this thesis, physiotherapists are well placed to determine and predict those who are at higher risk of developing unhealthy hip joint ROM that is associated with hip joint and other pathology and intervening to improve any ROM loss. Hip joint MR ROM has been quantified to be associated with pathology such as OA when it is either <24° or 15° less than what is found in their unaffected hip joint (Cibulka *et al*., 2017), but it is not known how much ROM loss is detrimental to joint health. It can only be assumed that normal rotation ROM is the value to maintain or recover in the event of loss, in order to help maintain joint health and reduce the risk of associated problems. Up to a decade ago, there was still very little published normative joint ROM data for healthy men and women across a wide span of ages and whilst many joint ROM values have been published on a publicly available database for comparative study purposes (Soucie, *et al*., 2011), MR and LR still do not appear to have been precisely determined to be included on this database (Centers for Disease Control and Prevention, 2020). This may suggest that insufficient research has been conducted to definitively determine normative hip rotation ROM values and dependence is therefore placed on guideline values. Guidelines advocate a value of 40° and 50° for MR and LR respectively when measured in neutral (AMA, 1984) in the recommended prone position for measurement (Rondinelli *et al*., 2008; AMA, 1993). The improved mean ROM values from the first study and the mean ROM found in the second study within this thesis are not too inconsistent with the guideline values. The mean MR and LR value of 36.46° and 51.56° was respectively found in the first study. However in the second study and calculated from Table 7 in Chapter 4, the mean value for MR for the two testers combined using the new measurement method was 43.1° and 42.5° using the standard; and for LR the mean value for the two testers combined using the new measurement method was 55.45° and 49.6° using the standard. By and large, the two studies within this thesis support the guideline rotation ROM values with a predominance of LR, but more research is required to establish normative values. Hip joint rotation has also been found to be reduced in those with back pain (Ellison *et al*., 1990) and those who participate in various sporting activity (Hogg *et al*., 2018; Cheatham *et al*., 2017; Nguyen *et al*., 2017; Sadeghisani *et al*., 2015; Tak *et al*., 2015; Deneweth *et al*., 2014; de Castro *et al*., 2013; Almeida *et al*., 2012; Ellenbecker *et al*., 2007) and whilst some advocate a normal ROM is required for joint health, injury prevention and performance in sport (Ellenbecker *et al*., 2007), or a full free ROM for an athlete's particular sport Meira and Wagner (2015), others assert it is not known whether a ROM restriction is advantageous or detrimental (Hoffman, Burgess and Bokermann, 2003). Research would be required to determine whether hip joint rotation ROM can be improved in populations known to have restrictions and determine whether it contributes to a reduction in back pain or whether it would be detrimental to sporting performance. Indeed, research is required to investigate the effects of the stretch protocol on hip joint rotation ROM, other joints where ROM is reduced and sequentially if not concurrently, the effects on other quality of life domains such as pain and daily activity and sporting function, as well as pathology. However, the research priority is to determine normative hip joint rotation ROM values and how to recover and maintain any loss in order to educate the wider population in the interest of joint health.

As indicated above, it will be necessary to investigate the means of maintaining hip joint rotation ROM in the future once it has been established whether it can be recovered. If ROM measurement values can be influenced by the time of day that measurement is undertaken (White and Norkin, 2016), there may be inter-day or inter-sessional influences on measurement. In order to evaluate whether ROM has been maintained, inter-day differences in ROM need to remain within measurement error and it is therefore recommended that inter-day reliability is investigated for both the new and standard measurement protocols.

Muscle strengthening is recommended for those with OA of the hip joint (NCGC, 2014; NICE, 2008). If a reduced hip joint rotation is pathological and places the health of the hip joint and adjacent structures at risk as discussed earlier, it is not known whether such muscle strengthening could place additional adverse stress on the same structures and be detrimental, if the associated rotation ROM remains reduced. It is therefore important to investigate the chronology of rehabilitation for those who dually have a reduced rotation ROM and a need for muscle strengthening.

This thesis may have implications for research and practice across physiotherapy and other professions; as well as the wider population in terms of joint health and associated healthcare systems, if the field of soft-tissue adaptation through stretching is progressively researched.

6. References

American Academy of Orthopaedic Surgeons (AAOS), (1965), *Joint motion method of measuring and recording*, Edinburgh, Churchill Livingstone.

Aefsky, B., Fleet, N., Myers, H. and Butler, R.J., (2016), 'Reliability and validity of a novel approach to measure hip rotation'. In: *Journal of Sport Rehabilitation*', Vol. 25, No. 4, pp. 330-337.

Agarwal, A., Kaur, A. and Ganesh, M.S.P., (2013), 'Effect of hip position and gender on active hip internal rotation and external rotation on the dominant side'. In: *Indian Journal of Physiotherapy and Occupational Therapy*, Vol. 7, No. 3, pp. 25-28. Available at: https://search.proquest.com/docview/1464664043/fulltextPDF/FAF7054BB71C445APQ/1?accountid=14089 (Accessed: 27 September 2018).

Ahlberg, A., Moussa, M. and Al-Nahdi, M., (1988), 'On geographical variations in the normal range of joint motion'. In: *Clinical Orthopaedics and Related Research*, No. 234, pp. 229-231.

Almeida, G.P.L., de Souza, V.L., Sano, S.S., Saccol, M.F. and Cohen, M., (2012), 'Comparison of hip rotation range of motion in judo athletes with and without history of low back pain'. In: *Manual Therapy*, Vol. 17, No. 3, pp. 231-235.

American Medical Association, (1984), *Guides to the evaluation of permanent impairment* (2nd edn.), Chicago, American Medical Association.

American Medical Association, (1993), *Guides to the evaluation of permanent impairment* (4th edn.), Chicago, American Medical Association.

Anderson, S.K., (2014), *Mosby's stretching pocket guide*, St. Louis, Elsevier.

Arthritis Care Organisation, (2015), *Exercise and arthritis*. Available at: https://www.arthritiscare.org.uk/what-is-arthritis/resources/218-exercise-and-arthritis (Accessed: 13 September 2016).

Arthritis Research UK (2014), *Keep moving*, Chesterfield, Arthritis Research UK.

Atkins, E., Kerr, J. and Goodlad, (2016), *A practical approach to musculoskeletal medicine: Assessment, diagnosis and treatment*, (4th edn.), Edinburgh, Elsevier.

Barak, M.M., Lieberman, D.E. and Hublin, J-J., (2011), 'A Wolff in sheep's clothing: Trabecular bone adaptation in response to changes in joint loading orientation'. In: *Bone*, Vol. 49, No. 6, pp. 1141-1151. Available at: https://www.sciencedirect.com/science/article/pii/S875632821101163X (Accessed: 4 October 2019).

Beaton, D.E., (2000), 'Understanding the relevance of measured change through studies of responsiveness'. In: *Spine*, Vol. 25, No. 24, pp. 3192-3199.

Ben, M. and Harvey, L.A. (2010), 'Regular stretch does not increase muscle extensibility: A randomized controlled trial'. In: *The Scandinavian Journal of Medicine and Science in Sports*, Vol. 20, No. 1, pp. 136-144.

Bennell, K.L., (2013), 'Physiotherapy management of hip osteoarthritis'. In: *Journal of Physiotherapy*, Vol. 59, No. 3, pp. 145-157.

Bennell, K.L., Egerton, T., Martin, J., Abbott, H., Metcalf, B., McManus, F., Sims, K., Pua, Y-H., Wrigley, T.V., Forbes, A., Smith, C., Harris, A. and Buchbinder, R., (2014), 'Effect of physical therapy on pain and function in patients with hip osteoarthritis'. In: *The Journal of the American Medical Association*, Vol. 311, No. 19, pp. 1987-1997.

Bennett, D., Hanratty, B., Thompson, N. and Beverland, D, (2009), 'Measurement of knee joint movement using digital imaging'. In: *International Orthopaedics (SICOT)*, Vol. 33, No. 6, pp. 1627-1631 Springer Link. Available at: https://doi.org/10.1007/s00264-008-0694-9 (Accessed: 27 September 2018).

Berchtold, A., (2016), 'Test-retest: Agreement of reliability?' In: Methodological Innovations, Vol. 9, No. 1, pp. 1-7. Available at: https://journals.sagepub.com/doi/pdf/10.1177/2059799116672875 (Accessed: 6 January 2022).

Bhave, A., Sodhi, N., Anis, H.K., Ehiorobo, J.O. and Mont, M.A., (2019), 'Static progressive stretch orthosis—consensus modality to treat knee stiffness—rationale and literature review'. In: *Annals of Translational Medicine*, Vol. 7, Supplement 7, pp. 1-11.

Bierma-Zeinstra, S.M.A., Bohnen, A.M., Ramlal, R. and Ridderikhoff, J., (1998), 'Comparison between two devices for measuring hip joint motions'. In: *Clinical Rehabilitation*, Vol. 12, No. 6, pp. 497-505.

Bland, J.H., (1993), 'Mechanisms of adaptation in the joint'. In: *Key Issues in Musculoskeletal Physiotherapy*, (Crosbie, J. & McConnell, J., eds.), Oxford, Butterworth Heinemann.

Bland, J.M. and Altman, D.G., (1986), 'Statistical methods for assessing agreement between two methods of clinical measurement'. In: *The Lancet*, Vol. 327, No. 8476, pp. 307-310.

Bland, J.M. and Altman, D.G., (1999), 'Measuring agreement in method comparison studies'. In: *Statistical Methods in Medical Research*, Vol. 8, No. 2, pp. 135-160.

Blonna, D., Zarkadas, P.C., Fitzsimmons, J.S. and Driscoll, S.W., (2012), 'Accuracy and Inter-observer reliability of visual estimation compared to clinical goniometry of the elbow'. In: *Knee Surgery Sports Traumatology Arthroscopy Journal*, Vol. 20, No. 7, pp. 1378-1385.

Bohlin, L., Sandstrom, S., Angstrom, L. and Lindstrom, B., (2005), 'Inter-tester reliability of active hip range of motion in patients with rheumatic diagnosis'. In: *Advances in Physiotherapy*, Vol. 7, No. 1, pp. 32-39.

Bonutti, P.M., McGrath, M.S., Ulrich, S.D., McKenzie, S.A., Seyler, T.M. and Mont, M.A., (2008), 'Static progressive stretch for the treatment of knee stiffness'. In: *The Knee*, Vol. 15, No. 4, pp. 272-276.

Boone, D.C., Azen, S.P., Lin, C-M, Spence, C., Baron, C. and Lee, L., (1978), 'Reliability of goniometric measurements'. In: *Physical Therapy*, Vol. 58, No. 11, pp. 1355-1360.

Boone, D.C. and Azen, S.P., (1979), 'Normal range of motion of joints in male subjects'. In: *The Journal of Bone and Joint Surgery*, Vol. 61, No. 5, pp. 756-759.

Bourn, J. Sir., (2003), Hip replacements: An update (Executive Summary and Recommendations), London, The Stationary Office.

Bowers, D., (2020), *Medical statistics from scratch: An introduction for health professionals*, (4th edn.), Chichester, Wiley Blackwell.

Bruton, A., Conway, J.H. and Holgate, S.T., (2000), 'Reliability: What is it, and how is it measured?'. In: *Physiotherapy*, Vol. 86, No. 2, pp. 94-99.

Butler, D.L., Grood, E.S., Noyes, F.R. and Zernicke, R.F., (1978), 'Biomechanics of ligaments and tendons'. In: *Exercise Sport Science Review*, Vol. 6, No. 1, pp. 125-182.

Cameron, H.U. and MacNab, I., (1975), 'Observations on osteoarthritis of the hip joint'. In: *Clinical Orthopaedic Related Research*, Vol. 108, pp. 31-40.

Cannon, A., Finn, K. and Yan, Z., (2010), 'Comparison of hip internal and external rotation between intercollegiate distance runners and non-running college students'. In: *International Journal of Sports Physical Therapy*, Vol. 13, No. 6, pp. 956-962. Available at: https://europepmc.org/backend/ptpmcrender.fcgi?accid=PMC6253754&blobtype=pdf (Accessed: 4 April 2020).

Carter, R. E. and Lubinsky, J., (2016), *Rehabilitation Research: Principles and Applications*, St. Louis, Elsevier.

Centers for Disease Control and Prevention, (2020), 'Normal joint range of motion study'. Available at: https://www.cdc.gov/ncbddd/jointrom/ (Accessed: 8 October 2020).

Chamberlain, A., Munro, W. and Rickard, A., (2013), 'Muscle imbalance'. In: Porter, S., (ed.) *Tidy's physiotherapy* (15th edn.), Edinburgh, Churchill Livingstone Elsevier.

Chamberlain, A., (2017), 'Supporting, complementary, alternative and evolving models of practice: Towards the development of your biopsychosocial practice'. In: Porter, S., (ed.) *Psychologically-informed physiotherapy: Embedding psychosocial perspectives within clinical management*, Edinburgh, Elsevier.

Cheatham, S., Hanney, W.J. and Kolber, M.J., (2017), 'Hip range of motion in recreational weight-training participants: A description report'. In: *The International Journal of Sports Physical Therapy*, Vol. 12, No. 5, pp. 764-772. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5685413/pdf/ijspt-12-764.pdf (Accessed: 4 April 2020).

Chevillotte, C.J., Mir, H.I., Trousdale, R.T. and Pagnano, M.W., (2009), 'Variability in hip range of motion on clinical examination'. In: *The Journal of Arthroplasty*, Vol. 24, No. 5, pp. 693-697. Available at: https://www.sciencedirect.com/science/article/pii/S0883540308004671 (Accessed: 23 October 2012).

