The Immediate and Sustained Effects of Mobilisations with Movement on the Hip Range of Motion and Power and Shoulder Range of Motion and Strength.

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List of Abbreviations

MWM	Mobilisation with Movement
SMWM	Self-Applied Mobilisation with Movement
ROM	Range of Motion
PPT	Pain Pressure Threshold
IR	Internal Rotation
ER	External Rotation
VAS	Visual Analogue Scale
WB	Weight Bearing
CMJ	Countermovement Jump
PFGS	Pain Free Grip Strength
TPT	Thermal Pain Threshold
SNS	Sympathetic Nervous System
ULTT	Upper Limb Tension Test
DF	Dorsiflexion
MCP	Metacarpophalangeal
NPRS	Numeric Pain Rating Scale
SDQ	Strength and Difficulties Questionnaire
HBB	Hand Behind Back
SPADI	Shoulder Pain and Disability Index
NSS	No Scapular Stabilisation
SS	Scapular Stabilisation
VI	Visual Inspection

NS	Not Specified
HGS	Hand Grip Sore

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Abstract

The Immediate and Sustained Effects of Mobilisations with Movement on the Hip Range of Motion and Power and Shoulder Range of Motion and Strength.

Introduction

The purpose of this study was to determine the effect of a mobilisation with movement (MWM) and self-applied mobilisation with movement (SMWM) treatment on hip extension ROM (°), jump height (cm) and power (N) output and shoulder ROM (°) and strength [Peak Torque per Body Weight (%) and Time to Peak Torque (ms)]. Studies have demonstrated that MWM treatment has an effect on shoulder IR ROM and isometric strength, however no previous study has determined the effect of a MWM and SMWM treatment on shoulder rotational ROM or isokinetic strength. While MWMs have been shown to significantly increase functional hip IR ROM, no previous research has explored the effects of MWM or SMWM treatment on hip extension. Previous studies have documented an increase in isometric muscle strength following hip mobilisations, however no research to date has explored the effects of MWM and SMWM treatment on hip power. Similarly, previous studies demonstrated an increase in isometric muscle strength following shoulder mobilisations, however no research to date has explored the effects of MWM and SMWM treatment on isokinetic shoulder rotational strength.

Methods

The first study investigated the effect of a single MWM and SMWM treatment bout on the hip joint (n=60), where the treatment effects where examined immediately, 24hrs and 48hrs post. The participants had a restricted hip extension ROM (<20°). Baseline hip

extension ROM (°) and hip power [jump height (cm) and power (N)] measures were obtained with a mobile phone inclinometer and a force plate. The participants were stratified and randomly allocated into groups; therapist applied MWM (n=20), self-applied MWM (n=20) or the control (n=20). The participants received treatment on the hip joint based on their respective group. Participants only received a single treatment application (3 sets of 10 repetitions). Outcome measures were reassessed immediately, 24hrs and 48hrs following the treatment application. The second study investigated the treatment effects of a single MWM and SMWM treatment bout immediately, 24hrs and 48hrs post treatment on the shoulder joint (n=73). Participants had a restricted shoulder IR ROM (<60°). Baseline shoulder IR ROM (°) and strength measures [Peak Torque per Body Weight (%) and Time to Peak Torque (ms)] were obtained using an inclinometer and an isokinetic Biodex Machine respectively. The participants were stratified and randomly allocated into groups; therapist applied MWM (n=19), self-applied MWM (n=21) or the control (n=22). The participants received treatment on the shoulder joint based on their respective group. Participants only received a single treatment application (3 sets of 10 repetitions). Outcome measures were reassessed immediately, 24hrs and 48hrs following the treatment application. The third study investigated the effects of multiple MWM and SMWM treatment applications immediately and up to 7 days post treatment (n=27). Participants had a restricted shoulder IR ROM (<60°). Baseline shoulder IR ROM (°) and strength measures [Peak Torque per Body Weight (%) and Time to Peak Torque (ms)] were obtained using an inclinometer and an isokinetic Biodex Machine respectively. The participants were stratified and randomly allocated into groups; therapist applied MWM (n=9), self-applied MWM (n=9) or the control (n=9). The participants received treatment on the shoulder joint based on their respective group.

Participants received 3 treatment applications (3 sets of 10 repetitions in each treatment application) over a period of a week. Outcome measures were reassessed immediately, 48hrs and 7 days following the final treatment. The data was analysed using the SPSS statistics package, the between group differences were compared using a split plot ANOVA with the post-hoc analysis and the paired t-test was utilised to identify within group changes.

Results

In study one, a split plot ANOVA revealed no significant between group effects for hip ROM or hip power immediately, 24hrs or 48hrs post treatment when compared to the baseline measurement. In study two, a split plot ANOVA revealed a significant between group effect (F=5.09 [df=2, SE=47], p=0.01), demonstrating a significant increase in the MWM and SMWM groups immediately (MWM=11°,SMWM=10°), 24 hours (MWM=8°,SMWM=8°) and 48 hours (MWM=7°,SMWM=6°) post treatment when compared to the baseline measurement. In study three, a split plot ANOVA revealed a significant between groups effects (F=8.4 [df=2, SE=27], p=0.01), demonstrating a significant statistical difference in the MWM and SMWM groups immediately (MWM=14°,SMWM=13°), 48 hours (MWM=13°,SMWM=15°) and 7 days (MWM=18°,SMWM=14°) post treatment when compared to the baseline measurement. No significant between group effect was found for shoulder ER ROM and strength measures for both SMWM and MWM in study two and three.

Conclusion

A single application of MWM and SMWM techniques did not significantly effect hip ROM, jump height or power output. A single application of MWM and SMWM treatment is equally effective at increasing shoulder IR ROM immediately and up to 48h post treatment application. Multiple MWM and SMWM treatments are effective in increasing shoulder IR ROM immediately and up to 7 days following the treatment application, furthermore it results in a greater ROM increase when compared to a single treatment application. The application of MWM or SMWM treatments has no negative impact on shoulder strength or shoulder ER ROM.

Chapter One
Introduction

Altered range of motion (ROM) may be associated with decreased performance (Feeley et al., 2008), pathology (Sankar, Laird and Baldwin, 2012) or even injury (Thacker et al., 2004;; Witvrouw et al., 2003;). Adequate ROM is essential for optimal performance in the athletic population. A reduced hip extension ROM can be detrimental to lower limb power generation. Hip extension is necessary to achieve the triple extension motion, where the hip, knee and ankle joints go through full ROM in order to produce a fully extended position (Willson and Davis, 2008; Willson and Davis, 2009). Triple extension is a movement used in power generation in sporting activities involved in acceleration, running, sprinting and jumping (Comfort, 2015). The athletic population taking part in overhead activity is at risk of altered shoulder mobility due to repetitive overhead motion that may lead to muscle imbalance, muscle tightness or capsular tightness (Wilk *et al.*, 2009; Braun *et al.*,2011). The reduction of shoulder IR ROM may lead to further dysfunctions which may impact on athlete's performance and lead to an inability to force throughout a full range.

There are a number of therapeutic techniques which can be performed by a therapist to improve joint range of motion and mobility, including stretching, soft tissue massage, joint mobilization, and various manual therapy techniques such as myofascial release (Beardsley and Škarabot, 2015), pin and stretch (Puentedura et al., 2011), PNF (Feland et al., 2001; Klein et al., 2002), hold relax techniques (Bonnar et al., 2004; Moore et al., 2011) and mobilizations with movement (MWM) [Al, 2007; Hoch et al., 2012; Shah and Nambi, 2012; Hing et al., 2009]. Furthermore, self-applied techniques can be employed by the athlete themselves such as stretching (Junker and Stöggl, 2015) or foam rolling (Mohr et al., 2014) to increase joint ROM and mobility. Self-correction exercises can also improve muscle balance (Mason, 2009) and posture (O'Sullivan et al., 2012) and may prove to increase the joint ROM. One of these self-correction exercises is self-applied mobilisations with movement (SMWM), however the research is limited as to the effects of SMWM treatment on joint ROM.

MWM is a treatment technique that can be both therapist applied and can be applied by the patient in the form of self-applied mobilisations with movement, which is often used as a useful adjunct to the home exercise programme. A single MWM treatment application has been documented to improve joint ROM in the elbow (Abbott *et al.,* 2001), shoulder (Abbott, 2001; Ribeiro et al., 2017), ankle (Vincezino *et al.,* 2006), and the hip joint (Walsh and Kinsella, 2016). A multiple MWM treatment application has also been documented to improve joint ROM in the elbow (Stephens, 1995), shoulder (Doner et al., 2013; Gelago-Gil et al., 2015; Satpute et al., 2015; Teys, 2013), ankle (Collins et al., 2004; O'Brien and Vicenzino, 1998;) and the thumb (DeSantis and Hasson, 2006) joint. Although both single and multiple MWM treatment applications seem to be effective in increasing joint ROM, there has been no study to date which has documented the optimal treatment frequency.

Only a single study has explored the effect of MWMs and SMWMs on the hip joint, demonstrating an increase in range of motion in functional internal rotation (IR) test following a single MWM treatment application, with no significant effect following a single SMWM treatment application (Walsh and Kinsella, 2016). The SMWM treatment and its' effects on ROM have only been explored in the hip and shoulder joints (Ribeiro *et al.*, 2017; Walsh and Kinsella, 2016). The SMWM treatment application showed to be ineffective in changing joint ROM, Walsh and Kinsella (2016) study indicated no change in the hip IR ROM following a single treatment application and Ribeiro *et al* (2017) demonstrated no change in shoulder ROM following single treatment application. The effects of both single and multiple MWM and SMWM treatment applications in any other hip plane of motion are so far unknown. The effects of SMWMs single or multiple treatment applications on ROM of the shoulder joint has been undocumented. Research should determine the effect of single and multiple MWM and SMWM treatment applications on joint ROM, as it would inform clinicians on the most appropriate treatment and home exercise programme.

The research presents clear effects of MWM treatment on joint ROM, however its effects on other functional outcome measures such as strength and power are scarcely known. The effects of MWM had been most frequently documented in the elbow, where single and multiple MWM treatment applications has been shown to improve grip strength (Vicenzino and Wright, 1995; Exelby, 1995; Abbott et al., 2001; Vicenzino et al., 2001; Kochar and Dogra, 2002; McLean et al., 2002; Paungmali et al., 2004; Paungmali et al., 2003a; Paungmali et al., 2003b; Collins et al., 2004; Mulligan, 2004; Bisset et al., 2006; DeSantis and Hasson, 2006; Vicenzino et al., 2007; Teys, Bisset and Vicenzino, 2008; Ahmad et al., 2013; Slater et al., 2015). Although no research to date had documented the effects of MWM or SMWM treatment on functional outcome measures at the hip joint, research by Yerys et al., (2002) and Makofsky et al., (2007) who examined grade IV hip mobilisation at the hip joint and reported a significant increase in hip isometric strength ($p=0.01$ and $p=0.01$ respectively), suggesting that manual therapy can result in an alteration in function of the joint. Future research need to examine if MWM or SMWM treatment may result in similar effects on the function of joints, such an in changes in other measures of muscle strength and by measuring power output.

Only one study to date has examined the effects of a multiple treatment applications of MWM on the shoulder joint and isometric strength following treatment (Neelapala et al., 2016). This study determined that isometric shoulder ER increases after an IR direction MWM treatment (Neelapala et al., 2016). Future studies may wish to examine the effects of a single MWM treatment on other measures of shoulder rotational strength. It is extremely important from a performance perspective to determine the effects of MWMs and SMWMs on joint strength and power, be it either positive or negative.

Most of the research to date has documented the immediate effects of the MWM treatment (Stephens, 1995; Vicenzino & Wright, 1995; Abbott et al., 2001; Vincezino et al., 2001; Kochar & Dogra, 2002; McLean et al., 2002; Paungmali et al., 2003a; Slater et al., 2006; Paungmali et al., 2003b; Paungmali et al., 2004; Hetherington, 1996; O'Brien & Vicenzino, 1998; Collins et al., 2004; Vincezino et al., 2006; Folk, 2001; Backstorm, 2002; Hsieh et al., 2002; DeSantis & Hasson, 2006; Balasundram et al., 2017; Abbott, 2001; Neelapla et al., 2006; Ribeiro et al., 2015; Satpute et al., 2015; Delgado-Gil et al., 2015; Rahman et al., 2016; Ribeiro et al., 2017; Yerys et al., 2002; Walsh and Kinsella, 2016). Certain studies have investigated the effects of MWM treatment for up to 52 weeks (Doner et al., 2013; Bisset et al., 2006). Only a single study has examined the effects of MWM treatment over the span of 7 days (Teys et al., 2013), which is the typical patient follow up period in a clinical setting. Future studies should consider the effects of MWM and SMWM treatment over a short follow up period.

Although the MWM treatment is examined in previous research, more insight is still needed to fully understand the effects of single and multiple MWM treatment applications. SMWM treatment application is often utilised as a home exercise programme in order to replicate the clinical scenario and maintain the benefits from the treatment session, however current research does not support the use of SMWMs. Future research should consider examining the effects of single and multiple MWM and SMWM treatment applications on joint ROM, strength and power.

Chapter Two
Literature Review

2.1. Mobilisations with movement (MWMs) and Self-Mobilisations with movement (SMWM)

Mobilisations with movement (MWMs) are a form of joint mobilisation treatment developed by Brian Mulligan (Mulligan, 2004; Vicenzino *et al.*, 2007). The literature also refers to this treatment as Mulligan mobilisation (Kochar and Dogra, 2002; Collins *et al.*, 2004; Teys *et al.*, 2008) or manipulative technique (Paungmali *et al.*, 2003; Vicenzino, *et al.*, 2007). MWM treatment is a manual therapy treatment in which a manual force, typically in the form of a joint glide is applied to a motion segment and sustained while an impaired movement or action is performed. The technique consists of many parameters which need to be fulfilled in order to use the technique correctly, including tenets, technical parameters and response parameters (Hing *et al.*, 2009). The tenets referrer to the PILL and CROCKS principles, technical parameters consist of considerations such as sets x reps, rest between sets and treatment frequency and the response parameters refer to the outcome measures such as ROM or strength. Practitioners should look for the PILL and CROCKS response, where the treatment is pain free (P) having immediate (I) results which are long lasting (LL). The practitioner should consider the treatment contraindications (C), and apply the treatment with appropriate repetitions (R), with overpressure (O) applied throughout the treatment. Clear communication (C) needs to be maintained between the patient and the practitioner. The practitioner needs to apply his knowledge (K) in order to use the appropriate treatment method for the pathology at hand. The mobilisation and overpressure needs to be sustained (S) throughout the movement. If performed correctly within the specified parameters, the treatment enables the impaired joint to move freely without pain (Vicenzino *et al.*, 2007, Bialosky *et al.,* 2009). Practitioners also utilise this concept in prescribing a home exercise programme (HEP) in the form of self-applied mobilisations with movement (SMWM), where the SMWM HEP technique resembles that of the MWM treatment (Wright and Hegedus, 2012).

2.2. Pathophysiology

The literature has established the clinical efficacy of MWM treatment for improving joint function, with a number of hypotheses for its cause and effect. Mulligan's original theory for the treatment's effectiveness was based on a concept related to a joint 'positional fault', where maltracking of joint causes secondary symptoms such a pain, stiffness, limitation of movement or weakness due to an injury (Mulligan, 1993, Mulligan, 2004). This theory was suggested due to changes following injury in the shape of articular cartilage, thickness of cartilage, orientation of fibres of ligament and capsules, or the directional pull of muscles and tendons. Numerous studies tried to validate this theory by examining pain, range of motion and function measures (Hetherington, 1996; O'Brien and Vicenzino, 1998), however only Kavanagh (1999) reported the actual bone displacement following an MWM application on the ankle joint. This may imply that a MWM may produce an increase in ROM by positional correction and a decrease in pain levels. A single case study by Hsieh *et al.*, (2002) utilised magnetic resonance imaging (MRI) to evaluate the positional fault hypothesis in a patient after a hyperabducation injury of the thumb, resulting in a 4° thumb pronation. Following a 3 week treatment protocol, the patient remained symptom free. A further MRI evaluation concluded that the initial treatments benefits were not due to the positional fault theory, although the patient was completely symptom free, the 4° thumb pronation still remained following the treatment application. This may imply that MWMs may correct the positional faults at the time of application, however the long term effects may occur via other mechanisms.

More recent studies have investigated further neurophysiologic mechanisms, including the hypoalgesic and sympathetic nervous system (SNS) excitation effects (Abbott *et al.*, 2001; Paungmali *et al.*, 2003; Paungmali *et al.*, 2004; Teys *et al.*, 2008). Abbott *et al.*, (2001) suggested that the MWM treatment may act neurophysiologically to decrease the level of muscular activity of the rotator cuff muscles after a treatment application. Numerous studies demonstrated a hypoalgesic effect after an MWM application on the elbow joint in patients with lateral epicondylitis (Vicenzino *et al.*, 2001; Kochar and Dogra, 2002; McLean *et al.*, 2002; Paungmali *et al.*, 2003; Paungmali *et al.*, 2003; Bisset *et al.*, 2006; Slater *et al.*, 2015). The hypoalgesic effect has been proposed that it may be non-opiod in nature, indicating the combination of sympathoexcitation, non-opioid hypoalgesia and improvements in motor functions (Vicenzino and Wright, 1995; O'Brien and Vicenzino, 1998; Sterling et al., 2001). Sypathoexciation is an involuntary response which refers to the excitation of, or by means of the sympathetic nervous system and hypoalgesia refers to decreased sensitivity to a painful stimuli. This suggests a possible involvement of endogenous pain inhibition systems in the MWM treatment (Vicenzino and Wright, 1995; O'Brien and Vicenzino, 1998; Sterling et al., 2001). Bialosky *et al.,* 2009 presented the most recent theory incorporating the biomechanical and neurophysiological mechanisms. This model suggests that the initial mechanical stimulus of manual therapy initiates a number of potential neurophysiological effects which produce the clinical outcomes associated with manual therapy. This neurophysiological effect involves the peripheral mechanisms, spinal cord mechanisms and supraspinal mechanisms to produce an inflammatory response, autonomic response, endocrine response, neuromuscular response and hypoalgesia (*figure 2.0*). The predominant explanation for the MWM effectiveness during and after a course of treatment to date was mechanical in nature, based on the positional fault theory and MWMs' ability to correct these faults. However, Bialosky *et al.,* 2009 presented a theory that combines both the biomechanical and neurophysiological mechanisms.

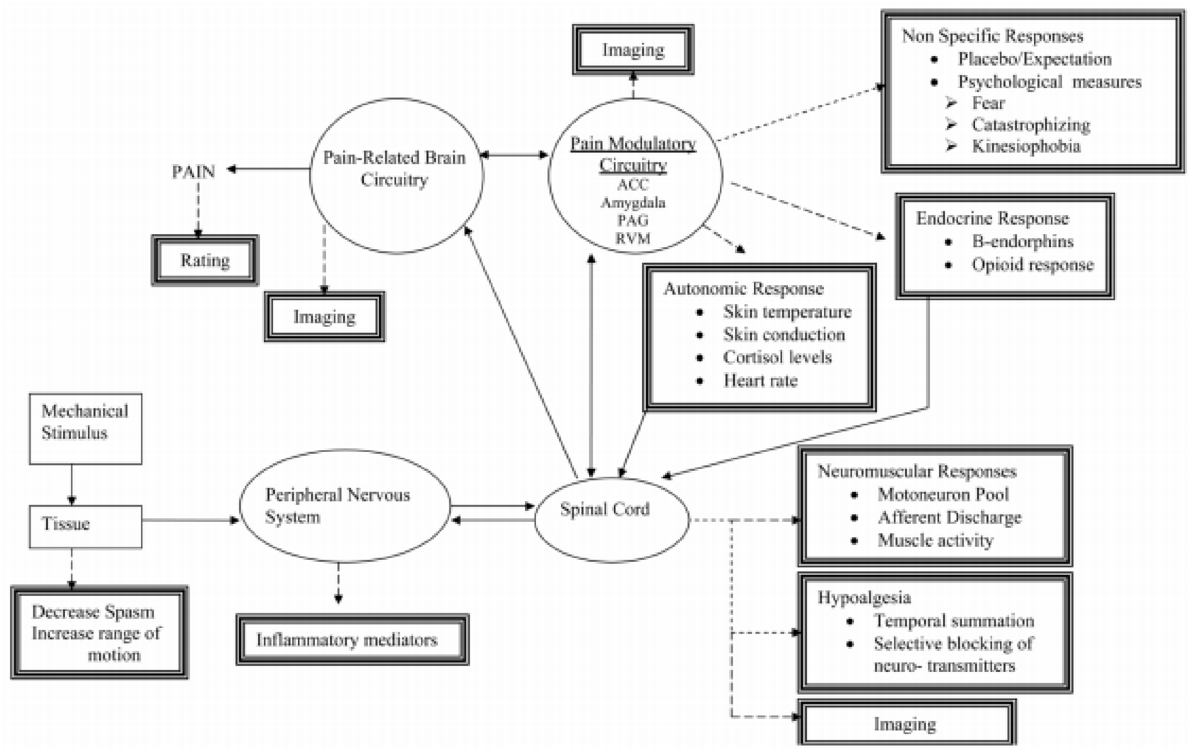
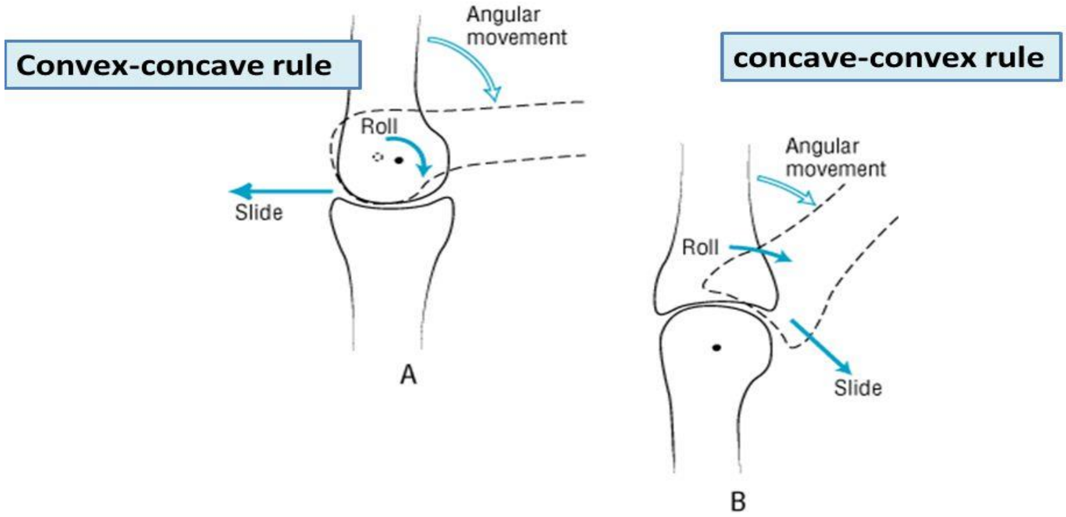


Figure 1. Comprehensive model of the mechanisms of manual therapy
Figure Key: The model suggests a transient, mechanical stimulus to the tissue produces a chain of neurophysiological effects. Solid arrows denote a direct mediating effect. Broken arrows denote an associative relationship which may include: ------▶ = an association between a construct and its measure Bold boxes indicate the measurement of a construct ACC = anterior cingular cortex; PAG = periaqueductal gray; RVM = rostral ventromedial medulla

Figure 2.0 A flow chart demonstrating the comptehensive model of the mechanisms of manual therapy proposed by Bialosky *et al.,* 2009.

2.3. Tenets and Parameters

The MWM treatment requires the practitioner to take many necessary parameters into consideration before treatment application. Mulligan has described five tenets that should be considered with MWM application, the accessory glide generated by the therapist, the physiological movement or action, pain reduction or elimination, an immediate effect and the use of overpressure (Exelby, 1995; Exelby, 2001; Exelby, 2002; Wilson, 1997; Collins *et al.*,2004; Hing *et al.*, 2009). Response parameters should also be closely monitored after the treatment application in order to establish if the treatment is effective or should be altered or discontinued. These response parameters refer to the PILL and CROCKS acronym (Hing *et al.*, 2009)[P = pain free, I = immediate, LL = long lasting, C = contra-indications, R = repetitions, O = overpressure, C = communication, K = knowledge, S = sustained]. The accessory glide should be performed in the right angle to the peripheral joint or follow the Kaltenborn's concave-covex rule [*Figure 2.1*](Exelby, 1995; Hing *et al.*, 2009). The movement performed during the MWM treatment application is typically the physiological movement or action which is pain provoking. The motion while performing the MWM treatment should reduce pain or remain pain free throughout the treatment application. It is pertinent for the application and effectiveness of an MWM that a reduction or elimination of pain is achieved throughout the treatment application. The MWM treatment needs to produce instantaneous and immediate positive effects during its application in order to be deemed effective. Immediate adaptations should be present after the MWM application (Exelby, 1995). The instant results need to have long lasting effects in order for the permanent changes to occur (Hing *et al.*, 2009). Follow up assessments of the outcome measures (*table 2.1.*) need to be proceeded in order to establish the deterioration or improvement from the treatment application (O'Brien and Vicenzino, 1998; Folk, 2001; Hsieh *et al.*, 2002; Kochar and Dogra, 2002; Maloney Backstrom, 2002; Paungmali *et al.*, 2003; Bisset *et al.*, 2006; Wright and Hegedus, 2012; Ahmad *et al.*, 2013). If any of Mulligan's PILL parameters are not established then the treatment should be altered, or ceased as the treatment may ineffective or painful. The treatment is contraindicated when there is malignancy in area of treatment, metabolic bone disease, septic arthritis, neoplastic disease, fusion or ankyloses, osteomyelitis, fracture or ligament rupture (Hing et al., 2007). In case of excessive pain or swelling, arthroplasty, pregnancy, hypermobility, spondylolisthesis, rheumatic arthritis or vertebrobasilar insufficiency the treatment can be proceeded with caution. There needs to be constant communication throughout the treatment application in order to monitor the symptoms and progression of the treatment. The MWM treatment requires to be client specific and outcome measures should be reassessed immediately after the treatment application in order to evaluate the treatments effectiveness (Exelby, 1995; Exelby, 2001; Wilson, 1997). Further pain relief may be provided with the use of passive overpressure at the end of the available physiological range of motion (Wilson, 1997; Collins *et al.*, 2004). Although specific guidelines for the use of MWM treatment exist, the literature does not explore alternative parameters such as treatment frequency or optimal number of repetitions.



- (A) If the surface of the moving bone is convex, sliding is in the direction opposite to that of the angular movement of the bone. (B) If the surface of the moving bone is concave, sliding is in the same direction as the angular movement of the bone.

Figure 2.1 Figure demonstrating the Kaltenborn concave-convex rule.

Table 2. 1 Table of studies demonstrating the MWM and SMWM parameters and outcome measures.

