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Normative Values for Hip Flexion Range of Motion and Strength in Professional Rugby Union Players.

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DECLARATION

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SUMMARY

Professional Rugby Union is a multi-directional field-based team sport. It involves intermittent periods of high-speed running, changes of direction, kicking, and a high volume of collision-based activities, such as tackling, rucking, mauling and scrummaging. The physical nature of Rugby Union means that it has one of the highest incidences of injury of any team sport (Williams et al, 2013).

The hip and groin region is among the most commonly injured site in Rugby Union. In the most recent Rugby World Cup (RWC), injuries to the hip and groin accounted for 5.8% of all injuries sustained during the competition (Fuller et al, 2017).

Recognised intrinsic risk factors for injury to the hip and groin include strength (or decreased strength specifically) (Tyler et al, 2001), and range of motion (Henderson et al, 2010).

Assessment of hip muscle strength and range of motion are routine and vital components in the continuous assessment and monitoring of injured and non-injured professional athletes. To date, all published data around hip strength in professional athletes has focused on hip adduction / abduction and rotational strength. To the knowledge of this author there is no published normative values on hip flexion strength and range of motion in professional rugby union players.

Forty-four professional Rugby Union players were recruited for this study. All were injury free at the time of testing. A hand-held dynamometer measured peak hip flexion strength of each player by way of an eccentric break-test. Hip flexion strength was assessed on both legs with the hip flexed to 90 degrees and also at maximal available inner range of motion (beyond 90 degrees). Active hip flexion range of motion was measured using a Universal Goniometer. The principal investigator was a Chartered Physiotherapist working in professional sport with experience in both methods of assessment.

For both hip flexion range of motion and hip flexion strength, percentile scores between 5 and 95% for each of the values were computed. This method produced a clinician friendly table of reference ranges and values. It also highlighted the heterogeneous make up of a professional Rugby Union team. The lowest reference strength value was 181.6 Nm while the 95% percentile range was 425 Nm.

Linear regression analysis was conducted to examine the influence of variables such as; 1) playing position, 2) kicking leg, and 3) history of hip and groin pain, on the clinical measurements of hip flexion range of motion and hip flexion strength.

The only significant finding from this analysis, was that if a player plays as a 'back', then their inner range hip flexion strength is significantly less than a player who is a 'backrow forward' ($p=0.018$).

All participants also completed two patient-reported outcome measures (PROM), which were; 1) The Copenhagen Hip and Groin Outcome Score (HAGOS), and 2) the International Hip Outcome Tool-33 (i-HOT 33). A linear regression analysis examined the influence of the variables of 1) hip flexion strength, 2) hip flexion range of motion, and 3) history of hip and groin pain, on the subsection scores of both PROMs.

The results revealed that despite being injury free at the time of completing the PROMs, players who had a previous history of hip and groin pain scored significantly lower in three of the four subsections of the i-HOT 33, and three of the six subsections of the HAGOS. Ultimately this meant that despite being at full strength and available for selection, players with a history of hip and groin pain had a significantly different perspective on their health than their colleagues without a history of hip and groin pain.

This study provides useful percentile ranges for hip flexion strength and range of motion for this unique cohort, that are user friendly for clinicians working with professional Rugby Union teams. The findings from this research also highlights the heterogeneity of a professional Rugby Union squad and emphasises the need for future research to examine each playing group as a separate population. This study also demonstrates the importance of using PROMs in ongoing player assessment and monitoring.

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LIST OF TABLES

Page

Number

Table 1: Incidence and severity of injuries in Rugby Union over the past 16 years	17
Table 2: Hip and groin injuries ranking in terms of most common injury site of lower limb injuries.....	18
Table 3: The increasing incidence and severity of injuries to the hip and groin region over the past two Rugby World Cups.....	19
Table 4: Strength as a risk factor for groin injury in sport.	25
Table 5: Hip ROM as a risk factor for injury in an athletic population.....	28
Table 6: Clinical hip tests when compared to gold standard diagnosis for hip pathology.	31
Table 7: Normative values for hip flexion strength in professional rugby union players.....	45
Table 8: Normative values for hip flexion range of motion in professional rugby union players.	46
Table 9: Influence of variables on hip flexion range of motion of the right leg.	47
Table 10: Influence of variables on hip flexion range of motion of the left leg.	48
Table 11: Influence of variables on peak hip flexion strength of the right leg leg at 90°.	49
Table 12: Influence of variables on peak hip flexion strength of the left leg leg at 90°.	49
Table 13: Influence of variables on peak hip flexion strength of the right leg at maximal available inner range (above 90°).	50
Table 14: Influence of variables on peak hip flexion strength of the left leg at maximal available inner range (above 90°).	50
Table 15: Significant findings on the effect of having a history of hip and groin pain on the subsections the i-HOT 33.	52
Table 16: Significant findings on the effect of having a history of hip and groin pain on the subsections of HAGOS.....	52
Table 17: Comparison of methods between this study and Hanna, 2010 for establishing normative hip flexion strength values.	55
Table 18: Differences of mean hip flexor strength values, between professional RU players and amateur footballers.	56

LIST OF FIGURES

Page

Number

Figure 1: Field dimensions of a professional rugby union playing pitch.....	12
Figure 2: The back squat	14
Figure :3 The 'clean' Olympic lift.....	14
Figure 4: The rugby scrum.....	15
Figure 5: The lineout in rugby.	15
Figure 6 : Anatomy of Iliopsoas muscle.	22
Figure 7: Jtec Powertrack II Commander Hand-held dynamometer	39
Figure 8: A Baseline, universal 12-inch goniometer.	40
Figure 9: Testing position protocol for hip flexion strength measurement.....	41

LIST OF ABBREVIATIONS

AU	Arbitrary Units
FABER	Flexion, Abduction, External Rotation
FADIR	Flexion, Adduction, Internal Rotation
FIFA	Federation Internationale de Football Association
HAGOS	The Copenhagen Hip and Groin Outcome Score
HHD	Hand-Held Dynamometer
HIA	Head Injury Assessment
ICC	Intraclass Correlation Coefficient
i-HOT 33	International Hip Outcome Tool
IRB	International Rugby Board
L	Left
LR	Leinster Rugby
MMT	Manual Muscle Testing
MRI	Magnetic Resonance Imaging
MVEC	Maximal Voluntary Eccentric Contraction
NCAA	National Collegiate Athletic Association
PROM	Patient Reported Outcome Measure
R	Right
ROM	Range of Motion
RU	Rugby Union

RWC	Rugby World Cup
UEFA	Union of European Football Association
UG	Universal Goniometer
°	Degrees
%	Percentage

TABLE OF CONTENTS

Page

Number

CHAPTER 1 - INTRODUCTION	12
1.1 Introduction	12
1.2 Epidemiology	16
1.2.1 Injury Epidemiology in professional rugby union	16
1.2.2 Hip and groin injuries in rugby	18
1.2.3 Comparison to other sports	20
1.2.4 Interpretation of epidemiological data	20
1.3 Hip and groin terminology	21
1.4 Functional anatomy of the hip	22
1.5 Risk factors for injury in professional sport	23
1.5.1 Extrinsic risk factors	24
1.5.2 Intrinsic risk factors	25
1.6 Risk factors for hip and groin injury	25
1.6.1 Muscle strength	25
1.6.2 Range of motion (ROM)	27
1.6.3 Leg Dominance	29
1.6.4 Previous injury	30
1.7 Clinical Assessment of the hip	30
1.7.1 Range of motion assessment	32
1.7.2 Muscle strength assessment	33
1.7.3 Methods of assessing hip muscle strength	33
1.7.4 Patient Reported Outcome Measure (PROM)	35