Chung, M-J and Wang, M-J., (2009), 'The effect of age and gender on joint range of motion of worker population in Taiwan'. In: *International Journal of Industrial Ergonomics*, Vol. 39, No. 4, pp. 596-600. Available at: https://www.sciencedirect.com/science/article/pii/S016981410700220X (Accessed: 20 October 2020).

Cibulka, M.T., Bloom, N.J., Enseki, K.R., MacDonald, C.W., Woehrle, J. and McDonough, C.M., (2017), 'Hip pain and mobility deficits – Hip osteoarthritis: Revision 2017 clinical practice guidelines linked to the International Classification of Functioning, Disability, and Health from the Orthopaedic Section of the American Physical Therapy Association'. In: *The Journal of Orthopaedic and Sports Physical Therapy*, Vol. 47, No 6, pp. A1-A37. Available at: https://www.jospt.org/doi/pdf/10.2519/jospt.2017.0301 (Accessed: 23 February 2018).

Cibulka, M.T., Strube, M.J., Meier, D., Selsor, M., Wheatley, C., Wilson, N.G. and Irrgang, J.J., (2010), 'Symmetrical and asymmetrical hip rotation and its relationship to hip rotator muscle strength'. In: *Clinical Biomechanics*, Vol. 25, No 1, pp. 56-62. Available at: https://www.sciencedirect.com/science/article/pii/S0268003309002198 (Accessed: 19 October 2020).

Cibulka, M.T., White, D.M., Woehrle, J., Harris-Hayes, M., Enseki, K., Fagerson, T.L., Slover, J. and Godges, J.J., (2009), 'Hip pain and mobility deficits – Hip osteoarthritis: Clinical practice guidelines linked to the International Classification of Functioning, Disability, and Health from the Orthopaedic Section of the American Physical Therapy Association'. In: *Journal of Orthopaedic and Sports Physical Therapy*, Vol. 39, No 4, pp. A1-A25.

Cicchetti, D. V., (1994), 'Guidelines, Criteria, and Rules of Thumb for Evaluating Normed and Standardized Assessment Instruments in Psychology'. In: *Psychological Assessment*, Vol. 6, No. 4, pp. 284-290.

Clarkson, H., (2013), *Musculoskeletal assessment: Joint motion and muscle testing* (3rd edn.), Philadelphia, Lippincott, Williams and Wilkins.

Cliborne, A.V., Wainner, R.S., Rhon, D.I., Judd, C.D., Fee, T.T., Matekel, R.L. and Whitman, J.M., (2004), 'Clinical hip tests in patients with knee osteoarthritis: Reliability, prevalence of positive test findings, and short-term response to hip mobilisation'. In: *Journal of Orthopaedic and Sports Physical Therapy*, Vol. 34, No. 11, pp. 676-685.

Cohen, J.W., (1988), *Statistical power analysis for the behavioural sciences* (2nd edn.), Hillsdale, New Jersey, Lawrence Erlbaum Associates.

Copay, A.G., Subach, B.R., Glassman, S.D., Polly, D.W. and Schuler, T.C. (2007), 'Understanding the minimum clinically important difference: A review of concepts and methods'. In: *The Spine Journal*, Vol. 7, No. 5, pp. 541-546.

Curwin, S., (2011), 'Joint structure and function'. In: Levangie, P.K. and Norkin, C.C., (eds.) *Joint structure and function: A comprehensive analysis*, (5th edn.), Philadelphia, F.A. Davis Company.

Davis, H.G., (1867), *Conservative surgery: As exhibited in remedying some of the mechanical causes that operate injuriously both in health and disease*, New York, D. Appleton & Co.

de Castro, J.V., Machado, K.C., Scaramussa, K. and Gomes, J.L.E., (2013), 'Incidence of decreased hip range of motion in youth soccer players and response to a stretching programme: A randomised clinical trial'. In: *Journal of Sport Rehabilitation*, Vol. 22, No. 2, pp. 100-107.

de Groot, I.B., Reijman, M. and Terwee, C.B., Bierma-Zeinstra, S.M.A., Favejee, M., Roos, E.M. and Vehaar, J.A.N., (2007), 'Validation of the Dutch version of the Hip disability and Osteoarthritis Outcome Score'. In: *Osteoarthritis and Cartilage*, Vol. 15, pp. 104-109. Available at:
https://www.oarsijournal.com/action/showPdf?pii=S1063-4584%2808%2900173-8 (Accessed: 26 August 2016).

Deneweth, J.M., Pomeroy, S.M., Russell, J.R., McLean, S.G., Zernicke, R.F., Bedi, A. and Grant, G.C., (2014), 'Position-specific hip and knee kinematics in NCAA football athletes'. In: *The Orthopaedic Journal of Sports Medicine*, Vol. 2, No. 6, pp. 1-6 h5983. Available at:
https://journals.sagepub.com/doi/pdf/10.1177/2325967114534591 (Accessed: 9 April 2020).

DePoy, E. and Gitlin, L.N., (2016), *Introduction to research: Understanding and applying multiple strategies* (5th edn.), Missouri, Elsevier.

Dijkstra, P.U., de Bont, L.G.M., van der Weele, L.Th. and Boering, G., (1994), 'Joint mobility measurements: Reliability of a standardised method'. In: *Journal of Craniomandibular Practice*, Vol. 12, No. 1, pp. 52-57.

Domb, B.G., Brooks, A.G. and Byrd, J.W., (2009), 'Clinical examination of the hip joint in athletes'. In: *Journal of Sport Rehabilitation*, Vol. 18, No. 1, pp. 3-23. Available at: https://www.benjamindombmd.com/pdf/clinical-examination-hip-joints-athletes-2009.pdf (Accessed: 29 October 2020).

Dos Santos, R.A., Derhon, V., Brandalize, M., Brandalize, D. and Rossi, L.P., (2017), '*Evaluation of knee range of motion: Correlation between measurements using a universal goniometer and a smartphone goniometric application*'. In: *The Journal of Bodywork and Movement Therapies*, Vol. 21, No. 3, pp. 699-703.

Dvořrák, J., Dvořrák, V., Gilliar, W., Schneider, W., Spring, H. and Tritschler, T., (2008), *Musculoskeletal manual medicine: Diagnosis and treatment*, Stuttgart, Thieme.

Ellenbecker, T.S., Ellenbecker, G.A., Roetert, E.P., Silva, R.T., Keuter, G. and Sperling, F., (2007), 'Descriptive profile of hip range of motion in elite tennis players and professional baseball pitchers'. In: *The American Journal of Sports Medicine*, Vol. 35, No. 8, pp. 1371-1375.

Ellenbecker, T., De Carlo, M. and DeRosa, C., (2009), *Effective functional progressions in sport rehabilitation*, Champaign, Human Kinetics.

Enseki, K., Harris-Hayes, M., White, D.M., Cibulka, M.T., Woehrle, J., Fagerson, T.L. and Clohisy, J.C., (2014), 'Nonarthritic hip joint pain: Clinical practice guidelines linked to the International Classification of Functioning, Disability, and Health from the Orthopaedic Section of the American Physical Therapy Association'. In: *The Journal of Orthopaedic and Sports Physical Therapy*, Vol. 44, No 6, pp. A1-A32.

Ellison, J.B., Rose, S.J. and Sahrmann, S.A., (1990), 'Patterns of hip rotation range of motion: A comparison between healthy subjects and patients with low back pain'. In: *Physical Therapy*, Vol. 70, No. 9, pp. 537-541.

Felson, D.T., (2004), 'An update on the pathogenesis and epidemiology of osteoarthritis'. In: *Radiologic Clinics of North America*, Vol. 42, No. 1, pp. 1-9.

Felson, D.T., (2013), 'Osteoarthritis as a disease of mechanics'. In: *Osteoarthritis and Cartilage*, Vol. 21, No. 1, pp. 10-15. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3538894/pdf/nihms412739.pdf (Accessed: 22 March 2018).

Felson, D.T. and Hodgson, R., (2014), 'Identifying and treating preclinical and early osteoarthritis'. In: *Rheumatic Disease Clinics of North America*, Vol. 40, No. 4, pp. 699-710.

Ferguson, S.J., Bryant, J.T., Ganz, R. and Ito, K., (2000), 'The influence of the acetabular labrum on hip joint cartilage consolidation: A poroelastic finite element model'. In: *Journal of Biomechanics*, Vol. 33, No. 8, pp. 953-960.

Ferguson, S.J., Bryant, J.T., Ganz, R. and Ito, K., (2003), ‘An *in-vitro* investigation of the acetabular labral seal in hip joint mechanics’’. In: *Journal of Biomechanics*, Vol. 36, No. 2, pp. 171-178.

Frank, C.B., (1996), ‘Ligament injuries: Pathophysiology and healing’. In: Zachazewski, J.E., Magee, D.J. and Quillen, W.S., (eds.) *Athletic injuries and rehabilitation*, Philadelphia, W.B. Saunders Co.

Frost, H.M., (1994), ‘Wolff’s Law and bone’s structural adaptations to mechanical usage: An overview for clinicians’. In: *The Angle Orthodontist*, Vol. 64, No. 3, pp. 175-188.

Frost, H.M., (2003), ‘New targets for fascial, ligament and tendon research: a perspective from the Utah paradigm of skeletal physiology’. In: *Journal of Musculoskeletal & Neuronal Interactions*, Vol. 3, No. 3, pp. 201-209.

Fuss, F.K. and Baccher, A., (1991), ‘New aspects of the morphology and function of the human hip joint ligaments’. In: *American Journal of Anatomy*, Vol. 192, No. 1, pp. 1-13.

Gajdosik, R. L. and Bohannon, R.W., (1987), ‘Clinical measurement of range of motion: Review of goniometer emphasising reliability and validity’. In: *Physical Therapy*, Vol. 67, No. 12, pp. 1867-1872.

Garber, C. E., Blissmer, B., Deschennes, M.R., Franklin, B.A., Lamonte, M.J., Lee, I-Min., Nieman, D.C. and Swain, D.P., (2011), ‘Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise’. In: *Medicine and Science in Sports and Exercise*, Vol. 43, No. 7, pp. 1334-1359.

Gilleard, W. and Smith, T., (2007), ‘Effect of obesity on posture and hip joint moments during a standing task, and trunk forward flexion motion’. In: *International Journal of Obesity*, Vol. 31, pp. 267-271.

Glynn, A. and Fiddler, H., (2009), *The physiotherapist’s guide to exercise: Assessment, prescription and training*, Edinburgh, Churchill Livingstone Elsevier.

Goldring, M.B. and Goldring, S.R., (2010), ‘Articular cartilage and subchondral bone in the pathogenesis of osteoarthritis’. In: *Annals of the New York Academy of Sciences*, Vol. 1192, No. 1, pp. 230-237.

Gould III, J.A. and Davies, G.J., (1985), *Orthopaedic and sports physical therapy*, St. Louis, Mosby.

Gradoz, M.C., Bauer, L.E., Grindstaff, T.L. and Bagwell, J.J., (2018), ‘Reliability of hip rotation range of motion in supine and seated positions’. In: *Journal of Sport Rehabilitation*, Vol. 27, No. 4, pp. 1-4. Available at:
https://doi.org/10.1123/jsr.2017-0243 (Accessed: 04 April 2020).

Greene, W.B. and Heckman, J.D., (eds.), (1994), *Clinical measurement of joint motion*, American Academy of Orthopaedic Surgeons, Rosemont, Illinois.

Griffin, T.M. and Guilak, F., (2005), 'The role of mechanical loading in the onset and progression of osteoarthritis'. In: *Exercise and Sport Science Reviews*, Vol. 33, No. 4, pp. 195-200.

Gulgin, H., Remski, L., Sugg, B., Van Dusen, A., Payton, D., Freybler, J. and Sommers, J., (2019), 'Establishing norms for weight-bearing hip rotation range of motion'. In: *Journal of Exercise, Sports and Orthopedics*, Vol. 6, No. 1, pp. 1-5. Available at: https://symbiosisonlinepublishing.com/exercise-sports-orthopedics/exercise-sports-orthopedics77.pdf (Accessed: 30 October 2020).

Hägg, O., Fritzell, P. and Nordwall, A., (2003), 'The clinical importance of changes in outcome scores after treatment for chronic low back pain'. In: *European Spine Journal*, Vol. 12, No. 1, pp. 12-20.

Haley, E.T., (1953), 'Range of hip rotation and torque of hip rotator muscle groups'. In: *American Journal of Physical Medicine*, Vol. 32, No. 5, pp. 261–270.

Haley, S.M. and Fragola-Pinkham, M.A., (2006), 'Interpreting change scores of tests and measures used in Physical Therapy'. In: *Physical therapy*, Vol. 86, No. 5, pp. 735-743.

Han, H., Kubo, A., Kurosawa, K., Maruichi, S. and Maruyama, H., (2015), 'Hip rotation range of motion in sitting and prone positions in healthy Japanese adults'. In: *Journal of Physical Therapy Science*, Vol. 27, No. 2, pp. 441-445. Available at: https://europepmc.org/article/PMC/4339156 (Accessed: 20 October 2020).

Hartigan, E. and White, D.J., (2016), 'The hip'. In: Norkin, C.C. and White, D.J., (eds.) *Measurement of joint motion: A guide to goniometry*, (5th edn.), Philadelphia, F.A. Davis Company.