Author	Sets x Reps, Frequency, Rest period	Outcome measures (Statistical Significance)	Follow up	Joint
Abbott et al., 2001	Up to 10 reps, 1 session, NS	PFGS (p=0.005) Maximal grip strength (p=0.05)	Immediate	Elbow
Abbott, 2001	Performed provoking movement 10 times, 1 session, NS	Passive shoulder internal and external ROM (p= 0.01, p=0.04)	Immediate	Shoulder
Backstorm, 2002	3 sets 10 reps, 12 sessions over 2 months, NS	Pain VAS scale (25% reduction initially, 50% reduction following 3rd intervention, 100% reduction at 2 months), Strength and ROM at wrist and thumb (NS)	Immediate	Thumb
Balasundram *et al.*, 2017	4 glides 3 sets 10 reps, 3 sessions 24 hours apart, NS	Active knee flexion ROM (p=0.00)	Immediate	Knee
Bisset *et al.*, 2006	NS, 8 sessions over 6 weeks, NS	Grip Force*, Pain VAS scale* (Statistical difference noted, however p value unreadable as presented on a graph,	3 week 6 week 12 week 26 week 52 week	Elbow

		p<0.01)		
Collins *et al.*, 2004	3 sets 10 reps, 3 Sessions 24 hours apart, 1 minute between sets	WB DF ROM (p=0.017), PPT, TPT	Immediate	Ankle
Delgado-Gil *et al.*, 2015	3 sets 10 repetitions, 2 sessions a week over 2 weeks, 30 seconds between sets	Pain VAS Scale (effect size = 1.8), Shoulder ROM (flexion effect size = 1.4), extension, external rotation (effect size = 0.9), abduction, internal rotation)	Immediate	Shoulder
DeSantis & Hasson, 2006	Initially: 2 sets 10 reps Follow up: 10 reps, 5 sessions over 2 weeks, NS	NPRS during active abduction (6/10 NPRS, where 3/10 is the clinical relevant change), Abduction active ROM (175°, where 80° is the clinical relevant change)	Immediate	Thumb
Doner *et al.*, 2013	3 sets 10 repetitions, 5 days a week for 3 weeks, 30 seconds between sets	Pain VAS scale (p=0.018), Constant score, Satisfaction of the patient and the therapist (p=0.00), SDQ, Active and passive shoulder flexion (p=0.01), abduction (p=0.02), internal (p=0.02) and external rotation ROM.	Immediate, 3 month follow up	Shoulder

Folk, 2001	2 sets 10 reps, 1 session, NS	Pain VAS scale*, End range MCP extension with overpressure* (Case report, measures reported significant*, however no statistical analysis was conducted)	Immediate	Thumb
Hetherington, 1996	3 sets 10 reps, 1 session, NS	Pain on inversion ROM*, Balance – single leg standing with eyes closed (Case report, measures reported significant*, however no statistical analysis was conducted)	Immediate	Ankle
Hsieh *et al.*, 2002	Self: 6 reps Therapist: NS, Every 2 hours for 3 weeks, 2 hours between sets	Pain VAS scale*, ROM (Case report, measures reported significant*, however no statistical analysis was conducted)	Immediate	Thumb
Kochar & Dogra, 2002	3 sets 10 reps, 10 sessions over 3 weeks, NS	PFGS (p=0.01), Pain VAS scale (p=0.01), Ability to lift 0-3kgs (p<0.01)	Immediate	Elbow
McLean *et al.*, 2002	4 force levels 2 reps at each force level, 1 session, 2 minutes between	PFGS (p=0.01)	Immediate	Elbow

	each rep			
Neelapla *et al.*, 2006	3 sets 5 repetitions, 3 sessions, NS	Pain VAS scale (p<0.01), Scapular upward rotation, Isometric shoulder external (p=0.04) and internal rotator strength	Immediate	Shoulder
O'Brien & Vicenzino, 1998	4 reps, Subject 1: 6 sessions over 2 weeks, 3 sessions over 1 week (1 week in between) Subject 2: 6 sessions over 2 weeks, NS	VAS (r=0.90), Inversion and WB DF ROM (r=0.92)	Immediate	Ankle
Paungmali *et al.*, 2003a	10 reps applied for 10 seconds, 1 session, 15 seconds between reps	PFGS (p=0.001), PPT (p=0.01), TPT (p=0.01), SNS parameters (p=0.01)	Immediate	Elbow
Paungmali *et al.*, 2003b	10 reps, 6 sessions 48 hours apart, 15 seconds between each rep	PFGS (p=0.02), PPT	Immediate	Elbow
Paungmali *et al.*, 2004	6 reps, 3 sessions 48 hours apart, 15 seconds between	PFGS (p=0.02), PPT, TPT, ULTT	Immediate	Elbow

	reps			
Rahman *et al.*, 2016	3 sets 10 repetitions, 12 sessions over 4 weeks, NS	Pain VAS Scale (p<0.01), HGS (p<0.00)	Immediate	Shoulder
Ribeiro *et al.*, 2015	4 sets 10 repetitions, 1 session, NS	Muscle activity level (supraspinatus, Infraspinatus, Middle deltoid, Posterior deltoid) [p=0.001]	Immediate	Shoulder
Ribeiro *et al.*, 2017	SMWM: 10 reps MWM: 10 reps, 1 session, 5 minutes interval between SMWM and MWM	Active shoulder abduction ROM, Muscle activity (upper trapezius, lower trapezius, serratus anterior, supraspinatus, infraspinatus, middle deltoid, posterior deltoid)	Immediate	Shoulder
Satpute *et al.*, 2015	3 sets 10 repetitions, 3 sessions per week over 3 consecutive weeks, 60 seconds between sets	Pain VAS scale (p<0.01), IR ROM (p<0.01), HBB ROM (p<0.01), SPADI score (p<0.01)	Immediate	Shoulder
Slater *et al.*, 2006	3 sets 6 reps (30 secs.) Total 2.5 mins, 1 session,	PPT (p=0.01), Maximal grip and wrist extension force (p=0.01)	Immediate	Elbow

	30 secs between sets			
Stephens, 1995	NS, 23 session, NS	VAS during active (p=0.01) & resisted wrist extension (p=0.02), and hand grip (p=0.01)	Immediate	Elbow
Teys *et al.*, 2013	3 sets 10 repetitions, 1 session, NS	Pain VAS Scale, PPT, Shoulder abduction ROM (p=0.001)	Immediate, 30 minutes, 24 hours, 7 days	Shoulder
Vicenzino & Wright, 1995	6 reps Sustained for 5-10 seconds, 4 sessions 2 weeks, No longer than 60 seconds between reps	PFGS (p<0.05)	Immediate	Elbow
Vincezino *et al.*, 2001	6 reps, 1 session, 15 seconds between reps	PFGS (p=0.01), PPT (p=0.01)	Immediate	Elbow
Vincezino *et al.*, 2006	4 reps of 2 glides maintained for 10 seconds at end range or onset of pain, 1 session, 20 seconds between reps	Posterior talar glide, WB ankle DF ROM (p=0.04)	Immediate	Ankle

Walsh and Kinsella, 2016	MWM and SMWM 3 sets 10 repetitions, 1 session, 30 seconds between sets	Seated hip internal rotation test, Functional hip internal rotation test (p=0.01)	Immediate	Hip
Yerys *et al.*, 2002	3 sets 1 minute each, 1 session, 30 seconds between sets	Isometric hip extension strength (p=0.002)	Immediate	Hip

Note: *significant statistical increase, NS = Not Specified, VAS = Visual Analogue Scale, WB = Weight Bearing, DF = Dorsiflexion, ROM = Range of motion, TPT = Thermal Pain Threshold, NPRS = Numeric Pain Rating Scale, HGS = Hand Grip Sore

The technical parameters such as repetitions, sets, frequency and rest periods are also an important factor that should be considered (*table 2.1.*). Although Mulligan (1995) recommends the MWM treatment should be applied in ten repetitions and three sets, the rationale for this is not clearly defined. The most commonly utilised sets and repetitions (*table 2.1.*) in the literature is 3 sets by 10 repetitions (Hetherington, 1996; Kochar and Dogra, 2002; Maloney Backstrom, 2002; Collins *et al.*, 2004; Teys *et al.*, 2008; Teys *et al.*, 2013b; Doner *et al.*, 2013; Teys *et al.*, 2013a; Delgado-Gil *et al.*, 2015; Satpute *et al.*, 2015; Slater *et al.*, 2015; Walsh and Kinsella, 2016; Rahman *et al.*, 2016), but the variations in this ranged from a single set (O'Brien and Vicenzino, 1998; Abbott *et al.*, 2001; Vicenzino *et al.*, 2001; Hsieh *et al.*, 2002; Paungmali *et al.*, 2003; Paungmali *et al.*, 2004; Ribeiro *et al.*, 2017) to 4 sets of 10 repetitions (Ribeiro *et al.*, 2016). No study to date has determined the optimal number of sets and reps for an MWM application. Furthermore, the frequency of the MWM application (*table 2.1.*) may play an important role on the outcome measures, while a single treatment application may provide notable changes, a treatment period consisting of multiple treatment sessions may promote these changes further. The literature to date has not demonstrated the most optimal treatment frequency. The most commonly reported frequencies were three or six sessions, with intervals between sessions varying from 24 to 48 hours (Vicenzino and Wright, 1995; O'Brien and Vicenzino, 1998; Kochar and Dogra, 2002; Paungmali *et al.*, 2003; Paungmali *et al.*, 2004; Collins *et al.*, 2004; DeSantis and Hasson, 2006; Teys *et al.*, 2008). There is also a large variation in the rest periods (*table 2.1.*) given between sets and repetitions, ranging from 30 seconds to two hours between sets (Hsieh *et al.*, 2002; McLean *et al.*, 2002; Collins *et al.*, 2004; Vicenzino *et al.*, 2007; Teys *et al.*, 2008; Slater *et al.*, 2015) and 15 to 60 seconds between repetitions, where the most common rest period was 15 seconds between repetitions (Vicenzino *et al.*, 2001; Paungmali *et al.*, 2003; Paungmali *et al.*, 2004).

The SMWM treatment follows the same principles, tenets and parameters as the MWM treatment, however research on SMWM is very scarce (Walsh and Kinsella, 2016; Ribeiro *et al.*, 2017). Two studies have utilised SMWM treatment in order to compare it to the MWM treatment, demonstrating no significant changes in ROM, functional ROM and muscle activation (Walsh and Kinsella, 2016; Ribeiro *et al.*, 2017). Both of these studies have only administered a single treatment application, with an immediate reassessment following the treatment application (*table 2.1.*) [Walsh and Kinsella, 2016; Ribeiro *et al.*, 2017]. Ribeiro *et al.*, (2017) used a single set of 10 repetitions, while Walsh *et al.*, (2016) has followed Mulligan's recommendations applying 3 sets of 10 repetitions. No study to date has explored multiple SMWM treatment application, or explored longer follow up period.

2.4. Outcome measures

2.4.1. Pain

MWM have been reported to significantly decrease pain, as measured by VAS, in the elbow (Vicenzino and Wright, 1995; Exelby, 1995; Abbott *et al.*, 2001; Vicenzino *et al.*, 2001; Kochar and Dogra, 2002; McLean *et al.*, 2002; Paungmali *et al.*, 2003; Paungmali *et al.*, 2003; Paungmali *et al.*, 2004; Collins *et al.*, 2004; Mulligan, 2004; Bisset *et al.*, 2006; DeSantis and Hasson, 2006; Vicenzino *et al.*, 2007; Teys *et al.*, 2008; Slater *et al.*, 2015), shoulder (Abbott *et al.*, 2001; Doner *et al.*, 2013; Teys *et al.*, 2013a; Delgado-Gil *et al.*, 2015; Satpute, Bhandari and Hall, 2015; Neelapala *et al.*, 2016; Rahman *et al.*, 2016; Ribeiro *et al.*, 2016; Ribeiro *et al.*, 2017), ankle (Hetherington, 1996; O'Brien and Vicenzino, 1998), thumb (Folk, 2001; Hsieh *et al.*, 2002; Maloney Backstrom, 2002) and hip (Wright and Hegedus, 2012) joints. Paungmali has completed a series of studies exploring MWM treatment in patients with lateral epicondylitis (Paungmali *et al.*, 2003; Paungmali *et al.*, 2003; Paungmali *et al.*, 2004). Although the application parameters differed, all three studies were successful in increasing PFGS significantly. Other parameters such as PPT and TPT were not constant and varied between studies. Paungmali *et al.*, (2003) demonstrated that a single treatment application consisting of 10 repetitions can alter significantly increase PPT (p=0.01) and TPT (p=0.01), while Paungmali *et al.*, (2004) demonstrated that a 3 session treatment application of 6 repetitions did not preduce significant results in PPT and TPT. No study to date demonstrated the optimal number of repetitions and sets in order to produce specific significant changes, in this case the application of 6 repetitions in 3 separate treatment sessions seemed to be insufficient to procude optimal treatment benefits. Interestingly, a MWM treatment applied on the elbow joint in patients with lateral epicondylitis decreased pain measures in both the elbow (p=0.01) and the wrist joint (p=0.01)[Slater *et al.*, 2006]. A single treatment application or a treatment period on the shoulder joint can reduce shoulder pain for up to 3 months (Doner *et al.*, 2013; Teys *et al.*, 2013a).

2.4.2. ROM

MWM treatment has been reported to significantly increase ROM in the shoulder (Abbott *et al.*, 2001; Doner *et al.*, 2013; Teys *et al.*, 2013a; Delgado-Gil *et al.*, 2015; Satpute *et al.*, 2015; Neelapala *et al.*, 2016; Ribeiro *et al.*, 2017), hip (Walsh and Kinsella, 2016), thumb (Folk, 2001; Hsieh *et al.*, 2002; Backstrom, 2002), ankle (Hetherington, 1996; O'Brien and Vicenzino, 1998; Vicenzino *et al.*, 2007) and knee (Balasundaram *et al.*, 2017) joints. Interestingly, a MWM treatment application on the elbow joint resulted in a significantly increased wrist ROM (Ahmad *et al.*, 2013). MWMs were successful in significantly increasing the shoulder ROM following both a single shoulder (Abbott *et al.*, 2001; Doner *et al.*, 2013; Teys *et al.*, 2013a; Delgado-Gil *et al.*, 2015; Satpute *et al.*, 2015; Neelapala *et al.*, 2016; Ribeiro *et al.*, 2017) and multiple (Doner et al., 2013; Satpute et al., 2015) treatment application. The increase in shoulder ROM (p=0.02) following a MWM treatment lasted for up to 3 months (Doner et al., 2013). Two studies to date have examined the effectiveness of SMWM treatment, one on the hip joint and one on the shoulder joint (Walsh and Kinsella, 2016; Ribeiro *et al.*, 2017). The results documented no significant change in the passive and functional hip IR test (Walsh and Kinsella, 2016) and no significant change in the shoulder ROM following the SMWM treatment application (Ribeiro *et al.*, 2017). There is a clear lack of supportive evidence to show the effects of SMWM treatment on joint ROM.

2.4.3. Strength

MWM treatment application on the elbow joint significantly increase grip strength in patients with lateral epicondylitis (Abbott *et al.*, 2001; Kochar and Dogra, 2002; McLean *et al.*, 2002; Stephens, 1995; Slater *et al.*, 2015). Slater *et al.*, (2015) has demonstrated that the tratment application not only significantly increases grip strength, but also produces a significant increase in wrist extension force. Neelapala *et al.*, (2016) utilised a 3 week MWM intervention period on patients with adhesive capsulitis demonstrating acute and sustained increases in isometric shoulder ER strength (p=0.04). No study to date has utilised the MWM treatment alone on healthy individuals to determine its' effect on functional isokinetic shoulder IR and ER strength. Althought Yerys *et al.*, (2002) and Makofsky *et al.*, (2007) demonstrated a statistically significant isometric hip peak torque increase in extension (p=0.01) and abduction (p=0.01) respectively after grade IV hip mobilisations, no study to date has examined the effects of MWM at the hip on hip power or strength. This further highlights the need for a performance specific outcome measures that can be directly be attributed to sporting performance such as jump power. A single study conducted by Backstorm (2002) has demonstrated that MWM treatment has a positive effect on thumb strength. No research to date has demonstrated the effects of SMWM treatment on strength or power.

2.5. The hip joint

The acetabulofemoral joint, or the hip joint, is a ball and socket joint formed by the femoral head and the acetabulum. Its function is to transmit load between the upper and lower body, allow mobility and to provide a stable base in weight bearing activities. The hip morphology consists of passive restraints such as bones, ligaments and capsule as well as a complex system of muscle groups (Hughes *et al.,* 2002). Reduced hip extension may predispose a person to hip pain, as during physical activity it may result in extra loads being placed on the anterior margins of the joint (Khan and Brukner, 2011). Hurwitz *et al.,* (2005) documented that patients presenting with hip OA often exhibited an alternation in the gait pattern, with decreased hip extension being the most affected movement ($p < 0.004$). The study established that a decreased hip extension was significantly correlated with an increased level of pain in the hip ($r=0.78$, $p < 0.001$). The compensations occurring as a result of a decreased hip extension ROM may also be a source of lumbar and sacral complaints (Eland *et al.*, 2002), and a possible cause of lumbar lordosis and anterior pelvic tilt (Riemann *et al.*, 2013). Therefore, maintaining optimal hip extension ROM may result in better biomechanical function and posture and subsequently reduce the risk of dysfunction and pain. Studies have demonstrated that various anthropometric and functional factors influence power generation during performance measures such as vertical jump height (Abidin and Adam, 2013; Ferreira *et al.*, 2013; Mackala *et al.*, 2013; Hoopingarner, 2015). Hoopingarner (2015) explored the relation between hip ROM and countermovement jump (CMJ) height and peak power output during a jump. The study concluded a negative correlation between hip flexion ROM and countermovement jump height ($r=0.66$), a positive relationship between hip internal rotation and countermovement jump height and hip extension ROM and counter-movement jump height (r=0.70) was demonstrated. As greater hip extension correlates with greater CMJ, deficits in hip extension ROM has the potential to negatively impact on power production. Therefore, hip extension ROM is a potentially modifiable factor that may influence not only lower body power, but also the development of pain, symptoms, change in activities of daily living or a reduced sport participation. Studies have confirmed the model proposed by Hoopingarner (2015), demonstrating that a hip flexor stretch increases hip extension ROM and in turn vertical jump height (Wakefield and Cottrell 2015). Therefore, altering the hip extension ROM may have positive effects on jump performance.

2.5.1. Hip ROM Normative Values

The measurement of hip extension has been explored in the literature and normative values for hip extension ROM have been reported to range from -4° to 59° (Gabbe *et al.*, 2004; L'Hermette *et al.*, 2006; Peeler and Anderson, 2007; Clapis *et al.*, 2008; Chevillotte *et al.*, 2009; Prather *et al.*, 2010; Kim and Ha, 2015; Roach *et al.*, 2015; Wakefield and Cottrell, 2015). There is considerable variation in the reported hip extension ROM, which may in part be due to the participant testing position. The testing positions used to assess hip extension have included the Thomas test, prone lying and side lying positions. The variations in hip extension ROM [(-)4.16° ± 8.81° - 59° ± 9.2°] may further be attributed to the spinal and hip positioning and stabilisation during the ROM measurement (*Table* 2.2). Another factor that may affect hip extension ROM values may be the condition of the participant. Chevillotte *et al.*, (2009), Roach *et al.*, (2015) and L'Hermette *et al.*, (2006) have compared hip extension ROM in healthy to pathological hips. Both Chevillotte *et al.*, (2009) and Roach *et al.*, (2015) have demonstrated a smaller hip extension ROM in participants with a pathology, however L'Hermette *et al.*, (2006) documented healthy participants to have a smaller hip extension ROM in comparison to patients presenting with pathology (*Table 2.2*.). The instrument of measurement may also affect hip extension ROM. The two most popular instruments to measure hip extension ROM are the goniometer and inclinometer (Gabbe *et al.*, 2004; L'Hermette *et al.*, 2006; Peeler and Anderson, 2007; Clapis *et al.*, 2008; Chevillotte *et al.*, 2009; Prather *et al.*, 2010; Roach *et al.*, 2014; Wakefield *et al.*, 2015). Clapis *et al.*, (2008) has directly compared the use of goniometer and inclinometer in the measurement of hip extension ROM [high interrater parallel-forms reliability also was found between instruments (r = 0.86-0.93; ICC = 0.86-0.92)], demonstrating that the inclinometer [(-)1.8° ± 2.1°] established a slightly higher hip extension ROM when compared to the goniometer [(-)2.8° ± 1.9°].

Table 2. 2 – Hip Extension ROM Normative Values

Author	Participants (n)	Condition	Position	Method of measurement	Hip Extension ROM Normative value
Chevillotte *et al.*, (2008)	62	Healthy = 20 OA = 21 Hip Arthroplasty = 21	Side lying	Visual evaluation	*Hip Arthroplasty Measures** Pre-operative 1.48° ± 5.75° Postoperative 0.97° ± 4.81°
Clapis *et al.*, (2008)	42	Healthy	Thomas Test Modified	Inclinometer Goniometer	Goniometer (-)2.8° ± 1.9° Inclinometer (-)1.8° ± 2.1°
Gabbe *et al.*, (2004)	15	Healthy	Thomas Test Modified	Goniometer	Examiner 1 1.5° ± 8.8° Examiner 2 1.9° ± 9.7°
Kim *et al.*, (2015)	24	Healthy	Thomas Test Modified General Measurement Active stabilisation Passive stabilization	Motion analysis software	General measurement 59° ± 9.2° 59° ± 8.7° Active stabilization 50.8° ± 8.3° 51° ± 8.7° Passive Stabilization 50.6° ± 9.9° 50.6° ± 9.3°
L'Hermette *et al.*, (2005)	59	Healthy = 39 OA = 20	Prone	Goniometer	Healthy 6° ± 6° OA 11° ± 10°
Peeler *et al.*, (2007)	108	Healthy	Thomas Test	Goniometer	Female 7° ± 2° Male 7° ± 1° Combined 7° ± 2°
Prather *et al.*, (2010)	28	Healthy	Prone	Goniometer	Measurement 1 Measurement 2 16.6±6 17.4° ± 7°

Roach *et al.*, (2015)	60	Healthy = 30 NSLBP = 30	Thomas Test Modified	Inclinometer	Healthy NSLBP	6.78° ± 7.18° (-)4.16° ± 8.81°
Wakefield *et al.*, (2015)	22	Healthy	Thomas Test Modified	Goniometer	15.4 °	

Note: OA= Osteoarthritis, NSLBP= Non-specific lower back pain. * Chevillotte et al., (2008) Only hip arthroplasty measures included in the paper, healthy and OA hip measures not included.

The Thomas Test Position and the Prone Lying position are the two most common hip extension ROM tests utilised in the literature and in clinical setting. The Thomas Test poses as a challenge, where the pelvis and lumbar spine may be hard to stabilise in order for the test to reflect the true hip extension ROM, while the prone lying hip extension test may be a little easier to control to obtain the true hip extension ROM value. Although many testing positions have been examined in the literature one key component which needs to be explored is the reliability of each position. The normal healthy hip ROM value ranges from -2° to -59°, with an approximate mean of 18° of extension. There is a huge variety in the hip extension ROM measurement, therefore reliability of the measurement must be explored.

2.5.2. Hip ROM Measurement Reliability

The inter-rater reliability of measuring hip extension ROM has varied in the literature from poor (ICC=0.2) to excellent (ICC=0.99) [Gabbe *et al.*, 2004; Currier *et al.*, 2007; Cibere *et al.*, 2008; Clapis *et al.*, 2008; Dennis *et al.*, 2008; Chevillotte *et al.*, 2009; Prather *et al.*, 2010; Moreside and McGill, 2011; Kim and Ha, 2015; Wakefield and Cottrell, 2015]{*Table 2.3*}. The ICC values of less than 0.40 is considered poor, between 0.40 and 0.59 is considered fair, between 0.60 and 0.74 is considered good and between 0.75 and 1.0 is considered excellent (Cicchetti, 1994). The inter-rater reliability of hip extension ROM had been explored in three positions; side lying (ICC=0.76)[Chevillotte et al 2008], prone lying (ICC=0.86)[Prather *et al.*, 2010] and in the most commonly measured position the modified Thomas test (0.3-0.99) [Gabbe *et al.*, 2004; Clapis *et al.*, 2008; Dennis *et al.*, 2008; Moreside and McGill, 2011; Kim and Ha, 2015; Wakefield and Cottrell, 2015] position. The instrument used to measure hip extension ROM proved to be a major factor in the reliability, where the inclinometer proved to be the most reliable instrument (ICC 0.92)[Clapis *et al.*,2008]. Other instruments explored by previous research also proved to be reliable, demonstrating ICC values of 0.76 for visual estimation (Chevillotte *et al.*, 2009), 0.2-0.97 for goniometry (Currier *et al.*, 2007; Gabbe *et al.*, 2004; Clapis *et al.*, 2008; Wakefield and Cottrell, 2015; Prather *et al.*, 2010), 0.90-0.95 for trigonometry (Wakefield and Cottrell, 2015) and 0.97-0.99 for motion system analysis (Moreside *and McGill,* 2011; Kim and Ha, 2015). Kim and Ha (2015) has also determined that a passive (ICC=0.98) or active (ICC=0.99) pelvis stabilisation has a slightly better reliability compared to no pelvis stabilisation (ICC=0.97).

Table 2. 3 - Hip Extension ROM Measurement Reliability

Author	Participants (n)	Condition	Position	Method of measurement	Hip Extension ROM Reliability (ICC)
Chevillotte *et al.*, (2008)	62	Healthy 20 OA 21 Hip Arthroplasty 21	Side lying	Visual evaluation	Hip Arthroplasty* 0.76
Cibere *et al.*, (2008)	6	OA	Not Specified	Not Specified	0.66
Clapis *et al.*, (2008)	42	Healthy	Thomas Test Modified	Inclinometer Goniometer	Inclinometer 0.92 Goniometer 0.89
Currier *et al.*, (2007)	60	OA	Not Specified	Goniometer	0.2
Dennis *et al.*, (2008)	10	Healthy	Thomas Test Modified	Goniometer	0.97
Gabbe *et al.*, (2004)	15	Not Specified	Thomas Test Modified	Goniometer	0.92
Kim *et al.*, (2015)	24	Healthy	Thomas Test Modified General Measurement Active stabilisation Passive stabilization	Motion analysis software	General measurement 0.97 Active stabilization 0.99 Passive Stabilization 0.98
Moreside *et al.*, (2011)	77	Healthy	Modified thomas test	Goniometer 3D motion system Vicon	Goniometer 0.97 3D system 0.98
Prather *et al.*, (2010)	28	Healthy	Prone	Goniometer	0.86

Wakefield *et al.*, (2015)	22	Healthy	Thomas Test Modified	Goniometer Tigonometry	<u>Intra-rater</u>		
					Examiner 1	Goniometric	0.51
						Trigonmeteric	0.90
					Examiner 2	Goniometric	0.54
						Trigonmeteric	0.95
					<u>Inter-rater</u>		
					Examiner 1	Goniometric	0.65
						Trigonmeteric	0.91
					Examiner 2	Goniometric	0.30
						Trigonmeteric	0.94

Note: OA = Osteoarthritis. * Chevillotte et al., (2008) Only hip arthroplasty reliability included in the paper, healthy and OA hip reliability not included.

The literature would suggest that the best and most reliable way to measure hip extension ROM is in either the Thomas Test position or the Supine Lying position. The Thomas Test position is most commonly utilised, however the supine lying position may be able to reflect the true hip extension ROM better as it may prove easier to stabilise the pelvis and the lumbar spine during measurement in the supine lying position. In the clinical scenario the supine lying position would be the most commonly used test in order to evaluate the passive hip extension, while the Thomas test would be utilised in order to assess the quadriceps muscles flexibility.

2.5.3. Hip Power Measurement Reliability

The literature has demonstrated an excellent reliability (ICC 0.97-0.99, r 0.90-0.99) of the instruments used to measure the hip power (Gallardo-fuentes *et al.*, 2015; Markovic *et al.*, 2004; Glatthorn *et al.*, 2011; Buckthorpe *et al.*, 2012; Balsalobre-Fernández, Glaister and Lockey, 2015; Hitmer *et al.*, 2015). It is clear that the gold standard measurement for jump height or peak power is the force plate, and many studies have used it as the reference point in order to establish the reliability of other instruments (Hitmer *et al.*,2015, Buckthorpe *et al.*, 2012, Glatthorn *et al.*, 2011). Instruments such as belt mat, contact mat, portable force plate, Vertec, Optojump, My Jump app have established an excellent reliability (ICC 0.97-0.99) in measuring the jump height, in the majority of those studies the force plate was the gold standard reference point that these instrument were compared to in order to achieve that (Hitmer *et al.*, 2015, Buckthorpe *et al.*, 2012, Glatthorn *et al.*, 2011, MArkovic *et al.*, 2004, Gallardo-Fuentes *et al.*, 2015, Balsalobre-Fernández et al 2015). Buckthorpe *et al.*, (2012) has concluded that the belt mat and the contact mat have both recorded a significantly lower jump heights when compared to the force plate ($p<0.001$). The countermovement jump, countermovement jump with arm swing and squat jump have proven to have an excellent reliability (*Table 2.4*.)[MArkovic *et al.*, 2004, Gallardo-Fuentes *et al.*, 2015, Balsalobre-Fernández *et al.*, 2015]. The most frequent number of jump repetitions presented in the literature is 3 (Buckthorpe *et al.*, 2012, Glatthorn *et al.*, 2011, MArkovic *et al.*, 2004), however other studies also utilise up to 5 jumps (Hitmer *et al.*, 2015, Gallardo-Fuentes *et al.*, 2015, Balsalobre-Fernández *et al.*, 2015).

Table 2. 4 - Hip Power Reliability

Study	Participants (n)	Instruments Used	Jump type (repetitions)	Reliability
Balsalobre-Fernández *et al.,* (2015)	20	My Jump app Force plate	Countermovement jump (5)	Countermovement jump ICC = 0.99 r = 0.99
Buckthorpe *et al.,* (2012)	40	Laboratory force plate A belt mat Contact mat Portable force plate Vertec	Countermovement Jump (3)	Belt mat r = 0.93 Contact mat r = 0.90 Portable force plate r = 0.97 Vertec r = 0.91 Laboratory force plate (considered as the gold standard, other instruments were compared to it)
Gallardo-Fuentes *et al.,* (2015)	21	My Jump app Contact platform	Countermovement jump (5) Squat Jump (5) 40 cm drop jump (5)	Countermovement jump ICC = 0.99 r = 0.99 Squat jump ICC = 0.99 r = 0.99

				40 cm drop jump ICC = 0.99 r = 0.99
Glatthorn *et al.,* (2011)	40	Optojump Force Plate	Countermovement jump (3) Countermovement jump with arm swing (3) Squat jump (3)	Countermovement jump ICC = 0.98 Countermovement jump with arm swing ICC = 0.98 Squat jump ICC = 0.98
Hitmer *et al.,* (2015)	35	Force Plate Vertical Jump Contact Mat	Countermovement Jump (4)	Flight Time Comparison r = 0.99 Vertical Jump Height Comparison r = 0.96
Markovic *et al.,* (2004)	93	Ergojump	Countermovement jump (3) Squat Jump (3)	Countermovement jump ICC = 0.98 Squat jump ICC = 0.97

This demonstrates that the force plate is the gold standard and the most desirable instrument to use when performing a jump height or power measurement. The jumps have all demonstrated similar reliability, however from the clinical and performance perspective, it is much easier, faster and safer to coach the participants on how to perform the countermovement jump. The literature most frequently uses 3 jump repetitions in order to measure the jump.

2.6. The shoulder joint

The glenohumeral joint is a shallow ball and socket joint formed by the humerous and the glenoid cavity (Culham and Peat, 1993). It consists of static stabilizers, including glenohumeral ligaments which are attached to the labrum and glenoid fossa and help to maintain it in the neutral position (Terry and Chop, 2000). The rotator cuff muscles and surrounding muscles, stabilise the glenohumeral joint through active movement (*Figure 2.2*). The glenohumeral joint is characterised by a magnitude of rotational ROM. The normal shoulder IR ROM is typically around 60° (Teys et al., 2008), where ROM deficit can result in compensations which may predispose to injury. The compensations can occur in the gleno-humeral, thoracic and cervical regions, leading to postural imbalance, affecting the spine, muscles and the nervous system. Overhead athletes require a balance of mobility and stability to meet the functional demands of the sport (Crockett *et al.*, 2002). During overhead activities a high degree of glenohumeral arthrokinematic precision is required to accomplish overhead motion. The rotator cuff muscles need to function in a balanced manner to maintain a centered position between the humeral head and the glenoid (Hirashima *et al.*, 2008; Wilk *et al.*, 2009). Overhead sporting activities produce large loads and forces on the joint tissues as a result of high velocities through a large range of motion, therefore an altered glenohumeral ROM puts the shoulder in a compromised position especially during dynamic motion (Kibler *et al.*, 2012). Decreased glenohumeral joint IR ROM may be predictive of a labral or a shoulder injury (Wilk *et al.*, 2009). Studies demonstrated that for every 5° of total shoulder arc of motion lost, the odds of a shoulder injury were increased by 23% (Clarsen *et al.*, 2014). It has also been demonstrated that shoulder IR ROM can alter as much as 15% immediately after throwing exposure and can last up to 24 hours (Reinold *et al.*, 2008; Kibler *et al.*, 2012;

Kibler *et al.*, 2013). A further decrease in shoulder IR ROM has been associated with years of throwing exposure (Roetert *et al.*, 2000; Burkhart, Morgan *et al.*, 2003), decreasing throughout the competitive season (Thomas *et al.*, 2009; Freehill *et al.*, 2011). Therefore, normal shoulder ROM is imperative, not only from a performance perspective, but also to reduce the risk of injury and pathology in the joint.