1.8 Summary.....	36
1.8.1 Justification for this study.....	37
1.9 Aims and objectives	37
CHAPTER 2 - METHODS	38
2.1 Participants.....	38
2.2 Ethical Considerations.....	38
2.3 Instrumentation	39
2.4 Procedures.....	40
2.4.1 Hip flexion strength testing protocol	40
2.4.2 Hip Flexion range of motion assessment	42
2.4.3 HAGOS and i-HOT 33.....	43
2.5 Statistical analysis	43
CHAPTER 3 - RESULTS.....	44
3.1 Demographic Profile.....	44
CHAPTER 4 - DISCUSSION	53
4.1 Introduction.....	53
4.2 Normative value of hip flexion strength	54
4.3 Normative values of active hip range of motion.	57
4.4 Influence of playing position, history of hip and groin pain and leg dominance on the clinical measures of hip flexion strength and hip flexion range of motion.	58
4.5 Influence of PROM subsection scores on the clinical measures of hip flexion strength and hip flexion range of motion.	59
4.6 Influence of having a history of hip and groin pain on the PROM subsection scores. ..	60
4.7 Interpretation of findings, and indications for future research	61
4.8 Study Limitations.....	62
4.9 Implications for Practice	63
CHAPTER 6 - CONCLUSION	64
CHAPTER 7 – REFERENCES.....	65
7.1 Journal references.....	65
7.2 Stock photo references	73
CHAPTER 8 - APPENDICES	74
8.1 Appendix 1 : The Copenhagen Hip and Groin Outcome Score (HAGOS).....	74
8.2 Appendix 2: Internation Hip Outcome Tool (i-HOT 33).....	81
8.3 Appendix 3: Ethical Approval.....	90
8.3 Appendix 4: Participant Information Leaflet.....	91
8.4 Appendix 5: Informed Consent.....	93

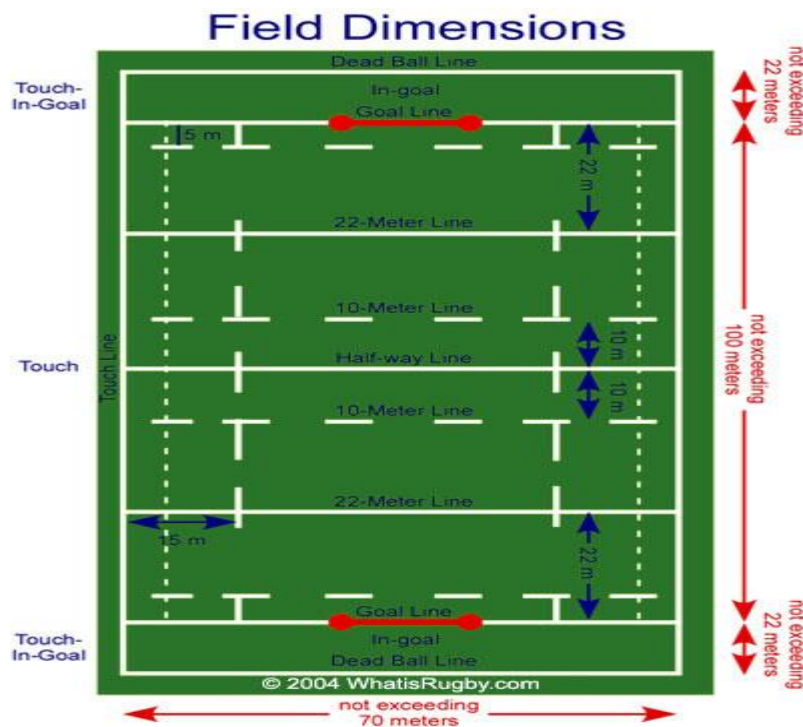
8.5 Appendix 6: Raw data output: iHOT subsections vs strength and range of motion	94
8.6 Appendix 6: Raw data - HAGOS subsections vs strength and range of motion	105
8.7 Appendix 7: Data: iHOT & HAGOS subsections vs history of hip and groin pain	122

CHAPTER 1 - INTRODUCTION

1.1 Introduction

Rugby union (RU) is one of the most popular sports in the world with nearly two hundred countries associated with the International Rugby Board (IRB). A RU match is played on a pitch one hundred metres in length and seventy metres in width (figure 1). Each match is played over eighty minutes, broken down into two halves of forty minutes each. A rugby union team is made up of fifteen players, consisting of two generic groups of eight forwards and seven backs. The primary distinction between forwards and backs is that forwards must contest for possession during the re-start phases of scrum and lineout.

Figure 1: Field dimensions of a professional rugby union playing pitch



(<http://picphotos.net/rugby-union-field-measurements/>,2017)

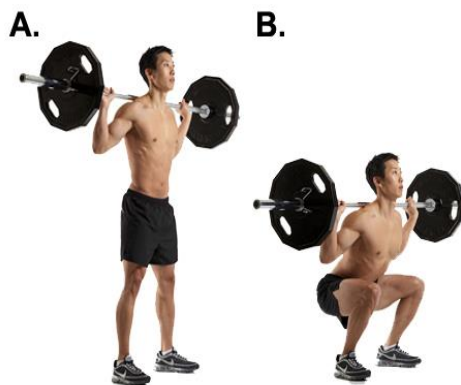
The objective of the game is to outscore the opposition. The attacking team possesses the ball and will run at the opposition defensive line, attempting to run through gaps in the line. A player may also pass to a team-mate or kick the ball forward. The defending team can use physical contact when tackling the opposition player with the ball in an attempt to stop the attack, and/or win possession of the ball back. A 'try' is scored when a player touches the ball down in the oppositions in-goal area.

Professional rugby union is a game characterised by periods of intermittent high-intensity sprinting, scrummaging, tackling, rucking and mauling, as well as periods of lower intensity aerobic work (Roberts et al, 2008). Backs are typically lighter and smaller than forwards and have significantly less body mass and lower body fat percentage than forwards (La Monica et al, 2016). Maximum distances covered in a match range from 5km to 6.4km depending on position (Austin et al, 2011), with backs typically covering more total distance and distance at high speed running than forwards (Lyndsay et al, 2015).

Each position on a team has specific requirements that are usually based around size, speed and skill (Lyndsay et al, 2015). In a study that analysed the movements and activities of 763 international players over a six-year period it was found that forwards (numbers one to eight) are involved in physical contacts and collisions contesting for the ball in scrums, mauls and rucks for three and a half minutes per match, compared to less than a minute for the backs (numbers nine to 15), (Quarrie et al, 2013). Another study aiming to quantify the movement characteristics of professional RU players during match play recruited 98 players from eight English premiership clubs, and found that the backs covered greater absolute distances (6545m) than the forwards (5850), (Cahill et al, 2013). This finding was in agreement with previous research (Roberts et al, 2008; Cunniffe et al, 2009; Coughlan et al, 2011).

Development of strength and power is important for RU players due to the physical collision-based nature of the sport. As such, resistance training is a vital component in the weekly schedule of RU players preparing for competition. There is limited research available on strength and conditioning practices in professional rugby, however a recent publication detailed the results of a survey sent to 43 strength coaches and sports scientists working in elite RU in both northern and southern hemispheres. All respondents reported that strength training formed an integral component of their players' schedule and all respondents believed that strength training benefitted RU performance. The back squat (figure 2) and clean (figure 3) were rated as the most important prescribed strength exercises in elite rugby union (Jones et al, 2016).

Figure 2: The back squat. A = starting and finishing position. B = Paralell squat position.



The purpose of the back squat is to strengthen the muscles around the knees, hips and lower back for optimal execution and performance of athletic movements (Gullert et al, 2009), such as scrummaging (figure 4), tackling and rucking, in RU.

(<http://seannal.com/wp-content/uploads/2013/04/squat-form.jpg>, 2017)

Figure :3 The ‘clean’ Olympic lift.

Explosively lifting the bar off the ground and achieving triple extension at the ankles, knees and hips (center image).

(www.jordanstrength.com/wp-content/uploads/2012/06/figure-3.jpg,2017)



The clean is an olympic style lift, explosive in nature. A lineout (figure 5) in rugby involves a player jumping while being lifted by team-mates to contest the possession of the ball from

the throw-in. The biomechanical action of this action is the simultaneous triple extension of the hips, knees, and ankle (Gamble et al, 2001). Olympic lifts such as the clean aim to develop this explosive triple extension power in the gym. Ultimately, the objective off all strength exercises prescribed to this population is to maximize carry-over of gains from the gym, onto the playing field.

Figure 4: The rugby scrum.



Note the position of the knees, hips and trunk, similar to a correctly performed back squat.

(<http://rate-sport.com/wp-content/uploads/images/scrum-rugby-9.jpg>,2017)



Figure 5: The lineout in rugby.

Note the triple extension action at the ankles, knees and hips, similar to the clean.

(http://coaching.r80rugby.com/thumbnails/6-006_thumb.jpg,2017)

Summary

Professional Rugby Union is a physically demanding sport that requires aerobic fitness as well as strength and power. Players are required to sprint for short distances, jump, lift other players, tackle, kick the ball, and also possess the skill to pass the ball with their hands while

running. Due to the multifaceted elements of the game, professional rugby union players must prepare for matches by training on a pitch as well as in a gym.