Harvey, L.A., Katalinic, O.M., Herbert, R.D., Moseley, A.M., Lannin, N.A. and Schurr, K., (2017), 'Stretching for the treatment and prevention of contractures', *Cochrane Database of Systematic Reviews*, Issue No. 1., Article No. CD007455. Available at: https://doi/10.1002/14651858.CD007455.pub3/full (Accessed: 19 September 2018).

Harvey, L.A., Glinsky, J.A., Katalinic, O.M. and Ben, M., (2011), 'Contracture management for people with spinal cord injuries'. In: *NeuroRehabilitation*, Vol. 28, No. 1, pp. 17-20.

Hennessy, C.M. and Paneris, J., (2018), 'Function and dysfunction of joints'. In: Petty, N.J. and Barnard, K., (eds.) *Principles of musculoskeletal treatment and management: A handbook for therapists* (3rd edn.), Edinburgh, Elsevier.

Heyward, V.H. and Gibson, A.L., (2014), *Advanced fitness assessment and exercise prescription*, (7th edn.), Leeds, Human Kinetics.

Hicks, C.M., (2009), *Research methods for clinical therapists: Applied project design and analysis*, (5th edn.), Edinburgh, Churchill Livingstone Elsevier.

Hogg, J.A., Schmitz, R.J., Nguyen, A-D. and Shultz, S.J., (2018), 'Passive hip range-of-motion values across sex and sport'. In: *Journal of Athletic Training*, Vol. 53, No. 6, pp. 560-567.

Holla, J.F.M., Steultjens, M.P.M., van der Leeden, M., Roorda, L.D. Bierma-Zeinstra, S.M.A., den Broeder, A.A. and Dekker, J., (2011), 'Determinants of range of joint motion in patients with early symptomatic osteoarthritis of the hip and/or knee: An exploratory study in the CHECK Cohort'. In: *Osteoarthritis and Cartilage*, Vol. 19, pp. 411-419.

Hollman, J.H., Burgess, B. and Bokermann, J.C., (2003), 'Passive hip rotation range of motion: effects of testing position and age in runners and non-runners'. In: *Physiotherapy Theory and Practice*, Vol. 19, No. 2, pp. 77-86. Available at: https://www.tandfonline.com/doi/abs/10.1080/09593980307954 (Accessed: 1 February 2018).

Holm, I., Bolstad, B., Lütken, T., Ervik, A., Røkkum, M. and Steen, H., (2000), 'Reliability of goniometric measurements and visual estimates of hip ROM in patients with osteoarthritis'. In *Physiotherapy Research International*, Vol. 5, No. 4, pp. 241-248.

Hudgins, T.H. and Alleva, J.T., (2012), 'Conservative management of hip pain'. In: *Disease-a-Month*, Vol. 58, No. 9, pp. 492-494.

Hussein, A.Z., Ibrahim, M.I., Hellman, M.A. and Donatelli, R.A., (2015), 'Static progressive stretch is effective in treating shoulder adhesive capsulitis: Prospective, randomized, controlled study with a two-year follow-up'. In: *European Journal of Physiotherapy*, Vol. 17, No. 3, pp. 138-147. Available at:
https://www.tandfonline.com/doi/full/10.3109/21679169.2015.1057863 (Accessed: 16 April 2020).

Ibrahim, M., Donatelli, R., Hellman, M. and Echternach, J., (2014), 'Efficacy of a static progressive stretch device as an adjunct to physical therapy in treating adhesive capsulitis of the shoulder: A prospective, randomised study'. In: *Physiotherapy*, Vol. 100, No. 3, pp. 228-234.

Ionising Radiation (Medical Exposure) Regulations 2017, (SI 2017/1322).

IBM Corp., (2016), *IBM SPSS Statistics for Windows* (Version 24.0), [Computer programme], Armonk, NY, IBM Corp.

Integrated Research Application System (2021), 'Integrated Research Application System'. Available at:
https://www.myresearchproject.org.uk/#:~:text=The%20Integrated%20Research%20Application%20System%20%28IRAS%29%20is%20a,is%20provided%20in%20our%20History%20of%20IRAS%20page (Accessed: 13 December 2021).

Irani, K., Vennix, M.J. and Jain, (1995), ‘Peripheral neuropathy and plexus injury’. In: Garrison, S.J., (ed.) *Handbook of physical medicine and rehabilitation books*, Philadelphia, Lippincott, Williams and Wilkins.

James, B. and Parker, A.W., (1989), ‘Active and passive mobility of lower limb joints in elderly men and women’. In: *Journal of American of Physical Medicine and Rehabilitation*, Vol. 68, No. 4, pp. 162-167.

Jewell, D.V., (2015), *Guide to evidence-based physical therapist practice* (3rd edn.), Burlington, Jones and Bartlett Learning.

Kapandji, A.I., (2019), *The physiology of the joints 2: The lower limb* (7th edn.), Pencaitland, Handspring Publishing.

Kapron, A.L., Anderson, A.E., Peters, C.L., Phillips, L.G., Stoddard, G. J., Petron, D.J., Toth, R. and Aoki, S.K., (2012), ‘Hip internal rotation is correlated to radiographic findings of cam femoroacetabular impingement in collegiate football players’: In: *Arthroscopy: The Journal of Arthroscopic and related Surgery*, Vol. 28, No. 11, pp. 1661-1670.

Katalinic, O.M., Harvey, L.A., Herbert, R.D., Moseley, A.M., Lannin, N.A. and Schurr, K., (2010), ‘Stretching for the treatment and prevention of contractures’, *Cochrane Database of Systematic Reviews*, Issue No. 9, Article No. CD007455; DOI: 10.1002/14651858.CD007455.pub2. Available at: https://www.cochranelibrary.com/cdsr/doi/10.1002/14651858.CD007455.pub2/pdf/full (Accessed: 11 March 2014).

Keating, J., Matyas, T.A. and Bach, T.M., (1993), ‘The effect of training on physical therapists’ ability to apply specified forces of palpation’. In: *Physical Therapy*, Vol. 73, No. 1, pp. 38-46.

Kegerreis, S., (1985), ‘The construction and implementation of functional progressions as a component of athletic rehabilitation’. In: *The Journal of Orthopaedic Sports Physical Therapy*, Vol. 5, No. 1, pp. 14-19.

Kennedy, C. and Levesque, L., (2016), ‘Therapeutic exercise for mechanical low back pain’. In: Fernández-de-las-Peñas, C., Cleland, J.A. and Dommerholt, J., (eds.) *Manual therapy for musculoskeletal pain syndromes: An evidence and clinical-informed approach*, London, Elsevier.

Kim, S., (2008), ‘Changes in surgical loads and economic burden of hip and knee replacements in the US: 1997–2004’. In: *Arthritis and Rheumatism (Arthritis Care and Research)*, Vol. 59, No. 4, pp. 481-488. Available at: https://onlinelibrary.wiley.com/doi/epdf/10.1002/art.23525.

Kim, C., Nevitt, M.C., Niu, J., Clancy, M.M., Lane, N.E., Link, T.M., Vlad, S., Tolstykh, I., Jungmann, P.M., Felson, D.T. and Guermazi, A., (2015), 'Association of hip pain with radiographic evidence of hip osteoarthritis: Diagnostic test study'. In: *British Medical Journal*, Vol. 351, h5983. Available at: https://www.bmj.com/content/351/bmj.h5983 (Accessed: 11 April 2019).

Klässbo, M., Harms-Ringdahl, K. and Larsson, G., (2003), 'Examination of passive ROM and capsular patterns in the hip'. In: *Physiotherapy Research International*, Vol. 8, No. 1, pp. 1-12.

Kolber, M.J. and Hanney, W.J., (2012), 'The reliability and concurrent validity of shoulder mobility measurements using a digital inclinometer and goniometer: A technical report'. In: *The International Journal of Sports Physical Therapy*, Vol. 7, No. 3, pp. 306-313.

Koo, T.K. and Li, M.Y., (2016), 'A guideline of selecting and reporting Intraclass correlation coefficients for reliability research'. In: *Journal of Chiropractic Medicine*, Vol. 15, No. 2, pp 155-163.

Kouyoumdjian, P., Coulomb, R., Sanchez, T. and Asencio, G., (2012), 'Clinical evaluation of hip joint rotation range of motion in adults'. In: *Orthopaedics & Traumatology, Surgery & Research*, Vol. 98, No. 1, pp. 17—23.

Krivickas, L.S., (1999), 'Training flexibility'. In: Frontera, W.F., Dawson, D.M. and Slovik, D.M., (eds.) *Exercise in rehabilitation medicine*, Champaign, Human Kinetics

Krivickas, L.S., (2006), 'Training flexibility'. In: Frontera, W.F., Slovik, D.M. and Dawson, D.M., (eds.) *Exercise in rehabilitation medicine*, (2nd edn.), Champaign, Human Kinetics.

Kwiecien, R., Kopp-Schneider, A. and Biettner, M., (2011), 'Concordance analysis-Part 16 of a series of evaluation of scientific publications'. In: *Deutsches Ärzteblatt International*, Vol. 108, No. 30, pp. 515-521. Available at: https://cdn.aerzteblatt.de/pdf/di/108/30/m515.pdf?ts=10%2E08%2E2011+15%3A48%3A40 (Accessed: 8 November 2019).

L'Hermette, M., Polle, G., Tourny-Chollet, C. and Dujardin, F., (2006), 'Hip passive range of motion and frequency of radiographic hip osteoarthritis in former elite handball players'. In: *British Journal of Sports Medicine*, Vol. 40, No. 1, pp. 45-49.

Light, K.E., Nuzik, S., Personius, W. and Barstrom, A., (1984), 'Low-load prolonged stretch vs. high-load brief stretch in treating knee contractures'. In: *Physical Therapy, the Journal of the American Physical Therapy Association*, Vol. 64, No. 3, pp. 330-333.

Lloyd-Roberts, G.C., (1953), 'The role of capsular changes in osteoarthritis of the hip joint'. In: *The Journal of Bone and Joint Surgery*, British Volume, Vol 35-B, No. 4, pp. 627-642.

Lunn, D.E., Lampropoulus, A. and Stewart, T.D., (2016), 'Basic biomechanics of the hip'. In: *Orthopaedics and Trauma*, Vol. 30, No. 3, pp. 239-246.

Macedo, L.G and Magee, D.J., (2008), 'Differences in range of motion between dominant and nondominant sides of upper and lower extremities'. In: *Journal of Manipulative and Physiological Therapeutics*, Vol. 31, No. 8, pp. 577-582. Available at: https://pubmed.ncbi.nlm.nih.gov/18984240/ (Accessed: 19 February 2021).

Macedo, L.G and Magee, D.J., (2009), 'Effects of age on passive range of motion of selected peripheral joints in healthy adult females'. In: *Physiotherapy Theory and Practice*, Vol. 25, No. 2, pp. 145-164. Available at: https://pubmed.ncbi.nlm.nih.gov/19212902/ (Accessed: 1 February 2018).

Malliaras, P., Hogan, A., Nawrocki, A., Crossley, K. and Schache, A., (2009), 'Hip flexibility and strength measures: reliability and association with athletic groin pain'. In: *British Journal of Sports Medicine*, Vol. 43, No. 10, pp. 739-744.

Martin, R. L. and Kivlan, B.R., (2011), 'The hip complex'. In: Levangie, P.K. and Norkin, C.C., (eds.) *Joint structure and function: A comprehensive analysis* (5th edn.), Philadelphia, F.A. Davis Company.

Martin, H.D., Khoury, A.N., Schröder, R., Johnson, E., Gómez-Hoyoz, J., Campos, S. and Palmer, I.J., (2017), 'Contribution of the pubofemoral ligament to hip stability: A biomechanical study''. In: *Arthroscopy: The Journal of Arthroscopic and Related Surgery*, Vol. 33, No. 2, pp. 305-313.

Martin, H.D., Savage, A., Braly, B.A., Palmer, I.J., Beall, D.P. and Kelly, B., (2008), 'The function of hip capsular ligaments: A quantitative report'. In: *Arthroscopy: The Journal of Arthroscopic and Related Surgery*, Vol. 24, No. 2, pp. 188-195.

McGrath, M.S., Ulrich, S.D., Bonutti, P.M., Marker, D.R., Johanssen, H.R. and Mont, M.A., (2009), 'Static progressive splinting for restoration of rotational motion of the forearm'. In: *Journal of Hand Therapy*, Vol. 22, No. 1, pp. 3-9.

Meira, E. P. and Wagner, M.B., (2015), 'Non-operative rehabilitation of hip stiffness and hip impingement (CAM/Pincer lesions)'. In: Reider, B., Davies, G.J. and Provencher, M.T., (eds.) *Orthopaedic rehabilitation of the athlete: Getting back in the game*, Philadelphia, Elsevier Saunders.

Microsoft Corp., (2010), *Microsoft Excel* (2010), [Computer programme], Redmond, WA.

Moromizato, K., Kimura, R., Fukase, H., Yamaguchi, K. and Ishida, H., (2016). 'Whole-body patterns of the range of joint motion in young adults: Masculine type and Feminine type'. In: *The Journal of Physiological Anthropology*, Vol. 23. No. 23. Available at: https://jphysiolanthropol.biomedcentral.com/articles/10.1186/s40101-016-0112-8 (Accessed: 1 February 2018).

Mosler, A.B., Crossley, K.M., Thorborg, K., Whiteley, R.J., Weir, A., Serner, A. and Hölmich, P., (2017), 'Hip strength and range of motion: Normal values from a professional football league'. In: *Journal of Science and Medicine in Sport*, Vol. 20, No. 4, pp. 339-343.