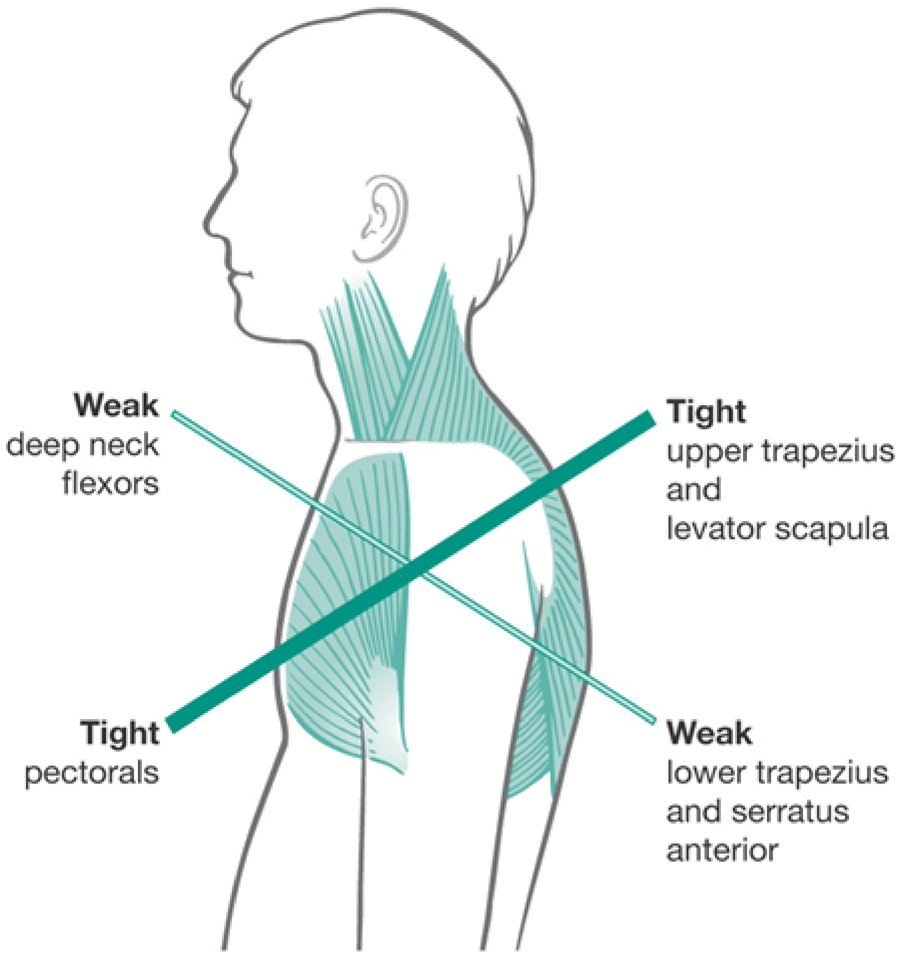


Figure 2.2 Diagram demonstrating muscle imbalance leading to poor upper body posture.

2.6.1. Shoulder ROM Normative Values

Numerous studies have established normative values for shoulder IR ROM, however they vary greatly ranging from 14° to 95° (Awan *et al.*, 2002; Lunden *et al.*, 2010; Kolber and Hanney, 2012; Cools *et al.*, 2014; Kevern, Beecher and Rao, 2014; Moreno-Pérez *et al.*, 2015; Poser *et al.*, 2015). The most commonly reported range for shoulder IR is approximately 60°. Research had demonstrated that the measurement of IR ROM in the shoulder is affected by a number of variables, such as presence of shoulder pathology, patient position at the time of measurement and the instrument used for measuring the ROM. These influencing factors may result in an altered ROM measurement, as pathological shoulders may present with either capsular or muscular restrictions or with bony abnormalities. The position of the patient at the time of measurement may influence the obtained ROM as different muscle groups may be on stretch, also when measuring the shoulder IR ROM in the inner range may prove to put the subacromial space in compromise, thus reducing the shoulder IR ROM read. The instruments used for the measurement influence the ROM obtained purely due to reliability of the instrument itself and the reliability of the person to use the instrument.

Two studies have compared shoulder IR ROM in healthy and pathological populations (Lunden *et al.*, 2010, Moreno-Pérez *et al.*, 2015). Both studies documented that healthy shoulders have a much greater shoulder IR ROM. Moreno-Pérez *et al.*, (2015) demonstrated 49.3° ± 11.3° in healthy participants and 40.6° ± 11.6° in symptomatic participants. Luden *et al.*, (2010) documented 57.8° ± 8.5° in healthy participants and 50.3° ± 7.8° in symptomatic participants in the supine positions and 39.6° ± 12.3° in healthy participants and 24.1° ± 13.3° in symptomatic participants in the side lying position (*Table 2.5.*). The effects of gender on ROM have been examined by Awan *et al.*, (2002). This study reported a greater shoulder IR ROM in females in all 3 measurement positions (IR without shoulder stabilization, IR shoulder stabilization, IR visual inspection) when compared to males, which may suggest that females have a much higher shoulder IR ROM (T*able 2.5*.). Despite considerable variation, healthy shoulders appear to have an average range of 14° to 95°, with the mean of approximately 60° of shoulder IR, however this is further subject to variation depending on the measurement position (Awan *et al.*, 2002; Lunden *et al.*, 2010; Kolber and Hanney, 2012; Cools *et al.*, 2014; Kevern *et al.*, 2014; Moreno-Pérez *et al.*, 2015; Poser *et al.*, 2015).

Table 2. 5 - Shoulder Normative Values

Author	Participants (n)	Condition	Position	Method of measurement	Normative value
Awan *et al.,* (2002)	56	Healthy	Supine, shoulder 90 Abd IR No shoulder stabilization (NSS) IR Shoulder Stabilization (SS) IR visual inspection (VI)	Inclinometer, vision	*Female* / *Male* IR NSS 95.4° ± 13.9° / IR NSS 88.0° ± 10.7° IR SS 65.7° ± 9.7° / IR SS 61.3° ± 8.6° IR VI 64.3° ± 9.4° / IR VI 57.9° ± 7.7°
Cools *et al.,* (2014)	30	Healthy	Sitting IR 90° abduction IR 90° forward flexion Supine IR 90° abduction IR 90° forward flexion Sitting IR 90° abduction IR 90° forward flexion Supine IR 90° abduction	Goniometer Inclinometer	*Sitting* IR 90° abduction 39.3° ± 17.91° IR 90° forward flexion 16.7° ± 4.86° Supine IR 90° abduction 30.4° ± 12.8° IR 90° forward flexion 17.9° ± 5.58° Sitting IR 90° abduction 37.1° ± 17.57° IR 90° forward flexion 14.4° ± 5.22° Supine IR 90° abduction 34.1° ± 12.74°
Lunden *et al.,* (2010)	70	Pathology n=19 Healthy n=51	Supine Side Lying	Goniometry	IR Supine Healthy 57.8° ± 8.5° IR Sidelying Healthy 39.6° ± 12.3° IR Supine Pathology 50.3° ± 7.8° IR Sidelying Pathology 24.1° ± 13.3°

Kevern *et al.*, (2014)	38	Healthy	Supine with overpressure Supine without overpressure Side lying	Inclinometer	IR Side Lying rater 1 54.5° ± 16.7° IR Side Lying rater 2 45.7° ± 12.0° IR Supine with overpressure, rater 1 42.1° ± 13.3° IR Supine with overpressure, rater 2 57.7° ± 9.9° IR Supine without overpressure, rater 1 65.6° ± 16.5° IR Supine without overpressure, rater 2 78.3° ± 15.1°
Kolber *et al.*, (2012)	30	Healthy	Prone	Goniometer Inclinometer	Internal Rotation 48° ± 10° Internal Rotation 43° ± 10°
Poser *et al.*, (2015)	23	Healthy	Supine	Inclinometer	Internal Rotation 51.3° ± 2.2°
Moreno -Perez *et al.*, (2015)	47	Shoulder pain n = 19 Healthy n = 28	Supine	Not Specified	Healthy / Painful Internal rotation: Healthy 49.3° ± 11.3°; Painful 40.6° ± 11.6°

Note: IR No shoulder stabilization = NSS, IR Shoulder Stabilization = SS, IR visual inspection = VI, Internal Rotation = IR

The testing position of the participant has an effect on the range of shoulder IR, with studies exploring positions such as prone, supine, sitting and side lying (Awan *et al.*, 2002; Lunden *et al.*, 2010; Kolber and Hanney, 2012; Cools *et al.*, 2014; Kevern *et al.*, 2014; Moreno-Pérez *et al.*, 2015; Poser *et al.*, 2015). Only a single study has explored the prone testing position, demonstrating a mean 51° of shoulder IR (Poser *et al.*,2015), which is slightly lower compared to other positions. A single study has compared the supine testing position to a seated testing position, these two positions were tested in a 90° forward shoulder flexion and a 90° shoulder abduction (Cools *et al.*, 2014). Cools' study clearly demonstrated that measuring ROM in the 90° shoulder abduction position, results in much greater shoulder IR ROM when compared to the 90° shoulder forward flexion (*Table 2.5*.). The authors believed this finding might be due to the compromise of the subacromial space in the 90° shoulder flexion position (Cools *et al.*, 2014). The sitting and supine positions have also produced different results, however there was no clear trend established when looking at the results (*Table 2.5*.). Luden *et al.*, (2010) has compared the supine to the side lying testing positions. The supine position produced a much higher shoulder IR ROM when compared to the side lying position in both healthy participants and participants with shoulder pathology. This can be compared to the study by Cools *et al.*, (2014), where in both studies the shoulder was brought into forward flexion, which resulted in a decrease in the shoulder IR ROM. The most often utilised testing position in the literature was the supine position (Awan *et al.*, 2002; Lunden *et al.*, 2010; Cools *et al.*, 2014; Kevern, *et al.*, 2014; Moreno-Pérez *et al.*, 2015; Poser *et al.*, 2015). Another factor explored in the supine testing position was the scapular movement, two studies compared no scapular stabilisation to a scapular stabilisation measurement method (Awan *et al.*, 2002, Kevern *et al.*, 2014). Both studies demonstrated that shoulder IR ROM is much higher when the scapula is allowed to move freely. The scapular stabilisation method may limit the amount of scapular rotation, thus allowing the measurement of only true shoulder IR ROM.

The majority of the research performed to date, on the measurement of IR of the shoulder has been in the supine position in 90° abduction (Awan *et al.*, 2002; Lunden *et al.*, 2010; Cools *et al.*, 2014; Kevern *et al.*, 2014; Moreno-Pérez *et al.*, 2015; Poser *et al.*, 2015). This may be due to the ease of measurement in a reliable manner, closely replicating the clinical environment. However, it needs to be noted that it will produce a much higher ROM in comparison to other testing positions, as other testing positions may compromise the subacromnial shoulder space, therefore limiting the shoulder ROM. Although many testing positions have been examined in the literature one key component which needs to be explored is the reliability of each position.

2.6.2. Shoulder ROM Measurement Reliability

Studies to date have determined the measurement of shoulder IR ROM to be reliable, with ICC values ranging from 0.48 to 0.99 for inter-rater reliability (Awan *et al.*, 2002; Lunden *et al.*, 2010; Kolber and Hanney, 2012; Cools *et al.*, 2014; Kevern *et al.*, 2014; Werner *et al.*, 2014; Moreno-Pérez *et al.*, 2015; Poser *et al.*, 2015)[*table 2.6.*]. The ICC values of less than 0.40 is considered poor, between 0.40 and 0.59 is considered fair, between 0.60 and 0.74 is considered good and between 0.75 and 1.0 is considered excellent (Cicchetti, 1994). Factors which have been found to influence the reliability of shoulder IR ROM measurements are; the condition of the participants, participant position at the time of testing and the instruments used. Luden *et al.*, (2010), Werner *et al.*, (2014) and Moreno-Pérez *et al.*, (2015) compared the reliability of shoulder IR ROM in healthy to pathological participants. The results are mixed, with Moreno-Pérez *et al.*, (2015) demonstrating that IR ROM measurement in shoulders which are painful (ICC=0.99) to be more reliable than those of healthy pain free shoulders (ICC=0.86). Similarly Werner *et al.*, (2014) found a higher reliability in participants presenting with a pathology (ICC=0.86) than healthy (ICC=0.81) participants while carrying out the measurement with an inclinometer, however a goniometer was found to be a more reliable measurement tool in healthy participants (ICC=0.64) than the symptomatic participants (ICC=56). Lunden *et al.*, (2010) has also reported mixed findings, presenting a higher reliability in healthy participants (ICC 0.81 vs 0.74) when measuring IR in the supine position, however the reliability was higher in participants presenting with a pathology in the side lying position (ICC 0.96 vs 0.88).

Table 2. 6 – Shoulder IR ROM Measurement Reliability

Author	Participants (n)	Condition	Position	Method of measurement	Reliability (ICC)
Awan *et al.,* (2002)	56	Healthy	IR No shoulder stabilisation (NSS) IR Shoulder Stabilisation (SS) IR visual inspection (VI)	Inclinometer, vision	IR NSS 0.71 IR SS 0.64 IR VI 0.71
Cools *et al.,* (2014)	30	Healthy	Sitting IR 90° abduction IR 90° forward flexion Supine IR 90° abduction	Inclinometer	Sitting IR 90° abduction 0.99 (0.98-0.99) IR 90° forward flexion 0.96 (0.91-0.98) Supine IR 90° abduction 0.98 (0.96-0.99)
Kevern *et al.,* (2014)	38	Healthy	Supine with overpressure Supine without overpressure Side lying	Inclinometer	IR Side Lying rater 1 0.98 IR Side Lying rater 2 0.98 IR Supine with overpressure, rater 1 0.98 IR Supine with overpressure, rater 2 0.96 IR Supine without overpressure, rater 1 0.97 IR Supine without overpressure, rater 2 0.96
Kolber *et al.,* (2012)	30	Healthy	Prone	Goniometer Inclinometer	Internal Rotation 0.95 Internal Rotation 0.97
Lunden *et al.,* (2010)	70	Pathology n=19 Healthy n=51	Supine - 90° abduction Side Lying - 90° adduction	Goniometry	IR Supine Healthy 0.81 IR Sidelying Healthy 0.88 IR Supine Pathology 0.74 IR Sidelying Pathology 0.96

Moreno -Perez *et al.*, (2015)	47	Shoulder pain = 19 Healthy = 28	Supine	Not Specified	Healthy / Painful Internal rotation: 0.86 / 0.99
Poser *et al.*, (2015)	23	Healthy	Supine	Inclinometer	Internal Rotation 0.97
Werner *et al.*, (2014)	39	Healthy n = 24 Symptomatic n = 15	Not Specified	Visual Estimation Goniometry Clinometry (phone app)	Healthy: Visiual Estimation IR 0.59; Goniometer IR 0.64; Clinometer IR 0.81 Sympto-matic: Visiual Estimation IR 0.48; Goniometer IR 0.56; Clinometer IR 0.86

Note: IR No shoulder stabilization = NSS, IR Shoulder Stabilisation = SS; shoulder stabilisation obtained by firm pressure application over the coronoid process, IR visual inspection = VI, Internal Rotation = IR

The testing position of participants has an effect on the reliability of shoulder IR ROM. Testing the shoulder IR in prone, supine, sitting and side lying positions effected the reliability of the measurement (Awan *et al.*, 2002; Lunden *et al.*, 2010; Kolber and Hanney, 2012; Cools *et al.*, 2014; Kevern *et al.*, 2014; Werner *et al.*, 2014; Moreno-Pérez *et al.*, 2015; Poser *et al.*, 2015). All of the testing positions had good reliability, with the most frequent position used being the supine measurement. Kobler and Hanney (2012) was the only study which documented a reliable way to measure prone shoulder IR ROM, with ICC values of 0.95-0.97. Cools et al (2014) compared the measurement of shoulder IR ROM in a seated and supine position and also compared shoulder IR ROM measured at 90° abduction and 90° of forward flexion. The study demonstrated that seated shoulder IR at 90° abduction (ICC=0.99) and seated shoulder IR at 90° forward flexion (ICC=0.96) and supine shoulder IR at 90° abduction (0.98) have excellent reliability. Lunden *et al.*, (2010) explored the side lying position in participants presenting with a pathology, as well as healthy participants, documenting a good reliability of ICC=0.88 in healthy participants and 0.96 in participants presenting with a pathology. In the literature the supine position was the most frequently utilised and proved to be the most reliable with the ICC values ranging from 0.64 to 0.99 (Awan *et al.*, 2002; Lunden *et al.*, 2010; Kolber and Hanney, 2012; Cools *et al.*, 2014; Kevern *et al.*, 2014; Moreno-Pérez *et al.*, 2015).

Awan *et al.*, (2002) and Kevern *et al.*, (2014) have both explored the effects of shoulder stabilisation on the reliability of assessing shoulder IR ROM. The studies have reported conflicting findings, with Awan *et al.*, (2002) demonstrating a higher reliability with no shoulder stabilisation (ICC=0.71) compared to with shoulder stabilisation (ICC=0.64), and Kevern *et al.*, (2014) reporting a slightly higher reliability in shoulder stabilisation measurement method (ICC 0.96-0.98) when compared to no shoulder stabilisation (ICC 0.96-0.97) measurement method.

Another parameter effecting the shoulder IR ROM measurement is the instrument utilised to take the measurement. Previous research has utilised the visual method, goniometer, inclinometer and clinometer, and the inclinometer has generally proved to be the most reliable option (Awan *et al.*, 2002; Lunden *et al.*, 2010; Kolber and Hanney, 2012; Cools *et al.*, 2014; Kevern *et al.*, 2014; Werner *et al.*, 2014; Poser *et al.*, 2015). Kolber and Hanny (2012) has compared the use of a goniometer to an inclinometer, documenting a superior reliability of the inclinometer (ICC=0.97) compared to the clinometer (0.95). Similarly, other studies also have shown greater reliability of the inclinometer than the goniometer (*table 2.6*.). Werner *et al.*, (2014) has compared visual estimation, goniometer and clinometer in measuring shoulder IR ROM, documenting average reliability of visual estimation (ICC 0.48-0.59) and goniometry (ICC 0.56-0.64), and good reliability for the clinometer (ICC 0.81-0.86).

The literature would suggest that the best and most reliable way to measure the shoulder IR ROM is in a supine position with the arm abducted to 90°, with the use of either an inclinometer or a goniometer. The shoulder may also be stabilised in order to attempt to obtain a true shoulder ROM reading, without any scapular discrepancies.

2.6.3. Shoulder Strength Measurement Reliability

The most frequently used tools to measure shoulder muscle strength are the biodex system and handheld dynamometer. Previous studies have explored both of these devices in measuring shoulder internal and external rotation strength (Meeteren *et al.*, 2002; Riemann *et al.*, 2010; Edouard *et al.*, 2013; Katoh, 2015; Holt *et al.*, 2016)[T*able 2.7*.]. The biodex system is considered to be the gold standard for muscle strength measurement and previous literature demonstrates that it generally has a higher reliability when compared to the handheld dynamometer (*table 2.7.*). The studies documented the biodex system reliability to be acceptable, with ICC values ranging from 0.74-0.97 for concentric and eccentric strength measurement (Meeteren *et al.*, 2002, Edouard *et al.*, 2013), while reliability of the handheld dynamometer was more inconsistent with ICC values of 0.50-0.98 for isometric strength measurement (Katoh, 2015; Riemann *et al.*, 2010, Holt *et al.*, 2016). Gender and the arm used for measurement have also been shown to effect the reliability of the measurement. Generally, males (ICC 0.87-0.92) have a higher reliability than females (ICC 0.74-0.81) in internal and external shoulder strength measurement (Meeteren *et al.*, 2002), as this may be due to the fact of a greater male strength and therefore increased effort consistency. The arm used for the strength measurement also influenced the measurement reliability. The right or dominant arm (ICC 0.54-0.97) proved to be slightly more reliable than the left or non-dominant arm (0.53-0.96) in the shoulder internal and external strength measurement (Meeteren *et al.*, 2002, Katoh *et al.*, 2015, Riemann *et al.*, 2010, Holt *et al.*, 2016). Edouard *et al.*, (2013) has examined the effects of angular velocities of 30°/sec, 60°/sec and 120°/sec on the reliability of shoulder peak torque measurements and has demonstrated excellent reliability measures for IR (ICC 0.96-0.97) and ER (ICC 0.92-0.93).

Table 2. 7 – Shoulder Strength Reliability

Study	Participants (n)	Instruments Used	Movements Performed	Angular Velocities (Repetitions)	Reliability (ICC)
Edouard *et al.,* (2013)	46	Biodex (System 3)	Shoulder Internal and External Rotation	60°/sec (5 concentric reps) 120°/sec (5 concentric reps) 30°/sec (5 eccentric reps)	IR Dominant 60°/sec = 0.97 120°/sec = 0.96 30°/sec =0.96 IR Non-Dominant 60°/sec = 0.94 120°/sec = 0.95 30°/sec = 0.91 ER Dominant 60°/sec = 0.93 120°/sec = 0.92 30°/sec = 0.92 ER Non-Dominant 60°/sec = 0.87 120°/sec = 0.91 30°/sec = 0.88
Holt *et al.,* (2016)	20 (10 male, 10 female)	Handheld Dynamometer, Externally Fixed Dynamometer	Shoulder External and Internal Rotation	HHD – 3 reps of 5 second max effort isometric contraction	HDD ER Left – 0.94 Right – 0.92 HDD IR Left – 0.96 Right – 0.96

				EFD – 60°/sec (3 con + ecc reps) 180°/sec (3 con + ecc reps) 240°/sec (3 con + ecc reps)	EFD ER Left – 0.95 Right – 0.95 EFD IR Left – 0.96 Right – 0.88
Katoh *et al.,* (2015)	40 (20 male, 20 female)	Handheld Dynamometer	Shoulder Flexion, Extension, Abduction, External and Internal Rotation, Horizontal Extension	3 second max effort isometric contraction	Flexion = 0.96 Extension = 0.95 Abduction = 0.98 ER = 0.90 IR = 0.96 Horizontal extension = 0.92
Meeteren *et al.,* (2002)	20 (10 male, 10 female)	Biodex (Multi joint system 2)	Shoulder Abduction, Adduction, Internal and External Rotation	60°/sec (5 concentric reps) 120°/sec (10 concentric reps) 180°/sec (10 concentric reps)	Abduction F = 0.86 M = 0.85 Adduction F = 0.69 M = 0.91 External Rotation F = 0.74 M = 0.87 Internal Rotation F = 0.81 M = 0.92

Riemann *et al.,* (2010)	181	Handheld Dynamometer	Prone at 90 IR Prone at 90 ER Seated at neutral IR Seated in neutral ER Seated at 30° -30° -30° IR Seated at 30°-30° -30° ER	5 second max effort isometric contraction	Prone IR L = 0.72 R = 0.87 Prone ER L = 0.64 R = 0.87 Seated IR L = 0.50 R = 0.54 Seated ER L = 0.78 R = 0.76 30° -30° -30° IR L = 0.53 R = 0.54 30° -30° -30° ER L = 0.56 R = 0.55

Note: IR = Internal Rotation, ER = External Rotation, HDD = Hand Held Dynamometer, EFD = Externally Fixed Dynanometer.

The literature suggests that the most reliable instrument to measure shoulder rotational strength is the biodex isokinetic machine in the sitting position. A systematic review carried out by Eduard *et al.*, (2013) stated that the most desirable position for isokinetic shoulder strength testing is in 90° of shoulder elevation in the scapular plane due to its biomechanically advantageous position, allowing more natural functional movements, potentially allowing higher performance and optimal safety. Edouard *et al.*, (2013) has also determined that the biodex isokinetic machine is reliable in measuring high to low angular velocities (30°/sec-120°/sec), however no study to date has demonstrated the effect of the number of repetitions on the reliability of shoulder strength measurement.

2.7. Conclusion

It is clear from the literature review that further research needs to be conducted in the area of MWM and SMWM. Even though MWM have been researched extensively, there are still gaps in our clinical knowledge regarding this manual therapy treatment. Research still has not established if this treatment has a negative or positive effect on strength measures other than isometrics or on power output. Certain joints in the body and the direction of the treatment plane have yet to be assessed, especially the hip joint.

SMWM have been poorly researched in the literature. This is a treatment which is frequently given as a home exercise programme. Future research needs to establish if this home exercise program is effective or not, at changing joint range of motion and also to establish if its' use has subsequent effects on strength or power around the treatment joint.

Future research needs to establish whether multiple treatments of MWM or SMWM are optimal in comparison to single treatments and also to establish how long the effects of this manual therapy treatment lasts following completion of treatment.

2.8. Hypotheses of the thesis

Study One

Title: The Effects of a Single Hip Extension MWM & SMWM on Hip ROM and Power.

Aim: This study will examine the effects of a single application of MWM and SMWM on passive hip extension ROM, jump height and hip power immediately, 24 hours and 48 hours following the treatment application.

Hypothesis: The hypothesis for this study is that a single MWM and SMWM treatment application on the hip joint will have an improvement on the passive hip extension ROM, jump height and hip power.

Study Two

Title: The Effects of a Single MWM & SMWM Treatment Application on Shoulder Joint Rotational ROM and Strength.

Aim: This study will examine the effects of a single application of MWM and SMWM on passive shoulder IR and ER ROM and shoulder rotational isokinetic strength immediately, 24 hours and 48 hours following the treatment application.

Hypothesis: The hypothesis for this study is that a single MWM and SMWM treatment application on the shoulder joint will have an improvement on passive shoulder IR ROM and shoulder rotational isokinetic strength.

Study Three

Title: The Effects of Multiple MWM & SMWM Treatment Applications on Shoulder Rotational ROM and Strength.

Aim: This study will examine the effects of multiple applications of MWM and SMWM on passive shoulder IR and ER ROM and shoulder rotational isokinetic strength immediately, 72 hours and 7 days following the treatment application.

Hypothesis: The hypothesis for this study is that a multiple MWM and SMWM treatment application on the shoulder joint will have an improvement on passive shoulder IR ROM and shoulder rotational isokinetic strength.

Chapter Three
The Effects of a Single Hip Extension MWM & SMWM on Hip ROM and Power

3.1. Methodology

This study will examine the effects of a single application of MWM and SMWM on passive hip extension ROM, jump height and hip power immediately, 24 hours and 48 hours following the treatment application. The hypothesis for this study is that MWM and SMWM treatment will have an improvement on the passive hip extension ROM, jump height and hip power immediately, 24 hours and 48 hours following the treatment application.

3.1.1. Participants

This study was approved by the Institute of Technology Carlow's Ethics Committee. Sixty-five active male and female (35 male, 30 female) participants between the age of 18 and 40 were recruited for this study (Age 22.5±4, Weight 72.9±11kg, Height 174.3±10cm). The participants were collegiate athletes taking part in multidirectional sports involving jumping (Gaelic Football, Hurling, Camogie, Basketball, Volleyball, Soccer). Participants were recruited via verbal invitation, poster advertisement or email in the Institute of Technology Carlow (Carlow Campus). Every participant voluntarily agreed to take part in this study, with no extra incentives. The permission to recruit student participants was obtained from course coordinators and the Head of the Department in the Institute of Technology Carlow. A written informed-consent form (*Appendix A*) was presented to the participants outlining all the procedures involved in the study. The participant was given time to read the provided information and all questions regarding the testing process were answered. Each subject read and signed the screening and consent forms (*Appendix A and B*) in the presence of the tester.

3.1.2. Sample Size

Sample size calculations were based on data from Walsh and Kinsella (2016). The sample size was calculated using Equation 2 (Gissane, 2015). The study determined the ICC value for functional internal rotation test (FIRT) ROM to be 0.89. The minimum detectable change, as illustrated in Equation 1 (Koo *et al.*, 2013), was calculated to have a power of 0.80 with an α level of 0.05 and a level of confidence of 1.96. It was determined that a minimum of eighteen subjects were needed for each group, but the sample was increased to twenty (n=20) to allow for dropout.

Equation 1

$$MDC = \left(SD\sqrt{(1 - ICC)}\right) * 1.96 * \sqrt{2}$$

Where SD is standard deviation and ICC is inter-class correlation.

Equation 2

$$n = 16 * \frac{SD^2}{MDC^2}$$

Where SD is standard deviation and MDC is minimal detectable change.

3.1.3. Reliability study

A reliability study was carried out to establish the intra-tester reliability for measurement of passive hip extension ROM. A total of twenty (10 male and 10 female) participants from the athletic population of Institute of Technology Carlow (Age 21.2±2, Weight 77.2±8kg, Height 177±10cm) took part of the reliability study. The participants attended

2 testing sessions, each separated by a 24-hour period, in which the passive hip extension ROM was measured. The measurement consisted of three repeated passive hip extension ROM measurements, where the average of the measurements was used for calculations. The procedure to measure passive hip extension ROM followed the same steps as the procedure carried out in the main study, see *3.1.7.2. Hip extension measurement* for a detailed description.

3.1.4. Inclusion Criteria

To be included in the study the participants must have a restricted passive hip extension ROM (<20°) [Roach and Miles, 1991; Manning and Hudson, 2009; Prather *et al.*, 2010; Moreside and McGill, 2011; Soucie *et al.*, 2011] and be physically active collegiate athletes taking part in multidirectional sports for a minimum 4 hours per week (soccer, basketball, hurling etc.) and be between the age of 18 and 40.