1.2 Epidemiology

1.2.1 Injury Epidemiology in professional rugby union

Rugby union has one of the highest injury incidences of any team sport (Williams et al, 2013). The sport has seen a significant increase in injury incidence since turning professional in 1995. In the last ever Rugby World Cup (RWC) of the amateur era in 1995, the injury incidence was recorded at 30/1,000 player hours (Jakoet et al, 1998). In the ten years post the transition to professionalism, the overall incidence of injury in rugby union match play increased to 91/1,000 hours (Brooks et al, 2005a).

There have been numerous injury epidemiological studies and injury surveillance projects examining professional rugby union tournaments published in the past fifteen years. Lower limb injuries make up the greatest proportion of injuries in professional rugby union (Brooks et al 2005; Fuller et al, 2008; Schneiders et al, 2009; Fuller et al, 2012; Fuller et al, 2016; Whitehouse et al, 2016)

Table 1 illustrates the incidence of injury per 1,000 player match hours in elite level RU competition. The data from the last four world cup tournaments show that while the incidence of injury has reduced from 97.9/1,000 in 2003 to 90.1/1,000 in 2015, the severity of injuries has steadily increased over this period from 18 days to 29.8 of time lost from match and training (Fuller et al, 2003; 2008; 2011; 2015). All studies reported that the most common mechanism of injury was that of being tackled.

Table 1: Incidence and severity of injuries in Rugby Union over the past sixteen years

Author	Tournament / Team	Incidence per 1,000 player match hours	Severity (if quoted)	Most common mechanism of injury
(Bathgate et al, 2001)	Australian national team	69		Being tackled
(Best et al, 2001)	RWC	97.9		Being tackled
(Brooks et al, 2005a)	English Premiership	91	18	Being tackled
(Fuller et al, 2008)	RWC	83.9	14.7	Being tackled
(Fuller et al, 2013)	RWC	89.7	23.6	Being tackled
(Williams et al, 2013)	Meta-analysis	81		Being tackled
(Williams et al, 2016)	Super Rugby	66		Being tackled
(Fuller et al, 2017)	RWC	90.1	29.8	Being tackled
(Moore et al, 2015)	Welsh national team (Autumn)	262.5		Being tackled
	Welsh national team (RWC)	178.6		Being tackled
(Brooks et al, 2005b)	English premiership training	2	24	Running

RWC: Rugby World Cup

Severity unit of measurement: Average number of days absent from play

Injury rates were considerably higher for the Welsh national rugby team during the two listed tournaments when compared to the other published data. This was acknowledged by the authors (Moore et al, 2015), however no explanation for why this occurred was given.

The *Brooks J, 2005 (b)* study reported the incidence of injuries during training. The figure reported was 2 /1,000 player hours, which is significantly different from the incidence of injuries in competition. This is an understandable difference, as the higher the level of play, ascending from training, to club match, to international match, the higher the incidence of injury (Williams et al, 2013).

Although the injury incidence has reduced (albeit marginally) over the past four RWCs, compared to football, another multi-directional international team sport, these figures are considerably higher. The Federal International Football Association (FIFA) World Cup competitions of 2010 and 2014 had an injury incidence of 61.1 and 50.8 per 1,000 player hours respectively, and 75% of those injuries resulted in less than eight days absence (Junge et al, 2015).

Comparing the RU epidemiological data to ice-hockey, another multi-directional team sport that involves collisions, the incidence of injuries in RU are, again significantly higher. A study that surveyed elite ice-hockey teams in qualifying for the World Cup and Olympic Games between 2006 and 2013 reported an injury incidence of 52.1/1,000 player hours. The same study stated that 53% of these injured players returned within seven days and only 14.3% of the injured players took a minimum of three weeks to return to play (exact number of days not quoted (Tuominen et al, 2015).

Muscle / tendon injuries and ligament / joint injuries are the most common injury types in RU, while lower limb injuries occurring more often than upper limb, however upper limb are reported as more severe than lower limb (Williams et al, 2013).

1.2.2 Hip and groin injuries in rugby

Injuries to the hip and groin are recorded in epidemiological data under one heading of hip/groin. This is due to the anatomical complexity of the region and that symptoms can often be referred. A Union of European Football Association (UEFA) study defined a hip/groin injury as an 'injury located to the hip joint or surrounding soft tissues or at the junction between the anteromedial part of the thigh, including the proximal part of the adductor muscle bellies, and the lower abdomen, leading to a player being unable to fully participate in future training or match play (Werner et al, 2009).

Of all the anatomic regions included in lower limb injury data for RU, injuries to the hip and groin region are among the most commonly injured sites. Table 2 outlines the numerical ranking (most commonly injured anatomical site of the lower limb) of injuries to the hip and groin from recent epidemiological publications.

Table 2: Hip and groin injuries ranking in terms of most common injury site of lower limb injuries

Author	Tournament / Team	Ranking of hip and groin in most common injury location
(Bathgate et al, 2001)	Australian national team	3rd
(Brooks et al, 2005a)	English Premiership	4th
(Fuller et al, 2008)	RWC	4th
(Fuller et al, 2013)	RWC	3rd
(Whitehouse et al, 2016)	Super Rugby	3rd
(Fuller et al, 2017)	RWC	3rd
(Moore et al, 2015)	Welsh national team (Autumn internationals, RWC and 6 Nations combined)	4th

RWC: Rugby World Cup

In the most recent RWC, (2015), injuries to the hip / groin complex accounted for 5.8% of all injuries sustained, making it the sixth most common overall injury site of the tournament (Fuller et al, 2017). This accounted for 7.8% of all injuries to backs and 3.6% of all injuries sustained by forwards. The 2011 RWC injury surveillance study also reported a hip and groin injury incidence of 3.6/1000 hours, with a mean severity of 8.1 days (Fuller et al, 2013). The 2007 RWC injury surveillance project reported a hip/groin injury incidence of 3.6/1000 hours with a mean severity of 15.6 days (Fuller et al, 2008).

When excluding cervical spine and knee ligament injuries from the 2011 RWC injury data, hip and groin injuries had the third highest time-loss injury from that tournament (Fuller et al, 2013).

The incidence and severity of hip / groin injuries in international rugby union has increased with each consecutive RWC. Table 3 highlights that between the 2007 and 2011 there was a 94% increase in hip and groin injury incidence across forwards and backs and an increase in days' absence of 74% across both forwards and backs (Fuller et al, 2017).

Table 3: The increasing incidence and severity of injuries to the hip and groin region over the past two Rugby World Cups.

RWC year	Incidence / 1,000 hours			Mean severity (days absent)	
	Forwards	Backs		Forwards	Backs
2007	0.2	0.3		2.0	4.0
2011	2.9	4.5		5.0	23.5

Away from the RWC, but still at international level RU performance, the Australian Super Rugby club competition in 2014 had a hip and groin injury incidence of 13/1,000 player hours and a mean severity of 27.23 days (Whitehouse et al, 2016).

When followed over three seasons the Welsh national team had a high incidence of hip/groin injuries of 21.3/1,000 player hours (Moore et al, 2015). This significant increase in injury rate corresponds with previous publications that show overall injury incidences are higher at international level and as the standard of play increases (Garroway et al, 2000).

1.2.3 Comparison to other sports

Hip and groin injuries are a significant burden in multi-directional field-based sports that involve kicking, change of direction and sudden acceleration and deceleration. In the National Collegiate Athletic Association (NCAA) of American ice-hockey, hip/groin injuries have an incidence of 1.03/1,000 player hours (Dalton et al, 2016), while in professional European soccer, an incidence of 3.5/1,000 hours with a mean absence of fifteen days has been reported (Werner et al, 2009). The same study stated that hip flexor / Iliopsoas injuries were among the most common diagnosed injured sites (Werner et al, 2009).

A separate study that followed elite European football teams over eight seasons, reported that adductor muscle injuries specifically were the second most common injury site (Ekstrand et al, 2011).

Due to different reporting methods, it is difficult to directly compare the incidence and severity of hip and groin injuries in RU to other sports. The RU data is labelled and reported under the regional term of hip and groin, whereas sports such as ice-hockey and football may report data under hip and groin as well as adductor muscle, hip flexor, or specific muscle injury.

1.2.4 Interpretation of epidemiological data

The epidemiological data on injuries in professional rugby union informs the following:

1. The lower limb is the most commonly injured region in the body (Williams et al, 2013).
2. Hip and groin injuries are routinely in the top six sites of injury, (Bathgate et al 2001; Brooks et al, 2005a; Fuller et al, 2008, 2013, 2017).