Mueller, M.J. and Maluf, K.S., (2002), 'Tissue adaptation to physical stress: A proposed "Physical Stress Theory" to guide physical therapist practice, education and research'. In: *Physical Therapy*, Vol. 82, No. 4, pp. 383-403.

Nade, S. and Newbold, P.J., (1983), 'Factors determining the level and changes in intra-articular pressure in the knee joint of the dog'. In: *The Journal of Physiology*, Vol. 338, No. 1, pp. 21-36.

National Clinical Guideline Centre, (2014), *Osteoarthritis care and management in adults: clinical guideline CG177, methods, evidence and recommendations*, London, National Clinical Guideline Centre.

National Health Service, (2014), NHS Choices: Hip replacement. Available at: http://www.nhs.uk/Conditions/Hip-replacement/Pages/Introduction.aspx (Accessed: 12 November 2015).

National Institute for Health and Clinical Excellence (NICE), (2008), *Osteoarthritis: The care and management*, London, National Institute for Health and Clinical Excellence.

Nguyen, A-D., Zuk, E.F., Baellow, A.L., Pfile, K.R., DiStefano, L.J. and Boling, M.C., (2017), 'Longitudinal changes in hip strength and range of motion in female youth soccer players: Implications for ACL injury, a pilot study'. In: *Journal of Sport Rehabilitation*, Vol. 26, No. 5, pp. 358-364.

Nigg, B.M., Nigg, C.R. and Reinschmidt, C., (1995), 'Reliability and validity of active, passive and dynamic range of motion tests'. In: *Sportverletzung Sportschaden*, Vol. 9, No. 2, pp. 51-57.

Nordin, M. and Frankel, V.H., (2012), *Basic biomechanics of the musculoskeletal system* (4th edn.), Philadelphia, Lippincott, Williams and Wilkins.

Norkin, C.C. and White, D.J., (2016), *Measurement of joint motion: A guide to goniometry*, (5th edn.), Philadelphia, F.A. Davis Company.

Norris, E.S., Wright, E., Sims, S., Fuller, M. and Neelly, K., (2016), 'The reliability of Smartphone and goniometric measurements of hip range of motion'. In: *The Journal of Rehabilitation Sciences and Research*, Vol. 3, No. 4, pp. 77-84.

Nussbaumer, S., Leung, M., Glatthorn, J.F., Stauffacher, S., Gerber, H. and Maffiuletti, N.A., (2010), 'Validity and test-retest reliability of manual goniometers for measuring passive hip range of motion in femoroacetabular impingement patients'. In: *BMC Musculoskeletal Disorders*, Vol. 11, No. 194. Available at: http://bmcmusculoskeletdisord.biomedcentral.com/articles/10.1186/1471-2474-11-194 (Accessed: 25 August 2016).

Özkaya, N., Leger, D., Goldsheyder, D. and Nordin, M., (2018), *Fundamentals of biomechanics: Equilibrium, motion and deformation* (4th edn.), Gewerbestrasse, Springer.

Özkaya, N. and Nordin, M., (1999), *Fundamentals of biomechanics: Equilibrium, motion and deformation* (2nd edn.), New York, Springer-Verlag.

Pallant, J., (2016), *SPSS survival manual: A step by step guide to data analysis using IBM SPSS* (6th edn.), Maidenhead, Open University Press, McGraw-Hill.

Pallant, J., (2020), SPSS survival manual: A step by step guide to data analysis using IBM SPSS (7th edn.), Maidenhead, Open University Press, McGraw-Hill.

Park, S-W., Kim, M-S., Bae, H-S. and Cha, Y-H., (2015), 'The reliability and validity of hip range of motion measurement using a smart phone operative patient'. In: *Journal of the Korean Society of Physical Medicine*, Vol. 10, No. 2, pp. 1-7. Available at: http://www.ndsl.kr/soc_img/society/ksphm/DGMHBK/2015/v10n2/DGMHBK_2015_v10n2_1.pdf (Accessed: 25 August 2016).

Perry, G.H., Smith, M.J.G. and Whiteside, C.G., (1972), 'Spontaneous recovery of the joint space in degenerative hip disease'. In: *Annals of the Rheumatic Diseases*, Vol. 31, No. 6, pp. 440-448.

Pescatello, L.S., (ed.), (2014), *American College of Sport Medicine's resource manual for exercise testing and prescription* (9th edn.), Philadelphia, Lippincott, Williams and Wilkins.

Petrie, A. and Sabin, C., (2020), *Medical statistics at a glance*, (4th edn.), Chichester, Wiley Blackwell.

Portney, L.G., (2020), *Foundations of clinical research: Applications to evidence-based practice*, (4th edn.), Philadelphia, F.A. Davis.

Portney, L.G. and Gross, K.D. (2020a), 'Measurement revisited: Reliability and validity statistics'. In: Portney, L.G., (ed.) *Foundations of clinical research: Applications to evidence-based practice* (4th edn.), Philadelphia, F.A. Davis.

Portney, L.G. and Gross, K.D. (2020b), 'Exploratory research: Observational designs'. In: Portney, L.G., (ed.) *Foundations of clinical research: Applications to evidence-based practice* (4th edn.), Philadelphia, F.A. Davis.

Poulsen, E., Christensen, H.W., Penny, J.Ø., Overgaard, S., Vach, W. and Hartvigsen, I., (2012), 'Reproducibility of range of motion and muscle strength measurements in patients with hip osteoarthritis – An inter-rater study'. In: *BioMed Central Musculoskeletal Disorders*, 13: 242. Available at: http://bmcmusculoskeletdisord.biomedcentral.com/articles/10.1186/1471-2474-13-242 (Accessed: 25 August 2016).

Prentice, W.E., (2011), 'Joint mobilisation and traction techniques in rehabilitation'. In: *Rehabilitation techniques for sports medicine and athletic training* (5th edn.), New York, McGraw-Hill.

Prietzel, T., Hammer, N., Schleifenbaum, S., Kaßebaum, E., Farag, M. and von Salis-Soglio, G., (2014), 'On the permanent hip-stabilising effect of atmospheric pressure'. In: *Journal of Biomechanics*, Vol. 47, No. 11, pp. 2660-2665.

Pua, Y-H., Wrigley, T.W., Cowan, S.M. and Bennell, K.L., (2008), 'Intrarater test-retest reliability of hip range of motion and hip muscle strength measurement in persons with hip osteoarthritis'. In: *Archives of Physical Medicine and Rehabilitation*, Vol. 89, No. 6, pp. 1146-1154.

Public Health England, (2008), Patient dose information: Guidance. Available at: https://www.gov.uk/government/publications/medical-radiation-patient-doses/patient-dose-information-guidance (Accessed: 27 September 2018).

Rannou, F. and Poiraudeau, S., (2010), 'Non-pharmacological Approaches for the Treatment of Osteoarthritis'. In: *Best Practice and Research Clinical Rheumatology*, Vol. 24, pp. 93-106.

Reese, N.B. and Bandy, W.D., (2010), *Joint range of motion and muscle length testing*, (2nd edn.), St Louise, Saunders Elsevier.

Reginster, J-Y. and Cooper, C., (2016), 'Optimising the management of osteoarthritis-transitioning evidence-based guidelines into practical guidance, for real-world clinical practice'. In: *Seminars in Arthritis and Rheumatism*, Vol. 45, No. 4, pp. S1-2. Available at: http://www.semarthritisrheumatism.com/article/S0049-0172(15)00276-0/pdf, (Accessed: 12 September 2016).

Retchford, T.H. Crossley, K.M., Grimaldi, A., Kemp, J.L. and Cowan, S.M., (2013), 'Can local muscles augment stability in the hip? A narrative literature review'. In: *Journal of Musculoskeletal and Neuronal Interactions*, Vol. 13, No. 1, pp. 1-12.

Riebe, D., (ed.), (2018), *ACSM's guidelines for exercising testing and prescription*, (10th edn.), Philadelphia, Wolters Kluwer.

Roach, K.E. and Miles, T.P., (1991), 'Normal Hip and Knee Active Range of Motion: The Relationship to Age'. In: *Physical Therapy*, Vol. 71, No. 9, pp. 656-665.

Roach, S., San Juan, J.G., Suprak, D.N. and Lyda, M., (2013), ‘Concurrent validity of digital inclinometer and universal goniometer in assessing passive hip mobility in healthy subjects’. In: *The International Journal of Sports Physical Therapy*, Vol. 8, No. 5, pp. 680-688.

Roaas, A. and Andersson, G.B.J., (1982), ‘Normal range of motion of the hip, knee and ankle joints in male subjects, 30–40 years of age’. In: *Acta Orthopaedica Scandinavica*, Vol. 53, No. 2, pp. 205-208. Available at: https://www.tandfonline.com/doi/pdf/10.3109/17453678208992202 (Accessed: 1 February 2018).

Roberts, L. and Langridge, N., (2018), ‘Principles of communication and its application to clinical reasoning’. In: Petty, N.J. and Barnard, K., (eds.) *Principles of musculoskeletal treatment and management: A handbook for therapists* (3rd edn.), Edinburgh, Elsevier.

Robiner, W.N., (2005), ‘Enhancing adherence in clinical research’. In: *Contemporary Clinical Trials*, Vol. 26, No. 1, pp. 59-77.

Robson, L. and Syndercombe-Court, D., (2014), ‘Bone, muscle, skin and connective tissue’. In: Naish, J. and Syndercombe-Court, D., (eds.) *Medical sciences* (2nd edn.), Edinburgh, Elsevier.

Rondinelli, R.D., Genovese, E., Katz, R.T., Mayer, T.G., Mueller, K.L., Ranavaya, M.I. and Brigham, C.R., (2008), *AMA Guides to the evaluation of permanent impairment* (6th edn.), Chicago, American Medical Association.

Rutherford, D.J., (2014), ‘Intra-articular pressures and joint mechanics: Should we pay attention to effusion in knee osteoarthritis’. In: *Medical Hypothesis*, Vol. 83, No. 3, pp. 292-295.

Ryder, D. and Van Griensven, H., (2018), ‘Physical examination’. In: Petty, N. J. and Ryder, D. (eds.) *Musculoskeletal examination and assessment: A handbook for therapists* (5th edn.), Edinburgh, Elsevier.

Sadeghisani, M., Manshadi, F.D., Kalantari, K.K., Rahimi, A., Namnik, N., Karimi, M.T., and Oskouei, (2015), ‘Correlation between hip rotation range-of-motion impairment and low back pain: A literature review’. In: *Ortopedia Traumatologia Rehabilitacja*, Vol. 17, No. 5, pp. 445-462. Available at: https://doi: 10.5604/15093492.1186813 (Accessed: 4 April 2020).

Safran, M.R., Lopomo, N., Zaffagnini, S., Signorelli, C., Vaughn, Z.D., Lindsey, D.P., Gold, G., Giordano, G. and Marcacci, M., (2013), ‘*In-vitro* analysis of peri-articular soft tissues passive constraining effect on hip kinematics and joint stability’. In: *Knee Surgery, Sports Traumatology, Arthroscopy*, Vol. 21, No. 7, pp. 1655-1663.

Sanghvi, S., (2013), ‘Cardiac rehabilitation’. In: Porter, S., (ed.) *Tidy’s physiotherapy* (15th edn.), Edinburgh, Churchill Livingstone Elsevier.

Sato, K., Uchiyama, E., Katayose, M. and Fujimiya, M., (2012), 'Microscopic analysis of the iliofemoral and ischiofemoral ligaments in the hip joint: Collagen fibre direction and crimp distribution'. In: *Anatomical Science International*, Vol. 87, No. 1, pp. 50-55. Available at:
https://doi.org/10.1007/s12565-011-0117-7 (Accessed: 20 September 2018).

Saunders, S. & Longworth, S., (2006), *Injection techniques in orthopaedic and sports medicine: A practical manual for doctors and physiotherapists*, (3rd edn.), Edinburgh, Elsevier Churchill Livingstone.

Scalzitti, D.A. and White, D.J., (2016), 'Validity and reliability in goniometric measurement'. In: Norkin, C.C. and White, D.J., (ed.) *Measurement of joint motion: A guide to goniometry*, (5th edn.), Philadelphia, F.A. Davis Company.

Selye, H, (1950), *The physiology and pathology of exposure to stress: A treatise based on the concepts of the general-adaptation-syndrome and the diseases of adaptation*, Montreal, Acta Incorporated.

Selye, H., (1978), *The stress of life*, New York, McGraw-Hill.

Senior, K., (2013), *What does private surgery and treatment cost? A short guide to what you can expect to pay for private surgery or private medical treatment*. Available at: https://www.netdoctor.co.uk/health-services/private-treatment/a4554/what-does-private-surgery-and-treatment-cost/ (Accessed: 27 September 2018).

Shipley, M., Rahman, A., O'Gradaigh, D. and Conway, R. (2012), 'Rheumatology and bone disease'. In: Kumar, P. & Clark, M., (eds.) *Clinical medicine* (8th edn.), London, Elsevier Saunders.

Shrout, P. and Fleiss, J.L., (1979), Intraclass correlations: Uses in assessing rater reliability. In: *Psychological Bulletin*, Vol. 86, No. 2, pp. 420-428.

Shultz, S.J., Nguyen, A., Windley, T.C., Kulas, A.S., Botic, T.L. and Beynnon, B.D., (2006), 'Intratester and intertester reliability of clinical measures of lower extremity anatomical alignment: Implications for multi-center studies'. In: *Clinical Journal of Sports Medicine*, Vol. 16, No. 2, pp. 155-161.