3.1.5. Exclusion Criteria

The participants were excluded from the study if they reported any recent hip injuries within the last 8 weeks, a history of hip trauma, recent surgery or dislocation, or any injury that disables the participant from fully participating in the research. Participants were also excluded if they had inflammatory joint disease, congenital hip disease, systemic diseases of the muscular or nervous system, malignancy, pregnancy, acute nerve irritation or compression, undiagnosed pain, psychological pain, steroid use affecting ligament laxity or unstable angina (Mangus *et al.*, 2002; Hing, Bigelow and Bremner, 2007; Vicenzino *et al.*, 2009; Delgado-Gil *et al.*, 2015).

3.1.6. Procedure

Once the participants satisfied the inclusion and exclusion criteria, their height and weight were measured and recorded. Each participant was required to attend four testing sessions, however the participant was free to leave the study at any time. Each participant attended familiarisation session, baseline measurement, treatment session with an immediate follow up and 2 follow up sessions, with 24 hours between each of those sessions (*Figure 3.1*). Some participants (n=5) dropped out during the experimental procedures as demonstrated in figure 4.1.

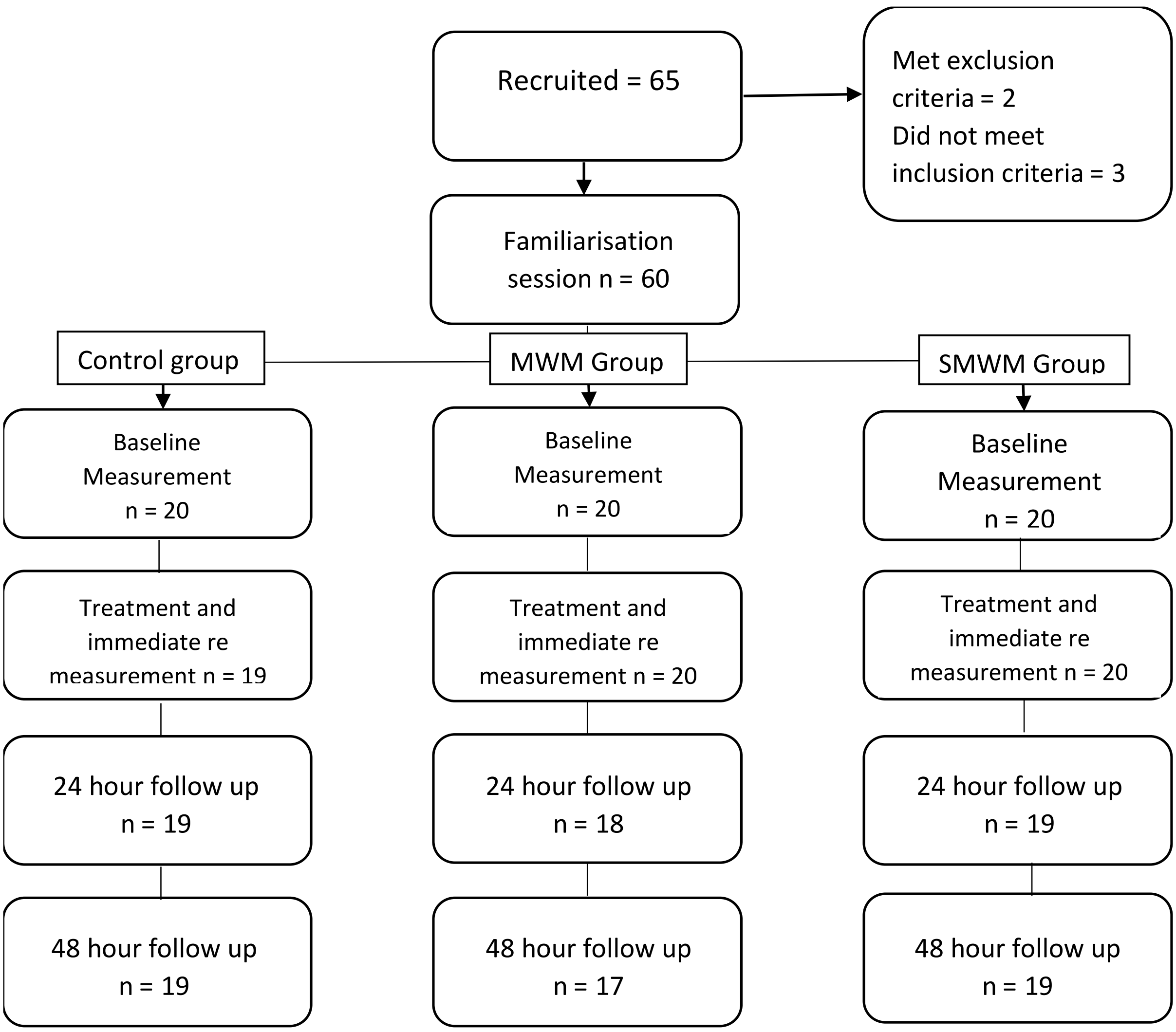


Figure 3. 1 Flow chart of chapter 3 of the study.

Before every session the participant took part in a standardised lower extremity warm up. The warm up was approximately 6 minutes long, consisting of jogging, knee hugs, forward lunges, side lunges, skipping and squats (*Appendix H*).

3.1.6.1. Session 1 (familiarization session)

The participants were familiarised with the study protocols, including the hip power and ROM measurements. Every participant had a trial session, where hip power measurements were assessed. The treatment procedures were clearly outlined to the participants. The participants had to obtain a consistent jump height measure, and a correct countermovement jump (CMJ) technique to proceed to the next phase of testing. The familiarisation session lasted approximately 30 minutes, however extra time was allocated when necessary.

3.1.6.2. Session 2 (Baseline)

The baseline measurement session typically took place 24 hours following the familiarization session. Passive hip extension ROM baseline measurements were taken from all the participants in the hip joint. Baseline hip power tests were taken by performing a CMJ, as described in *3.1.7.3. Power measurement – Countermovement Jump (Power plate and MyJump app)* section below, and jump height (cm) and jump power (N) were measured.

The participants were randomly stratified into one of three homogenous groups, therapist applied MWM group (N=20), self-applied MWM group (N=20) or the control group (N=20). Random stratification is used to make the groups homogeneous in order to avoid heteroscedasticity. The participants were divided into groups based on their baseline hip jump height (cm).

3.1.6.3. Session 3 (Treatment)

The participants received treatment on the hip joint based on the group they were allocated to. The SMWM treatment carried out by the participants was directly supervised by the main researcher. Hip ROM and Power measures were reassessed immediately following the treatment application.

3.1.6.4. Session 4 (Follow up sessions)

The participants attended 2 follow up sessions in order to re-test the outcome measures. During these sessions passive hip extension ROM and hip power were reassessed. The participants were retested at 24 hours and 48 hours after the initial treatment application.

3.1.7. Testing Description

3.1.7.1. Range of motion measurement

The passive hip extension measurements were taken from both limbs of the participant, if both limbs prove to have a decreased range of motion, the participant's dominant limb will be used for examination (Farthing *et al.,* 2009). Otherwise the limb which had a unilateral range of motion discrepancy was examined.

3.1.7.2. Passive hip extension measurement

The participant was positioned prone throughout the examination, with their legs fully extended. The participant was instructed to remain in a relaxed positioned throughout the examination. The participant's sacrum and ilium was secured to the plinth with the use of a mobilization belt. Additional pressure was provided with the examiner's palm, keeping the sacrum and ilium stable to eliminate any lumbar extension, providing a pure hip extension measure. The examiner passively brought the participants' limb into end range hip extension in order to obtain the extension range of motion. The end range was determined by patient comfort and capsular end feel of the joint (Vairo *et al.*, 2012). The mobile phone clinometer (Smart Level – Clinometer, version 1.0) was secured to mid-femur and was reset before every measurement on a horizontal surface and placed on the posterior aspect of the mid femur for measurement (*Figure 3.2*). The limb was returned into neutral after every measurement. The patient was tested 3 times and the mean of the measures will be used.

Figure 3.2. Passive hip ROM measurement.

3.1.7.3. Power measurement – Countermovement Jump (Power plate and MyJump app)

Participants were asked to place and keep their hands at their hips while performing the maximal effort CMJs. Each participant was instructed to start in an upright position, rapidly squat down and immediately perform a maximal jump into the air. They were asked to land back on the force plate during all performance trials. The downward depth and speed in which all subjects performed the CMJ was self-selected by the participant. The participant was given an option for 2 practice jumps before the data was recorded (Suchomel *et al.,* 2016). Each trial was recorded from the beginning of the movement until contact with the force plate after the flight phase of the jump (*Figure 3.3*).

Figure 3.3. Countermovement jump height and power measurement with the aid of a force plate and MyJump Application.

During each testing session, data from three CMJs were collected with a force plate and the My Jump application. Kinetic data were recorded at 1000 Hz and smoothed with a 4th order low-pass Butterworth filter at 15 Hz. Eccentric and concentric movement phases were identified from the velocity- and position-time records, which were derived through numerical integration of the force-time record.

To record the CMJ with the My Jump application (My Jump application, version 3.8), the researcher positioned the iPad in the frontal plane facing the participant. The iPad was positioned 1m from the force plate, recording the participant's feet throughout all jumps.

3.1.7.4. Therapist applied treatment application - Hip Extension MWM

The patient was positioned standing resting the unaffected limb on a bench. The therapist was positioned on the lateral side of the patient. The mulligan mobilization belt was positioned around the proximal femur, as close as possible to the femoroacatebular joint. The mobilization followed the PIL and CROCKS principles (Al, 2007). The therapist applied and sustained a lateral distraction with the use of the mulligan mobilization belt throughout application of the treatment. The participants were instructed to avoid extension of the lumbar spine and cues were given to avoid any abduction or adduction movements of the legs. The participant performed 3 sets of 10 repetitions, by bringing the pelvis forward in a lunge like manner (as demonstrated in *figure 3.2.* below), with one-minute rest in between sets (Al, 2007). The treatment of 3 sets of 10 repetitions will be referred to a 'single treatment application' throughout this text.

Figure 3. 4 Hip Extension MWM

3.1.7.5. Self-applied treatment application - Hip Extension MWM

The participant was positioned half kneeling on a stable surface. A power band was positioned around the proximal femur, as close as possible to the femoroacetabular joint. The power band was put on tension, providing a lateral distraction of the femur. The participant was instructed to maintain the same pressure throughout the mobilization. The patient was cued to perform 3 sets of 10 mobilizations (as demonstrated in figure 3.3. below), by bringing their pelvis forward in a lung like manner. The participant was corrected if any leg adduction/abduction or their lumbar spine extension was present. (Al, 2007). There was one-minute rest in between sets.

Figure 3. 5 Hip Extension self MWM

3.1.7.6. Control Group - Hip

The participant remained half kneeling for the duration of time it would take to finish the treatment application, which is approximately 3 minutes (as demonstrated in *figure 3.4.* below).

Figure 3. 6 Hip Extension Control Group

3.1.7.7. Data Analysis

The independent variables were treatment group (therapist applied MWM group, self-applied MWM group, control group) and time (pre-treatment, immediate post treatment, 24h post treatment, 48h post treatment).

The dependent variables were hip extension ROM (degrees), Jump Height (cm) and Power output (N).

All data was screened for normality by using the Shaprio-Wilk test. All the data was found to be normally distributed ($p>0.05$), therefore a parametric test was utilised to assess statistical significance.

A split plot ANOVA was used to test for the significance of time and the time by treatment interaction. A post hoc analysis was used to examine between group difference between the different groups. A paired t-test was used to identify at which time interval the significance occurred. The SPSS Statistics package (Version 23) was used to calculate the statistical analysis. The level of significance was set at $\alpha=0.05$.

3.1.7.7.1 Reliability Study

The results of the reliability study showed high intra rater reliability for the measurement of passive hip extension ROM with an ICC value of 0.97 (Hopkins, 2000; Dvir, 2015). The ICC values of less than 0.40 is considered poor, between 0.40 and 0.59 is considered fair, between 0.60 and 0.74 is considered good and between 0.75 and 1.0 is considered excellent (Cicchetti, 1994). The SEM was 1.3° and the MDC was 3.5°. The ICC (3,k) value was calculated using the SPSS software package. The SEM and MDC values were calculated using the formulas shown below.

Equation 1

$$MDC = \left(SD\sqrt{(1 - ICC)}\right) * 1.96 * \sqrt{2}$$

Where SD is standard deviation and ICC is inter-class correlation.

Equation 2

$$SEM = SD * \sqrt{(1 - ICC)}$$

Where SD is standard deviation and ICC is inter-class correlation.

All data will be calculated to 95% confidence interval.

3.2. Results

3.2. Range of Motion

3.2.1. Passive Hip Extension ROM

A split plot ANOVA revealed a significant within subjects' time effect for passive hip extension ROM (F=40 [df=3, SE=156], p=0.000, ηp2 = 0.44 with the observed power of 1.0), indicating a change in Hip ROM between the time points. A significant time by treatment interaction was also seen for passive hip extension ROM (F=11 [df=6, SE=156], p=0.00, ηp2 = 0.00 with the observed power of 1). Between groups effects revealed no significant difference between the treatment methods (F=1.8 [df=2, SE=52], p=0.16, ηp2 = 0.07 with the observed power of 0.38).

Post hoc analysis revealed that the SMWM group showed no statistical significant difference (p=0.06, 95% confidence interval, -3.0 – 0.1) when compared to the control group in passive hip extension ROM. The MWM group also showed no significant statistical difference in passive hip extension ROM (p=0.21, 95% confidence interval, -2.6 – 0.5) when compared to the control group. There were also no significant statistical differences between the SMWM and the MWM groups (p=0.57, 95% confidence interval, -1.1 – 0.4). Although the SMWM group had a 23% (3.5°±0.2°) increase in passive hip extension ROM, the result was not statistically different when compared to the control group. Similarly, this can be seen in the MWM group, where the hip extension ROM has increased by 20% (3.1°±0.2°), but the results were not statistically significant when compared to the control group.

A paired t-test demonstrated a significant statistical difference in passive hip extension ROM in the MWM group immediately post treatment [t(18) = -6.9, p=0.00] when compared to the baseline measurement. The 24 hour follow up [t(18) = -4.7, p=0.00] and 48 hour follow up [t(17) = -4.9, p=0.00] also demonstrated a significant improvement in ROM when compared to the baseline measurement. A paired t-test demonstrated a significant improvement in passive hip extension ROM in the SMWM group immediately post treatment [t(18) = -7.9, p=0.00] when compared to the baseline measurement. The 24 hour follow up [t(19) = -4.5, p=0.00] and 48 hour follow up [t(19) = -5.3, p=0.00] also demonstrated a significant improvement in passive hip extension ROM when compared to the baseline measurement (*Table 3.1*). There was no significant difference seen between any of the time point in the Control group. Although there was no statistically significant difference was seen between the groups, a statistically significant improvement can be seen within the MWM and SMWM groups. Both groups demonstrated the greatest improvement in passive hip extension ROM to be immediately after the treatment application. The improvements in passive hip extension ROM decreased over time from a 20% (3.1°±0.2°) improvement immediately following MWM treatment to a 17% (2.5°±0.3°) increase after 24 hours, and a 15% (2.2°±0.2°) increase after 48 hours following the treatment application. Similarly, the improvements decreased over time following the SMWM treatment application from a 23% (3.5°±0.2°) improvement immediately after the treatment to a 14% (2.1°±0.1°) increase following 24 hours and a 13% (2.0°±0.0°) increase following 48 hours (*Figure 3.5*).

Table 3. 1 Hip Extension ROM pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (°)	MWM (°)	SMWM (°)
Baseline	15.7 ± 2.5	14.8 ± 2.3	15.3 ± 2.4
Immediate	15.6 ± 2.5	17.9 ± 2.5[b]	18.8 ± 3.0[b]
24 h	15.7 ± 2.4	17.3 ± 2.8[b]	17.4 ± 2.5[b]
48 h	15.8 ± 2.3	17.0 ± 2.5[b]	17.3 ± 2.4[b]

Note: Data expressed as mean ± SD

[a] significant between group difference ($p<0.05$).

[b] significant within group difference ($p<0.05$).

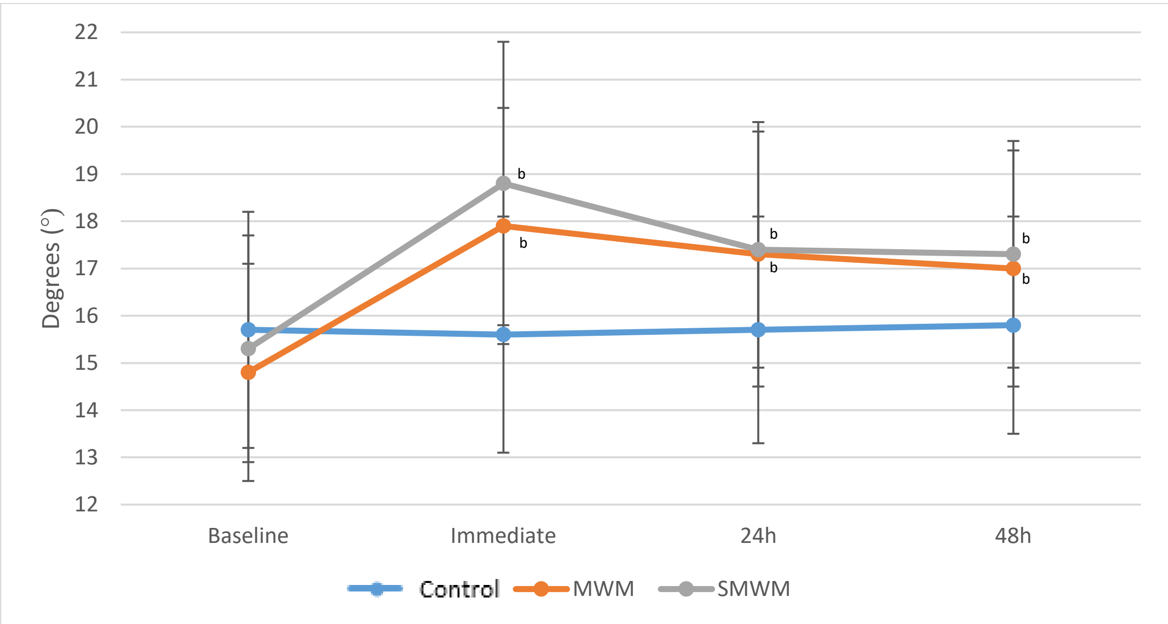


Figure 3. 2 Hip Extension ROM pre and post treatment application in the Control, MWM and SMWM group.

[b] significant within group difference ($p<0.05$).

3.2.2. Jump

3.2.2.1. Jump Height (cm) - Force Plate

A split plot ANOVA revealed a non-significant statistical within subjects' time effect for jump height (F=0.29 [df=2, SE=75], p=0.73, ηp2 = 0.01 with the observed power of 0.09), indicating no change between the time points (*Table 3.2*). A non-significant time by treatment interaction was also seen for jump height (F=1.2 [df=1, SE=75], p=0.30, ηp2 = 0.05 with the observed power of 0.35). Between groups effects revealed no significant statistical difference between the treatment methods for jump height (F=0.78 [df=2, SE=41], p=0.47, ηp2 = 0.04 with the observed power of 0.17).

Table 3. 2 Jump Height (cm) pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (cm)	MWM (cm)	SMWM (cm)
Baseline	28.3 ± 5.9	27.3 ± 7.9	30.6 ± 6.6
Immediate	27.8 ± 5.8	26.4 ± 7.5	31.7 ± 10.6
24 h	31.1 ± 11.4	26.7 ± 8.3	31.0 ± 5.7
48 h	26.9 ± 10.0	30.3 ± 18.5	30.9 ± 6.0

Note: Data expressed as mean ± SD

3.2.2.2. Jump power (N) - Force Plate

A split plot ANOVA revealed a non-significant statistical within subjects' time effect for jump power (F=1.0 [df=3, SE=123], p=0.38, ηp2 = 0.02 with the observed power of 0.27), indicating no change between the time points (*Table 3.3*). A non-significant time by treatment interaction was also seen for jump power (F=0.95 [df=4, SE=123], p=0.46, ηp2 = 0.05 with the observed power of 0.37). Between groups effects revealed no significant statistical difference between the treatment methods for jump power (F=0.53 [df=2, SE=41], p=0.59, ηp2 = 0.03 with the observed power of 0.13).

Table 3. 3 Power output (N) pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (N)	MWM (N)	SMWM (N)
Baseline	1168 ± 304	1068 ± 247	1062 ± 364
Immediate	1163 ± 384	1072 ± 217	984 ± 399
24 h	1232 ± 224	1072 ± 376	1126 ± 383
48 h	1111 ± 362	1046 ± 238	1121 ± 339

Note: Data expressed as mean ± SD

3.2.2.3. Jump Height (cm) - My Jump Application

A split plot ANOVA revealed a non-significant statistical within subjects' time effect for jump height (F=3.0 [df=2, SE=81], p=0.05, ηp2 = 0.07 with the observed power of 0.61), indicating no change between the time points (*Table 3.4*). A non-significant time by treatment interaction was also seen for jump height (F=0.56 [df=4, SE=81], p=0.70, ηp2 = 0.03 with the observed power of 0.19). Between groups effects revealed no significant statistical difference between the treatment methods for jump height (F=1.0 [df=2, SE=39], p=0.31, ηp2 = 0.06 with the observed power of 0.25).

Table 3. 4 Jump Height (cm) pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (cm)	MWM (cm)	SMWM (cm)
Baseline	30.0 ± 6.7	28.5 ± 7.1	32.1 ± 6.2
Immediate	28.5 ± 6.1	27.5 ± 8.3	30.9 ± 6.5
24 h	30.0 ± 5.9	27.2 ± 8.9	31.8 ± 6.0
48 h	30.0 ± 6.3	28.0 ± 9.3	31.9 ± 6.3

Note: Data expressed as mean ± SD

3.2.2.4. Jump Power (N) - My Jump Application

A split plot ANOVA revealed a significant statistical within subjects' time effect for jump power (F=3.0 [df=2, SE=92], p=0.045, ηp2 = 0.07 with the observed power of 0.62), indicating a change between the time points (*Table 3.5*). A non-significant time by treatment interaction was seen for jump power (F=0.66 [df=4, SE=92], p=0.65, ηp2 = 0.03 with the observed power of 0.23). Between groups effects revealed no significant statistical difference between the treatment methods for jump power (F=0.98 [df=2, SE=39], p=0.39, ηp2 = 0.05 with the observed power of 0.21). A paired t-test demonstrated no significant difference between any of the time points in the Control, SMWM and MWM groups.

Table 3. 5 Power output (N) pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (N)	MWM (N)	SMWM (N)
Baseline	1213 ± 408	1083 ± 144	1183 ± 201
Immediate	1181 ± 381	1067 ± 163	1166 ± 198
24 h	1208 ± 386	1066 ± 156	1179 ± 188
48 h	1204 ± 391	1064 ± 154	1185 ± 188

Note: Data expressed as mean ± SD

3.3. Discussion

3.3.1. Introduction

The purpose of this study was to investigate the effects of a single MWM and SMWM treatment application on the passive hip extension ROM, jump height and power. This is the only study to date that examined the effects of a single MWM and SMWM treatment application on passive hip extension ROM, jump height and jump power. The null hypothesis for this study is rejected, as it stated that the passive hip extension ROM, jump height and jump power will significantly increase. The results demonstrated that both of the treatment techniques resulted in no statistically significant between the groups differences in regard to passive hip extension ROM, jump height and power outcomes measures. There was a statistical significant difference demonstrating within group changes through time following the MWM and MWM treatment. The hypothesis of this study stated that there would be a statistically significant change in ROM and power outcome measures at the hip joint following treatment, therefore we can partly reject the null hypothesis as there was a statistical significant within group difference present for the hip extension ROM, but no statistical significance was found in the jump height and jump power.

3.3.2. ROM

Although previous studies investigated the effects of MWM treatment on hip ROM, no previous study has demonstrated the effects of MWMs and SMWMs on passive hip extension ROM. Previous research has demonstrated that MWMs are effective in increasing joint ROM following a treatment application to the elbow (Stephens, 1995), shoulder (Doner *et al.*, 2013; Satpute *et al.*, 2015; Neelapala *et al.*, 2016; Delago-Gil *et al.*, 2015; Teys, 2013; Ribeiro *et al.*, 2017; Abbott *et al.*, 2001), hip (Walsh and Kinsella 2016), thumb (Backstorm 2002; Folk, 2001; Hsieh 2002), ankle (Vincezino *et al.*, 2006; Obrien and Vicenzino 1998; Hetherington, 1996; Gilbreath *et al.*, 2016) and the knee (Balasundram *et al.*, 2017) joint. Only one previous study has examined the effects of MWM and SMWM treatment on hip joint ROM (Walsh and Kinsella 2016). Walsh and Kinsella (2016) examined the effect of a single MWM and SMWM treatment application, examining the immediate effect on hip passive internal rotation (IR) and hip functional IR. Walsh and Kinsella (2016) documented a significant 6° increase in functional hip IR ROM immediately after an MWM application, however they reported no change in passive hip IR ROM. No significant change was reported in either functional or passive hip IR following the SMWM treatment. Similarly to Walsh and Kinsella (2016) research, the current study found significant changes in the passive hip extension ROM immediately, and up to 48 hours post MWM and also SMWM treatment application. The results of the present study indicated no between group differences in passive hip extension ROM following MWM or SMWM treatment application at any of the time points up to 48 hours post treatment. The between group effect size ($\eta p2 = 0.07$) proved to be moderate, highlighting that the clinical change may be negligible (Fritz et al., 2012). However, within group significant differences were seen immediately, 24 hours and 48 hours post MWM and SMWM application when compared to the baseline passive hip extension ROM, indicating increase of passive hip ROM through time. Both MWM and SMWM treatment produced similar results, where immediately after the MWM treatment application the passive hip extension ROM was found to be 3.1°, the ROM decreased over time to a 2.5° increase after 24 hours, and a 2.2° increase after 48 hours following the treatment application. The SMWM resulted in similar findings, where immediately after the SMWM treatment application the passive hip extension ROM was found to be 3.5°, decreasing to a 2.1° increase following 24 hours and a 2.0° increase following 48 hours after the treatment application. The results of the current study can facilitate clinicians to compare both the MWM and SMWM treatment and make an informed decision on which treatment is most appropriate for the patient. Vicenzino *et al.*, (2011) stated that MWMs are often performed in a weight bearing position to enable the patient to utilize a functional movement, promoting an active muscular engagement throughout the joint movement. This study performed the MWM and SMWM treatment application in a weight bearing functional position, however hip extension ROM was only measured as a passive measure. Walsh and Kinsella (2016) utilised a functional ROM measurement, which might have better reflected the treatment benefits compared to just the passive ROM measurement. Although the current study did not find any between group statistically significant changes, within the group changes were seen. Future research may want to examine the effect of MWM and SMWM multiple treatment applications, as a single treatment expose was insufficient to produce any statistically significant changes in passive hip extension ROM. Future studies may also wish to explore the effects of SMWM treatment on other joints.

3.3.3. Power

Although previous studies investigated the effects of hip mobilisations on hip strength (Yerys et al., 2002; Makofsky et al., 2007), no previous study has demonstrated the effects of MWM and SMWM treatment on hip power and jump height. Previous research has demonstrated that MWMs are effective in altering joint strength or muscular activation following a treatment application at the elbow (Vicenzino and Wright, 1995; Exelby, 1995; Abbott *et al.*, 2001; Vicenzino *et al.*, 2001; Kochar and Dogra, 2002; McLean *et al.*, 2002; Paungmali *et al.*, 2003; Paungmali *et al.*, 2003; Paungmali *et al.*, 2004; Collins *et al.*, 2004; Bisset *et al.*, 2006; DeSantis and Hasson, 2006; Vicenzino *et al.*, 2007; Teys *et al.*, 2008; Ahmad *et al.*, 2013; Slater *et al.*, 2015), shoulder (Neelapala *et al.*, 2016, Ribeiro *et al.*, 2015, Ribeiro *et al.*, 2017), hip (Yerys *et al.*, 2002, Makofsky *et al.*, 2007) and thumb (Backstorm, 2002) joints. Ribeiro *et al.*, (2017) compared the use of MWM and SMWM treatment on the shoulder muscle activity, demonstrating no statistically significant difference post treatment intervention, however they demonstrated muscle activity changes during the treatment application. This may be due to the distraction of the joint provided by the glide of the treatment itself. Hoopingarner *et al.*, (2015) demonstrated a positive relationship between hip extension ROM and counter-movement jump (CMJ) height. Wakefield *et al.*, (2015) determined a statistically significant increase in hip extension ROM and vertical jump height after a hip flexor stretch, which correlates to the findings of the study of Hoopingarner *et al.*, (2015). This implies that an increase in hip extension ROM may result in an increase in jump height. Yerys *et al.*, (2002) and Makofsky *et al.*, (2007) demonstrated a statistically significant isometric hip peak torque increase in extension and abduction range respectively after grade IV hip mobilisations, however these studies did not report any ROM findings. The current study did not find any statistically significant changes in hip power or jump height following MWM or SMWM treatment application at any of the time points. The between group effect size for the hip power ($\eta p2 = 0.03$) and jump height ($\eta p2 = 0.04$) proved to be small, highlighting that the MWM and SMWM treatment produces no clinically relevant change (Fritz et al., 2012). Hoopingarner *et al.*, (2015) stated that an increase of hip extension ROM results in an increase in jump height, and the current study found no statistically significant between group effects for hip extension ROM or hip power changes. A single

MWM and SMWM treatment application was insufficient to produce any statistically significant changes in hip extension ROM or hip extension power. Further research may want to examine the effect of a multiple MWM and SMWM treatment applications. Based on Hoopingarner *et al.*, (2015) study increasing hip extension ROM may also in turn produce some changes in hip power, therefore future studies may want to examine if multiple MWM or SMWM maybe more effective at producing significant changes in hip ROM and in turn on hip power.