3. Muscle / tendon is the most commonly injured group in the lower limb (Williams et al, 2013).

While this data is useful, what it doesn't reveal in detail, is which specific muscle / tendon groups in the hip and groin are sustaining an injury.

Only one study (Brooks et al, 2005a) reported adductor muscle injury having an incidence of 2.5/1,000 and hip flexor muscle injury of 2.2/1,000 match play hours. All other published data relating to injuries in professional rugby union report injuries under the umbrella term of 'hip and groin' (Bathgate et al, 2001; Fuller et al, 2008, 2013, 2017; Williams et al, 2013; Moore et al, 2015; Whitehouse et al, 2016;).

Summary

Rugby Union has one of the highest injury rates of any team sports. Lower limb injuries make up the largest proportion of all injuries sustained in Rugby Union. Within the lower limb, the hip and groin region are one of the most commonly injured sites, with muscle and tendons being the most frequently injured in the hip and groin. This is important as this results in time-loss from training and playing competitive matches.

1.3 Hip and groin terminology

As most of the injuries are reported under the heading of hip and groin, it cannot be clearly defined as to what entity around the hip and groin is injured. In a review of the management of groin pain in sport, it was revealed that there were 33 different diagnostic terms used in the literature to explain groin pain (Serner et al, 2015). In 2015 the Doha agreement on terminology and definitions in groin pain in athletes was published. Unanimous agreement was reached among the expert group on a classification system and defined clinical entities for groin pain, of which one is 'Iliopsoas (hip flexor) related groin pain'. It was agreed that Iliopsoas related groin pain is likely if there is pain on resisted hip flexion (Weir et al, 2015). The terminology agreed and published by the expert group is welcome and useful, however the epidemiological data does not break down hip and groin pain as of yet.

1.4 Functional anatomy of the hip

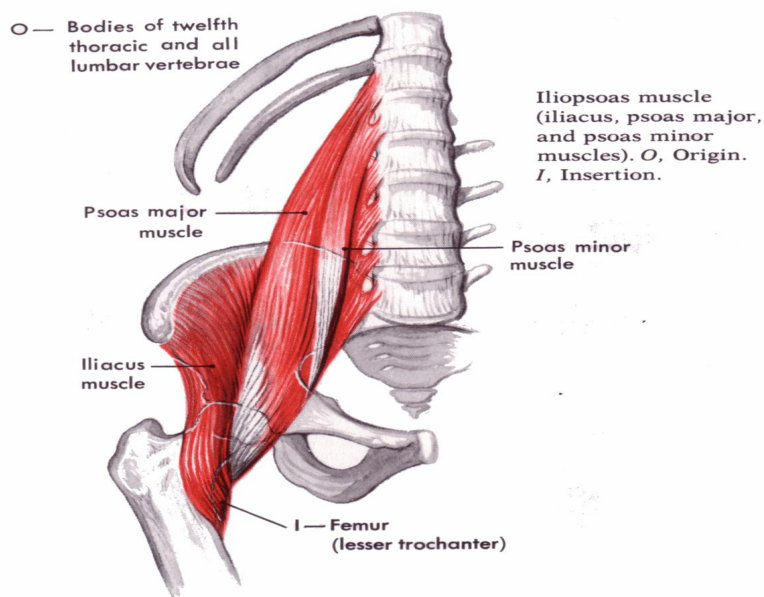
The hip is a multi-axial ball and socket joint. The femoroacetabular joint is unique as it is never fully unloaded during activities of daily living (Bowman et al, 2010). The articular surfaces of the hip joint experience a residual compressive force acting on the joint at all times, equal to body weight (Ferguson et al, 2003). There are many supporting structures around the hip joint and the principal contributors to joint reaction forces are the surrounding muscular forces (Bowman et al, 2010).

The hip flexor musculature of Iliopsoas, Rectus Femoris and Sartorius have an important role in running and kicking. The Rectus Femoris stabilises the pelvis on the femur in weight bearing, flexes the hip and extends the knee (Bordalo-Rodrigues et al, 2005). It has a high proportion of type II muscle fibres, and during running and kicking is often brought to a maximal stretch before being required to powerfully eccentrically and concentrically contract.

Iliopsoas (figure 6) is described as a conjoined tendon of Psoas Major (originating from the transverse process of the lumbar vertebrae) and iliacus (which originates from the upper two-thirds of the iliac fossa) and inserts onto the lesser trochanter of the hip (Phillipon et al, 2014). The Iliopsoas plays an important role in pelvic control and lumbar posture (Anderson et al, 2016). Psoas Major has been described as the main hip flexor in the stride pattern (Warwick and Williams, 1980). It flexes the thigh in walking and running patterns (Copaver et al, 2012) and is a primary hip flexor if its spinal attachment is the fixed point. It has been shown that increased cross-sectional area of Psoas Major as well as increased hip flexion power has a strong correlation to increased sprint performance over 50m and 120m (Copaver et al, 2012). This is important as sprinting accounts for 25% of game movements in rugby union for backs and 4% for forwards, with distances covered typically between 10-20m (Duthie et al, 2006).

Figure 6 : Anatomy of Iliopsoas muscle.

(<http://anatomyorgan.com/Iliopsoas-muscle-anatomy/jpg>,2017)



Iliacus and Psoas Major together form Iliopsoas. They have a common insertion on the lesser trochanter of the femur, however originate from the ilium and lumbar spine respectively. They are separately innervated, which make selective recruitment possible (Anderson, 2016).

Sartorius assists in flexing, abducting and laterally rotating the thigh at the hip joint, as well as aiding flexion of the knee joint (Alyssa and Shivajee, 2018).

Hip flexor muscle injuries primarily occur during kicking, running and change of direction (Serner et al, 2015), all characteristic demands of professional rugby union. There are no available publications that breakdown the proportion of hip flexor strength attributable from each hip flexor muscle, however Rectus Femoris, and Iliopsoas are the most commonly injured muscles in sports that require sprinting and kicking (Mendiguchia et al, 2013).

1.5 Risk factors for injury in professional sport

Identifying and attempting to address risk factors for injury in sport is an ongoing pursuit. At the outset, it is important to acknowledge that a sporting injury is unlikely to be as a direct result from a single risk factor, rather more likely to be as a consequence of interactions from a myriad of risk factors and / or inciting events (Meeuwisse et al, 2007). Often, risk factors can be divided into extrinsic and intrinsic risk factors.

1.5.1 Extrinsic risk factors

- It has been reported that intrinsic factors are far more predictive of muscle strain injuries than extrinsic factors in professional level team sports (Orchard et al, 2001). While some of the extrinsic risk factors outlined below, may not be specific to hip flexor injuries, it is important to include all reported extrinsic risk factors for injury in professional rugby, to highlight the attritional nature of the sport.
- **Level of play.** A higher level of play is associated with an increased incidence in injury (Williams et al, 2013). There is also a substantial increase in injury risk between training and a competitive match. The injury incidence is twenty-seven times higher between match play and training (Quarrie et al, 2013).
- **Tackling.** Tackling, or being tackled in RU is the number one mechanism of injury in professional RU (Bathgate et al, 2001; Fuller et al, 2008, 2013, 2017; Williams et al, 2013; Moore et al, 2015). When just examining concussive events in RU, the player who is the tackler has a significantly higher propensity of undergoing a Head Injury Assessment (HIA) than the player being tackled in RU. 76% of all HIA events in professional RU occur as the result of a tackle (Tucker et al, 2017).
- **Training load.** In a prospective study over seven seasons in the English premiership rugby, it was reported that if a player played either less than fifteen games or more than thirty-five games in a twelve-month period, then they were more susceptible to injury (Williams et al, 2013). There have been numerous recent studies published that have cited a sudden spike in training load as an increase for injury. A week to week increase in load of > 1250 AU (Arbitrary units) significantly related to a large injury risk ($p < 0.5$) (Rogalski et al, 2013). Under-preparedness for competition may also be a training load related risk factor for injury, reported as a lower acute workload. An acute workload is the total of 1-week total distance ran, whereas a chronic workload is a 4-week average acute workload. It has been reported that professional rugby league players who had an acute: chronic workload ratio of 1.5-2.1 on week five / average of weeks 1-4, were at a higher risk of injury (Hulin et al, 2015).