Siff, M.C., (2005), 'Muscle and connective tissue – Key concepts for rehabilitation'. In: Shamley, D. (ed.) *Pathophysiology: An essential text for the allied health professions*, Edinburgh, Elsevier Butterworth Heinemann.

Silver, F.H. and Shah, R.G., (2017), 'Mechanical analysis of multi-component tissues'. In: *World Journal of Mechanics*, Vol. 7, No. 4, pp. 121-132. Available at: https://www.scirp.org/pdf/WJM_2017041116241574.pdf (Accessed: 31 October 2019).

Simoneau, G.G., Hoenig, K.J., Lepley, J.E. and Papanek, P.E., (1998), 'Influence of hip position and gender on active hip internal and external rotation'. In: *Journal of Orthopaedic and Sports Physical Therapy*, Vol. 28, No. 3, pp. 158-164.

Sims, K., (1999), 'The development of hip osteoarthritis: Implications for conservative management'. In: *Manual Therapy*, Vol. 4, No. 3, pp. 127-135.

Soucie, J.M., Wang, C., Forsyth, A., Funk, S., Denny, M., Roach, K.E. and Boone, D., (2011), 'Range of motion measurements: Reference values and a database for comparison studies'. In: *Haemophilia*, Vol. 17, No. 3, pp. 500-507.

Standring, S.M., (Editor in Chief), (2005), *Gray's anatomy: The Anatomical basis for clinical practice*, (39th edn.), Edinburgh, Churchill Livingstone.

Stratford, P., Agostino, V., Brazeau, C. and Gowitzke, B.A., (1984), 'Reliability of joint angle measurement: a discussion of methodology issues'. In: *Physiotherapy Canada*, Vol. 36, No. 1, pp. 5-9.

Surya, P.M., Srinivasan, S. and Menon, (2018), 'Advances in osteoarthritis of the hip'. In: Mohan Iyer, K., (ed.) *The hip joint in adults: Advances and developments*, Singapore, Pan Stanford.

Svenningsen, S., Terjesen, T., Auflem M. and Berg, V., (1989), 'Hip motion related to age and sex'. In: *Acta Orthopaedica Scandinavica*, Vol. 60, No. 1, pp. 97-100. Available at: https://www.tandfonline.com/doi/abs/10.3109/17453678909150103 (Accessed: 4 December 2020).

Swain, D.P., (ed.), (2014), *American College of Sport Medicine's resource manual for exercise testing and prescription* (7th edn.), Philadelphia, Lippincott, Williams and Wilkins.

Szabo, S., Tache, Y. and Somogyi, A., (2012), 'The legacy of Hans Selye and the origins of stress research: A retrospective 75 years after his landmark brief "Letter" to the Editor of *Nature*'. In: *Stress*, Vol. 15, No. 5, pp. 472-478.

Tak, I., Glasgow, P., Langhout, R., Weir, A., Kerkhoffs, G. and Agricola, R., (2015), 'Hip range of movement is lower in professional soccer players with hip and groin symptoms or previous injuries, independent of cam deformities'. In: *The American Journal of Sports Medicine*, Vol. 44, No. 3, pp. 682-688. Available at: https://doi.org/10.1177/0363546515617747 (Accessed: 9 April 2020).

Takechi, H., Nagashima, H. and Ito, S., (1982), 'Intra-articular pressure of the hip joint outside and inside the limbus'. In: *The Journal of the Japanese Orthopaedic Association*, Vol. 56, No. 6, pp. 529-536.

Teichtahl, A.J., Wluka, A.E., Wijethilake, P., Wang, Y., Ghasem-Zadeh, A. and Cittutini, F.M., (2015), 'Wolff's law in action: A mechanism for early knee osteoarthritis'. In: *Arthritis Research and Therapy*, Vol. 17, No. 207, pp. 1-9. Available at: https://link.springer.com/article/10.1186/s13075-015-0738-7 (Accessed: 30 January 2019).

Teirlinck, C.H., Dorleijn, D.M.J., Bos, P.K., Rijkels-Otters, J.B.M., Bierma-Zeinstra, S.M.A. and Luijsterburg, P.A.J., (2019), 'Prognostic factors for progression of osteoarthritis of the hip: A systematic review'. In: *Arthritis Research and Therapy*, Vol. 21, No. 192, pp. 1-19. Available at: https://doi.org/10.1186/s13075-019-1969-9 (Accessed: 17 October 2019).

Tippett, S.R. and Voight, M.L., (1995), *Functional progressions for sport rehabilitation*, Champaign, Human Kinetics.

Turner, C.H., (1998), 'Three rules for bone adaptation to mechanical stimuli'. In: *Bone*, Vol. 23, No. 5, pp. 399-407.

Van Dillen, L.R., Bloom, N.J., Gombatto, S.P. and Susco, T.M., (2008), 'Hip rotation range of motion in people with and without low back pain who participate in rotation-related sports'. In: *Physical Therapy in Sport*, Vol. 9, No. 2, pp. 72-81.

van Trijffel, E., van de Pol, R.J., Oostendorp, R.A.B. and Lucas, C., (2010), 'Inter-rater reliability for measurement of passive physiological movements in lower extremity joints is generally low: A Systematic review'. In: *Journal of Physiotherapy (Australia)*, Vol. 56, No. 4, pp. 223-235.

Vogelgesang, S., (2015), 'Osteoarthritis'. In: West, S.G., (ed.) *Rheumatology secrets*, (3rd edn.), Philadelphia, Elsevier Mosby.

Wallis, E. L. and Logan, G. A., (1964), *Figure improvement and body conditioning through exercise*, Englewood Cliffs, Prentice-Hall.

Watkins, M.A., Riddle, D.A., Lamb, R.L. and Personius, W.J., (1991), 'Reliability of goniometric measurements and visual estimates of knee range of motion obtained in a clinical setting'. In: *Physical Therapy and Rehabilitation Journal*, Vol. 71, No. 2, pp. 90-96.

White, D.J. and Norkin, C.C., (2016), 'Basic concepts'. In: Norkin, C.C. and White, D.J., (eds.) *Measurement of joint motion: A guide to goniometry*, (5th edn.), Philadelphia, F.A. Davis Company.

Williams, A., Newell, R.L.M., Davies, M.S. and Collins, P., (eds.), (2005), *Pelvic girdle and lower limb*. In: Standring, S.M., (Editor in Chief) *Gray's anatomy: The anatomical basis for clinical practice*, (39th edn.), Edinburgh, Churchill Livingstone.

Xsens Technologies, (2012), 3D Motion Tracking, Products, MTw Development Kit Lite. Available at: https://www.xsens.com/products/mtw-development-kit-lite/ (Accessed: 16 July 2015).

Zhang, Q., Adam, N.C., Nasab, S.H.H., Taylor, W.R. and Smith, C.R., (2021), 'Techniques for *in-vivo* measurement of ligament and tendon strain: A Review'. In: *Annals of Biomedical Engineering*, Vol. 49, No. 1, pp. 7-28.

Zippel, H., (1993), *Julius Wolff and the Law of bone remodelling*. In: Regling, G., (ed.) *Wolff's Law and connective tissue regulation*, Berlin, Walter de Gruter.

7. Appendices

Appendix 1: Ethical clearance for retrospective analysis of clinical records

University of Cumbria

Alan Chamberlain
MSS
Lancaster

University of Cumbria, Research Office,
Lancaster Campus, Bowerham Road,
Lancaster, LA1 3JD

01524 590804
Research.office@cumbria.ac.uk
www.cumbria.ac.uk

4 June 2019

Request for Ethical Clearance – Our Ref: 18/62 (14/46)
Project: Retrospective analysis of clinical records: Evidence from practice for a stretch protocol to improve medial and lateral rotation of the hip joint

Dear Alan

Thank you for your recent request as explained in your email of 25 May 2019.

Approval is granted through Chair's Action.

Kind regards

Professor Diane Cox
Chair
Research Ethics Panel

Appendix 2: Prospective participant invitation letter

Dept. of Psychology, Health & Social Studies
Faculty of Health and Science
University of Cumbria
Fusehill Street
Carlisle CA1 2HH
email: contactemailaddress@server
Telephone contact No. +44 (0) [contact tel. no.]

[Addressee details]
[Addressee details]
[Address details]
[Addressee details] Date Month
Year

Dear [Addressee],

I am writing to you in regard to a forthcoming study being conducted within the University of Cumbria during [Date] and to invite you to be involved in the study in a highly valuable way.

Title of Investigation

The measurement of active medial and lateral rotation of the hip joint: A validity and reliability study.

Research Background

The aim of this study is to evaluate the accuracy of methods of measuring hip joint range of movement in preparation for a clinical study at a later date. Without being able to demonstrate the accuracy of joint range of movement measurement, it will not be possible to undertake a planned clinical study that will focus on a physiotherapy intervention and the effects on range of movement. Hence, asking for your great help with this study.

Please would you be kind enough to consider taking part in the study? If you provisionally agree to participate, you will shortly be contacted, provided with more information and given the opportunity to ask any further questions about what is involved and how you will gain from participating in the study, should you agree to do so.

Taking part in the study should not inconvenience you beyond taking approximately 10-15 minutes for measurement. It is intended to measure your hip range of movement twice using two different measurement protocols. Whilst this is very little for each individual, the collective value of you and your fellow class members taking part in the study would be very high and the results may go on to impact on clinical practice across the physiotherapy profession.

You are being asked to volunteer to participate in the study that you will gain from by having your hip rotation examined and on completion of analysis of the results, you will be invited to be taught self-monitoring, maintenance and where necessary in the event of any loss, how to recover the range of movement.

Thank you in anticipation of you considering participating in the study and I shall look forward to explaining the details of the study when I meet you at a mutually agreed point in the not too distant future.

Yours faithfully,

Alan Chamberlain
Lead researcher

Appendix 3: Volunteer participant study information documentation, screening questionnaire and informed consent form

Title of Investigation

The measurement of active medial and lateral rotation of the hip joint: A validity and reliability study.

Participant Examinee Information, Screening, Consent and Non-disclosure Form

The aim of this study is to determine the most accurate methods of measuring joint range of movement in preparation for a clinical study at a later date.

Please would you be kind enough to read through the following information and answers to questions regarding this study. If on completion of reading, you agree to volunteer to have your hip movement measured for the duration of the study, please complete the answers to questions at the end of this leaflet, sign to consent and agree not to discuss or disclose information relating to the study to others.

Your Questions Answered

Below is an attempt to anticipate and answer all of the questions you may wish to ask and obtain answers to. If any of your questions remain unanswered, or should you feel you would like to ask further questions, please do not hesitate to ask the lead researcher.

What is this research for?

This research is contributory to exploring different ways of measuring the range of movement of the hip joint, which is the large *ball and socket* joint at the top of your leg.

What will be involved and what will I have to do and not do?

This study will involve taking measurements of your hip joint movements using two different protocols in one single attendance.

If you agree to participate, you will be required to complete the information and screening questionnaire at the end of this information sheet before being considered eligible for the study. If you agree to participate and are considered eligible for the study you will be required to attend a designated measurement session. A timetable will be provided for you to book your measurement time, but it is subject to change in the unlikely event of one of the research team being unable to attend for legitimate reasons such as illness.

It involves having your hip movements measured whilst you lie on your front. You would need to wear a pair of shorts, long legged garment that can reveal your lower leg, or in the absence of these, a blanket can be provided to just leave your legs exposed for measurement purposes.

You will be measured with a slight variation on each occasion, but the most this will affect you is by having your leg placed in a specific position. Any simple minor adjustment, difference or variation of movement measurement that may be required will only be to either increase or decrease measurement accuracy and will be explained as necessary, at the time of being measured.

Could there be any harmful effects from this study?
The study involves measurements of your hip joint movement and nothing else and so there should not be any possibility of any harmful effects. You will have some information and screening questions to answer at the end of this information sheet to make sure you understand what is involved and that you are eligible and fulfil the criteria to safely participate in the study prior to doing so. If you have any concerns or wish to clarify any aspect of your eligibility and involvement, please do not hesitate to ask the lead researcher at any point before, or during the course of the study.

You will be required on measurement, to have your greatest available range of movement measured, which can give a sense of discomfort and if and when this is experienced, please just let the person measuring know.

When will I be required?
The study will take place during the early evening over set dates during [Month Year]. You will be asked to book a measurement time that best suits you, on a timetable provided.

So, you will be required to attend a single measurement session for 10-15 minutes.

What happens if I decide for any reason that I do not wish to participate in the study?
You are free to withdraw from the study at any point without giving a reason. However, please do not hesitate to ask the lead researcher any further questions or seek further information or clarification should you need to at any point, if you have any concerns regarding participation in the study.

What will happen to information about me and the measurements that are taken during the study?
All information about you will be treated as highly confidential, stored in a secure environment and not be made available to anyone outside of the research team. Any paper-based information about you will be stored in a lockable storage cabinet/container and any electronic information will be stored and encrypted with a password. Only the lead researcher will have access to your personal details.

All measurements and other information used for analysis and reporting purposes will be completely anonymised and so please be assured that it will not be traceable back to you personally by anyone outside of the research team.

Can I discuss any aspect of the study with others?
In short, the answer to this question is no, but for good commercial and research practice reasons. The techniques for measurement are commercially sensitive and discussion with others could place commercial and research prospects at great risk and so your cooperation in preserving confidentiality is hugely important. You will be free to discuss and feel free to share and celebrate your involvement of any successes that transpire from this study at some point in the future, as and when any information is placed in the public domain following publication of any reports or other literature.