3.2.4. Limitations and recommendations

This research demonstrates that a single application of the MWM and SMWM treatment does not change passive hip extension ROM, power and jump height. Neither MWM nor SMWM treatments had any negative impact on performance as measured by hip power or jump height. This research aimed to determine the effect of a single MWM and SMWM treatment application on asymptomatic individuals, however a larger and perhaps a more significant effect could be found if the treatment frequency were to increase.

Future studies may wish to examine multiple MWM and SMWM treatment applications on hip extension ROM, jump height and power output. This research focused solely on passive hip extension and the hip joint, future studies need to examine the effects of SMWM treatment on other joints, such as the shoulder. The outcome measures in the current study were uniplanar, examining only hip extension ROM only, future studies may wish to examine the effects of the treatment of the opposite movement in the treatment plane, which would be hip flexion in this case. The current study used only jump height and jump power as performance outcomes, future studies may wish to examine other performance measures such as isokinetic strength as no previous research has explored that measure.

3.3.5. Conclusions

This is the first research which investigated the effects of the MWM and SMWM treatment on passive hip extension ROM, jump height and jump power. A single application of MWM and SMWM techniques proved to have no effect in changing passive hip extension ROM, jump height or jump power initially after the treatment, as well as up to 48 hours post treatment application.

Chapter four
The Effects of a Single MWM & SMWM Treatment Application on Shoulder Joint Rotational ROM and Strength

4.1. Methodology

This study will examine the effects of a single application of MWM and SMWM on passive shoulder IR and ER ROM and shoulder rotational isokinetic strength immediately, 24 hours and 48 hours following the treatment application. The hypothesis for this study is that MWM and SMWM treatment will have an improvement on passive shoulder IR ROM and shoulder rotational isokinetic strength immediately, 24 hours and 48 hours following the treatment application.

4.1.1. Participants

This study was approved by the Institute of Technology Carlow's Ethics Committee. Seventy-three active male and female (37 male, 36 female) participants between the age of 18 and 40 were recruited for this study (Age 21.9±4, Weight 70.4±9kg, Height 176.3±11cm). The participants were collegiate athletes taking part in multidirectional sports involving overhead activity (basketball, volleyball, cricket, badminton, hurling, camogie). Participants were recruited via verbal invitation, poster advertisement or via email, in the Institute of Technology Carlow (Carlow Campus). Every participant voluntarily agreed to take part in this study, with no extra incentives. The permission to recruit student participants was obtained from course coordinators and the Head of the Department of Science and Health in the Institute of Technology, Carlow. A written informed-consent form (*Appendix C*) was presented to the participants outlining all the procedures involved in the study. The participant was given time to read the provided information and all questions regarding the testing process were answered. Each subject read and signed the screening and consent forms (*Appendix C and D*) in the presence of the tester.

4.1.2. Sample size

Sample size calculations were based on data from Satpute *et al.*, 2015. The sample size was calculated using Equation 2 (Gissane, 2015). The ICC value for passive internal rotation ROM was determined to be 0.88 based on previous literature (Lunden *et al.*, 2010). The minimum detectable change, as illustrated in Equation 1 (Koo *et al.*, 2013), was calculated to have a power of 0.80 with an α level of 0.05 with a level of confidence of 1.96. It was determined that a minimum of seventeen subjects were needed for each group, but the sample was increased to twenty (n=20) to allow for dropout.

Equation 1

$$MDC = \left(SD\sqrt{(1 - ICC)}\right) * 1.96 * \sqrt{2}$$

Where SD is standard deviation and ICC is inter-class correlation.

Equation 2

$$n = 16 * \frac{SD^2}{MDC^2}$$

Where SD is standard deviation and MDC is minimal detectable change.

4.1.3. Reliability study

A reliability study was undertaken to establish the intra-tester reliability for measurement of IR ROM. A total of twenty (10 male and 10 female) participants from the athletic population in Institute of Technology Carlow took part of the reliability study (Age 21.2±2, Weight 77.2±8kg, Height 177±10cm). The participants attended 2 testing sessions, each separated by a 24 hour period, in which the shoulder IR ROM was measured. The measurement consisted of three repeated shoulder IR ROM measurements, where the average of the measurements was used for calculations. The procedure to measure the shoulder IR ROM followed the same steps as the procedure carried out in the main study, see *4.1.7.2. Shoulder internal and external rotation measurement* for a detailed description. Previous studies have documented excellent reliability for measurement of ER ROM in the supine position with the arm abducted to 90° with the ICC values of 0.97-0.99 (Mullarney et al., 2010; Kobler et al., 2012; Cools et al., 2014) The SEM proved to be 5-7° (Mullarney et al., 2010).

4.1.4. Inclusion Criteria

To be included in this study the participants were required to have a restricted shoulder IR range of motion (<65°) [Tyler *et al.*, 2000; Wilk *et al.*, 2009; Yang *et al.*, 2009; Vairo *et al.*, 2012]. Participants were required to be physically active collegiate athletes taking part in sport involving overhead activity for a minimum 4 hours per week (basketball, volleyball, cricket, badminton, hurling, camogie) and be between the age of 18 and 40.

4.1.5. Exclusion Criteria

The participants were excluded from the study if they reported any recent shoulder injuries within the last 8 weeks, a history of shoulder trauma, recent surgery or dislocation, or any injury that disables the participant from fully participating in the research project. Participants were also excluded if they had inflammatory joint disease, systemic diseases of the muscular or nervous system, malignancy, pregnancy, acute nerve irritation or compression, recent whiplash, undiagnosed pain, psychological pain, steroid use affecting ligament laxity or unstable angina (Mangus *et al.*, 2002; Hing, Bigelow and Bremner, 2007; Vicenzino *et al.*, 2009; Delgado-Gil *et al.*, 2015).

4.1.6. Procedure

Once the participants satisfied the inclusion and exclusion criteria, their height and weight were measured and recorded. Each participant was required to attend five testing sessions, however the participant was free to leave the study at any time (*Figure 4.1*). Some participants (n=11) dropped out during the experimental procedures as demonstrated in figure 4.1.

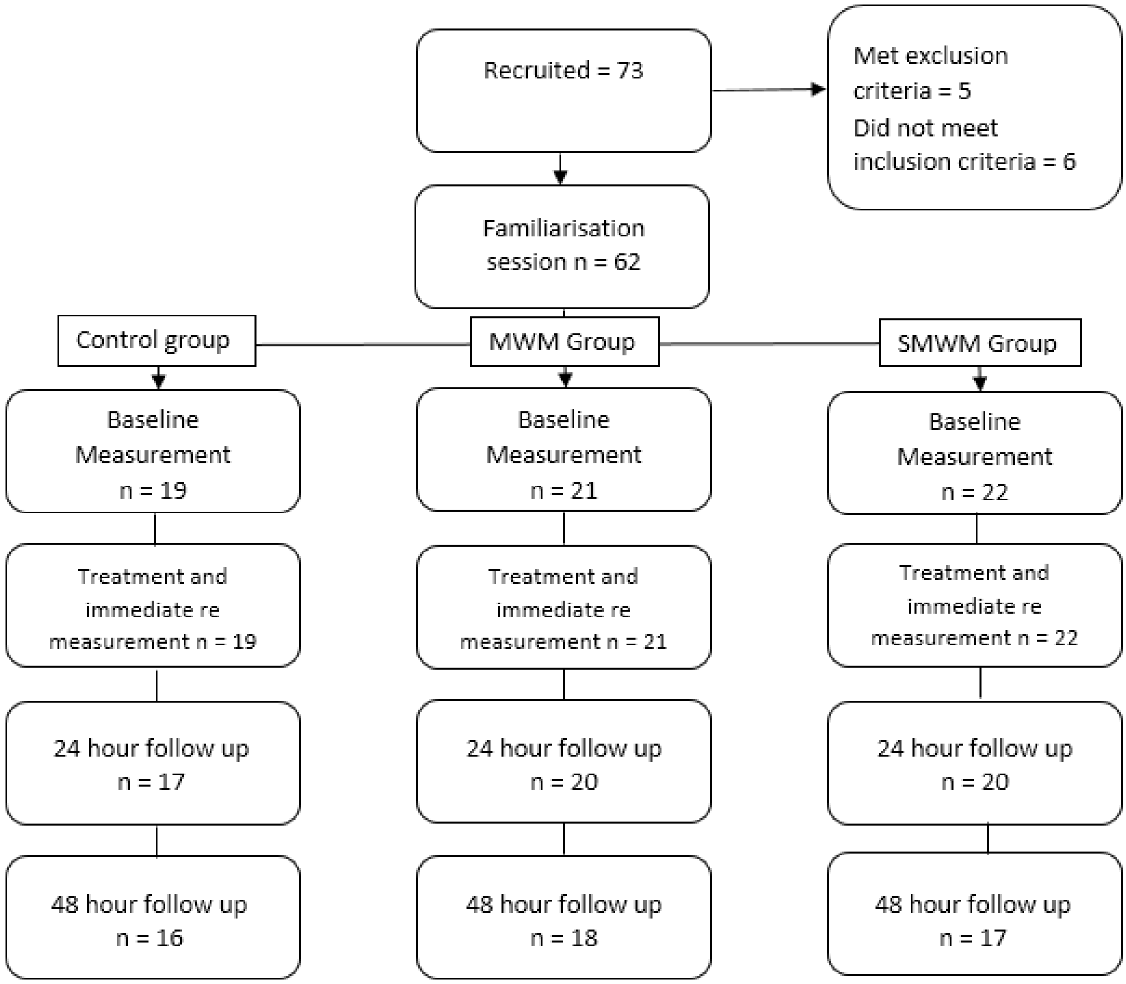


Figure 4. 1 Flow chart of the study.

Before every session the participant took part in a standardised upper extremity warm up. The warm up was approximately 6 minutes long, consisting of jogging with arm movement, push ups plus, push up and internal and external rotations with a resistance band (*Appendix I*).

4.1.6.1. Session 1 (familiarization session)

The participants were familiarised with the study protocols, including the shoulder IR and ER strength and shoulder IR and ER ROM measurements. Every participant had a trial session, where shoulder strength measurements were assessed. The treatment procedures were clearly outlined to the participants. Participants were required to obtain < 15 % in the coefficient of variance in the isokinetic test in order to go through to the next phase of testing (Biodex Medical systems, Inc.). The familiarisation session lasted approximately 30 minutes, however extra time was allocated when necessary.

4.1.6.2. Session 2 (Baseline)

The baseline measurement session typically took place 24 hours following the familiarization session. Baseline measures for shoulder IR and ER range of motion were taken from all the participants using an inclinometer as described in section *4.1.7.2. Shoulder internal and external rotation measurement* below. Baseline shoulder strength measurements were performed using the Biodex as described in section *4.1.7.3. Shoulder strength measurement - Isokinetic Biodex machine* below.

The participants were randomly stratified into one of three homogenous groups, therapist applied MWM group (N=21), self-applied MWM group (N=22) or the control group (N=19). Random stratification is used to make the groups homogeneous in order to avoid heteroscedasticity. The participants were divided into groups based on their baseline shoulder strength measures (peak torque/body weight percentage).

4.1.6.3. Session 3 (Treatment)

The participants received treatment to the shoulder joint based on the group they were allocated to. The SMWM treatment carried out by the participants was directly supervised by the main researcher. Shoulder rotation ROM and strength measures were reassessed immediately following the treatment application.

4.1.6.4. Session 4-5 (Follow up sessions)

The participants attended 2 follow up sessions to re-test the outcome measures. During these sessions shoulder joint rotation ROM and strength were reassessed. The participants were retested at 24 hours and 48 hours after the initial treatment application.

4.1.7. Testing Description

4.1.7.1. Range of motion measurement

The measurements were taken from both limbs of the participant, if both limbs had a decreased range of motion, the participant's dominant limb was used for examination (Farthing, 2009). Otherwise the limb which had a unilateral range of motion discrepancy was examined.

4.1.7.2. Shoulder internal and external rotation measurement

The participant was positioned supine lying on a plinth, with their arm resting at 90 degrees of glenohumeral abduction and 90 degrees of elbow flexion. The participant was instructed to relax their arm while the examiner positioned their limb into end range of a movement from a neutral position. The end range was determined by patient comfort and capsular end feel of the joint (Vairo *et al.*, 2012).

In order to determine the internal rotation of the participant, the hand was brought forward so the palm was facing the ground (*Figure 4.2*). The end range of internal rotation was determined as a point at which the posterolateral acromion was visualized to rise off the plinth (Awan *et al.*, 2002). External rotation was determined by bringing the participant's hand backwards, so the palm was facing the ceiling until the movement reached the soft end point at the end range of the movement had been reached or the participant experienced discomfort (*Figure 4.3*).

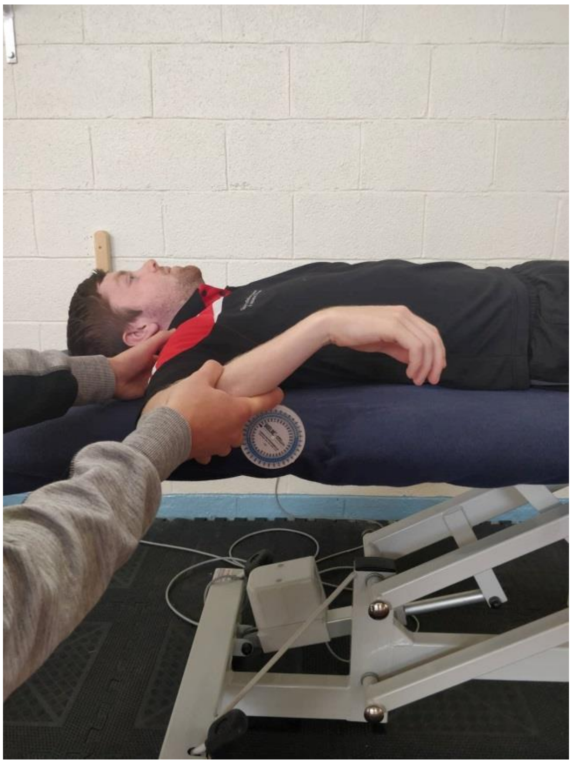


Figure 4.2. Passive shoulder IR ROM measurement.

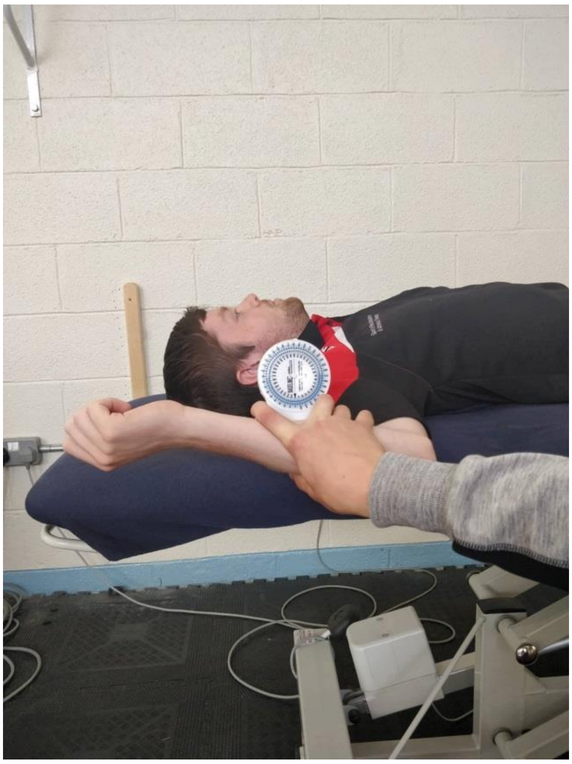


Figure 4.3. Passive shoulder ER ROM measurement.

The inclinometer was utilized to determine the internal/external rotation of the shoulder. The inclinometer was positioned on the mid portion of the forearm, on the anterior surface for external rotation measurement and on the posterior surface for internal rotation measurement. The inclinometer was zeroed on a vertical surface before every measure (Cools *et al.*, 2014). The measurements were repeated 3 times and the mean of the measures was used (Vairo *et al.*, 2012). Before every measurement the limb was brought back to neutral.

4.1.7.3. Shoulder strength measurement - Isokinetic Biodex machine

The participant remained seated throughout the procedure, safely secured to the biodex seat using safety straps. The participant's hip and chest was secured to the seat and the participant's arm was safely secured to the biodex leaver with the use of a Velcro strap at the elbow. The shoulder was positioned at a 45-degree shoulder abduction in the scapular plane, this was established with the use of a goniometer (Edouard *et al.*, 2013; Kim *et al.*, 2014). The biodex chair was rotated 15° away from the dynamometer, which was rotated 20° and tilted 50° (Kim *et al.*, 2014) [as demonstrated in *figure 4.2.* below]. The participant's arm was weighted in a static position to provide gravity compensation data. Before the procedure commenced the participant performed a warm up set of three submaximal reps in order to familiarize themselves with range of motion and the accommodating resistance of the dynamometer (Noffal, 2003; Kim *et al.*, 2014; Wang *et al.*, 2016). The participant was cued to "push as hard and as fast as possible" to generate maximal effort (Noffal, 2003). The participant performed maximal concentric exertion internal/external rotation against different resistances. The speeds that the participant was tested were 60/sec for 5 reps and 180/sec for 10 reps through a range of 55° of internal rotation to 55° of external rotation (Papotto *et al.*, 2015).

Figure 4. 4 Biodex system shoulder (A) External Rotation and (B) Internal Rotation strength protocol in the modified neutral position.

4.1.7.4. Therapist applied treatment application - Shoulder IR MWM

The participant was positioned standing, facing away from the therapist. The participant was instructed to stand in an upright relaxed position with their arm behind their back, with their elbow bend at approximately 90 degrees. The therapist positioned the mulligan mobilization belt securely in a figure eight shape over the elbow joint. The therapist adjusted the mobilization belt's length so that the end of it was sitting just above the ground (Vicenzino *et al.*, 2010).

The mobilization followed the PIL and CROCKS principles (Hing *et al.*, 2007). The therapist applied a downward pressure through the belt by stepping on the belt. The pressure was distracting the humerus downwards and obliquely across the body, throughout the mobilisation. The pressure was sustained throughout full range of motion in the mobilization. The scapula was also stabilized throughout the mobilization. This was achieved by the therapist putting his hands in the participant's axilla, stabilizing the lateral rotation or excessive movement of the scapula. The patient's elbow was allowed to rest on the therapist's abdomen in order to limit the patient abducting their arm (Vicenzino *et al.*, 2010).

The participant was instructed to perform active internal rotation by bringing their hand as far back from their body as possible (as demonstrated in *figure 4.3.* below). The participant performed 3 sets of 10 repetitions (Hing *et al.*, 2007). The treatment of 3 sets of 10 repetitions will be referred to a 'single treatment application' throughout this text. There was a one-minute rest in between sets.

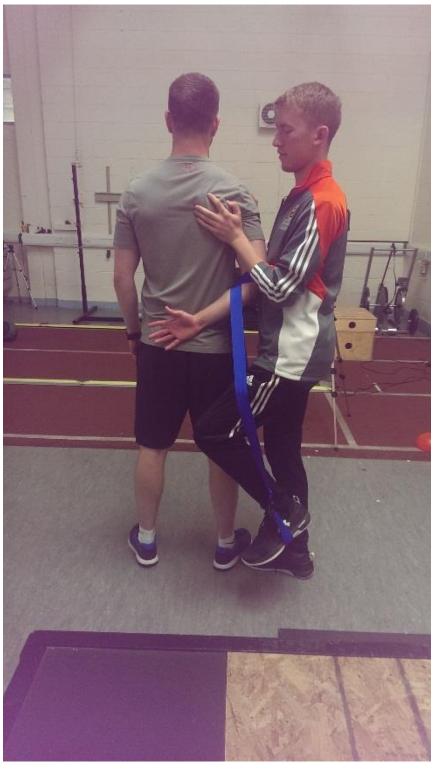


Figure 4. 5 Shoulder IR MWM

4.1.7.5. Self-applied treatment application - Shoulder Internal Rotation MWM

Self-applied internal rotation mobilization with motion is very similar to a therapist applied MWM except the distraction is applied with a power band instead of a mobilization belt and the therapist.

Similar to the internal rotation MWM, the participant during SMWM treatment application was positioned standing up. The power band was attached onto a squat rack and the other end was looped around the participant's arm. The participants' arm was positioned behind their back, flexed approximately to 90 degrees of elbow flexion. The power band provided a longitudinal distraction of the glenohumeral joint, which was sustained throughout the mobilizations. The patient was instructed to perform 3 sets of 10 internal rotation self MWMs, performing active internal rotation by lifting their arm as far away from their back as possible (as demonstrated in *figure 4.4.* below). The participant rested one minute between sets.

Figure 4. 6 Shoulder Internal Rotation self MWM

4.1.7.6. Control group - Shoulder

The participant remained seated with their hand behind their back for the duration of time that it took to apply the MWM treatment, approximately 3 minutes (as demonstrated in *figure 4.5.* below).

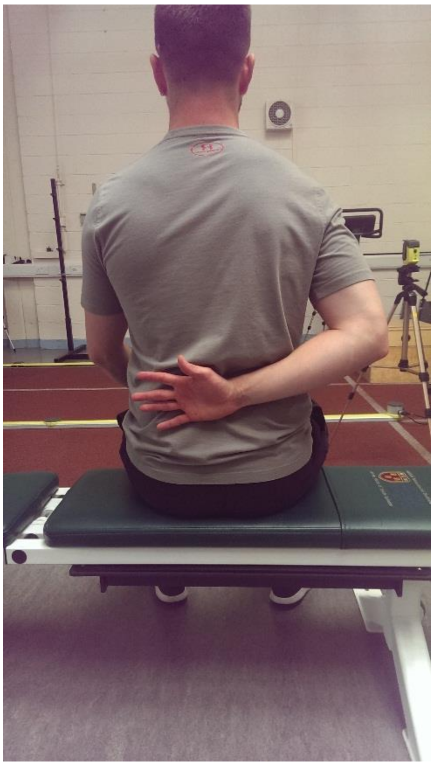


Figure 4. 7 Shoulder Internal Rotation Control Group

4.1.7.7. Data Analysis

The independent variables were treatment group (therapist applied MWM group, self-applied MWM group, control group) and time (pre-treatment, immediate post treatment, 24h post treatment, 48h post treatment).

The dependent variables were shoulder ROM (Internal rotation [°], external rotation [°]) and strength measures (Peak torque/body weight [%] and Time to peak torque [ms] at 60°/sec and 180°/sec).

All data was screened for normality by using the Shaprio-Wilk test. All the data was found to be normally distributed (p>0.05), therefore a parametric test was utilised to assess statistical significance.

A split plot ANOVA was used to test for the significance of time and the time by treatment interaction. A post hoc analysis was used to test the significance between the different groups. A paired t-test was used to identify at which time interval the significance occurred. The SPSS Statistics package (Version 23) was used in order to calculate the statistical analysis. The level of significance was set at α=0.05.

4.1.7.8. Reliability Study

The results of the intra-rater reliability study demonstrated high reliability for measurement of passive internal rotation of the shoulder (Hopkins, 2000; Dvir, 2015), with an ICC value of 0.99, with the SEM of 2.1°, and the MDC was 6°. The ICC values of less than 0.40 is considered poor, between 0.40 and 0.59 is considered fair, between 0.60 and 0.74 is considered good and between 0.75 and 1.0 is considered excellent (Cicchetti, 1994).The ICC (3,k) value was calculated using the SPSS software package. The SEM and MDC values were calculated using the formulas shown below.

Equation 1

$$MDC = \left(SD\sqrt{(1 - ICC)}\right) * 1.96 * \sqrt{2}$$

Where SD is standard deviation and ICC is inter-class correlation.

Equation 2

$$SEM = SD * \sqrt{(1 - ICC)}$$

Where SD is standard deviation and ICC is inter-class correlation.

All data will be calculated to 95% confidence interval.

4.2. Results

4.2. Range of Motion

4.2.1. Passive Shoulder Internal Rotation ROM

A split plot ANOVA revealed a significant within subjects' time effect (F=32.37 [df=1, SE=47], p=0.000, ηp2 = 0.407 with the observed power of 1.0), indicating a change in passive IR ROM between the time points (*Table 4.1*). A significant time by treatment interaction was also seen for passive IR ROM of the shoulder (F=9.35 [df=2, SE=47], p=0.00, ηp2 = 0.285 with the observed power of 0.97). Between groups effects revealed a significant difference between the treatment methods (F=5.09 [df=2, SE=47], p=0.01, ηp2 = 0.18 with the observed power of 0.8).

Post hoc analysis revealed that the SMWM group showed a significant statistical difference in passive shoulder IR ROM (p=0.003, 95% confidence interval, -10.82 - -2.38) when compared to the control group. The MWM group showed a significant statistical difference (p=0.036, 95% confidence interval, -8.63 - -0.29) in passive shoulder IR ROM when compared to the control group. There were no significant statistical differences between the SMWM and the MWM groups in passive shoulder IR ROM (p=0.29, 95% confidence interval, -6.16 – 1.89).

A paired t-test demonstrated a significant statistical difference in the MWM group immediately post treatment in passive shoulder IR ROM [t(20) = -9.8, p=0.00] when compared to the baseline measurement. The 24 hour follow up [t(20) = -6.1, p=0.00] and 48 hour follow up [t(17) = -7.23, p=0.00] also demonstrated a significant difference when compared to the baseline measurement. A paired t-test demonstrated a significant difference in passive shoulder IR ROM in the SMWM group immediately post treatment [t(21) = -7.9, p=0.00] when compared to the baseline measurement. The 24 hour follow up [t(18) = -4.6, p=0.00] and 48 hour follow up [t(19) = -5.6, p=0.00] also demonstrated a significant difference when compared to the baseline measurement (*Figure 4.6*). There was no significant difference seen in passive shoulder IR ROM between any of the time point in the Control group.

Table 4. 1 Shoulder IR ROM pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (°)	MWM (°)	SMWM (°)
Baseline	53.0 ± 4.5	51.8 ± 5.4	52.7 ± 5.8
Immediate	53.7 ± 4.3	61.0 ± 7.1 [a b]	62.1 ± 8.5 [a b]
24 h	52.8 ± 5.0	59.1 ± 7.9 [a b]	60.4 ± 7.6 [a b]
48 h	52.3 ± 4.4	57.6 ± 7.3 [a b]	58.4 ± 7.7 [ab]

Note: Data expressed as mean ± SD.

[a] significant between group difference (p<0.05).

[b] significant within group difference (p<0.05).

The *table 4.1* above demonstrates the passive shoulder IR ROM pre and post treatment in the Control, MWM and SMWM group and the changes occur immediately, 24 hours and up to 48 hours post treatment. The shoulder passive IR ROM increased by 11° immediately, 8° 24 hours and 7° 48 hours following the MWM treatment application. The shoulder passive IR ROM increased by 10° immediately, 8° 24 hours and 6° 48 hours following the SMWM treatment application. *Figure 4.6* highlights the greatest significant increase in passive shoulder IR ROM immediately following the MWM and SMWM treatment application, which decreases with time at 24 hours and 48 hours, but remains significant.

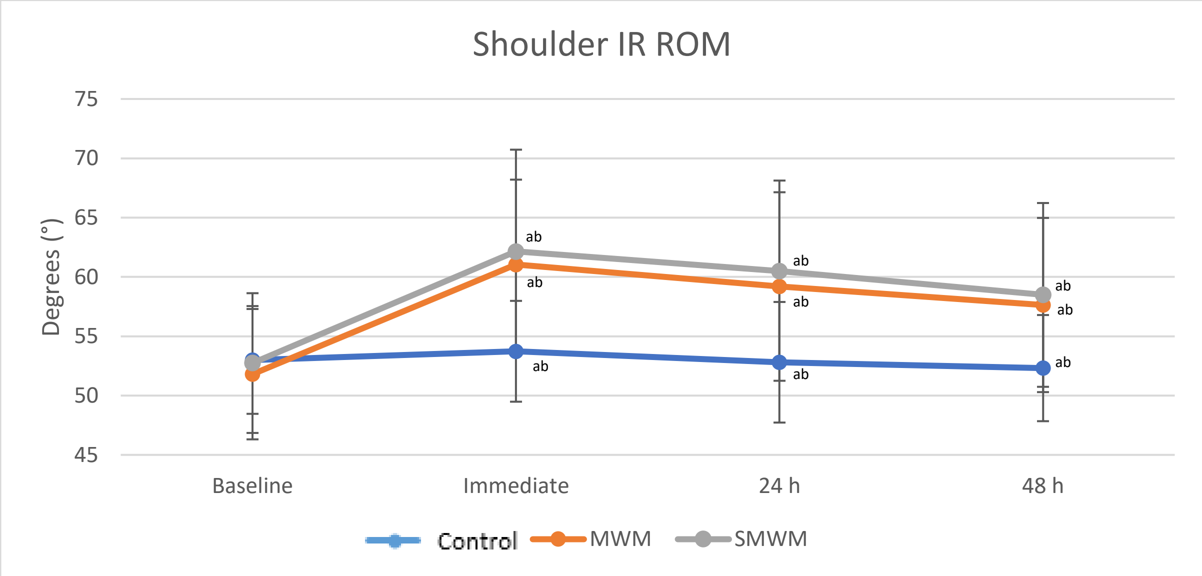


Figure 4. 3 Shoulder IR ROM pre and post treatment application in the Control, MWM and SMWM group.

[a] *significant between group difference (p<0.05).*

[b] *significant within group difference (p<0.05).*

4.2.2. Passive Shoulder External Rotation ROM

A split plot ANOVA revealed a non-significant within subjects' time effect (F=0.90 [df=2, SE=103], p=0.42, ηp2 = 0.02 with the observed power of .21), indicating no change in passive ER ROM between the time points. A non-significant time by treatment interaction was also seen in passive shoulder ER ROM (F=0.91 [df=4, SE=103], p=0.47, ηp2 = 0.04 with the observed power of 0.29). Between groups effects revealed no significant difference between the treatment methods for passive shoulder ER ROM (F=0.44 [df=2, SE=47], p=0.65, ηp2 = 0.18 with the observed power of 0.12). As demonstrated in *table 4.2*, the changes in passive shoulder ER ROM were minimal and remained insignificant following the treatment application at the follow up periods.