1.5.2 Intrinsic risk factors

- **Previous injury.** There are many publications in the literature that have reported that having a previous muscle injury is a risk factor for re-injuring that same muscle. This has been reported for Rectus Femoris (Mendiguchia et al, 2013), hamstrings (Gabbe et al, 2006) calf injuries (Green et al, 2017) and quadriceps (Orchard et al, 2001).
- **Between limb strength imbalance.** In a prospective study over one season in Australian professional rugby union it was found that a between limb imbalance in eccentric knee flexor strength increased the risk of a hamstring injury by 2.4-fold (95% CI, 1.1-5.5; $P = 0.33$) (Bourne et al, 2015).
- **Leg dominance.** Two recent studies have cited leg dominance as a risk factor for injury (Orchard et al 2001; Ekstrand et al, 2011). Both studies referred to quadricep muscle injuries. If a player has a preferred leg for kicking then the demand placed on that leg will be greater than the non-kicking leg. Kicking requires eccentric hip flexor action and with the bi-articular nature of the Rectus Femoris muscle it may leave it vulnerable to injury (Mendiguchia et al, 2013).

1.6 Risk factors for hip and groin injury

1.6.1 Muscle strength

It has been shown that muscle strength imbalance around the hip is associated with an increased risk of athletic groin pain (Tyler et al, 2001; Malliaras et al, 2009; Crow et al, 2010; Engebretsen et al, 2010; Belhaj et al, 2016, Moreno-Perez et al, 2017), however these studies primarily assessed hip abduction and adduction strength.

Table 4 outlines the measurements used in each study, the population examined and the findings. Each study had a different design and methodology; however, each study reported their finding as a reduction in hip adduction strength being a risk factor for developing hip and groin pain.

Table 4: Strength as a risk factor for groin injury in sport.

Author	Population	n	Control group?	Measure used	Finding
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(Tyler et al, 2001)	Professional hockey players	81	No	Hand Held Dynamometer	Pre-season adduction strength in players who went on to develop groin injury was on average 18% lower than players who remained injury free ($P=0.021$)
(Malliaris et al, 2009)	Junior elite footballers	10	Yes	Sphygmomanometer (mmHg)	Players with hip and groin symptoms had a significantly reduced adductor squeeze strength score compared to aged and activity matched controls ($p 0.01$)
(Engebretson et al, 2010)	Amateur footballers	508	No	Hand Held Dynamometer	Weak adductor musculature is a significant predictor of increased risk for a groin injury, 95% CI, 1.31 - 14.0), OR: 4.28
(Crow et al, 2010)		86	No	Sphygmomanometer (mmHg)	Players who developed a groin injury had significantly lower adductor strength scores from baseline when injured, and also had a decrease on average of 4.25% in adductor strength two weeks preceding the injury
(Belhaj et al, 2016)	Professional football players	49	Yes	Isokinetic testing	Players who went on to develop hip and groin pain had a significantly higher adduction to adduction ratio when compared to aged match controls
(Moreno-Perez, et al, 2017)	Professional tennis players	61	No	HHD	Players who developed a groin injury had on average 16.4% lower adduction strength scores than players without groin injury

HHD: Hand-held dynamometer **CI:** Confidence Interval **OR:** Odds Ratio

All of the above studies (outlined in Table 4) demonstrate that a reduction in hip adduction strength is a risk factor for sustaining a groin injury.

There is minimal published data on the assessment of hip flexor strength in an athletic population. A small study involving twenty amateur soccer players who were symptomatic for osteitis pubis demonstrated a significantly higher hip flexor / extensor strength ratio than a healthy control group when tested isokinetically ($P < 0.05$) (Mohamad et al, 2014). While this study highlighted a strength imbalance between hip flexors and extensors in the symptomatic population, it was a small study and it could not be ascertained if the strength imbalance was a cause of, or as a result of the injury or indeed pain inhibition. Also, Mohammad (2014) did not examine hip flexion strength as an independent potential risk factor for injury.

It is acknowledged through published studies (Table 4, above), that a reduction in adductor strength is a risk factor for groin injury. There are however, no publications that examine the relationship between hip flexor strength and history of injury, or risk of injury.

1.6.2 Range of motion (ROM)

The most important prescribed strength exercise in professional rugby union is the back-squat exercise (Jones et al, 2016). This is due to its strengthening effects on the knee, hip and trunk and for these strength gains to result in optimal execution and performance of athletic movements on the field of play (Gullet et al, 2009). The mean hip ROM during a back squat has been reported to be $95.4^\circ \pm 26.6^\circ$ of flexion to reach a maximal squat (Hemmerich et al, 2006). If hip flexion mobility is reduced then a person may compensate by using excessive trunk flexion, a strategy that may lead to increased stress on the lumbar spine and potential overload and injury (Schoenfeld et al, 2010).

In a recently published systematic review by (Tak et al, 2017) examining the relationship between hip ROM and groin pain in athletes it was reported that a total rotational hip ROM (internal rotation plus external rotation) of less than 85° was the most consistent risk factor for developing groin pain (Tak et al, 2017). The review included 11 studies in total (7 prospective, and 4 case-control studies). Only 2 of the 11 studies assessed hip flexion ROM. All studies assessed hip internal and external rotational ROM. The authors used the Critical Appraisal Skills Programme (CASP) to critically appraise the trustworthiness, relevance and results of the published studies included in their review. According to the CASP criteria checklist, the methodological quality of the papers ranged from 29% to 92%. While the review concluded that there was strong evidence that total rotational ROM of the hip below 85° screened at pre-season

was a risk factor for groin pain, it must be noted that this was based on only 2 of the 11 studies included in the review. This was due to heterogeneous hip ROM measures and assessment methods. The review also highlighted the lack of publications examining hip flexion ROM as a risk factor for hip and groin injury.

Henderson et al examined active hip flexion range in professional footballers and found that a player's odds of incurring a hamstring injury were increased 1.29-fold for every 1° reduction in active hip flexion range of movement, and that a decreased hip flexion ROM was significantly associated with an increased risk of hamstring injury (Henderson et al 2010). The method of assessing active hip flexion ROM in this study was an active straight leg raise, so it could be argued that this may be more of a hamstring flexibility assessment than a true assessment of fully available active hip flexion ROM.

Table 5 summarises the studies that examined hip ROM as a risk factor for hip and groin injury in an athletic population.

Table 5: Hip ROM as a risk factor for injury in an athletic population.

Author	Population	n	Measure used	Finding
(Henderson et al, 2010)	Professional footballers	36	Active <u>Hip Flexion</u> ROM	1 - A decreased hip flexion (active) ROM was significantly associated with an increased propensity of incurring a hamstring injury ($P = <0.05$) 2 - Odds of getting a hamstring injury increased by 1.29 for each 1° reduction in active hip flexion ROM
(Li et al, 2015)	Professional Baseball players	201	Hip internal and external ROM	Reported a weak correlation between a reduced total hip rotational ROM and hip and groin injury (data not available)

ROM: Range of Motion

Table 5 lists studies that assessed range of motion in a clinical setting on an examination table, which of course is routine clinical practice for clinicians working in sport. There are however

recent studies that attempt to analyse movement patterns in an athletic population with long standing hip and groin pain, and their findings, while not conclusive, should be considered.

One such study that analysed movement strategies used by three hundred and eighty-three athletes with athletic groin pain during a maximum effort cutting task, found that hip flexion angles differed (mean difference of 17°) between participants during the task. The implication from this analysis is that there are significant differences in anterior hip joint compressive forces depending on the angle of hip flexion during the cutting task (a task routinely carried out in professional rugby (Franklyn-Miller et al, 2017)). While there is no direct published link between hip flexion angles and hip pathology, a paper by Franklyn-Miller, theorised, that different hip flexion angles will alter the shear forces of the anterior hip and as such, high shear forces may overload anterior hip joint musculature (Franklyn-Miller et al, 2017). The athletes in this study all had long standing athletic groin pain, so these findings cannot state for certain that the movement strategies are a cause of their pain or as a result of their pain.

Dostal et al examined hip joint forces during locomotion and found that any change in the angle of hip flexion alters muscular action around the hip (Dostal et al, 1986). It has been shown that a change of only 2 degrees in hip extension during gait can alter anterior hip joint forces by up to 24% (Lewsi et al, 2010). It must be noted that Dostal, 1986, and Lewis 2010, used three-dimensional models to estimate hip joint forces and muscular actions around the hip, and that there is no evidence that these findings lead to hip and groin pathology.

Aside from the aforementioned study from *Henderson 2010*, there is no literature available that examines the relationship between active hip flexion range of motion and risk of injury or history of hip and groin injury in an athletic population.