If you would like to be informed of the results of the study or of any research publication that results from the study, please indicate this at the end of this form.

Information and Screening Questions

Your family name:

Your first name(s):

Your age in full years:

Your gender:

Your height (to the nearest ¼ inch or ½ cm): Your weight (to the nearest lb or kg):

Your preferred contact postal address:

Your preferred contact email address:

Your preferred contact telephone number:

Please answer the following questions by circling your responses and commenting as necessary:

1. Which is your dominant hand and leg (*please ring the correct response and delete the other, but if you do not know which is your dominant hand and leg, or are equally ambidextrous, please explain in the space provided*)?

   My left/right hand and left/right leg is the most dominant.

2. Do you have any history of any symptoms, disease, conditions or surgery involving your spine or legs?

   Yes/No (*please ring the correct response and delete the other. If the answer is yes to the above question, please explain in the space provided below*).

3. Have you read and understood the above information sheet about this study?

   Yes/No (*please ring the correct response and delete the other*)

4. Have you been able to ask questions and had enough information?

   Yes/No (*please ring the correct response and delete the other*)

5. Do you understand that you are free to withdraw from this study at any time, and without having to give a reason for withdrawal?

   Yes/No (*please ring the correct response and delete the other*)

6. Your responses will be anonymised. Do you give permission for members of the research team to analyse and quote your anonymous data?

   Yes/No (*please ring the correct response and delete the other*)

7. Would you like to be informed of the study outcomes, or of any resulting publications?

   Yes/No (*please ring the correct response and delete the other*)

Please sign here if you agree to take part in the research, understand what is/is not required of you (including non-disclosure) and feel you have had enough information about what is involved:

Signature of participant:________________________________ **Date:**_________

Name (block letters):____________________________

Signature of witness:____________________________ **Date:**_________

Name (block letters):____________________________

Signature of research lead:_______________________ **Date:**_________

Name (block letters): Alan Chamberlain

Thank you very much for agreeing to participate in this highly valuable study and without your agreement, such as useful study would not be possible.

The lead researcher details are as follows for contact purposes and should you wish to discuss any aspect of the study, please do not hesitate in getting in touch.

Lead researcher: Alan Chamberlain Email: contact_email_address@server

Appendix 4: Tester participation invitation letter

Dept. of Psychology, Health & Social Studies
Faculty of Health and Science
University of Cumbria
Fusehill Street
Carlisle CA1 2HH
email: contactemailaddress@server

[Date Month Year]

Dear [Name],

I am writing to you in regard to a forthcoming study being conducted within the University of Cumbria during [Date] and to thank you for agreeing to be involved in the first study starting this weekend, which is outlined below and will be taking place at the following address.

Address
Address
Address Postcode

Title of Investigation

The measurement of active medial and lateral rotation of the hip joint: A validity and reliability study.

Research Background

The aim of this study is to evaluate the accuracy methods of measuring joint range of movement in preparation for a clinical study at a later date. Without being able to demonstrate the accuracy of joint range of movement measurement, it will not be possible to undertake a highly valuable clinical study that will focus on a physiotherapy intervention and its effects on range of movement and hence asking for your help with this study.

Having agreed to participate, you will shortly be contacted to be provided with more information and given the opportunity to ask any further questions about what is involved.

Taking part in the study should not inconvenience you for too long, but will involve taking four measurements on hopefully, up to 40 volunteer participants [Time scale Frequency]. [Number] data collection sessions should last up to four hours with the first session confirmed to be taking place on [Day Date Month] and [Day Date Month]. It is planned to set-up at [Time] giving 30 minutes to ask any further questions or seek further clarification.

It cannot be overstated just how grateful I am for your help in this initial study where the collective value of you, and those volunteering to have their hip range of movement measured for the study will be very high with the results possibly going on to impact on other future planned studies and later, on clinical practice across the physiotherapy profession.

Your help will greatly contribute to the research output of the University and you will be invited to be one of the first to read any subsequent reporting and publications resulting from this and further associated studies.

Thank you in anticipation of your help in the study and I shall look forward to providing more details of the study shortly and answering any further questions you may have.

Yours sincerely,

Alan Chamberlain
Lead researcher

Appendix 5: Tester study information documentation, screening questionnaire and informed consent form

University of Cumbria

Title of Investigation

The measurement method of active medial and lateral rotation of the hip joint: A validity and reliability study.

Participant Examiner Information, Screening, Consent and Non-disclosure Form

The aim of this study is to determine the most accurate methods of measuring joint range of movement in preparation for a clinical study at a later date.

Please would you be kind enough to read through the following information and answers to questions regarding this study. If on completion of reading, you can agree to volunteer to conduct hip movement measurement for the duration of the study, please sign to consent and agree not to discuss or disclose information relating to the study to others.

Your Questions Answered

Below is an attempt to anticipate and answer all of the questions you may wish to ask and obtain respective answers to. If any of your questions remain unanswered, or should you feel you would like to ask further questions, please do not hesitate to ask the lead researcher.

What is this research for?
This research is contributory to exploring different ways of measuring the range of movement of the hip joint.

What will be involved and what will I have to do and not do?
This study will involve taking measurements of the hip joint movements of up to 40 volunteer examinee participants.

Prior to measurement, examinee participants will be prepared for measurement by the researcher and you will be asked to take two measurements of each hip of each examinee participant using two different measurement protocols and measuring with a Universal Goniometer (UG).

If you agree to participate, you would be required to complete the information and screening questionnaire at the end of this information sheet before being considered eligible for the study. A timetable will be confirmed dependent on the availability of those involved in having their measurements taken, but two examiners should be able to obtain four measurements, twice within 10-12 minutes, which is the time allocated for each examinee participant. Hip movement measurements will be obtained by using a UG with the examinee lying on their front (prone). Examinees will be wearing a pair of shorts or in the absence of shorts, a blanket will be provided to just leave their legs sufficiently exposed for measurement purposes.

All that can be done will be, in order to avoid the study extending over more than a couple of sessions maximum, but if for any reason some measurements are missed or if additional measurements are required, you may be asked to return to obtain these measurements later. In this low likelihood event, you will be informed by the time of the second measurement session and a mutually convenient time/day will be arranged to obtain these measurements.

You will be directed to obtain active end of range measurements and there will be a short interruption whilst hip position adjustments are made between each required measurement. You will be blinded from the measurement itself by an adaptation of the UG for research purposes.

Could there be any harmful effects from this study?
The study involves repeated measurements of examinee hip joint movement and nothing else and so there should not be any possibility of any harmful effects. Participant examinees and you will have some information and screening questions to answer at the end of this information sheet, in order to make sure you understand what is involved; and that you are eligible and fulfil the criteria to safely participate in the study prior to doing so. If you have any concerns or wish to clarify any aspect of your eligibility and involvement, please do not hesitate to ask the lead researcher at any point before, or during the course of the study.

When will I be required?
The study will take place on [Day Date Month Year] and [Day Date Month Year] and you will be required for both hip movement measurement sessions, until all participants have been measured. It is hoped to conduct all the required measurements in these two sessions.

So, you will be required to attend for up to [Time Period] on [Number] days i.e. [Set-up Time] to set up and prepare for data collection starting at [Start Time] and aiming to complete each session by [Completion Time], which allows 30 minutes for any delays and clearing up after the session.

What happens if I decide for any reason that I do not wish to participate in the study?
You are free to withdraw from the study at any point without giving a reason. However, please do not hesitate to ask the lead researcher any further questions or seek further information or clarification, should you need to at any point, if you have any concerns regarding participation in the study. If you do decide to withdraw from the study, please do try to inform the lead researcher as soon as possible and preferably before data collection commences, in order to avoid inconveniencing those having their measurements taken further than necessary.

What will happen to information about me and the measurements that are taken during the study?
All information about you will be treated as highly confidential, stored in a secure environment and not be made available to anyone outside of the research team. Any paper-based information will be stored in a lockable storage cabinet/container and any electronic information will be stored and encrypted with a password.

All measurements and other information used for analysis and reporting purposes will be anonymised and so please be assured that it will not be traceable back to you personally by anyone outside of the research team.

Can I discuss any aspect of the study with others?
In short, the answer to this question is no, but for good commercial and research practice reasons. The techniques for measurement are commercially sensitive and discussion with others could place commercial and research prospects at great risk and so your cooperation in preserving confidentiality is hugely important. You will be free to discuss and feel free to share and celebrate your involvement of any successes that transpire from this study at some point in the future, as and when any information is placed in the public domain following publication of any reports or other literature.

If you would like to be informed of the results of the study or of any research publication that results from the study, please indicate this at the end of this form.

Information and Screening Questions

Your surname:

Your first name(s):

Length of time in years (months if less than 3 years) of experience since being trained to use a Universal Goniometer:

Your gender:

Your preferred contact postal address:

Your preferred contact email address:

Your preferred contact telephone number:

Please answer the following questions by circling your responses and commenting as necessary:

1. Have you read and understood the above information sheet about this study?

   Yes/No (*please ring the correct response and delete the other*)

2. Have you been able to ask questions and had enough information?

   Yes/No (*please ring the correct response and delete the other*)

3. Do you understand that you are free to withdraw from this study at any time, and without having to give a reason for withdrawal?

   Yes/No (*please ring the correct response and delete the other*)

4. Your responses will be anonymised. Do you give permission for members of the research team to analyse and quote your anonymous data?

   Yes/No (*please ring the correct response and delete the other*)

5. Would you like to be informed of the study outcomes or of any resulting publications?

   Yes/No (*please ring the correct response and delete the other*)

Please sign here if you agree to take part in the research, understand what is/is not required of you (including non-disclosure) and feel you have had enough information about what is involved:

Signature of participant:_________________________________ **Date:**_________

Name (block letters):____________________________________

Signature of witness:____________________________________ **Date:**_________

Name (block letters):____________________________________

Signature of research lead:_______________________________ **Date:**_________

Name (block letters): Alan Chamberlain

Thank you very much for agreeing to participate in this highly valuable study and without your agreement, such a useful study would not be possible.

The lead researcher details are as follows for contact purposes and should you wish to discuss any aspect of the study, please do not hesitate in getting in touch.

Lead researcher: Alan Chamberlain Email: [Contact email address]

Appendix 6: Tester measurement procedures for the standard measurement protocol

University of Cumbria

Examiner Participant Instructions

Thank you for volunteering for conducting measurement of active medial and lateral rotation of the hip joint range of movement in part contribution to a validity and reliability study.

Study Aim

The aim of this study is to determine the most accurate methods of measuring joint range of movement in preparation for a clinical study at a later date.

Please would you be kind enough to read through the following information and guidance for measuring hip joint medial and lateral range of movement. If on completion of reading you have any questions or need for further clarification, please do not hesitate to ask the lead researcher.

The procedure for measuring hip joint medial and lateral rotation for this study, using a Universal Goniometer

You will be asked to conduct hip range of movement (ROM) measurements using a Universal Goniometer (UG) see Figure 1.

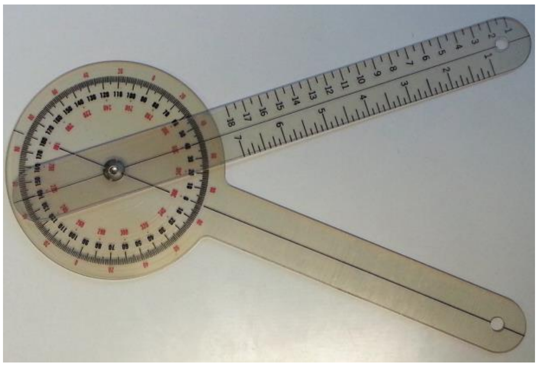

Figure 1: A Universal Goniometer for measuring joint ROM in degrees

Each measurement you are asked to conduct will be measured and recorded for analysis. It is important that you as one of the participant examiners do not observe the other examiner measuring the angle of hip ROM being measured and so you will be asked to turn away from the participant examinee when they are having their hip ROM measured by the other examiner.

End of active range of medial and lateral hip ROM measurement is to be obtained from both hips of each participant examinee on two separate occasions.

Medial and lateral rotation measurements of the left and right hip are to be conducted with examinees in a prone starting position on an examination couch, with the hip extended into neutral, aligned with the mid-line and the knee flexed at 90°.

The examiner will need to have their eyes level with a point of the fulcrum of movement (i.e. the centre of the apex of the patella).

The examinee will be set up by the research assistant, in preparation for examiner measurement.

The method of measurement for the purpose of this study is to be conducted in accordance with (Greene and Heckman, 1994), where Zero/0° is the Starting Position and the axis of the tibia provides the clear anatomical landmark for hip rotation ROM measurement. The axis of rotation of the UG is to be placed level with the centre of the apex of the patella in the midline. Medial rotation measurement is obtained by rotating the leg outwards and the degree of medial rotation is the angle that the tibia makes with the Zero Starting Position (see Figure 2).