Table 4. 2 Shoulder ER ROM pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (°)	MWM (°)	SMWM (°)
Baseline	102.9 ± 11.1	108.0 ± 9.2	104.2 ± 15.9
Immediate	102.5 ± 11.0	110.4 ± 9.2	104.3 ± 14.6
24 h	102.5 ± 10.9	108.9 ± 9.6	103.8 ± 12.5
48 h	104.7 ± 10.3	108.2 ± 9.6	105.3 ± 13.1

Note: Data expressed as mean ± SD (95% Cl).

4.2.2. Biodex

4.2.2.1. Peak Torque/Body Weight - Internal Rotation (60°/sec)

A split plot ANOVA revealed a non-significant within subjects time effect in peak torque/body weight for IR at 60°/sec (F=0.4 [df=3, SE=144], p=0.72, ηp2 = 0.01 with the observed power of 0.14), indicating no change between the time points. A non-significant time by treatment interaction was also seen (F=0.11 [df=6, SE=144], p=0.99, ηp2 = 0.05 with the observed power of 0.76). Between groups effects revealed no significant difference between the treatment methods in peak torque/body weight for IR at 60°/sec (F=0.06 [df=2, SE=48], p=0.94, ηp2 = 0.03 with the observed power of 0.06). As demonstrated in *table 4.3*, the changes in shoulder peak torque per body weight at IR at

60°/sec were minimal and remained insignificant following the treatment application at the follow up periods.

Table 4. 3 Shoulder Peak Torque per Body Weight IR 60°/sec (%) pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (%)	MWM (%)	SMWM (%)
Baseline	52 ± 18.0	51 ± 13.9	50 ± 15.8
Immediate	48 ± 12.6	49 ± 14.9	49 ± 16.1
24 h	49 ± 14.7	49 ± 16.6	49 ± 16.1
48 h	52 ± 17.7	50 ± 18.0	50 ± 14.1

Note: Data expressed as mean ± SD (95% Cl).

4.2.2.2. Peak Torque/Body Weight - Internal Rotation (180°/sec)

A split plot ANOVA revealed a non-significant within subjects' time effect in peak torque/body weight for IR at 180°/sec (F=0.80 [df=3, SE=144], p=0.50, ηp2 = 0.02 with the observed power of 0.14), indicating no change between the time points. A non-significant time by treatment interaction was also seen (F=0.80 [df=6, SE=144], p=0.88, ηp2 = 0.02 with the observed power of 0.16). Between groups effects revealed no significant difference between the treatment methods in peak torque/body weight for IR at 180°/sec (F=0.02 [df=2, SE=48], p=0.98, ηp2 = 0.01 with the observed power of 0.05). As demonstrated in *table 4.4*, the changes in shoulder peak torque per body weight at IR at 180°/sec were minimal and remained insignificant following the treatment application at the follow up periods.

Table 4. 4 Shoulder Peak Torque per Body Weight IR 180°/sec (%) pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (%)	MWM (%)	SMWM (%)
Baseline	48 ± 16.1	47 ± 12.5	46 ± 15.1
Immediate	42 ± 11.3	46 ± 13.6	46 ± 14.5
24 h	46 ± 13.3	44 ± 12.8	45 ± 13.1
48 h	46 ± 15.4	47 ± 14.7	45 ± 11.4

Note: Data expressed as mean ± SD (95% Cl).

4.2.2.3. Peak Torque/Body Weight - External Rotation (60°/sec)

A split plot ANOVA revealed a non-significant within subjects time effect in peak torque/body weight for ER at 60°/sec (F=1 [df=3, SE=144], p=0.40, ηp2 = 0.02 with the observed power of 0.27), indicating no change between the time points. A non-significant time by treatment interaction was also seen (F=0.35 [df=6, SE=144], p=0.91, ηp2 = 0.01 with the observed power of 0.15). Between groups effects revealed no significant difference between the treatment methods in peak torque/body weight for ER at 60°/sec (F=0.38 [df=2, SE=48], p=0.69, ηp2 = 0.02 with the observed power of 0.11). As demonstrated in *table 4.5*, the changes in shoulder peak torque per body weight at ER at 60°/sec were minimal and remained insignificant following the treatment application.

Table 4. 5 Shoulder Peak Torque per Body Weight ER 60°/sec (%) pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (%)	MWM (%)	SMWM (%)
Baseline	42 ± 10.4	40 ± 11.5	43 ± 8.1
Immediate	41 ± 8.3	41 ± 10.0	43 ± 8.1
24 h	42 ± 8.2	40 ± 9.3	41 ± 8.5
48 h	42 ± 9.3	39 ± 12.8	41 ± 8.2

Note: Data expressed as mean ± SD (95% Cl).

4.2.2.4. Peak Torque/Body Weight - External Rotation (180°/sec)

A split plot ANOVA revealed a non-significant within subjects' time effect in peak torque/body weight for ER at 180°/sec (F=1 [df=3, SE=48], p=0.31, ηp2 = 0.02 with the observed power of 0.18), indicating no change between the time points. A non-significant time by treatment interaction was also seen (F=1 [df=2, SE=48], p=0.34, ηp2 = 0.04 with the observed power of 0.23). Between groups effects revealed no significant difference between the treatment methods in peak torque/body weight for ER at 180°/sec (F=1 [df=2, SE=48], p=0.33, ηp2 = 0.05 with the observed power of 0.24). As demonstrated in *table 4.5*, the changes in shoulder peak torque per body weight at ER at 180°/sec were minimal and remained insignificant following the treatment application.

Table 4. 6 Shoulder Peak Torque per Body Weight ER 180°/sec (%) pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (%)	MWM (%)	SMWM (%)
Baseline	37 ± 9.2	35 ± 8.9	37 ± 7.8
Immediate	36 ± 7.8	37 ± 8.8	37 ± 7.8
24 h	37 ± 8.8	36 ± 7.9	40 ± 15.8
48 h	37 ± 7.9	37 ± 8.2	37 ± 7.2

Note: Data expressed as mean ± SD (95% Cl).

4.2.2.5. Time to Peak Torque - Internal Rotation (60°/sec)

A split plot ANOVA revealed a non-significant within subjects time effect in time to peak torque for IR at 60°/sec (F=0.93 [df=3, SE=144], p=0.43, ηp2 = 0.02 with the observed power of 0.25), indicating no change between the time points. A non-significant time by treatment interaction was also seen (F=0.30 [df=6, SE=144], p=0.94, ηp2 = 0.01 with the observed power of 0.13). Between groups effects revealed no significant difference between the treatment methods in time to peak torque for IR at 60°/sec (F=0.23 [df=2, SE=48], p=0.80, ηp2 = 0.01 with the observed power of 0.08). As demonstrated in *table 4.7*, the changes in shoulder time to peak torque at IR at 60°/sec were minimal and remained insignificant following the treatment application.

Table 4. 7 Shoulder Time to Peak Torque IR 60°/sec (ms) pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (ms)	MWM (ms)	SMWM (ms)
Baseline	630 ± 186	712 ± 299	660 ± 375
Immediate	638 ± 298	646 ± 294	618 ± 338
24 h	693 ± 415	697 ± 442	752 ± 338
48 h	740 ± 337	642 ± 394	790 ± 474

Note: Data expressed as mean ± SD (95% Cl).

4.2.2.6. Time to Peak Torque - Internal Rotation (180°/sec)

A split plot ANOVA revealed a non-significant within subjects' time effect in time to peak torque for IR at 180°/sec (F=0.26 [df=3, SE=144], p=0.85, ηp2 = 0.05 with the observed power of 0.99), indicating no change between the time points. A non-significant time by treatment interaction was also seen (F=0.21 [df=6, SE=144], p=0.98, ηp2 = 0.08 with the observed power of 0.10). Between groups effects revealed no significant difference between the treatment methods in time to peak torque for IR at 180°/sec (F=4 [df=2, SE=48], p=0.09, ηp2 = 0.15 with the observed power of 0.70). As demonstrated in *table 4.8*, the changes in shoulder time to peak torque at IR at 180°/sec were minimal and remained insignificant following the treatment application.

Table 4. 8 Shoulder Time to Peak Torque IR 180°/sec (ms) pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (ms)	MWM (ms)	SMWM (ms)
Baseline	275 ± 127	335 ± 183	383 ± 187
Immediate	285 ± 130	378 ± 175	362 ± 230
24 h	265 ± 85	305 ± 169	366 ± 213
48 h	246 ± 120	350 ± 211	343 ± 199

Note: Data expressed as mean ± SD (95% CI).

4.2.2.7. Time to Peak Torque - External Rotation (60°/sec)

A split plot ANOVA revealed a non-significant within subjects' time effect in time to peak torque for ER at 60°/sec (F=1 [df=3, SE=97], p=0.35, ηp2 = 0.02 with the observed power of 0.24), indicating no change between the time points. A non-significant time by treatment interaction was also seen (F=3.7 [df=4, SE=97], p=0.09, ηp2 = 0.14 with the observed power of 0.88). Between groups effects revealed no significant difference between the treatment methods in time to peak torque for ER at 60°/sec (F=0.96 [df=2, SE=47], p=0.40, ηp2 = 0.04 with the observed power of 0.21). As demonstrated in *table 4.9*, the changes in shoulder time to peak torque at ER at 60°/sec were minimal and remained insignificant following the treatment application.

Table 4. 9 Shoulder Time to Peak Torque ER 60°/sec (ms) pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (ms)	MWM (ms)	SMWM (ms)
Baseline	326 ± 166	345 ± 181	373 ± 111
Immediate	252 ± 79	320 ± 162	303 ± 64
24 h	264 ± 129	287 ± 181	439 ± 423
48 h	233 ± 114	230 ± 111	380 ± 170

Note: Data expressed as mean ± SD (95% Cl).

4.2.2.8. Time to Peak Torque - External Rotation (180°/sec)

A split plot ANOVA revealed a non-significant within subjects' time effect in time to peak torque for ER at 180°/sec (F=0.26 [df=3, SE=144], p=0.86, ηp2 = 0.05 with the observed power of 0.10), indicating no change between the time points. A non-significant time by treatment interaction was also seen (F=0.79 [df=6, SE=144], p=0.59, ηp2 = 0.03 with the observed power of 0.30). Between groups effects revealed no significant difference between the treatment methods in time to peak torque for ER at 180°/sec (F=1.4 [df=2, SE=48], p=0.24, ηp2 = 0.06 with the observed power of 0.30). As demonstrated in *table 4.10*, the changes in shoulder time to peak torque at ER at 180°/sec were minimal and remained insignificant following the treatment application.

Table 4. 10 Shoulder Time to Peak Torque ER 180°/sec (ms) pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (ms)	MWM (ms)	SMWM (ms)
Baseline	202 ± 183	244 ± 272	257 ± 170
Immediate	179 ± 129	270 ± 272	312 ± 225
24 h	212 ± 176	248 ± 231	317 ± 238
48 h	182 ± 148	210 ± 242	325 ± 243

Note: Data expressed as mean ± SD (95% Cl).

4.3. Discussion

4.3.1. Introduction

This was the first study to examine the effects of an IR MWM and SMWM treatment techniques on passive shoulder rotation ROM and rotational strength in healthy individuals. The null hypothesis of this study is partly rejected as it stated that both the passive shoulder IR rotation and the shoulder rotational strength will significantly increase, however this was not the case as only the passive shoulder IR rotation increased significantly. The main finding of this study demonstrated a statistically significant increase in passive shoulder IR ROM immediately, as well as up to 48 hours one MWM and SMWM treatment application. No changes in shoulder rotational strength outcome measures or passive shoulder ER ROM were noted.

4.3.2. ROM

Previous studies have explored the effect of shoulder MWMs on shoulder IR ROM, however this is the first study to demonstrate the effects of an IR specific MWM treatment on asymptomatic individuals present with a limited internal rotation ROM (Satpute *et al.,* 2015; Doner *et al.,* 2013). The positive effects of MWM on joint range of motion reported in the present study has also been supported in previous studies which also demonstrated that a single treatment of MWMs can significantly increase ROM in many joints including the shoulder (Abbott, Patla and Jensen, 2001; Teys *et al.*, 2013b; Ribeiro *et al.,* 2017), hip (Walsh and Kinsella 2016), and the ankle (Hetherington, 1996; Vicenzino, Paungmali and Teys, 2007; Hidalgo *et al.*, 2018). Multiple MWM treatment applications have been shown to further increase joint ROM in the shoulder (Delago-Gil *et al.*, 2015; Satpute *et al.*, 2015; Doner *et al.*, 2013; Neelapala *et al.*, 2016) knee

(Balasundaram *et al.*, 2017), thumb (Folk, 2001; Hsieh *et al.*, 2002; Backstrom, 2002), ankle (Collins *et al.*, 2004; Obrien and Vicenzino 1998), and the elbow (Ahmad *et al.*, 2013) joints.

Satpute *et al.*, (2015) and Doner *et al.*, (2013) studies both demonstrated a greater improvement in the shoulder IR ROM than the present study, as both studies reported an average increase of 35° immediately after their MWM treatment intervention, compared to 11° in the current study. The differences between the present study and that of Satpute et al., (2015) and Doner et al., (2013) may be due to a few factors such as the population used, multiple MWM treatment sessions and a combination of other therapeutic techniques. Satpute et al., (2015) performed the treatment intervention on participants with painful shoulder with less than 25° of shoulder IR. Doner et al., (2013) used a pathological population with a diagnosed shoulder adhesive capsulitis and shoulder range of motion less than 50% of the normal values. While this is hard to compare to healthy participants, it appears that MWMs have the potential to increase the ROM around the shoulder joint in both a healthy and pathological population. Furthermore, Doner *et al.*, (2013) utilised a single 3 month follow up, demonstrating an even greater increase of 46° in shoulder IR ROM. The current study documented an 11° ($p=0.00$) statistically significant increase in passive shoulder IR ROM immediately after the MWM treatment, reducing slightly to 8° ($p=0.00$) and 7° ($p=0.00$), 24 hours and 48 hours respectively after the treatment application when compared to baseline. The increase in passive shoulder IR ROM following the MWM treatment is significant, this can be further highlighted where the between group effect size ($\eta p2 = 0.18$) proved to be high (Fritz et al., 2012). Although Doner *et al.,* (2013) carried out the treatment 5 days a week for the duration of 3 weeks, and Satpute *et al.,* (2015) carried out the treatment 3 days a week for the duration of 3 weeks, this study demonstrates that a single MWM or SMWM application can also result in a significant passive shoulder IR ROM. Doner et al., (2013) also examined passive shoulder ER ROM, documenting no change in passive shoulder ER ROM following the treatment period. This can be further highlighted by the high between group effect size ($\eta p2 = 0.18$), demonstrating that the MWM and SMWM treatment may be clinically negligible. The current study has confirmed those findings, demonstrating no change in passive shoulder ER ROM following a single MWM and SMWM treatment application. Therefore, IR MWM application seems to have no effect on passive ER ROM. Interestingly, chapter 3 of the current study determined that a single MWM and SMWM treatment application also results in a within group statistically significant increase to passive hip extension ROM. This demonstrates that MWM treatment is effective in increasing joint ROM when applied correctly in both the hip and the shoulder joints. In chapter 3 the statistically significant increase occurred only within the groups, and no statistical significant difference was found, this might be due to structural differences between the shoulder and the hip joint. The hip joint is a weight bearing joint which transmits a lot of load and force, while having a much smaller arc of motion when compared to the shoulder joint. This may explain why the shoulder joint is much easier to influence by treatment, in turn resulting a significant improvement in ROM. Further studies may wish to examine multiple MWM treatment applications and its' effect on joint ROM in healthy individuals.

This is the first study to compare the effects of a MWM and SMWM treatment on passive shoulder IR ROM. Previously, Walsh and Kinsella (2016) compared the use of MWM and SMWM treatment on hip IR ROM and found the SMWM to have no difference on the passive and functional hip IR ROM. Walsh and Kinsella (2016) only found a statistically significant increase in the functional hip IR following a MWM treatment, but not the SMWM treatment. The current study determined that the SMWM treatment resulted in a 10° (p=0.00) increase in passive shoulder IR ROM immediately post treatment. Similar to the MWM treatment application the statistically significant increase decreased slightly over time in the SMWM group, remaining to be 8° (p=0.00) at 24 hours and 6° (p=0.00) at 48 hours following treatment application. The increase in passive shoulder IR ROM following the SMWM treatment is significant, this can be further highlighted where the between group effect size ($\eta p2 = 0.18$) proved to be high (Fritz et al., 2012). The varying results between the studies may be again due to the anatomical differences between the shoulder and the hip joint. However, the limited body of research makes it difficult to make direct comparisons. Chapter 3 of the current study presented a significant within group increase at each of the examined time points following the SMWM treatment, demonstrating an increase of passive hip extension ROM. This conflicts the findings established by Walsh and Kinsella (2016), therefore more research is needed to demonstrate the effects of SMWM treatment on the hip joint as well as other joints. This research established that both the MWM and SMWM treatment is effective in increasing passive hip extension and passive shoulder IR ROM immediately and up to 48 hours following the treatment application. SMWM treatment can be utilised as a standalone treatment technique, but it can also be used as a part of a home exercise programme in order to maintain the progression made between treatment sessions. This may allow the clinician to make an informed decision when choosing an appropriate treatment for increasing shoulder and hip passive ROM.

No previous study has documented SMWM effects on the opposite direction to which the treatment was intended, which is passive shoulder ER ROM. Similar to the MWM treatment, the IR SMWM treatment resulted in no change in passive shoulder ER ROM, suggesting that IR SMWMs do not influence ROM in the opposing direction to that of the treatment. Although the single SMWM application demonstrated a very marginal greater increase compared to the MWM group, there was no statistically significant differences between the groups (p>0.05). This indicates that both the MWM and SMWM treatment are equally effective in increasing shoulder IR ROM initially as well as up to 48 hours after the treatment application. This can be utilised in practice, as the MWM treatment can be supplemented by the SMWM treatment as a home exercise programme in order to maintain the benefits of the treatment.

4.3.3. Strength

This is the first study to demonstrate the isokinetic strength effect of a single shoulder MWM and SMWM treatment. No previous study has examined the effects of SMWM treatment on strength. Previous studies have determined that MWMs are effective in increasing joint strength or muscular activation following a treatment application on the elbow (Bisset *et al.*, 2006; Paungmali *et al.*, 2003; Collins *et al.*, 2004; Teys *et al.*, 2006), the shoulder (Neelapala *et al.*, 2016; Ribeiro *et al.*, 2016; Ribeiro *et al.*, 2017), the hip (Yerys *et al.*, 2002; Makofsky *et al.*, 2007) and the joint of the thumb (Backstorm ,2002). Neelapala *et al.*, (2017) demonstrated a significant 64% increase (p=0.04) in external rotation isometric strength in the shoulder immediately following a MWM intervention period in a population with painful overhead movements. Ribeiro *et al.*, (2017) compared the use of MWM and SMWM treatment on the shoulder muscle activity, demonstrating no statistically significant difference post treatment intervention, however muscle activity changes were reported during the treatment application. In the hip joint, Yerys *et al.*, (2002) and Makofsky *et al.*, (2007) demonstrated a statistically significant isometric hip peak torque increase in extension (p=0.002) and abduction (p=0.03) range respectively after grade IV hip mobilisations. The current study has examined a more functional approach of strength testing, utilising an isokinetic shoulder internal and external rotation (p=0.04), however contrary to Neelapa et al. (2017) this study did not demonstrate any significant between group changes in the shoulder strength outcome measures. All of the strength outcome measures did not change following the MWM and SMWM treatment application at any of the follow up time periods. The results of chapter 3 of the current study have also determined that a single MWM and SMWM treatment application has no statistically significant effect on jump height or jump power and although the outcome measures for the current shoulder study were different, it would certainly appear that MWMs and SMWMs have no effect on power or strength measures. The practitioner can safely apply both the MWM and SMWM treatment on the athletic population to increase passive hip extension and passive shoulder internal rotation without consequences to performance. The current study has only investigated the effects of a single treatment application, however future studies may explore a multiple treatment intervention on healthy participants and its' effect on shoulder strength. The results of this study demonstrated that both the MWM and SMWM treatment techniques are effective in increasing the shoulder IR ROM without having an impact on the shoulders' strength.

4.3.4. Limitations and recommendations

This study examined the effect of a single MWM and SMWM treatment application on shoulder IR ROM and strength measures, however in a clinical setting multiple treatment applications may be used. The MWM and SMWM treatment displayed promising by increasing the passive IR ROM in the shoulder, without effecting shoulder rotational strength. A longer follow up period may offer further insight on the extent of these effects. A typical follow up in a clinical scenario is approximately 7 days, which may be a more appropriate follow up period.

Future studies may wish to examine the effect of multiple MWM and SMWM treatment applications on the shoulder joint and how they effect the shoulder passive IR ROM and strength measures for extended follow up period.

4.3.5. Conclusions

In conclusion, a single application of an IR MWM and SMWM treatment is equally effective at increasing passive shoulder IR ROM immediately and up to 48 hours post treatment application. Furthermore, the use of either an IR MWM or SMWM treatment has no negative impact on shoulder internal and external rotation strength parameters.

Chapter five
The Effects of Multiple MWM & SMWM Treatment Applications on Shoulder Rotational ROM and Strength

5.1. Methodology

This study will examine the effects of multiple applications of MWM and SMWM on passive shoulder IR and ER ROM and shoulder rotational isokinetic strength immediately, 72 hours and 7 days following the treatment application. Based on the previous study, the hypothesis for this study is that the multiple MWM and SMWM treatment application will produce a statistically significant improvement in passive shoulder IR ROM and that the shoulder rotational isokinetic strength will significantly increase immediately, 72 hours and 7 days following the treatment application.

5.1.1. Participants

Twenty-seven active male and female participants between the age of 18 and 40 were recruited for this study. The participants were collegiate athletes taking part in multidirectional sports involving overhead activity. Participants were recruited via verbal invitation, poster advertisement or via email, in Institute of Technology Carlow (Carlow Campus). Every participant voluntarily agreed to take part in this study, with no extra incentives. The permission to recruit student participants was obtained from course coordinators and the head of the science and health department in the Institute of Technology, Carlow. A written informed-consent form (*Appendix E*) was presented to the participants outlining all the procedures involved in the study in a language that is understandable to them. The participant was given time to read the provided information and all the questions regarding the testing process were clearly explained to them. The requirements of the study were made clear to the subject and participation required the subjects to fulfil the inclusion and exclusion criteria as outlined below. Each subject read and signed the screening and consent forms (*Appendix E and F*) in the presence of the tester.

5.1.2. Sample size

The sample size was calculated using the G-power software. The sample size was calculated to have a power of 95% with an α level of 0.05. In order to calculate the effect size, partial eta squared of 0.18 was used from the results (shoulder internal rotation) of the first phase of this study. It was determined that eighteen subjects were needed in the whole study, but the sample was increased to twenty-seven (n=27) to allow for dropout.

5.1.3. Inclusion Criteria

The participants were required to have a restricted range of motion (<65°) of internal shoulder rotation (Tyler *et al.*, 2000; Wilk *et al.*, 2009; Yang *et al.*, 2009; Vairo *et al.*, 2012). The participants were physically active collegiate athletes between the age of 18 and 40, taking part in overhead sports.

5.1.4. Exclusion Criteria

The participants were excluded from the study if they reported any recent shoulder injuries within the last 8 weeks, a history of shoulder trauma, recent surgery or dislocation, or any injury that disables the participant from fully participating in the research. Participants were also excluded if they had inflammatory joint disease, systemic diseases of the muscular or nervous system, malignancy, pregnancy, acute nerve irritation or compression, recent whiplash, undiagnosed pain, psychological pain, steroid use affecting ligament laxity or unstable angina (Mangus *et al.*, 2002, Vicenzino *et al.*, 2009, Delgado-Gil *et al.*, 2015, Hing *et al.*, 2008).

5.1.5. Procedure

Once the participants satisfied the inclusion and exclusion criteria, their height and weight were measured and recorded (*Table 5.1*). Each participant was required to attend six testing sessions. Written consent was obtained from the participant, highlighting the fact that the participant is free to leave the study at any time.

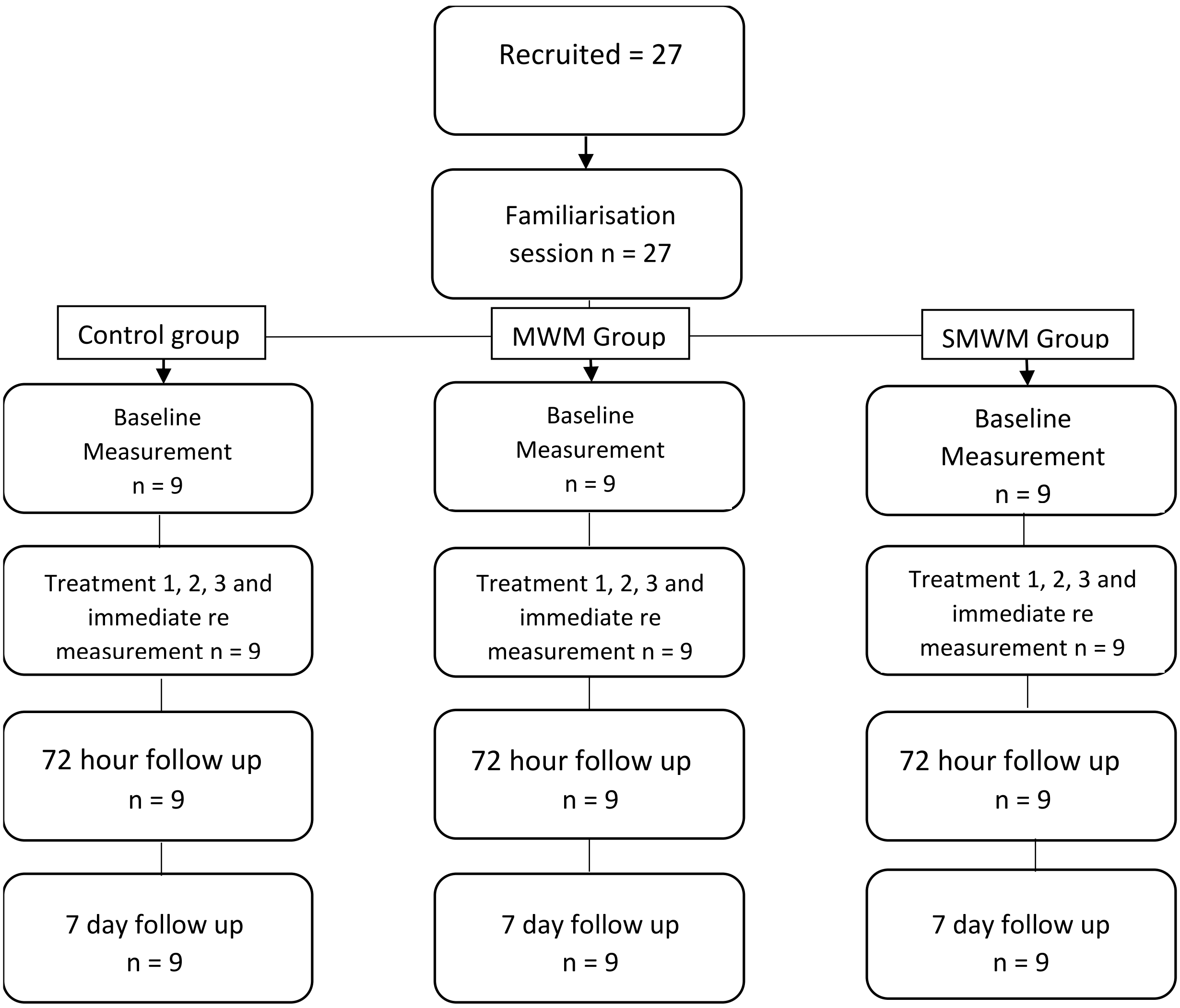


Figure 5. 1 Flow chart of the study.

Before every session the participant took part in a standardised upper extremity warm up. The warm up was approximately 6 minutes long, consisting of jogging with arm movement, push ups plus, push up and internal and external rotations with a resistance band (*Appendix I*).

5.1.5.1. Session 1 (familiarization session)

The participants were familiarised with the study protocols, including shoulder rotation strength and ROM measurements. Every participant had a trial session, where shoulder strength measurements were assessed. The treatment procedures were clearly outlined to the participants. Participants were required to obtain < 15 % coefficient of variance in the biodex test to go through the next phase of testing (Biodex Medical systems, Inc.). The familiarisation session lasted approximately 30 minutes, however extra time was allocated when necessary.

5.1.5.2. Session 2 (Baseline)

The baseline measurement session typically took place 24 hours following the familiarization session. Baseline measures for shoulder IR and ER range of motion were taken from all the participants. Baseline shoulder strength measurements were performed using the Biodex as described in section *5.1.6.3. Shoulder strength measurement - Isokinetic Biodex machine* below.

The participants were randomly stratified into one of three homogenous groups, therapist applied MWM group (N=9), self-applied MWM group (N=9) or the control group (N=9). Random stratification is used to make the groups homogeneous to avoid heteroscedasticity. The participants were divided into groups based on their baseline shoulder power measures (peak torque/body weight percentage).

5.1.5.3. Session 3-5 (Treatment)

The participants received treatment to the shoulder joint based on the group they were assigned to. The participants attended 3 treatment sessions which were administered over a week period, with a day rest period between the treatment sessions. The SMWM treatment carried out by the participants was directly supervised by the main researcher. The MWM and SMWM treatment had 3 sets and 10 repetitions on each of the treatment days. After the last treatment session, the outcome measures were reassessed to indicate the outcomes immediately post the intervention period.