Summary

The literature shows that a reduction in muscle strength, when compared to the contralateral side or baseline strength is a risk factor for injury for the hamstrings, calf muscles and adductors, however there is currently no known publication examining the strength of hip flexor musculature and its relationship with injury risk.

There is also a lack of known studies that examine hip flexion range of motion as a risk factor for injury to the hip flexors.

1.6.3 Leg Dominance

Having a preferred leg for kicking may be a risk factor for hip flexor muscle injuries. In a prospective study that followed over two thousand players from fifty-one professional teams for eight years, it was found that of all quadricep muscle strains incurred during this period, 66% involved the dominant leg (Ekstrand et al, 2011). In Australian rules football, quadricep muscle strains are significantly more common in the dominant kicking leg (relative risk 2.13, 95% CI 1.59 to 28.6), (Orchard et al, 2001). Kicking is the most common mechanism of injury for the Rectus Femoris muscle in professional football (Woods et al, 2002). Kicking imposes a high demand for eccentric muscle contraction on the hip flexor musculature. During the early swing phase, the hip flexors must contract eccentrically to decelerate hip extension, while at maximum knee flexion, with the hip in extension (also known as the 'wind-up phase'), the Rectus Femoris must eccentrically contract to prevent excessive knee flexion, before again forcefully concentrically contracting to extend the knee prior to kicking the ball. Because of the greater angular velocity and greater knee flexion present during the wind-up phase, it is believed that this segment of the kicking action is related to Rectus Femoris injuries (Mendiguchia et al, 2013).

1.6.4 Previous injury

Having a history of a previous muscle injury to hip flexors (Mendiguchia et al, 2013), Calf (Green et al, 2017), Hamstring (Bourne et al, 2015) or groin (Whittaker et al, 2015) is commonly reported as a major risk factor for a re-injury of the same muscle in the literature. In a study that followed professional Australian football league teams over a seven-year period it was reported that the strongest risk factor for a Rectus Femoris injury was a recent history of that same injury, and the second strongest risk factor was a history of that same injury. This study by Orchard followed over 2,200 professional Australian football players over seven seasons. It was a prospective cohort study. All injuries were diagnosed by each clubs' medical staff and were included in the study if the injury resulted in at least one game being missed. As well as a previous injury being a risk factor for re-injury for Rectus Femoris, it was also more commonly injured in the kicking leg (relative risk 2.13; 95% confidence interval, 1.59 to 2.86). Interestingly, calf and hamstring muscle injuries were distributed equally between both legs (Orchard et al, 2001).

1.7 Clinical Assessment of the hip

Clinical assessment of the athletic hip can be challenging due to the multiple potential causes for hip symptoms. As well as musculoskeletal injuries, an athlete may for example, have pelvic

or genitourinary issues that present with hip symptoms that may need urgent onward referral or investigation. As such, it is of paramount importance that the assessing clinician has a comprehensive understanding of common and pathologic hip conditions (Braly et al, 2006),

To define the pathology of the hip and groin clinically, a thorough assessment of the region should ensue. This will include a detailed subjective examination as well as an objective assessment which will include range of motion assessment, muscle strength assessment, as well as hip joint special tests.

All of the published literature that has examined the diagnostic accuracy of clinical hip tests against the gold standard of arthroscope and Magnetic Resonance Imaging (MRI) have examined the provocative tests of FADIR (Flexion, Adduction and Internal Rotation), and FABER (Flexion, Abduction and External Rotation). A positive sign for FABER or FADIR test is provocation of the patients' symptoms.

Table 6 outlines recent publications that detail the accuracy and sensitivity of both FABER and FADIR when compared to gold standard of diagnosis.

Table 6: Clinical hip tests when compared to gold standard diagnosis for hip pathology.

Author	Study design	n	Measure used	Findings
(Reiman et al, 2013)	Meta-analysis examining diagnostic accuracy of clinical tests for diagnosing FAI	Review 14 high quality studies included	Compared provocative hip joint special tests to gold standard arthroscope	<u>FABER</u> SN: 42-81% SP: 18 -75% <u>FADIR</u> SN: 59-100% SP: 4-75%

(Tijssen et al, 2017)	Retrospective cohort study examining the relationship between patient history, physical tests and arthroscopic findings in hip joint pathology	77	Clinical tests compared to arthroscopic findings. Did not test FADIR	1 - FABER had a high sensitivity of 81%. 2 - Absence of groin pain and a negative FABER test is suggested to rule out a diagnosis of symptomatic intra-articular hip joint pathology.
(Casartelli et al, 2017)	Cross-sectional	74	FADIR test compared to magnetic resonance imaging (MRI)	FADIR SN 41% SP 47%

FABER: Flexion, Abduction & External Rotation of the hip

FADIR: Flexion, Adduction & Internal Rotation of the hip

SN: Sensitivity

SP: Specificity

1.7.1 Range of motion assessment

Assessment of range of motion of the hip joint should form an integral part of every clinical assessment of the hip. Objective measurement of range of motion along with precise interpretation of the results can greatly contribute to devising a treatment plan and also in tracking patients progress or response to the rehabilitation program. In an evaluation of the techniques used by orthopaedic surgeons who assessed up to seventy adult hips per week in their clinics, it was revealed that hip flexion range of motion assessment was performed 98% of the time (Martin et al, 2010).

A Universal Goniometer is an easily accessible and cheap hand-held device that allows a clinician to measure angles and joint ranges of motion. Even in an unskilled examiner, a goniometer has excellent intra-rater reliability (ICC of 0.906, $P < 0.05$) (Kim et al, 2016) and good to excellent intra-rater, test-retest reliability for measuring hip flexion range of motion (ICC 2.2 (.97) and 95% confidence interval), (Pua et al, 2008). The universal goniometer has also been shown to be a valid measurement device when compared to radiography for measuring knee joint angle (Pearson's $r \geq 0.97$, ICC: 0.98 – 0.99) (Goggia et al, 1987).

1.7.2 Muscle strength assessment

Lower limb weakness can be a key factor affecting performance in field-based sports such as rugby union. As such, assessment of hip muscle strength is recommended for athletes with hip and groin symptoms (Thorborg et al, 2010). Hip muscle strength measurement scores can assist in the decision-making process of determining whether a player can return to play or not. An objective marker of a strength deficit of between 5-10% of the unaffected limb or baseline strength is often used clinically as part of the return to play criteria for athletes returning from injury (van der Horst et al, 2016).

1.7.3 Methods of assessing hip muscle strength

Historically, manual muscle testing (MMT) has been used to assess muscle strength in a clinical setting. MMT measures muscle strength on six levels on a scale of zero to five. The six levels are:

- 0- No contraction.
- 1- Muscle can be felt to twitch or tighten, but no movement is produced.

- 2- The muscle being tested can move with gravity eliminated, but cannot produce movement against gravity.
- 3- The muscle can lift or move against gravity.
- 4- The muscle can move against external resistance and gravity combined.
- 5- The muscle can overcome a greater amount of external resistance than level '4'.

This method (MMT) of testing is cost-free and easy to apply; however, it is limited in its use when testing people who are stronger than level three. In a population of professional rugby players, all players would most likely score five on this scale, despite having significant muscular deficits.

Assessing muscle strength using a hand-held dynamometer (HHD) is valid (Roy et al, 2009) and reliable (for a young athletic population) (Thorborg et al, 2010), and is regularly used for assessing hip muscle function (Tyler et al, 2001). A HHD is a portable quantitative measurement device for assessing unilateral muscle strength.

A HHD is commonly used clinically, primarily because it is relatively inexpensive, portable and easily applied (Andrews et al, 1996). Assessing lower limb strength with a HHD (including hip flexion strength) has been shown to have good intra-rater reliability of above 0.90 and excellent inter-rater reliability of above 0.80 when conducted by different examiners and when measured many different times (Kim et al, 2015). Importantly, when clinically assessing hip flexion muscle strength using a hand-held dynamometer, the test-retest measurement variation is below 5%, making it possible to detect small changes in hip strength at an individual level (Thorborg et al, 2010) and thus further assisting in determining the effect, if any, on prescribed rehabilitation.

Strength testing using a HHD is typically performed by way of a 'make test', or a 'break test'. With a make test, the examiner holds the HHD stationary while resisting the subject's maximal isometric contraction. During a break test, the examiner pushes the HHD against the subject's limb until the subject's maximal muscular effort is overcome. Eccentric muscle testing by way of a break test has been shown to yield greater strength values than an isometric make test (Bohannon et al 1988). If attempting to measure the maximal strength of strong muscles around the hip joint, the strength measured by a break test will be greater than that of a make test (Lu et al, 2011). A study comparing make and break tests using a HHD on the elbow flexion strength of thirty-two healthy participants reported that the magnitude of force from the break tests were significantly greater (1.06 times greater) than the make tests (Stratford et al, 1994), thus supporting the theory that a break test will obtain a maximal voluntary contraction from the

participant, provided the examiners strength is greater than the specific group of muscles that are being tested.