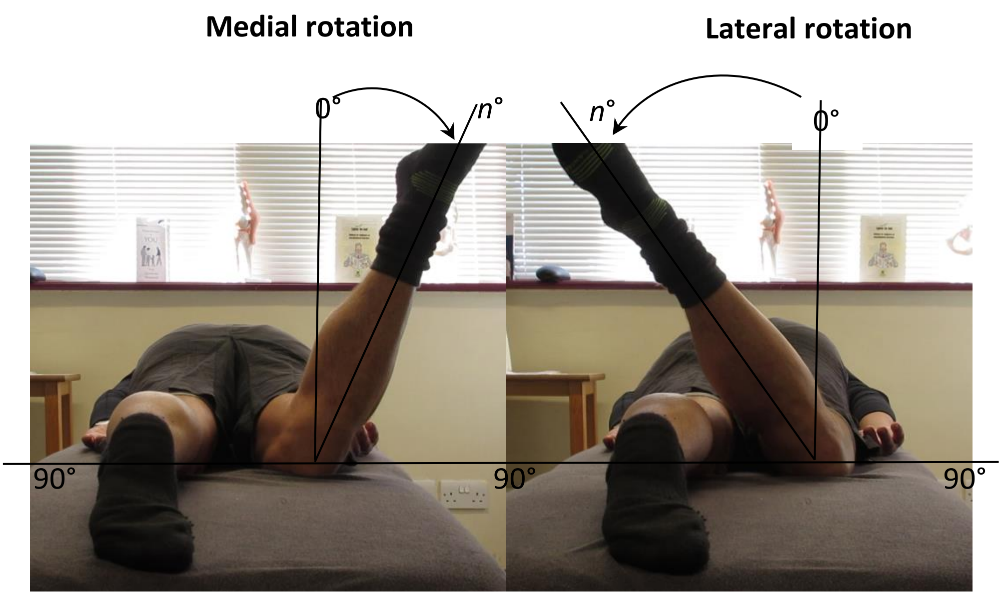

Figure 2: Medial and lateral rotation of the right hip respectively, in prone

For each medial and lateral rotation measurement, Zero/0° is the Starting Position on each occasion and the axis of the tibia remains the clear anatomical landmark for hip rotation ROM measurement. For measuring lateral rotation, the axis of rotation of the UG is to be placed level with the centre of the apex of the patella in the midline. Lateral rotation measurement is obtained by rotating the leg inwards and the degree of lateral rotation is the angle that the tibia makes with the Zero Starting Position.

When you are satisfied that a measurement has been made the UG is to be locked in position at the point of measurement and handed to the researcher for recording.

On completion of each of your measurements, you will be asked to turn away whilst another examiner obtains a measurement.

References

Greene, W.B. and Heckman, J.D., (Eds.), (1994), Clinical Measurement of Joint Motion, American Academy of Orthopaedic Surgeons, Rosemont, Illinois, pp. 1-2, pp. 106-108

Appendix 7: Tester measurement procedures for the new measurement protocol

University of Cumbria

Examiner Participant Instructions

Thank you for volunteering for conducting measurement of active medial and lateral rotation of the hip joint range of movement in part contribution to a validity and reliability study.

Study Aim

The aim of this study is to determine the most accurate methods of measuring joint range of movement in preparation for a clinical study at a later date.

Please would you be kind enough to read through the following information and guidance for measuring hip joint medial and lateral range of movement. If on completion of reading you have any questions or need for further clarification, please do not hesitate to ask the lead researcher.

The procedure for measuring hip joint medial and lateral rotation for this study, using a Universal Goniometer following further protocol training

You will again be asked to conduct hip range of movement (ROM) measurements using a Universal Goniometer (UG) see Figure 1.

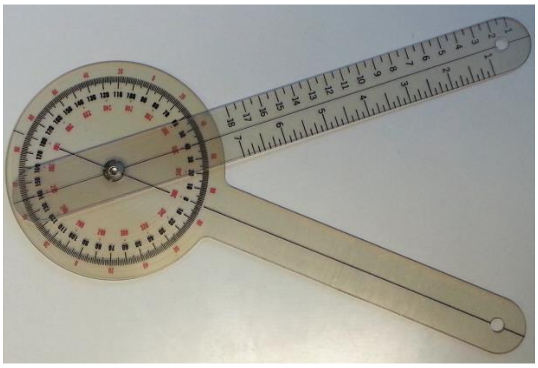

Figure 1: A Universal Goniometer for measuring joint ROM in degrees

Each measurement you are asked to conduct will be measured and recorded for analysis. It is important that you as one of the participant examiners do not observe the other examiner measuring the angle of hip ROM being measured and so you will be asked to turn away from the participant examinee when they are having their hip ROM measured by the other examiner.

End of active range of medial and lateral hip ROM measurement is to be obtained from both hips of each participant examinee twice on two separate occasions.

Medial and lateral rotation measurements of the left and right hip are to be conducted with examinees in a prone starting position on an examination couch, with the hip extended into neutral, aligned with the mid-line and the knee flexed at 90°.

The examiner will need to have their eyes level with a point of the fulcrum of movement (i.e. level with the centre of the apex of the patella).

The examinee will be set up by the research assistant in preparation for examiner measurement.

The method of measurement for the purpose of this part of the study is to be conducted in accordance with (Greene and Heckman, 1994), but the Zero/0° Starting Position will be adjusted to accommodate any variability in pelvic and trunk rotation that can occur in clinical practice. The axis of the tibia provides the clear anatomical landmark for hip rotation ROM measurement. The axis of rotation of the UG is to be placed level with the centre of the apex of the patella in the midline. Medial rotation measurement is obtained by rotating the leg outwards and the degree of medial rotation is the angle that the tibia makes with the adapted Zero Starting Position, which is explained below.

The stationary arm of the UG has to be aligned with the Zero/0° Starting Position, which is identified by an imaginary perpendicular line (line X-Y) to the tangential line (line A-B) running across the pelvis/glutei (see Figure 2).

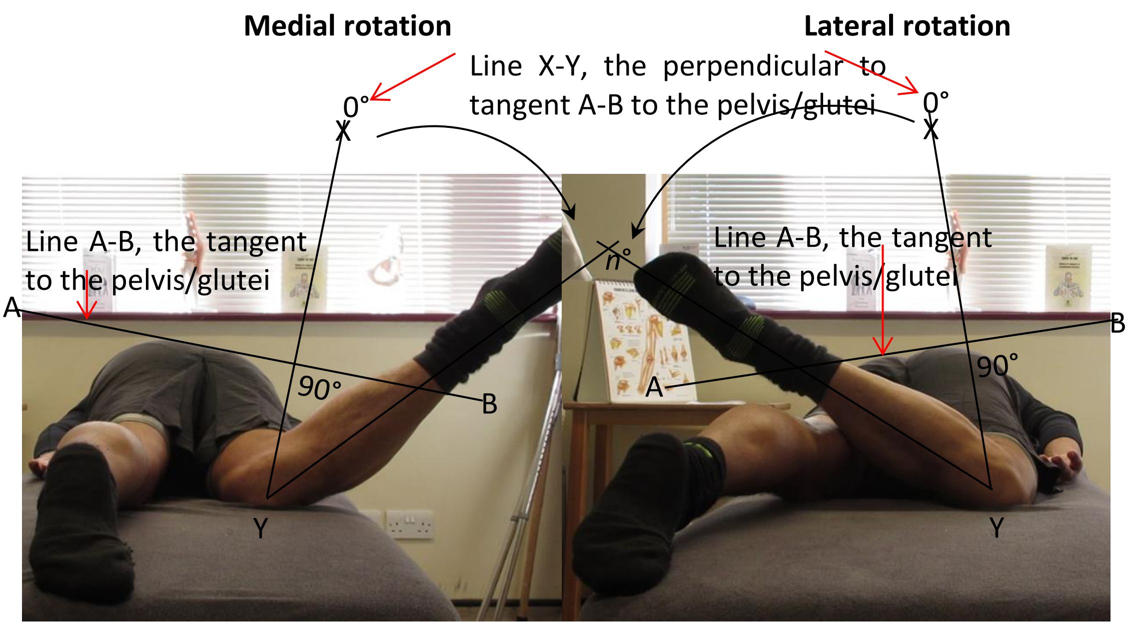

Figure 2: Medial and lateral rotation of the right hip respectively, in prone

For repeat measurements and for both medial and lateral rotation measurements, the adjusted Zero/0° is the Starting Position on each occasion and the axis of the tibia remains the clear anatomical landmark for hip rotation ROM measurement. For measuring lateral rotation, the axis of rotation of the UG is to be placed level with the centre of the apex of the patella in the midline. Lateral rotation measurement is obtained by rotating the leg inwards and the degree of lateral rotation is the angle that the tibia makes with the Zero Starting Position.

When you are satisfied that a measurement has been made the UG is to be locked in position at the point of measurement and handed to the research assistant for recording.

On completion of each of your measurements, you will be asked to turn away whilst another examiner obtains a measurement.

References

Greene, W.B. and Heckman, J.D., (Eds.), (1994), Clinical Measurement of Joint Motion, American Academy of Orthopaedic Surgeons, Rosemont, Illinois, pp. 1-2, pp. 106-108

Appendix 8: Research assistant instructions

University of Cumbria

Research Assistant Instructions

Thank you for volunteering your help as a research assistant for this study involving the measurement of active medial and lateral rotation of the hip joint range of movement in part contribution to a validity and reliability study.

Study Aim

The aim of this study is to determine the most accurate methods of measuring joint range of movement in preparation for a clinical study at a later date.

Please would you be kind enough to read through the following information and guidance for measuring hip joint medial and lateral range of movement (ROM). If on completion of reading you have any questions or need for further clarification, please do not hesitate to ask the lead researcher.

The procedure for obtaining data

You will be provided with the following materials:

- A blanked and lockable Universal Goniometer (UG)
- ROM measuring method instructions for examiner participants/those who will be conducting hip ROM measurements
- ROM data recording sheets
- A list of examiner participants/those who will be conducting hip ROM measurements
- A list of hip ROM to be measured
- A randomised list of examinee participants/those who will be having their hip ROM measured

You are to prepare the examinee for having their hip ROM measured and to be measured. Please ensure the following procedure:

- Signed consent has been obtained and that the signature of the witness (usually you the research assistant) and lead researcher has been obtained to not only signify that the examinee participant has consented, but also that they fulfil the inclusion/exclusion criteria
- The dignity of the examinee participant is preserved by the wearing of shorts or being covered by a blanket for the duration of their involvement, if their clothing cannot be adjusted to reveal the lower leg and knee sufficiently
- Ensure the examining couch/plinth is safe with the breaks applied
- Ask the examinee participant to lie down on their front/prone

- On arrival of the participant examinee, ask them to lie down in a prone position, set up the first hip measurement by flexing the knee to 90° of the hip to be measured
- Ensure the examiner will be able to have your/their eyes level with a point of the fulcrum of movement (i.e. level with the centre of the apex of patella)
- Set up the participant examinee hip angle to be measured according to measurement method instructions and in the manner you have been taught
- Before the participant examiner is asked to conduct measurement, ask the other examiner to face away during the measurement
- Ask the participant examiner to conduct the measurement in the manner they have been taught
- On completion of the first ROM measurement, being very careful not to disturb the stationary and moving arms of the blanked UG, apply a bull-dog clip to the UG to ensure an accurate reading can be obtained from the other side of the UG for recording on the data collection sheet. On completion, ask the participant examiner to face away, whilst the second examiner obtains a measurement and then record their reading in the same manner as above
- On recording each measurement, repeat the process for each angle of ROM required, but ensuring each participant examiner turns to face away during the time the other examiner is obtaining a measurement

The procedure for participant examiner measuring of hip joint medial and lateral rotation for this study, using a Universal Goniometer

Participant examiners will be asked to conduct hip range of movement (ROM) measurements using a Universal Goniometer (UG) see Figure 1.

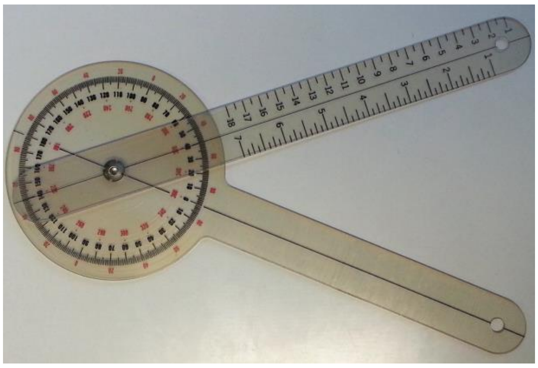

Figure 1: A Universal Goniometer for measuring joint ROM in degrees

End of range of medial and lateral hip ROM measurement will need to be obtained from each hip of each participant examinee by each participant examiner consecutively.

Medial and lateral rotation measurements of the left and right hip are to be conducted with examinees in a prone starting position on an examination couch, with the hip extended into neutral, aligned with the mid-line and the knee flexed at 90° (see Figure 2).

As the research assistant you will set up the examinee in preparation for examiner measurement. For medial rotation measurement, both hips can be placed in position to keep the pelvis neutral. Each hip needs to be passively taken to the final end point of ROM where resistance is felt and the participant examinee is to be asked to actively maintain the position whilst both examiners obtain their measurement. You must ensure the position is maintained throughout the procedure from set up to completion of measurement, which includes manually stabilising the pelvis as you have been taught.

For lateral rotation, passively take the hip to the final end point of ROM where resistance is felt and the opposite pelvis begins to rise. Ensure the pelvis is flat and in neutral and that the hip remains at the end point where resistance was felt. Then ask the participant examinee to actively maintain the position whilst both examiners obtain the measurement, which includes manually stabilising the pelvis as you have been taught. You must ensure the position of the pelvis and hip being measured is maintained.

For ROM measurement examination the examiner will need to have their eyes level with a point of the fulcrum of movement (i.e. level with the centre of the apex of the apex of the patella).