5.1.5.4. Session 6-7 (Follow up sessions)

The participants attended 2 follow up sessions to re-test the outcome measures. During these sessions shoulder joint rotation ROM and strength were reassessed. The participants were retested at 72 hours and 7 days after the final treatment application in the intervention period.

5.1.6. Testing Description

5.1.6.1. Range of motion measurement

The measurements were taken from both limbs of the participant, if both limbs had a decreased IR range of motion, the participant's dominant limb was used for examination (Farthing *et al.*, 2009). Otherwise the limb which had a unilateral range of motion discrepancy was examined.

5.1.6.2. Shoulder internal and external rotation measurement

The participant was positioned supine lying on a plinth, with their arm resting at 90 degrees of glenohumeral abduction and 90 degrees of elbow flexion. The participant was instructed to relax their arm while the examiner positioned their limb into end range of a movement from a neutral position. The end range is determined by patient comfort and capsular end feel of the joint (Vairo *et al.*, 2012).

In order to determine the internal rotation of the participant, the hand was brought forward so the palm was facing the ground (*Figure 5.2*). The end range of internal rotation was determined as a point at which the posterolateral acromion was visualized to rise off the plinth (Awan *et al.*, 2002). External rotation was determined by bringing the participant's hand backwards so the palm was facing the ceiling (*Figure 5.3*).

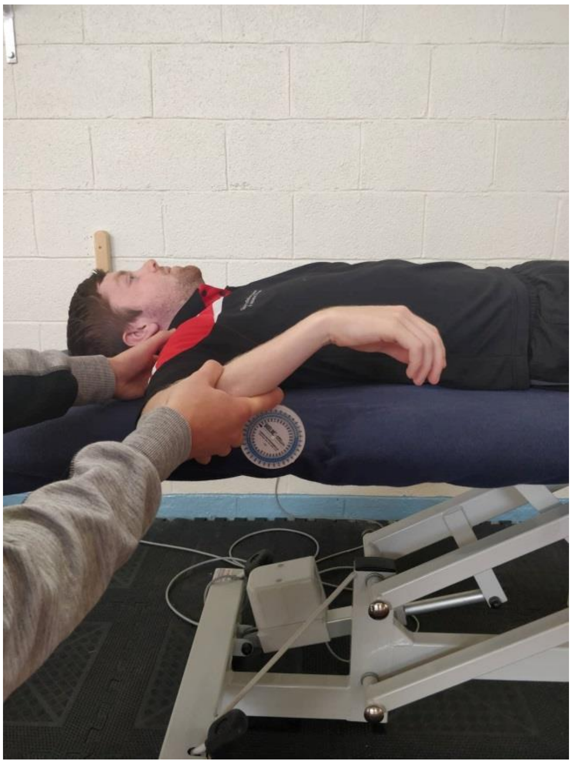


Figure 5.2. Passive shoulder IR ROM measurement.

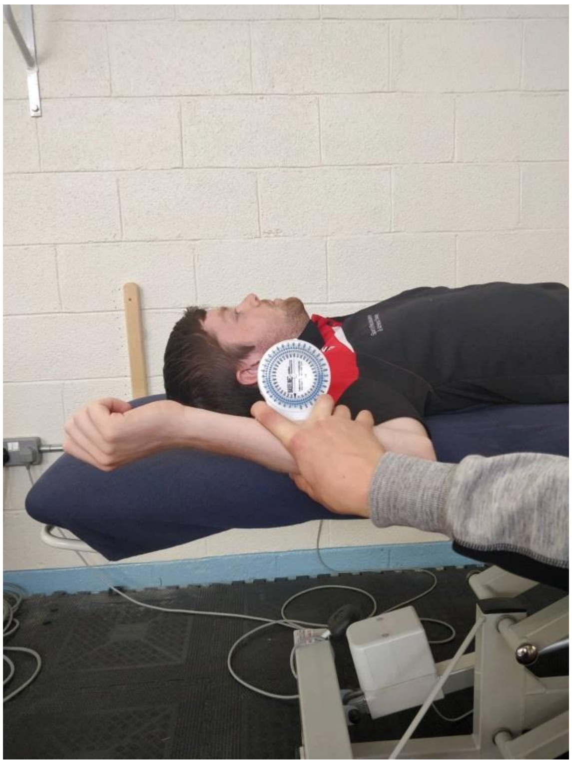


Figure 5.3. Passive shoulder ER ROM measurement.

The inclinometer was utilized to measure the internal/external rotation of the shoulder. The inclinometer was positioned on the mid portion of the forearm, on the anterior surface for external rotation measurement and on the posterior surface for the internal rotation measurement. The inclinometer was zeroed on a vertical surface before every measure (Cools *et al.*, 2014). The measurements were repeated 3 times and the mean of the measures will be used (Vairo *et al.*, 2012). Before every measurement the limb was brought back to neutral.

5.1.6.3. Shoulder strength measurement - Isokinetic Biodex machine

The participant remained seated throughout the procedure, safely secured to the biodex seat using safety straps. The participant's hip and chest was secured to the seat and participant's arm was safely secured to the biodex leaver with the use of a Velcro strap at the elbow. The shoulder was positioned at a 45-degree shoulder abduction in the scapular plane, this was established with the use of a goniometer (Eduard *et al.*, 2013, Kim *et al.*, 2014). The biodex chair was rotated 15° away from the dynamometer, which was rotated 20° and tilted 50° (Kim *et al.*, 2014)[*Figure 5.2.*]. The participant's arm was weighted in a static position in order to provide gravity compensation data. Before the procedure commences the participant performed a warm up set of three submaximal reps in order to familiarize themselves with range of motion and the accommodating resistance of the dynamometer (Noffal, 2003; Kim *et al.*, 2014; Wang *et al.*, 2016). The participant was cued to "push as hard and as fast as possible" in order to generate maximal effort (Noffal, 2003). The participant performed maximal concentric exertion internal/external rotation against different resistances. The speeds that the participant was tested were 60/sec for 5 reps and 180/sec for 10 reps through a range of 55° of internal rotation to 55° of external rotation (Papotto *et al.*,2015).

Figure 5. 4 Biodex system shoulder (A) External Rotation and (B) Internal Rotation strength protocol in the modified neutral position.

5.1.6.4. Therapist applied treatment application - Shoulder IR MWM

The participant was positioned standing, facing away from the therapist. The participant was instructed to stand in an upright relaxed position with their arm behind their back, with their elbow bend at an approximately 90 degrees. The therapist positioned the mulligan mobilization belt securely in a figure eight shape over the elbow joint. The therapist adjusted the mobilization belt's length so the end of it was sitting just above the ground (Vicenzino *et al.*, 2010)[*Figure 5.3*.].

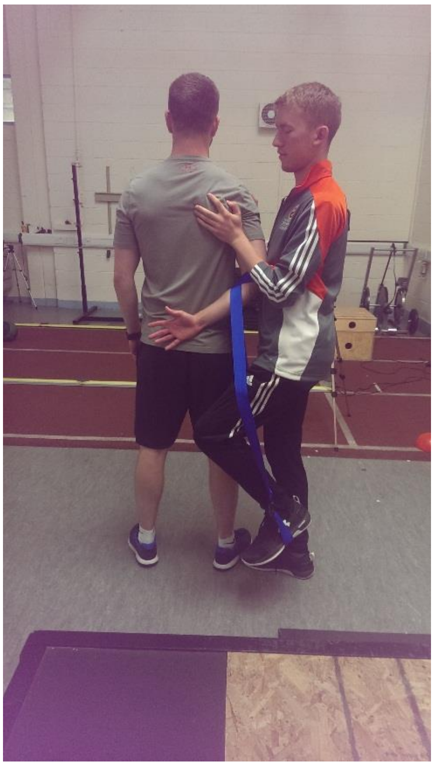


Figure 5. 5 Shoulder IR MWM

The mobilization followed the PIL and CROCKS principles (Hing *et al.*, 2007). The therapist applied a downward pressure through the belt by stepping on the belt. The pressure was distracting the humerus downwards and obliquely across the body, throughout the mobilisation. The pressure was sustained throughout full range of motion in the mobilization. The scapula was also stabilized throughout the mobilization. This was achieved by the therapist putting his hands in the participant's axilla, stabilizing the lateral rotation or excessive movement of the scapula. The patient's elbow was allowed to rest on the therapist's abdomen to limit the patient abducting their arm (Vicenzino *et al.*, 2010).

The participant was instructed to perform active internal rotation by bringing their hand as far back from his body as possible. The participant performed 3 sets of 10 repetitions (Hing *et al.*, 2007). There was one-minute rest in between sets.

5.1.6.5. Self-applied treatment application - Shoulder Internal Rotation MWM

Self-applied internal rotation mobilization with motion is very similar to a therapist applied MWM except the distraction is applied with a power band instead of a mobilization belt and the therapist.

Similar to the internal rotation MWM, the participant during SMWM treatment application was positioned standing up. The power band was attached onto a squat rack and the other end was looped around the participant's arm. The participants' arm was positioned behind their back in approximately to 90 degrees of elbow flexion. The power band provided a longitudinal distraction of the glenohumeral joint, which was sustained throughout the mobilizations (*Figure 5.4.*). The participant was instructed to perform 3 sets of 10 internal rotation self MWMs in the presence of the main researcher, performing active internal rotation by lifting their arm as far away from their back as possible. The participant rested one minute between sets. Each treatment session lasted approximately 10 minutes.

Figure 5. 6 Shoulder Internal Rotation self MWM

5.1.6.6. Control group - Shoulder

The participant remained seated with the hand behind the back for the duration of time that it took to apply the real treatment, approximately 3 minutes (*Figure 5.5*.).

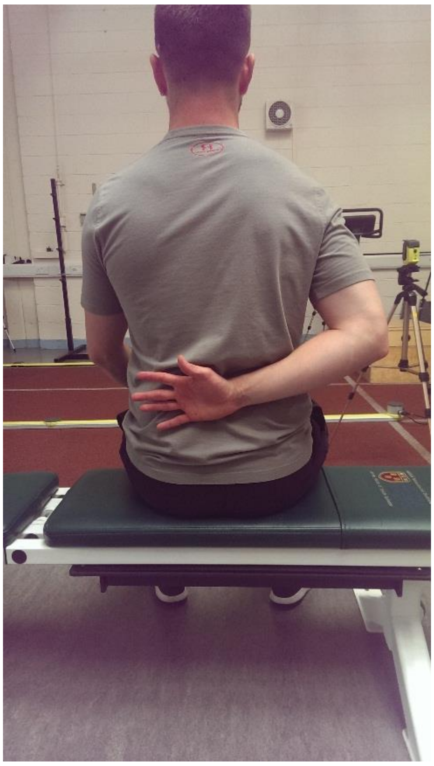


Figure 5. 7 Shoulder Internal Rotation Control Group

5.1.6.7. Data Analysis

The independent variables were treatment group (therapist applied MWM group, self-applied MWM group, control group) and time (pre-treatment, immediate post treatment, 72 hours post treatment, 7 days post treatment).

The dependent variables were shoulder ROM (Internal rotation [°], external rotation [°]) and strength measures (Peak torque/body weight [%] and Time to peak torque [ms] at 60°/sec and 180°/sec).

All data was screened for normality by using the Shaprio-Wilk test. All the data was found to be normally distributed ($p>0.05$), therefore a parametric test was utilised to assess statistical significance.

A split plot ANOVA was used to test for the significance of the time and time by treatment interaction. A post hoc analysis was used to test the significance between the different groups. A paired t-test was used to identify at which time interval the significance occurred. The SPSS Statistics package (Version 23) was used in order to calculate the statistical analysis.

5.2. Results

5.2.0. Range of Motion

5.2.1. Passive Shoulder Internal Rotation ROM

A split plot ANOVA revealed a significant within subjects' time effect in passive shoulder IR ROM ($F=72.8$ [df=3, SE=81], $p=0.00$, $\eta p2 = 0.73$ with the observed power of 1.0), indicating a change in IR ROM between the time points (*Figure 5.6*). A significant time by treatment interaction was also seen in passive shoulder IR ROM ($F=18.6$ [df=6, SE=81], $p=0.00$, $\eta p2 = 0.58$ with the observed power of 1.0). Between groups effects revealed a significant difference between the treatment methods in passive shoulder IR ROM ($F=8.4$ [df=2, SE=27], $p=0.01$, $\eta p2 = 0.38$ with the observed power of 0.9).

Post hoc Bonferroni analysis revealed that the SMWM group showed a significant statistical difference in passive shoulder IR ROM (p=0.002, 95% confidence interval, -17.4 - -3.4) when compared to the control group. The MWM group showed a significant statistical difference (p=0.009, 95% confidence interval, -15.9 - -1.9) when compared to the control group. There were no significant statistical differences between the SMWM and the MWM groups in passive shoulder IR ROM (p=1.0, 95% confidence interval, -8.5 – 5.5).

A paired t-test demonstrated a significant statistical difference in passive shoulder IR ROM in the MWM [$t(9) = -12.7$, $p=0.00$] and SMWM[$t(9) = -6.4$, $p=0.00$] group immediately post treatment when compared to the baseline measurement. The 72 hour follow up also demonstrated a significant improvement in the MWM [$t(9) = -11.0$, $p=0.00$] and SMWM [$t(9) = -6.9$, $p=0.00$] groups. Similarly, the 7 day follow up has also demonstrated a significant statistical improvement in the MWM[t(9) = -12.5, p=0.00 and SMWM [t(9) = -8.0, p=0.00] groups (*Table 5.2*).

Table 5. 1 Shoulder IR ROM pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (°)	MWM (°)	SMWM (°)
Baseline	51.2 ± 4.4	48.6 ± 5.8	51.2 ± 7.7
Immediate	51.1 ± 5.0	63.0 ± 6.3 $^{a\ b}$	64.3 ± 10.0^{ab}
72 hours	51.5 ± 5.4	62.1 ± 5.4 $^{a\ b}$	66.2 ± 9.0 $^{a\ b}$
7 days	51.7 ± 4.0	67.0 ± 6.3 $^{a\ b}$	65.4 ± 7.7 ^{ab}

Note: Data expressed as mean ± SD (95% Cl).

^{a} significant between group difference (p<0.05).

^{b} significant within group difference (p<0.05).

Table 5.2 above demonstrates the shoulder passive IR ROM pre and post MWM and SMWM treatment application and the changes occurring immediately, 72 hours and 7 days following the treatment. The shoulder passive IR ROM increased by 14.4° immediately, 13.5° 72 hours and 18.4° 7 days following the MWM treatment application. The shoulder passive IR ROM increased by 13.4° immediately, 15° 72 hours and 14.2° 7 days following the SMWM treatment application. The greatest improvement in passive shoulder IR ROM was seen 7 days following the MWM treatment application (*Figure 5.6*).

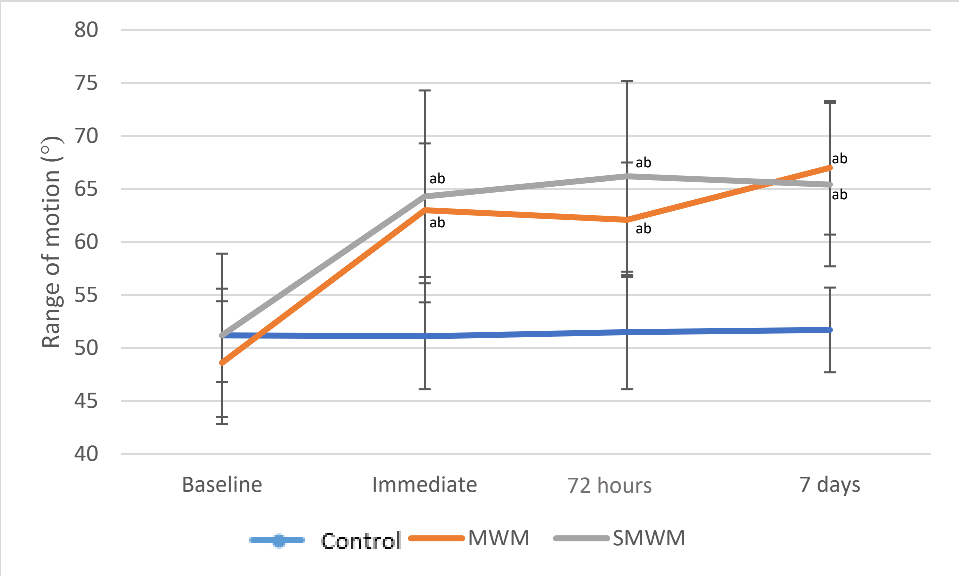


Figure 5. 8 Shoulder IR ROM pre and post treatment application in the Control, MWM and SMWM group.

Note: Data expressed as mean ± SD.

[a] significant between group difference ($p<0.05$).

[b] significant within group difference ($p<0.05$).

5.2.2. Passive Shoulder External Rotation ROM

A split plot ANOVA revealed a non-significant within subjects' time effect in passive shoulder ER ROM (F=1.18 [df=3, SE=81], p=0.32, ηp2 = 0.04 with the observed power of .30), indicating no change in ER ROM between the time points. No statistical significant time by treatment interaction was found (F=1.53 [df=6, SE=81], p=0.17, ηp2 = 0.10 with the observed power of 0.56). Between groups effects revealed no statistically significant difference between the treatment methods in passive shoulder ER ROM (F=2.13 [df=2, SE=27], p=0.14, ηp2 = 0.14 with the observed power of 0.40). As demonstrated in *table 5.3*, the changes in passive shoulder ER ROM were minimal and remained insignificant following the treatment application at the follow up periods.

Table 5. 2 Shoulder ER ROM pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (°)	MWM (°)	SMWM (°)
Baseline	111.8 ± 12.9	116.8 ± 9.8	112.4 ± 12.9
Immediate	113.7 ± 11.3	118.5 ± 9.4	113.3 ± 9.7
72 hours	111.0 ± 13.1	121.5 ± 6.9	112.3 ± 4.1
7 days	111.1 ± 12.2	118.9 ± 5.8	112.5 ± 9.7

Note: Data expressed as mean ± SD.

5.2.3. Biodex

5.2.3.1. Peak Torque/Body Weight - Internal Rotation (60°/sec)

A split plot ANOVA revealed a non-significant within subjects' time effect in peak torque/body weight for IR at 60°/sec (F=0.4 [df=3, SE=81], p=0.75, ηp2 = 0.02 with the observed power of 0.12), indicating no change between the time points. No statistical significant time by treatment interaction was found (F=0.66 [df=6, SE=81], p=0.71, ηp2 = 0.04 with the observed power of 0.24). Between groups effects revealed no statistically significant difference between the treatment methods in peak torque/body weight for IR at 60°/sec (F=2.83 [df=2, SE=27], p=0.08, ηp2 = 0.17 with the observed power of 0.51). As demonstrated in *table 5.4*, the changes in shoulder peak torque per body weight in IR at 60°/sec were minimal and remained insignificant following the treatment application at the follow up periods.

Table 5. 3 Shoulder Peak Torque per Body Weight IR 60°/sec (%) pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (%)	MWM (%)	SMWM (%)
Baseline	61.1 ± 14.2	44.1 ± 10.2	50.6 ± 17.4
Immediate	57.6 ± 15.3	45.6 ± 11.6	50.1 ± 16.2
72 hours	58.6 ± 13.1	45.6 ± 10.8	51.7 ± 16.2
7 days	58.0 ± 13.7	43.6 ± 9.4	50.9 ± 17.1

Note: Data expressed as mean ± SD (95% CI).

5.2.3.2. Peak Torque/Body Weight - Internal Rotation (180°/sec)

A split plot ANOVA revealed a non-significant within subjects' time effect in peak torque/body weight for IR at 180°/sec (F=1.52 [df=3, SE=81], p=0.22, ηp2 = 0.05 with the observed power of 0.38), indicating no change between the time points. No statistical significant time by treatment interaction was found (F=1.07 [df=6, SE=81], p=0.38, ηp2 = 0.07 with the observed power of 0.40). Between groups effects revealed no statistically significant difference between the treatment methods in peak torque/body weight for IR at 180°/sec (F=2.20 [df=2, SE=27], p=0.13, ηp2 = 0.14 with the observed power of 0.41). As demonstrated in *table 5.5*, the changes in shoulder peak torque per body weight in IR at 180°/sec were minimal and remained insignificant following the treatment application at the follow up periods.

Table 5. 4 Shoulder Peak Torque per Body Weight IR 180°/sec (%) pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (%)	MWM (%)	SMWM (%)
Baseline	55.5 ± 10.8	40.1 ± 9.9	48.6 ± 16.3
Immediate	54.4 ± 12.9	44.0 ± 9.9	49.1 ± 15.4
72 hours	54.4 ± 12.1	44.2 ± 9.9	51.6 ± 16.8
7 days	55.5 ± 10.9	43.3 ± 9.3	51.4 ± 21.1

Note: Data expressed as mean ± SD.

5.2.3.3. Peak Torque/Body Weight - External Rotation (60°/sec)

A split plot ANOVA revealed a non-significant within subjects' time effect in peak torque/body weight for ER at 60°/sec (F=1 [df=3, SE=144], p=0.40, ηp2 = 0.02 with the observed power of 0.27), indicating no change between the time points. No statistical significant time by treatment interaction was also seen (F=0.35 [df=6, SE=144], p=0.91, ηp2 = 0.01 with the observed power of 0.15). Between groups effects revealed no statistically significant difference between the treatment methods in peak torque/body weight for ER at 60°/sec (F=0.38 [df=2, SE=48], p=0.69, ηp2 = 0.02 with the observed power of 0.11). As demonstrated in *table 5.6*, the changes in shoulder peak torque per body weight in ER at 60°/sec were minimal and remained insignificant following the treatment application at the follow up periods.

Table 5. 6 Shoulder Peak Torque per Body Weight ER 60°/sec (%) pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (%)	MWM (%)	SMWM (%)
Baseline	45.6 ± 4.0	38.7 ± 9.7	40.3 ± 6.9
Immediate	45.4 ± 7.0	36.9 ± 10.1	41.2 ± 11.2
72 hours	45.4 ± 7.2	36.9 ± 10.5	40.6 ± 9.6
7 days	44.5 ± 5.7	37.9 ± 10.9	40.9 ± 10.3

Note: Data expressed as mean ± SD.

5.2.3.4. Peak Torque/Body Weight - External Rotation (180°/sec)

A split plot ANOVA revealed a non-significant within subjects' time effect in peak torque/body weight for ER at 180°/sec (F=2.34 [df=3, SE=81], p=0.08, ηp2 = 0.08 with the observed power of 0.57), indicating no change between the time points. No statistical significant time by treatment interaction was found (F=0.57 [df=6, SE=81], p=0.75, ηp2 = 0.04 with the observed power of 0.22). Between groups effects revealed no statistically significant difference between the treatment methods in peak torque/body weight for IR at 180°/sec (F=1.55 [df=2, SE=27], p=0.23, ηp2 = 0.10 with the observed power of 0.30). As demonstrated in *table 5.7*, the changes in shoulder peak torque per body weight in ER at 180°/sec were minimal and remained insignificant following the treatment application at the follow up periods.

Table 5. 7 Shoulder Peak Torque per Body Weight ER 180°/sec (%) pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (%)	MWM (%)	SMWM (%)
Baseline	40.8 ± 4.6	33.8 ± 7.2	36.4 ± 7.8
Immediate	40.6± 7.8	34.7 ± 7.2	38.4 ± 8.3
72 hours	41.5 ± 8.5	35.4 ± 8.2	38.1 ± 8.3
7 days	41.1 ± 6.7	35.9 ± 8.9	39.7 ± 10.9

Note: Data expressed as mean ± SD.

5.2.3.5. Time to Peak Torque - Internal Rotation (60°/sec)

A split plot ANOVA revealed a non-significant within subject's time effect in time to peak torque for IR at 60°/sec ($F=1.09$ [df=3, SE=81], $p=0.35$, $\eta p2 = 0.04$ with the observed power of 0.29), indicating no change between the time points. No statistical significant time by treatment interaction was found ($F=2.27$ [df=6, SE=81], $p=0.053$, $\eta p2 = 0.14$ with the observed power of 0.72). Between groups effects revealed no statistically significant difference between the treatment methods in time to peak torque for IR at 60°/sec ($F=2.43$ [df=2, SE=27], $p=0.10$, $\eta p2 = 0.15$ with the observed power of 0.44). As demonstrated in *table 5.8*, the changes in shoulder time to peak torque in IR at 60°/sec were minimal and remained insignificant following the treatment application at the follow up periods.

Table 5. 8 Shoulder Time to Peak Torque IR 60°/sec (ms) pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (ms)	MWM (ms)	SMWM (ms)
Baseline	603 ± 233	667 ± 462	439 ± 233
Immediate	633 ± 381	644 ± 292	548 ± 259
72 hours	712 ± 415	772 ± 343	566 ± 201
7 days	936 ± 402	566 ± 296	413 ± 268

Note: Data expressed as mean ± SD.

5.2.3.6. Time to Peak Torque - Internal Rotation (180°/sec)

A split plot ANOVA revealed a non-significant within subject's time effect in time to peak torque for IR at 180°/sec (F=0.42 [df=3, SE=81], p=0.66, ηp2 = 0.01 with the observed power of 0.11), indicating no change between the time points. No statistical significant time by treatment interaction was found (F=0.31 [df=6, SE=81], p=0865, ηp2 = 0.02 with the observed power of 0.11). Between groups effects revealed no statistically significant difference between the treatment methods in time to peak torque for IR at 180°/sec (F=0.48 [df=2, SE=27], p=0.48, ηp2 = 0.05 with the observed power of 0.16). As demonstrated in *table 5.9*, the changes in shoulder time to peak torque in IR at 180°/sec were minimal and remained insignificant following the treatment application at the follow up periods.

Table 5. 9 Shoulder Time to Peak Torque IR 180°/sec (ms) pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (ms)	MWM (ms)	SMWM (ms)
Baseline	306 ± 149	436 ± 219	354 ± 204
Immediate	301 ± 167	375 ± 225	337 ± 183
72 hours	296 ± 160	361 ± 222	344 ± 186
7 days	282 ± 166	371 ± 213	373 ± 214

Note: Data expressed as mean ± SD.

5.2.3.7. Time to Peak Torque - External Rotation (60°/sec)

A split plot ANOVA revealed a non-significant within subject's time effect in time to peak torque for ER at 60°/sec (F=0.16 [df=3, SE=81], p=0.16, ηp2 = 0.06 with the observed power of 0.78), indicating no change between the time points. No statistical significant time by treatment interaction was found (F=0.57 [df=6, SE=81], p=0.75, ηp2 = 0.04 with the observed power of 0.21). Between groups effects revealed no statistically significant difference between the treatment methods in time to peak torque for ER at 60°/sec (F=1.10 [df=2, SE=27], p=0.34, ηp2 = 0.07 with the observed power of 0.22). As demonstrated in *table 5.10*, the changes in shoulder time to peak torque in ER at 60°/sec were minimal and remained insignificant following the treatment application at the follow up periods.

Table 5. 10 Shoulder Time to Peak Torque ER 60°/sec (ms) pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (ms)	MWM (ms)	SMWM (ms)
Baseline	326 ± 166	345 ± 181	373 ± 111
Immediate	252 ± 79	320 ± 162	303 ± 64
72 hours	264 ± 129	287 ± 181	439 ± 423
7 days	233 ± 114	230 ± 111	380 ± 170

Note: Data expressed as mean ± SD.

5.2.3.8. Time to Peak Torque - External Rotation (180°/sec)

A split plot ANOVA revealed a non-significant within subject's time effect in time to peak torque for ER at 180°/sec (F=0.51 [df=3, SE=81], p=0.64, ηp2 = 0.01 with the observed power of 0.14), indicating no change between the time points. No statistical significant time by treatment interaction was found (F=1.24 [df=6, SE=81], p=0.29, ηp2 = 0.08 with the observed power of 0.40). Between groups effects revealed no statistically significant difference between the treatment methods in time to peak torque for ER at 180°/sec (F=0.33 [df=2, SE=27], p=0.71, ηp2 = 0.02 with the observed power of 0.09). As demonstrated in *table 5.11*, the changes in shoulder time to peak torque in ER at 180°/sec were minimal and remained insignificant following the treatment application at the follow up periods.

Table 5. 11 Shoulder Time to Peak Torque ER 180°/sec (ms) pre and post treatment application in the Control, MWM and SMWM group.

Timeframe	Control (ms)	MWM (ms)	SMWM (ms)
Baseline	278 ± 112	275 ± 182	267 ± 170
Immediate	261 ± 137	370 ± 161	236 ± 100
72 hours	298 ± 192	263 ± 112	302 ± 217
7 days	295 ± 171	258 ± 136	209 ± 81

Note: Data expressed as mean ± SD.

5.3. Discussion

5.3.1. Introduction

This study examined the effect of multiple MWM and SMWM treatments over a period of one week on shoulder rotation ROM and strength in healthy individuals. The hypothesis of this study is patrly rejected as it stated that both the passive shoulder IR ROM and shoulder rotational strength will increase, however only the passive shoulder IR ROM had a statistically significant increase. The main finding of this study demonstrated a statistically significant increase in shoulder IR ROM immediately, as well as up to 7 days after the final MWM and SMWM treatment application. No change in shoulder strength outcome measures was noted over the time period.

5.3.2. ROM

Previous studies have determined that both single and multiple MWM treatment applications can significantly increase joint ROM in the elbow (Stephens, 1995), shoulder (Doner *et al.*, 2013; Satpute *et al.*, 2015; Neelapala *et al.*, 2016; Delago-Gil *et al.*, 2015; Teys, 2013; Ribeiro *et al.*, 2017; Abbott, 2001), hip (Walsh and Kinsella 2016), thumb (Backstorm, 2002; Folk, 2001; Hsieh, 2002), ankle (Vincezino *et al.*, 2006, Obrien and Vicenzino, 1998; Hetherington, 1996; Gilbreath *et al.*, 2016) and the knee (Balasundram *et al.*, 2017) joints.