1.7.4 Patient Reported Outcome Measure (PROM)

Patient-reported outcome measures (PROMs) have become an important tool in narrowing the gap between the patients and clinicians view of the clinical reality of an injury or disability (Nelson et al, 2015). PROMs can be used to evaluate the effectiveness of an intervention or rehabilitation program, and indeed subjects who complete a validated PROM may feel that their clinician is fully invested in their care through showing an interest in gaining their perspective on their injury and progress (Dawson et al, 2010).

The Copenhagen Hip and Groin Outcome Score (HAGOS), (appendix 1) was developed in 2011 in response to the perception that a valid and reliable patient-reported outcome questionnaire for young physically active individuals was lacking (Thorborg et al, 2011).

The process of developing this tool involved identifying a population (young to middle aged physically active individuals), item generation, interviewing clinical experts, and patient interviews. Validity and reliability were then evaluated in a clinical study including one-hundred and one physically active patients. Test-retest reliability was substantial with ICC ranges of 0.82 to 0.91 for each subscale (subscales listed below). Construct validity for the HAGOS was also confirmed with a statistically significant correlation coefficient of 0.37 – 0.73, $p < 0.01$ (Thorborg et al, 2011).

The HAGOS consists of six subscales that assess and score symptoms, pain, physical function in daily living, physical function in sport & recreation, participation in physical activities and quality of life.

In a study aiming to establish reference values for HAGOS in hip and groin free injury soccer players, it was revealed that players who had hip and groin pain the previous season but were pain free at the time of completing the questionnaire displayed lower scores than players without for all HAGOS subscales ($P < 0.001$), (Thorborg et al, 2014).

In a systematic review of PROM questionnaires for adults with hip and groin disability, HAGOS was recommended for use on young physically active adults (Thorborg et al, 2015).

Another PROM, the International Hip Outcome Tool - 33 (iHOT-33), (appendix 2), was developed in 2012 as a quality-of-life reported outcome measure for a young active individual with hip pathology. It uses a visual analog scale (VAS) response format. It is reliable (pearson

correlation 0.80) and valid (0.81, $P < 0.01$) for self-administration by young, active patients with hip pathology (Mohtadi et al, 2012).

The iHOT-33 has four domains that assess symptoms & functional limitations, sports and recreational limitations, job-related concerns, and social and lifestyle concerns. In a systematic review of the clinimetric evidence for PROMs for young to middle-aged adults with hip and groin disability, it was recommended for assessing young and middle-aged adults with pain and dysfunction related to the hip (Thorborg et al, 2015).

1.8 Summary

Professional rugby union has one of the highest incidences of injury of any team sport (Williams et al, 2013). The game is characterised by its physical nature, including scrummaging, tackling, rucking, line outs and mauls. The lower limb is the most commonly injured site in professional rugby union players (Williams et al, 2013), with the hip and groin region commonly in the top three injured regions of the lower limb (Bathgate et al, 2001; Fuller et al, 2013, Whitehouse et al, 2016). The severity (time-loss) for hip and groin injuries have also been substantially increasing over the past three RWCs (Fuller et al, 2008; 2013; 2017).

Hip muscle strength imbalance around the hip is a risk factor for hip and groin pain (Engebretsen et al, 2010; Crow et al, 2010; Belhaj et al, 2016; Moreno-Perez et al, 2017). A reduction in hip flexion ROM has also been cited as a risk factor for injury (Henderson et al, 2010).

Assessment of hip muscle strength and range of motion are vital components in the ongoing pursuit of attempting to prevent and reduce injuries in professional rugby union. The use of reliable and valid PROMs can also aid clinicians in monitoring a player's perspective on their injury and recovery.

To the knowledge of this author there is no published normative values on hip flexion strength and range of motion in professional rugby union players.

1.8.1 Justification for this study

Hip and groin injuries are among the most commonly reported injury in professional rugby union resulting in significant time-loss from match play. The published literature around hip strength assessment and hip range of movement assessment primarily involved hip rotational and frontal plane movements. This has highlighted a gap in the literature around hip flexion strength and kinematics in a sporting population, and their association (if any) with a risk of injury or a history of hip and groin injury. Not only will this study address the aforementioned gap in the literature, the assessments used in this study are valid, reliable and easily reproducible clinically with minimal cost.

1.9 Aims and objectives

The primary aims of this study are:

- To establish normative reference values for hip flexion strength in professional rugby union players using a hand-held dynamometer during a maximal voluntary eccentric contraction (MVEC).
- To establish normative reference values for hip flexion range of motion in professional rugby union players using a Universal Goniometer.

The objectives of this study are:

- To establish whether players' hip flexion range of motion or strength are influenced by: playing position; having a history of hip and groin pain; or leg dominance.
- To establish if there is a correlation between: 1) hip flexion strength and HAGOS scores; 2) hip flexion strength and i-HOT 33 scores; 3) hip flexion ROM and HAGOS score; 4) hip flexion ROM and i-HOT 33 scores.
- To establish if HAGOS and i-HOT 33 scores are influenced by a player having a history of hip and groin pain, despite being injury and symptom free at the time of testing.

CHAPTER 2 - METHODS

2.1 Participants

Sixty-five male professional rugby union players were invited to participate in this study voluntarily. Every player received a copy of the Participant Information Leaflet (appendix 3). Players were excluded from participating in the study if they had hip, groin, or lumbar surgery in the previous two years. Twenty-one players were excluded in total, due to unavailability at the time of testing or having a long-term lower limb injury or having ongoing hip and groin symptoms that were at risk of being aggravated from the testing procedure. The remaining 44 gave their written informed consent (appendix 4) to participate in the study. All of the participants were professionally contracted players with Leinster Rugby (LR). Testing took place during the in-season at LR headquarters, and was conducted on the day after a recovery day (a fully day off from exercise) for the players.

2.2 Ethical Considerations

This study was approved by the Trinity College Faculty of Health Science Research Ethics Committee (see appendix 3). The objectives of the study were explained fully and written consent was obtained from all participants.

Participants identities were protected by being assigned a code, that was only available to the research team. Only one participant was tested at a time, so their identity was only known by the investigator. Their interest and involvement was not divulged to anyone outside of the research team.

Collected data was stored in secure computer files by a password known only to the lead researcher.

All participants were advised that they could withdraw from the study at any stage.

2.3 Instrumentation

The measurement device used for measuring strength in this study was a digital load cell hand-held dynamometer (HHD; Jtec Powertrack II Commander), figure 7 below.

Figure 7: Jtec Powertrack II Commander Hand-held dynamometer



(<http://jtechmedical.com/Commander/commander-muscle-tester.jpg>, 2017)

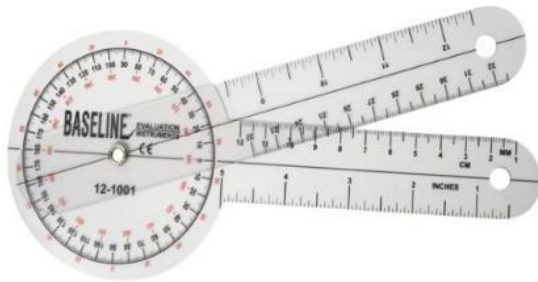
A HHD is regularly used in the clinical assessment of muscle strength and function around the hip (Tyler et al, 2001). In a clinical measurement - validity study, the specific model of HHD used in this study was shown to have good concurrent validity when compared with a stationary dynamometer (pearson correlations between the two dynamometers of $r=0.81$). Correlations remained similar in the same study when results were further divided by gender or tester (Roy et al, 2009).

The HHD model used in this study is was also found to be a reliable measurement tool for assessing hip flexion strength in young, physically active people (Thorborg et al, 2015).

The hand-held dynamometer (HHD) was calibrated prior to testing by the bio-engineering department of Trinity College Dublin.

A standard Universal Goniometer (Baseline, 12-inch, figure 8 below) was used to measure hip flexion range of motion.

Figure 8: A Baseline, universal 12-inch goniometer.