The method of measurement for the purpose of this study is to be conducted in accordance with (Greene and Heckman, 1994), where Zero/0° is the Starting Position and the axis of the tibia provides the clear anatomical landmark for hip rotation ROM measurement. The axis of rotation of the UG is to be placed level with centre of the apex of the patella in the midline. Medial rotation measurement is obtained by rotating the leg outwards and the degree of medial rotation is the angle that the tibia makes with the Zero Starting Position (see Figure 2).

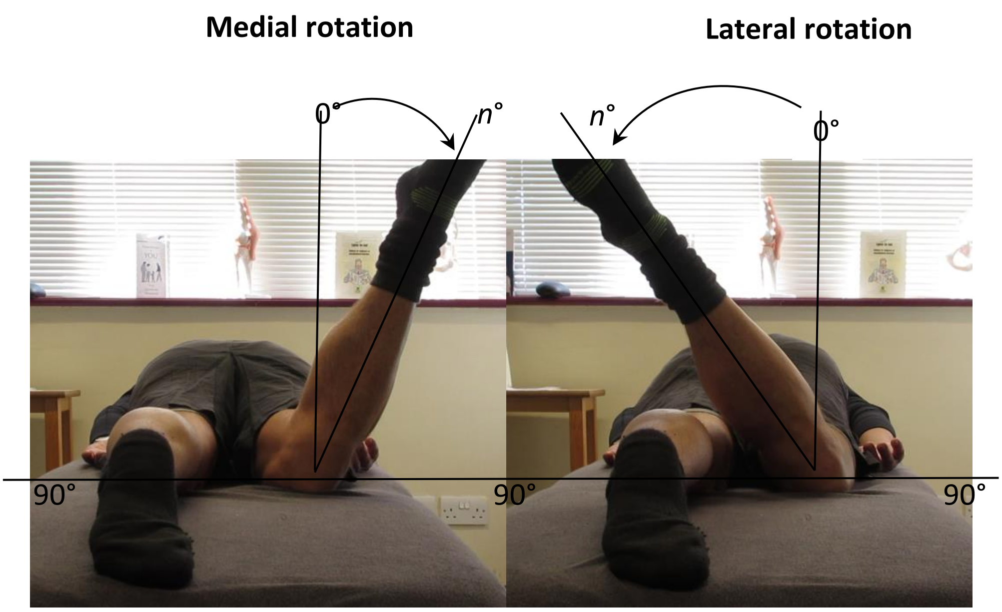

Figure 2: Medial and lateral rotation of the right hip respectively, in prone

For repeat measurements and for both medial and lateral rotation measurements, Zero/0° is the Starting Position on each occasion and the axis of the tibia remains the clear anatomical landmark for hip rotation ROM measurement. For measuring lateral rotation, the axis of rotation of the UG is to be placed level with centre of the apex of the patella in the midline. Lateral rotation measurement is obtained by rotating the leg inwards and the degree of lateral rotation is the angle that the tibia makes with the Zero Starting Position.

When the participant examiner is satisfied that a measurement has been made the UG is to be locked in position at the point of measurement using a bull-dog clip and handed to the research assistant for recording.

The above procedure is repeated for each end of active hip ROM measured.

References

Greene, W.B. and Heckman, J.D., (Eds.), (1994), Clinical Measurement of Joint Motion, American Academy of Orthopaedic Surgeons, Rosemont, Illinois, pp. 1-2, pp. 106-108

The procedure for the research assistant measuring of hip joint medial and lateral rotation for this study, using a Universal Goniometer to allow for variation in any pelvic/trunk rotation

You will be asked to conduct hip range of movement (ROM) measurements using a Universal Goniometer (UG) see Figure 1. It is important that this method is not divulged to any other participants, or any other person, as the following procedure is the intervention that will be conducted to test whether validity and reliability can be improved by a strict protocol for hip range of movement measurement.

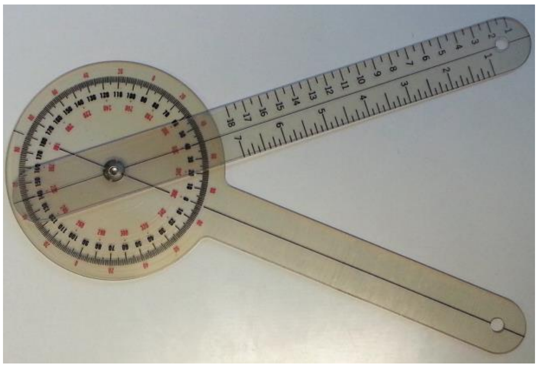

Figure 1: A Universal Goniometer for measuring joint ROM in degrees

End of range of medial and lateral hip ROM measurement will need to be obtained from each hip of each participant examinee by each participant examiner consecutively.

Medial and lateral rotation measurements of the left and right hip are to be conducted with examinees in a prone starting position on an examination couch, with the hip extended into neutral, aligned with the mid-line and the knee flexed at 90° (see Figure 2).

As the research assistant you will set up the examinee in preparation for examiner measurement. For medial rotation measurement and on this occasion the hip not being measured can be placed in neutral and the pelvis can be allowed to rotate. Each hip needs to be passively taken to the final end point of ROM where resistance is felt and the participant examinee is to be asked to actively maintain the position whilst both examiners obtain their measurement. You must ensure the position is maintained throughout the procedure from set up to completion of measurement.

For lateral rotation, passively take the hip to the final end point of ROM where resistance is felt and the opposite pelvis begins to rise. The pelvis does not on this occasion, need to remain flat or in neutral and can be allowed to rise, but ensure that the hip remains at the end point where resistance is felt. Then ask the participant examinee to actively maintain the position whilst both examiners obtain the measurement. You must ensure the position of the pelvis and hip being measured is maintained.

For ROM measurement examination the examiner will need to have their eyes level with a point of the fulcrum of movement (i.e. level with centre of the apex of the patella).

The method of measurement for the purpose of this part of the study is to be conducted in accordance with (Greene and Heckman, 1994), but the Zero/0° Starting Position has been adjusted to accommodate any variability in pelvic and trunk rotation that can occur. The axis of the tibia provides the clear anatomical landmark for hip rotation ROM measurement. The axis of rotation of the UG is to be placed level with the centre of the apex of the patella in the midline. Medial rotation measurement is obtained by rotating the leg outwards and the degree of medial rotation is the angle that the tibia makes with the adapted Zero Starting Position, which is explained below.

The stationary arm of the UG has to be aligned with the Zero/0° Starting Position, which is identified by an imaginary perpendicular line (line X-Y) to the tangential line (line A-B) running across the pelvis/glutei (see Figure 2).

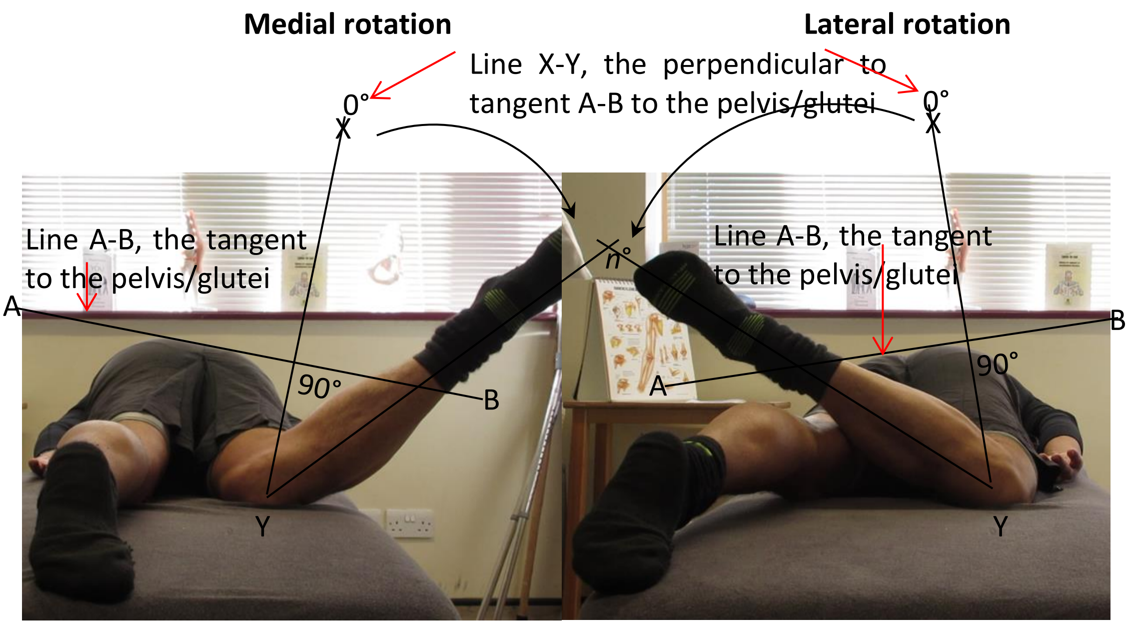

Figure 2: Medial and lateral rotation of the right hip respectively, in prone

For repeat measurements and for both medial and lateral rotation measurements, the adjusted Zero/0° is the Starting Position on each occasion and the axis of the tibia remains the clear anatomical landmark for hip rotation ROM measurement. For measuring lateral rotation, the axis of rotation of the UG is to be placed level with the centre of the apex of the patella in the midline. Lateral rotation measurement is obtained by rotating the leg inwards and the degree of lateral rotation is the angle that the tibia makes with the Zero Starting Position.

When the participant examiner is satisfied that a measurement has been made the UG is to be locked in position at the point of measurement using a bull-dog clip and handed to the research assistant to be read for recording.

When you are satisfied that a measurement angle has been set up, measured and read for recording, hand the blanked UG to the next participant examiner to obtain a measurement as instructed.

The following are additional notes for you as the research assistant for setting up participant examinees for having their hip ROM angles set up.

The hip being measured will need to be extended into neutral by lying prone and is to be aligned with the mid-line and the knee flexed at 90°. The contralateral lower limb will need to be placed in sufficient abduction to prevent approximation of the ipsilateral onto the contralateral lower limb during lateral rotation, but in neutral or the mid-line for medial rotation (as per Greene and Heckman, 1994).

Measurements will be undertaken on each hip in the following order with the pelvis manually stabilised using the first protocol, as taught. The measurements are then repeated using the second protocol without stabilising the pelvis and ensuring the pelvis is visibly rotated, as taught:

Left MR – The EOR medial rotation is to be ensured by passively rotating the left hip medially until EOR tight resistance is felt. The research assistant must try and ensure the range is held by instructing the participant examinee to “now please hold that position”. The research assistant will need to continue to control for and maintain the examinee angle position and instruct the examiner to measure the position using a blanked, lockable UG.

Right MR – The EOR medial rotation is to be ensured by passively rotating the right hip medially until EOR tight resistance is felt. The research assistant must try and ensure the range is held by instructing the participant examinee to “now please hold that position”. The research assistant will need to continue to control for and maintain the examinee angle position and instruct the examiner to measure the position using a blanked, lockable UG.

Left LR – The EOR lateral rotation is to be ensured by passively rotating the left hip laterally until EOR tight resistance is felt. The research assistant must try and ensure the range is held by instructing the participant examinee to “now please hold that position”. The research assistant will need to continue to control for and maintain the examinee angle position and instruct the examiner to measure the position using a blanked, lockable UG.

Right LR – The EOR lateral rotation is to be ensured by passively rotating the right hip laterally until EOR tight resistance is felt. The research assistant must try and ensure the range is held by instructing the participant examinee to “now please hold that position”. The research assistant will need to continue to control for and maintain the examinee angle position and instruct the examiner to measure the position using a blanked, lockable UG.

If by any chance, the participant examinee does not manage to maintain the angles of active end of range ROM from one participant examiner measurement to the other, the process of set up and measurement must be repeated.

References

Greene, W.B. and Heckman, J.D., (Eds.), (1994), Clinical Measurement of Joint Motion, American Academy of Orthopaedic Surgeons, Rosemont, Illinois, pp. 1-2, pp. 106-108

Appendix 9: Ethical clearance for hip joint measurement study

22 April 2016

Our Ref: DC/SB 14/46

Alan Chamberlain
Health, Psychology & Social Studies
Fusehill Street

Research Office
University of Cumbria
Lancaster Campus
Lancaster, LA1 3JD

Tel: 01524 384175
Fax: 01524 384385
Email: sonia.barnes@cumbria.ac.uk

Dear Alan

Request for Ethical Clearance – Our Ref 14/46 – 1a/1c
Project: A concurrent validity and reliability study of active medial and lateral rotation of the hip joint using a universal goniometer and newly designed electronic measuring device

Thank you for seeking advice regarding the change of devise. As this appears to be the only change the panel are happy to approve this amendment.

With regards

Professor Diane Cox
Chair
Ethics Panel

Appendix 9 (cont.): Ethical clearance for hip joint measurement study

20 June 2016

Our Ref: DC/SB 14/46

Alan Chamberlain
Health and Science
Fusehill Street

University of Cumbria
Research Office
University of Cumbria
Lancaster Campus
Lancaster, LA1 3JD

Tel: 01524 384175
Fax: 01524 384385
Email: sonia.barnes@cumbria.ac.uk

Dear Alan

Request for Ethical Clearance – Our Ref 14/46 1a/1c
Project: A concurrent validity and reliability study of active medial and lateral rotation of the hip joint using a universal goniometer and newly designed electronic measuring device

Thank you for your revised Participant Information Sheet and Consent forms regarding the new participant examiners and those having their hip movement examined. The Panel are now able to give approval for your project.

With regards

Professor Diane Cox
Chair
Ethics Panel