Satpute *et al.*, (2015) and Doner *et al.*, (2013) both demonstrated an immediate increase in the shoulder IR ROM following a MWM treatment period in shoulder joints with pathology. Satpute *et al.*, (2015) performed the MWM treatment 3 times a week for the duration of 3 weeks, while Doner *et al.*, (2013) performed the MWM treatment 5 times a week for the duration of 3 weeks. There was an increase of 35° of shoulder IR ROM immediately post the treatment period in both of these studies. This demonstrates that the application frequency of 5 treatments per week was not different to that of 3 treatments per week. The current study documented a 14.4° increase in shoulder IR ROM immediately following 3 treatment applications of MWM over a period of 5 days. The significant increase noted in IR ROM in the present study is considerably less than both Satpute *et al.*, (2015) and Doner *et al.*, (2013). However, Satpute *et al.*, (2015) performed the treatment intervention on participants with painful shoulder with less than 25° of shoulder IR and Doner *et al.*, (2013) used a pathological population with a diagnosed shoulder adhesive capsulitis and shoulder range of motion less than 50% of the normal values, therefore there was potentially more scope for greater improvements. Satpute *et al.*, (2015) and Doner *et al.*, (2013) performed the MWM treatment period over a period of 3 weeks with 3-5 days of treatment each week, while the current study utilised a treatment period performed over single week, having a smaller treatment exposure. The follow up period following treatment determined that there was a significant 13.5° increase in shoulder IR at 72 hours and an 18.4° increase at 7 days following the MWM treatment intervention, when compared to the baseline. The increase in passive shoulder IR ROM following the MWM treatment is significant, this can be further highlighted by the between group effect size ($\eta p2 = 0.38$) which proved to be high (Fritz et al., 2012). It is interesting to note that the shoulder IR ROM is greater at 72 hours after the treatment intervention than immediately post the treatment intervention. Therefore, an application of MWM treatment could potentially produce optimal effects once applied 72 hours before a sporting event. Doner *et al.*, (2013) study also reported a greater increase in ROM in their follow up period, however it was 3 months later (25° immediately vs 46° at three months). If we compare the study results in Chapter 4 to the present study, it can be seen that the addition of 2 more treatment sessions resulted in a greater increase in shoulder IR by 3.4° immediately after the MWM treatment application and by 6.5° 72 hours following the treatment application. These results would suggest that an increased treatment exposure resulted in a greater increase in shoulder IR ROM. Future studies may wish to directly compare the effects of frequencies and durations of MWM treatment on shoulder ROM. Similarly to the results of Chapter 4 the present study did not find any changes in shoulder ER ROM, as an IR MWM treatment was applied. This implies that the treatment application works only in the direction it was applied to target, and not the opposing direction.

The current study also examined and compared the effect of multiple SMWM treatments on shoulder IR ROM. Previously, only one study compared the use of a single MWM and SMWM treatment on hip IR ROM, however no difference in the passive and functional hip IR ROM was reported following the SMWM treatment (Walsh and Kinsella, 2016). Walsh and Kinsella (2016) determined that MWM treatment was effective in increasing functional hip IR ROM, however no change was found in passive hip IR ROM. The current study is the first study that demonstrated a statistically significant increase following a SMWM treatment application immediately, 72 hours and 7 days following the treatment. The SMWM treatment demonstrated a 13.4° increase in shoulder IR ROM immediately post treatment. Similar to the MWM treatment application this changed slightly over time, increasing to 15.0° at 72 hours and 14.2° at 7 days following treatment application. The increase in passive shoulder IR ROM following the SMWM treatment is significant, this can be further highlighted by the between group effect size ($\eta p2 = 0.38$) which proved to be high (Fritz et al., 2012). In Chapter 4 of this study shoulder IR did not increase to the same extent, where the ROM increased 10° immediately, 8° at 24h and 6°

48h following a single SMWM treatment application. The results of the present study further support that an increase in treatment frequency causes a greater increase in shoulder IR ROM. It can be concluded that both the MWM and SMWM treatment are effective in increasing shoulder IR ROM initially as well as up to 7 days following the treatment application. This can be utilised in practice, as the MWM treatment can be supplemented by the SMWM treatment as a home exercise programme in order to maintain the benefits of the treatment.

The ROM increase as a result of MWM and SMWM is commonly explained by the positional fault theory (Mulligan, 1993; Exelby, 1995; Exelby, 1996; Hetherington, 1995; O'Brien and Vinencizno, 1998; Kavanagh, 1999; Mulligan, 1999; Exelby, 2001; Folk, 2001; Backstorm, 2002). This theory is based on an argument that an injury or a dysfunction is associated with a minor positional fault, which results in pain or limitation of movement (Mulligan, 1995; Folk, 2001; Backstrom, 2002; Hubbard and Hertel, 2008). Previous studies have hypothesised that MWM reduced minor positional faults in joints, therefore the application of MWM and SMWM treatment may aid in improving the positional fault, in turn increasing function and ROM around the joint (O'Brien and Vinencizno, 1998; Exelby, 2001; Folk, 2001; Backstorm, 2002; Collins *et al.,* 2004; Kavanagh, 1999; Hsieh *et al.,* 2002). Joint mobilisation also stimulates proprioceptors and mechanoreceptors, increasing the sensory input to the higher centres (Colloca *et al.*, 2004; Colloca *et al.*, 2006; Grindstaff *et al.*, 2009), potentially altering the muscle motor recruitment pattern, restoring normal arthrokinematics, improving motor function and motor control (Schmid *et al.*, 2008; Hsu *et al.*, 2009; Bialosky *et al.*, 2010). Bialosky *et al.*, (2010) presented a theory proposing that the changes may occur due to a combination of the above biomechanical and neurophysiological factors, which may explain the results of this study. A combination of these factors may effect the outcomes of the treatment, as initially the positional fault is corrected in the direction that the treatment was applied in, producing changes to the joint ROM. This study applied a treatment application in the direction of shoulder IR, therefore the statistically significant increase of ROM was present in the direction of shoulder IR and the shoulder ER was unaffected by the treatment. The present statistically significant increase in passive shoulder IR initially and up to 7 days following the treatment, however the biggest ROM increase was seen 72 hours following the treatment application. The greatest increase at 72 hour follow up may be explained due to the corrected positional fault, which lead to much better arthrokinematics, in turn the neurophysiological effects may have stimulated the proprioceptors and mechanoroceptors improving the joint ROM (Colloca *et al.*, 2004; Colloca *et al.*, 2006; Grindstaff *et al.*, 2009). Multiple MWM or SMWM treatment applications may result in this effect being greater to when a single MWM or SMWM treatment application is applied, therefore a greater shoulder IR ROM is present following multiple treatment application. MWM and SMWM treatment is equally effective in increasing the passive shoulder IR ROM, therefore the practitioner can utlise either of the treatments. MWM treatment may be used initially by the practitioner to increase the passive shoulder IR ROM, then the SMWM treatment may be perscribed as a home exercise programme to maintain the improvements made in the treatment sessions. This study did not examine a combination of MWM and SMWM treatmets, but it has established that SMWM treatment is an effective treatment method.

5.3.3. Strength

Previous studies have determined that the use of MWMs are effective in increasing joint strength or muscular activation following a treatment application on the elbow (Bisset *et al.*, 2006; Paungmali *et al.*, 2003; Collins *et al.*, 2004; Teys *et al.*, 2006), shoulder (Neelapala *et al.*, 2016, Ribeiro *et al.*, 2015, Ribeiro *et al.*, 2017), hip (Yerys *et al.*, 2002, Makofsky *et al.*, 2007) and thumb (Backstorm ,2002) joints. Isometric shoulder external rotation increased by 67% immediately (p=0.04) following a MWM treatment period in a population with painful overhead movements (Neelapala *et al.*, 2017). Ribeiro *et al.*, (2017) compared the use of MWM and SMWM treatment on the shoulder muscle activity, demonstrating no statistically significant difference post treatment intervention, however muscle activity changes during the treatment application were reported. A similar isometric strength increase can be found in the hip joint, Yerys *et al.*, (2002) and Makofsky *et al.*, (2007) demonstrated a statistically significant isometric hip peak torque increase in extension (p=0.002) and abduction (p=0.03) range respectively after grade IV hip mobilisations. The current study has evaluated strength using isokinetic testing of shoulder internal and external rotation, however contrary to Neelapa *et al.*, (2017) this study did not demonstrate any significant strength changes to the shoulder joint. The study results in chapter 4 of this study found no significant change in shoulder rotational isokinetic strength post treatment intervention in both the MWM and SMWM groups. Therefore, it was hypothesised that an increase in the treatment frequency may result in a significant increase in shoulder rotational strength, however that was not the case. The current study found no change in shoulder rotational strength following the MWM and SMWM treatment at any of the time points. Practitioners can safely apply the MWM and SMWM treatment on an athletic population without any consequences on performance, as the treatment does not produce any decrease in strength. The optimal timeframe to apply the treatment application is 72 hours prior to the sporting event for greatest increase in passive shoulder IR ROM.

Many previous studies demonstrating an increase of strength following MWM treatment were carried out on symptomatic participants with pain or pathology (Bisset *et al.*, 2006; Kochat and Dogra, 2002; Slater *et al.*, 2006; McLean *et al.*, 2002; Abbott *et al.*, 2001). Previous studies indicate that MWM treatment produces hypoalgesia and sympathoexcitation, in turn reducing pain and increasing function, motor control and the muscle activity (Wright, 1995; Vincenzino *et al.*, 1998; Sterling *et al.*, 2001; Bialosky *et al.*, 2009; Hsu *et al.*, 2000; Schmid *et al.*, 2008). The results of the current study would certainly suggest MWMs and SMWMs have no effect on shoulder strength in healthy individuals with a decreased shoulder IR ROM. The pathomechanism might also be related to pain, as the participants in studies of Bisset et al., (2006) and Teys et al., (2006) had lateral epicondylitis. The conditioned caused pain, which may have lead to a decreased strength, therefore reliving pain may in turn facilitated the participants to use their full strength. This can be seen in a statistically significant ($p<0.05$) increase in PFGS (Bisset *et al.*, 2006; Teys *et al.*, 2006). The current study recruited participants that had no pain or muscular weakness, future studies should consider further exploring this concept.

5.3.4. Recommendations for future studies

This study has explored the effects of 3 MWM and SMWM treatment applications on the passive shoulder IR ROM and shoulder isokinetic rotational strength. Future studies should consider exploring and determining the optimal MWM and SMWM treatment dosage in order to achieve the greatest improvement is shoulder IR ROM. This implies determining the optimal sets and repetitions of the treatment, how long the treatment is effective for and when is the optimal timeframe before a sporting event to apply the treatment.

5.3.5. Conclusions

This research clearly demonstrates the effectiveness of multiple MWM and SMWM treatments applied over a duration of a single week on shoulder IR ROM immediately and up to 7 days following the treatment application. The application of MWM and SMWM treatment has no negative impact on shoulder internal and external rotation strength parameters or shoulder ER ROM.

Conclusion

This study examined the effects of MWM and SMWM treatment application on hip and shoulder ROM, hip power and shoulder strength. A single hip extension MWM or SMWM treatment application on the hip joint resulted in a within group statistically significant increase in hip extension ROM, however no change in hip power immediately or up to 48 hours post treatment application was present. Therefore, the clinical application of an extension MWM or SMWM treatment on the hip joint produced an increase in passive hip extension ROM, but has no effect on hip power or jump height.

A single IR MWM or SMWM treatment application on the shoulder joint had a beneficial effect in increasing the shoulder IR ROM, without having an impact on shoulder strength. This ROM improvement was present immediately, as well as, up to 48 hours following the treatment application. The study demonstrated that MWM and SMWM treatment is equally as effective in increasing shoulder IR ROM, which poses as a huge advantage, where, in the clinical setting patients can maintain their treatment benefits by utilising the SMWM treatment as a part of the home exercise programme. Athletes can also utilise the treatments in order to obtain the ROM benefits, and without suffering any loss of shoulder strength.

Furthermore, the effects of an IR MWM or SMWM on shoulder IR ROM are even greater with multiple treatments. This was observed immediately and well as up to 7 days following the treatment application. Interestingly, multiple treatment applications increase the treatment benefits. Furthermore, MWM treatment demonstrated the greatest ROM increase 72 hours following the treatment period, accordingly application of the MWM treatment 72 hours prior a sporting event would achieve in optimal benefits.

Clinical Implications:

- A single MWM and SMWM hip extension treatment application increases hip extension ROM, without effecting hip power or jump height.
- A single MWM and SMWM shoulder IR treatment application increases the shoulder IR ROM immediately as well as up to 48 hours following the treatment application, without having any negative effects on ER ROM and shoulder IR and ER isokinetic strength.
- A multiple MWM and SMWM shoulder IR treatment application increases the shoulder IR ROM immediately as well as up to 7 days following the treatment application, without have any negative effects on ER ROM and shoulder ER and ER isokinetic strength.
- Multiple MWM and SMWM shoulder IR treatment applications produce greater shoulder IR ROM increase compared to a single MWM and SMWM treatment application.
- The optimal time frame to apply the MWM and SMWM in order to achieve the greatest passive shoulder IR ROM is 72 hours before a sporting event.
- The SMWM treatment is an effective standalone treatment in increasing passive shoulder IR ROM, but it can also be a great home exercise programme to maintain to progress achieved during treatment.

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Appendices

Appendix A

INSTITUTE *of* TECHNOLOGY CARLOW

HUMAN PARTICIPANTS INFORMATION SHEET and

INFORMED CONSENT FORM

Project Title:

"The Immediate and Sustained Effects of Mobilisations with Movement on the Hip and Shoulder Range of Motion, Strength and Power."

Introduction to the study:

Mobilisations with movement is an often utilised treatment technique in manual therapy. This investigation will examine the effects of mobilisations with movement on the hip joint.

You are being asked to take part of this study. This investigation will take place in the physiology lab (c149) in Institute of Technology Carlow. You are required to attend three testing sessions which will take approximately 20-30 minutes. A follow up testing session may be required.

Day one:

During your first visit to the testing facility you will be familiarised with the procedures of this study. Your height and weight will be recorded and you are going to be allocated into one of the three testing groups. The investigator will explain how the treatment will be applied. You are going to be screened by the investigator for your hip range of motion restrictions. You are going to have an opportunity to practice the tests that will measure the power of your hip joint. Once you are confident that you understand your role in this study and are comfortable with performing the test you may return to the testing facility after 24 hours.

Day two:

1) The investigator will record baseline measures of:
- Your hip range of motion (ROM), using a clinometer.
- Your hip joint power using a countermovement jump.

You will be asked to perform repeated testing in order to facilitate obtaining the best outcome measures.

2) The investigator will perform mobilisations with movement according to the group you were allocated to.

Group 1 (Therapist applied mobilisations with movement):
The therapist will apply mobilisations with movement with the aid of a mulligan belt to your hip joint.

Group 2 (Self-applied mobilisation with movement):
You are going to apply mobilisations with movement with the aid of a powerband on your hip joint.

Group 3 (Control group):
You are going to take a passive rest in a designated position replicating treatment procedure for the duration of approximately 3 minutes.

3) Following the treatment session, the post-treatment measurements of hip ROM and hip power will be taken. The procedure will be exactly the same to that of baseline measures. After the completion of day two testing session you may be required to return to the testing facility again for up to 2 retests in the following week.

Sometimes there are problems associated with this type of study. These are:

- You may experience minor discomfort in the following days due to delayed onset of muscle soreness.
- You may experience local discomfort at the site of the treatment application, which should cease immediately after treatment.
- You may experience an injury during one of the maximal performance tests, due to the nature of the test, however this risk is minimal.

There may be some benefits to you from participating in this study:

- You may experience an increase in flexibility in the hip joint.
- You may experience an increase in power in the hip joint.

You will not be allowed to participate in this study if you have any of the following:

- Signs, symptoms or known cardiovascular, pulmonary or metabolic diseases.
- Congenital hip disease
- History of hip trauma
- Recent surgery or dislocation
- Inflammatory joint disease
- Any upper or lower limb or spine injury within the last 8 weeks.
- Any injury that disables the participant from fully participating in the research.
- Systemic diseases of the muscular or nervous system
- Sedentary lifestyle
- Tumours
- Bone disease
- Malignancy
- Pregnancy
- Acute nerve irritation or compression
- Undiagnosed pain
- Psychological pain
- Steroid use affecting ligament laxity
- Unstable angina

Your identity will remain confidential. Your name will not be published and will not be disclosed to anyone besides the researcher. You are assigned with an ID number to which all the data you provided will be linked to. Details linking the ID number and your name will not be stored with the data. All data will be stored in a safe and secure location for the period of two years, then it will be destroyed and disposed of properly. All of the data collected in this study will not be used for any other purpose than this study. The results of the study may be published and used in further studies.

If you have any questions about the study, you are free to call Bartosz Lelental on 0873547538 or email bartosz.lelental@itcarlow.ie. Taking part in this study is your decision. If you do agree to take part, you may withdraw at any point including during the study. There will be no penalty for withdrawal before the completion of the research. You will not be rewarded financially for your participation in this study.

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to take part in this research project entitled **“The Immediate and Sustained Effects of Mobilisations with Movement on the Hip and Shoulder Range of Motion, Strength and Power.”**

Signature of participant: ______________________ Date: ____________________

Appendix B

INSTITUTE of TECHNOLOGY CARLOW

Subject Screening Form

Department of Science and Health
School of Science
Institute of Technology Carlow
Carlow

Name: Case number:

D.O.B: Age:

Weight: Height:

The information obtained from this screening form is confidential and will not be disclosed to anyone without your permission.

• Do you suffer from any lower back or lower/upper limb injury(ies) which is currently preventing you from participating in you sport?	Yes / No
• Do you suffer from any neurological signs/symptoms (altered sensation, pins and needles, weakness) in the back, buttock, legs or arms?	Yes / No
• Do you suffer from any rheumatoid/systemic arthritis?	Yes / No
• Do you, to your knowledge, have any congenital or acquired hip deformities?	Yes / No
• Have you ever had pelvic or lower back surgery?	Yes / No
• Have you been treated for any lower back or lower limb injury(ies) in the past 6 months?	Yes / No
• Do you train? If so, how often? ……hours per week.	Yes / No
• Do you have any signs, symptoms or known cardiovascular, pulmonary or metabolic diseases?	Yes / No

Signature of participant: ______________________ Date: ____________________

Signature Witness: ________________________

Witness printed name: __________________________

Appendix C

INSTITUTE of TECHNOLOGY CARLOW

HUMAN PARTICIPANTS INFORMATION SHEET and INFORMED CONSENT FORM

Project Title:

"The Immediate and Sustained Effects of Mobilisations with Movement on the Hip and Shoulder Range of Motion, Strength and Power."

Introduction to the study:

Mobilisations with movement is an often utilised treatment technique in manual therapy. This investigation will examine the effects of mobilisations with movement on the shoulder joint.

You are being asked to take part of this study. This investigation will take place in the physiology lab (c149) in Institute of Technology Carlow. You are required to attend three testing sessions which will take approximately 20-30 minutes. A follow up testing session may be required.

Day one:

During your first visit to the testing facility you will be familiarised with the procedures of this study. Your height and weight will be recorded and you are going to be allocated into one of the three testing groups. The investigator will explain how the treatment will be applied. You are going to be screened by the investigator for shoulder range of motion restrictions. You are going to have an opportunity to practice the tests that will measure the strength of your shoulder joint. Once you are confident that you understand your role in this study and are comfortable with performing the test you may return to the testing facility after 24 hours.

Day two:

1) The investigator will record baseline measures of:

- Your shoulder range of motion (ROM), using an inclinometer.
- Your shoulder joint strength using a Biodex isokinetic machine.

You will be asked to perform repeated testing in order to facilitate obtaining the best outcome measures.

2) The investigator will perform mobilisations with movement according to the group you were allocated to.

Group 1 (Therapist applied mobilisations with movement):
The therapist will apply mobilisations with movement with the aid of a mulligan belt to your shoulder joint.

Group 2 (Self-applied mobilisation with movement):
You are going to apply mobilisations with movement with the aid of a powerband on your shoulder joint.

Group 3 (Control group):
You are going to take a passive rest in a designated position replicating treatment procedure for the duration of approximately 3 minutes.

3) Following the treatment session, the post-treatment measurements of shoulder ROM and shoulder strength will be taken. The procedure will be exactly the same to that of baseline measures. After the completion of day two testing session you may be required to return to the testing facility again for up to 2 retests in the following week.

Sometimes there are problems associated with this type of study. These are:

- You may experience minor discomfort in the following days due to delayed onset of muscle soreness.
- You may experience local discomfort at the site of the treatment application, which should cease immediately after treatment.
- You may experience an injury during one of the maximal performance tests, due to the nature of the test, however this risk is minimal.

There may be some benefits to you from participating in this study:

- You may experience an increase in flexibility in the shoulder joint.
- You may experience an increase in strength in the shoulder joint.

You will not be allowed to participate in this study if you have any of the following:

- Signs, symptoms or known cardiovascular, pulmonary or metabolic diseases.
- History of shoulder trauma
- Recent surgery or dislocation
- Inflammatory joint disease
- Any upper or lower limb or spine injury within the last 8 weeks.
- Any injury that disables the participant from fully participating in the research.
- Systemic diseases of the muscular or nervous system
- Sedentary lifestyle
- Tumours
- Bone disease
- Malignancy
- Pregnancy
- Acute nerve irritation or compression
- Recent whiplash
- Undiagnosed pain
- Psychological pain
- Steroid use affecting ligament laxity
- Unstable angina

Your identity will remain confidential. Your name will not be published and will not be disclosed to anyone besides the researcher. You are assigned with an ID number to which all the data you provided will be linked to. Details linking the ID number and your name will not be stored with the data. All data will be stored in a safe and secure location for the period of two years, then it will be destroyed and disposed of properly. All of the data collected in this study will not be used for any other purpose than this study. The results of the study may be published and used in further studies.

If you have any questions about the study, you are free to call Bartosz Lelental on 0873547538 or email bartosz.lelental@itcarlow.ie. Taking part in this study is your decision. If you do agree to take part, you may withdraw at any point including during the study. There will be no penalty for withdrawal before the completion of the research. You will not be rewarded financially for your participation in this study.

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to take part in this research project entitled **“The Immediate and Sustained Effects of Mobilisations with Movement on the Hip and Shoulder Range of Motion, Strength and Power.”**

Signature of participant: ______________________ Date: ____________________

Appendix D

INSTITUTE of TECHNOLOGY CARLOW

Subject Screening Form

Department of Science and Health
School of Science
Institute of Technology Carlow
Carlow

Name: Case number:

D.O.B: Age:

Weight: Height:

The information obtained from this screening form is confidential and will not be disclosed to anyone without your permission.

• Do you suffer from any lower back upper limb injury(ies) which is currently preventing you from participating in you sport?	Yes / No
• Do you suffer from any neurological signs/symptoms (altered sensation, pins and needles, weakness) in the back, buttock, legs or arms?	Yes / No
• Do you suffer from any rheumatoid/systemic arthritis?	Yes / No
• Have you ever had shoulder back surgery?	Yes / No
• Have you been treated for any lower back or upper limb injury(ies) in the past 6 months?	Yes / No
• Do you train? If so, how often? ……hours per week.	Yes / No
• Do you have any signs, symptoms or known cardiovascular, pulmonary or metabolic diseases?	Yes / No

Signature of participant: ______________________ Date: ____________________

Signature Witness: ________________________

Witness printed name: __________________________

Appendix E

INSTITUTE *of* TECHNOLOGY CARLOW

HUMAN PARTICIPANTS INFORMATION SHEET and

INFORMED CONSENT FORM

Project Title:

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Mobilisations with movement is an often utilised treatment technique in manual therapy. This investigation will examine the effects of mobilisations with movement on the shoulder joint.

You are being asked to take part of this study. This investigation will take place in the physiology lab (c149) in Institute of Technology Carlow. You are required to attend five testing sessions which will take approximately 20-30 minutes. A follow up testing session may be required.

Day one:

During your first visit to the testing facility you will be familiarised with the procedures of this study. Your height and weight will be recorded and you are going to be allocated into one of the three testing groups. The investigator will explain how the treatment will be applied. You are going to be screened by the investigator for your shoulder range of motion restrictions. You are going to have an opportunity to practice the tests that will measure the strength of your shoulder joint. Once you are confident that you understand your role in this study and are comfortable with performing the test you may return to the testing facility after 24 hours.

Day two:

1) The investigator will record baseline measures of:
- Your shoulder of motion (ROM), using an inclinometer.
- Your shoulder joint strength using a Biodex isokinetic machine.

You will be asked to perform repeated testing in order to facilitate obtaining the best outcome measures.

2) The investigator will perform mobilisations with movement according to the group you were allocated to. You will be required to attend 3 treatment sessions over a period of 1 week, each testing session being separated by approximately 24 hours.

Group 1 (Therapist applied mobilisations with movement):
The therapist will apply mobilisations with movement with the aid of a mulligan belt to your shoulder joint.

Group 2 (Self-applied mobilisation with movement):
You are going to apply mobilisations with movement with the aid of a powerband on your shoulder joint.

Group 3 (Control group):
You are going to take a passive rest in a designated position replicating treatment procedure for the duration of approximately 3 minutes.

3) Following the treatment period, the post-treatment measurements of shoulder ROM and shoulder strength. The procedure will be exactly the same to that of baseline measures. After the completion of treatment period you may be required to return to the testing facility again for up to 2 retests in the following week.

Sometimes there are problems associated with this type of study. These are:

- You may experience minor discomfort in the following days due to delayed onset of muscle soreness.
- You may experience local discomfort at the site of the treatment application, which should cease immediately after treatment.
- You may experience an injury during one of the maximal performance tests, due to the nature of the test, however this risk is minimal.

There may be some benefits to you from participating in this study:

- You may experience an increase in flexibility in the shoulder joint.
- You may experience an increase in strength in the shoulder joint.

You will not be allowed to participate in this study if you have any of the following:

- Signs, symptoms or known cardiovascular, pulmonary or metabolic diseases.
- History of shoulder trauma
- Recent surgery or dislocation
- Inflammatory joint disease
- Any upper or lower limb or spine injury within the last 8 weeks.
- Any injury that disables the participant from fully participating in the research.
- Systemic diseases of the muscular or nervous system
- Sedentary lifestyle
- Tumours
- Bone disease
- Malignancy
- Pregnancy
- Acute nerve irritation or compression
- Recent whiplash
- Undiagnosed pain
- Psychological pain
- Steroid use affecting ligament laxity
- Unstable angina

Your identity will remain confidential. Your name will not be published and will not be disclosed to anyone besides the researcher. You are assigned with an ID number to which all the data you provided will be linked to. Details linking the ID number and your name will not be stored with the data. All data will be stored in a safe and secure location for the period of two years, then it will be destroyed and disposed of properly. All of the data collected in this study will not be used for any other purpose than this study. The results of the study may be published and used in further studies.

If you have any questions about the study, you are free to call Bartosz Lelental on 0873547538 or email bartosz.lelental@itcarlow.ie. Taking part in this study is your decision. If you do agree to take part, you may withdraw at any point including during the study. There will be no penalty for withdrawal before the completion of the research. You will not be rewarded financially for your participation in this study.

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to take part in this research project entitled **“The Immediate and Sustained Effects of Mobilisations with Movement on the Hip and Shoulder Range of Motion, Strength and Power.”**

Signature of participant: ______________________ Date: ____________________

Appendix F

INSTITUTE of TECHNOLOGY CARLOW

Subject Screening Form

Department of Science and Health
School of Science
Institute of Technology Carlow
Carlow

Name: Case number:

D.O.B: Age:

Weight: Height:

The information obtained from this screening form is confidential and will not be disclosed to anyone without your permission.

• Do you suffer from any lower back or upper limb injury(ies) which is currently preventing you from participating in you sport?	Yes / No
• Do you suffer from any neurological signs/symptoms (altered sensation, pins and needles, weakness) in the back, buttock, legs or arms?	Yes / No
• Do you suffer from any rheumatoid/systemic arthritis?	Yes / No
• Have you ever had shoulder back surgery?	Yes / No
• Have you been treated for any lower back or lower/upper limb injury(ies) in the past 6 months?	Yes / No
• Do you train? If so, how often? ……hours per week.	Yes / No
• Do you have any signs, symptoms or known cardiovascular, pulmonary or metabolic diseases?	Yes / No

Signature of participant: ______________________ Date: ____________________

Signature Witness: ________________________

Witness printed name: __________________________

Appendix G

Participant Number:

Data Collection Sheet

Shoulder IR Day 1				LL:
Shoulder IR Day 2				SD:
Shoulder IR Day 3				KG:
Shoulder IR Day 4				
Shoulder ER Day 1				
Shoulder ER Day 2				
Shoulder ER Day 3				
Shoulder ER Day 4				
Hip Extension Day 1				
Hip Extension Day 2				
Hip Extension Day 3				
Hip Extension Day 4				
	(CM)	Peak Concentric Power (N)		
Jump height FP day 1				
Jump height FP day 2				
Jump height FP day 3				
Jump height FP day 4				
Jump Height MJ day 1				
Jump Height MJ day 2				
Jump Height MJ day 3				
Jump Height MJ day 4				
Jump Power MJ day 1				
Jump Power MJ day 1				
Jump Power MJ day 1				
Jump Power MJ day 1				

Appendix H

Warm up procedure – lower limb (chapter 3)

The warm up took approximately 6 minutes to complete, however more time was allocated if necessary. Each participant completed this warm up at beginning of every experimental day.

Warm up:

Jogging - approximately 100m

Knee hugs – 10 on each leg

Forward lunges – 10 on each leg

Side lunges – 10 on each leg

Skipping – over 20 meter distance

Squats – 10 body weight squats

Appendix I

Warm up procedure – upper limb (chapter 4 and 5)

The warm up took approximately 6 minutes to complete, however more time was allocated if necessary. Each participant completed this warm up at beginning of every experimental day.

Warm up:

Jogging – with forward and backward arm movement

Push up plus – shoulder movement 10 repetitions

Push ups – 10 body weight push ups

Band – Internal and external rotations performed with a green resistance band, 10 repetitions on each arm in each direction