(www.feiretail.com/media/02_Evaluation/12-1001.jpg,2017)

2.4 Procedures

2.4.1 Hip flexion strength testing protocol

The strength testing procedure was standardized. The dominant and non-dominant legs of all participants were tested. Leg dominance was self-identified and established by the preferred kicking leg of each player. A single physiotherapist working in professional sport with experience in using a HHD performed all the testing. All of the strength tests were eccentric break tests (Stratford et al, 1994).

Players were familiarised to the testing protocol by way of written (appendix 2) and verbal explanation. Each participant went through a standardised lower body warm up consisting of five body weight squats, and a 40-metre run prior to testing. The 40-metre run was instructed to be run at an easy pace, self-selected by each participant.

An eccentric break test was used to establish peak hip flexor strength. During a break test the examiner pushes the HHD against the participants limb until the participants maximal effort is overcome. Isometric make tests are often performed on symptomatic individuals so as not to exacerbate their pain, however the participants in this study were injury free at time of testing, meaning a maximal effort break test was deemed low risk and would provide values of maximal strength.

The test position chosen to measure hip flexion strength was with the participant lying supine on a plinth. This position has been described previously as a commonly used position in a clinical setting (Pua et al, 2008) and testing hip flexion strength in this position with a HHD has also been shown to be reliable (ICC of 0.94, CI of 95%) (Thorborg et al, 2010). For this study, one Mulligan belt was used to stabilise the abdomen at the level of the umbilicus, and another Mulligan belt stabilised the contralateral leg 5cm proximal to the proximal pole of the patella. This was according to the protocol reported by *Thorborg K, 2010*. The use of the belts was to minimise any potential stabilisation problems during the participants maximal muscular effort. Belt stabilisation is commonly used clinically and for research purposes when using a HHD (Thorborg et al, 2010). The participant also self-stabilised by holding onto the side of the table during testing. Mulligan belts are easily accessible and inexpensive, making the set-up of this test easily replicable in a clinical setting.

Once the participant was supine on the plinth and with the belt stabilisations in place, they were requested to flex their hip to ninety degrees, which was confirmed by goniometer measurement (all participants were able to actively flex their hips to a minimum of ninety degrees). The HHD was placed 5cm proximal to the proximal pole of the patella on the limb being tested as per *Thorborg K, 2009*. The participant was then asked to perform one sub-maximal contraction into the examiners hand, in order to ensure the correct action was executed. The participant then performed a sub-maximal trial effort against the HHD. The actual test was then performed three times on each limb with a 60 second rest between each effort (timed using an Apple iPhone stopwatch). The participant was instructed to flex the hip (from a starting position of ninety degrees) against the resistance of the HHD over three seconds while encouraged by the examiners command of 'push, push, and push' (figure 9). At three seconds, the examiner broke the participant's maximum effort and the force was recorded by the HHD. The highest value of the three consecutive readings was recorded. A two-minute rest period (measured by an Apple iPhone stopwatch) was given before testing the contralateral hip. By allowing resting periods between repetitions, the risk of a decline in strength is minimised (Sisto et al, 2007).

Figure 9: Testing position protocol for hip flexion strength measurement.



After both limbs were tested in 90 degrees of hip flexion a further two-minute rest period was granted. The participant was asked to actively flex their hip to their maximum available inner range (measured by goniometer and recorded). The same break test procedure was performed with their hip actively flexed to their maximal available inner range (which was beyond 90 degrees for all participants). The purpose of also testing hip flexion strength beyond 90 degrees was because the iliopsoas muscle has been shown to be at its most active in 90 degrees and above and during maximal hip flexion efforts (Juker et al, 1998). In a study examining the electromyogram (EMG) activity of the hip flexor musculature during different training exercises, it was reported that iliopsoas performs in greater isolation in inner range (90 degrees and above) hip flexion than Rectus Femoris and Sartorius (Andersson et al, 1997).

2.4.2 Hip Flexion range of motion assessment

A 'Baseline' standard universal goniometer (UG) was the instrument used to measure active hip flexion range of movement. The protocol for measurement of hip flexion ROM was standardized as suggested by (Clarkson et al, 2000). The participant lay supine on the plinth. The axis of the UG was placed over the greater trochanter of the femur. The stationary arm was parallel to the lateral pelvic mid-line and pointing towards the glenohumeral joint of the ipsilateral side. The moveable arm of the UG was lined up with the lateral mid-line of the femur, pointing towards the lateral femoral condyle. The contralateral limb remained in the anatomical position throughout, and the pelvis was not allowed to lift during the movement.

The participant was requested to maximally flex their hip (with their knee joint in flexion). AROM was performed three times on each hip and the mean value recorded by the assessor in degrees.

2.4.3 HAGOS and i-HOT 33

All participants were furnished with a HAGOS and i-HOT 33 Patient-Reported Outcome Measure (PROM). It was explained verbally and in writing (on informed consent form) that their responses would remain confidential and that by filling out these forms it would help inform the researchers of any hip symptoms they had. Each participant filled out the form on their own in a meeting room and then returned the completed form into a closed box, only accessible to the main researcher.

2.5 Statistical analysis

The statistical software package SPSS was used to analyse the raw data. The level of statistical significance was set at 0.05.

Normative values of active hip flexion range of motion

Percentile scores between 5 and 95% were computed for each of the values.

Normative values of hip strength

Percentile scores between 5 and 95% were computed for each of the values.

To calculate the percentile values, the 'frequencies' tab was chosen in the Analysis section of SPSS. The boxes 'percentiles' and 'equal groups' were ticked, with 20 equal groups enabling the percentile values to be shown in increments of five.

In the results section, each table clearly shows which variable was the dependent variable or outcome variable, and which variables were the independent variables or predictor variables.

Previous hip and groin history

All participants were injury free and symptom free during the testing procedure. Those participants who had a history of hip and groin pain were identified by the lead team physiotherapist from their injury history records.

Playing position, kicking leg and history of hip and groin pain.

A multivariate linear regression analysis of data was used to determine the influence of playing position, kicking leg, and history of hip and groin pain on the clinical measures of hip flexion strength and range of motion. Regression was chosen as the players were in self-selected groups of playing position, kicking leg and history of hip and groin pain.

Clinical measures of hip flexion strength and hip flexion range of motion.

A linear regression analysis of data was used to determine if a correlation existed between the clinical measures of strength and range of motion and the subsections of i-HOT 33 and HAGOS.

HAGOS and i-HOT 33

A linear regression analysis of data was used to establish if HAGOS and i-HOT 33 subsection scores were influenced by a player having a history of hip and groin pain, despite being injury and symptom free at the time of testing. Regression was chosen as the players were in self-selected groups of playing position, kicking leg and history of hip and groin pain.

CHAPTER 3 - RESULTS

3.1 Demographic Profile

The demographic profile of the participants are presented in table 7 below.

Table 7: Demographic profile of participants.

Demographics	Participants (n =44)
Age (years): mean $\pm$ SD	25.3 $\pm$ 4.9

BMI (Kg/m ²): mean $\pm$ SD	102.4 $\pm$ 13.3
Height (cm): mean $\pm$ SD	187 $\pm$ 7.66

The primary aim of this study was to establish normative values for hip flexion strength, and hip flexion range of motion for male professional rugby union players. Tables 7 and 8 below illustrate these values.

Table 7: Normative values for hip flexion strength in professional rugby union players.

Participant Percentiles	STR Right @ 90 °	STR Left @ 90°	Inner range R Peak (Nm)	Inner range L Peak (Nm)
5%	242.0	225.4	181.6	195.8
10%	266.6	241.1	211.0	211.0
15%	281.0	246.0	211.9	222.2
20%	288.0	255.0	220.0	229.2
25%	296.5	258.2	226.5	249.0
30%	301.0	265.9	238.2	263.3
35%	305.0	267.1	266.5	269.3
40%	312.8	271.0	282.4	292.0
45%	316.0	277.1	290.0	308.7
50%	321.0	283.5	298.5	313.0
55%	325.0	288.0	313.3	315.3
60%	332.4	296.8	329.0	317.6
65%	343.0	300.9	344.9	322.9
70%	354.2	308.8	367.6	325.5

75%	378.0	320.5	382.5	331.0
80%	384.0	327.0	395.8	347.8
85%	389.2	334.0	407.3	364.9
90%	398.8	345.8	412.7	387.7
95%	410.2	385.1	425.4	409.6

STR: Strength **Nm:** Newton-meters per kg of body-weight Nm/kg

Table 8: Normative values for hip flexion range of motion in professional rugby union players.

Participant Percentiles	Hip flex Right mean °	Hip flex Left mean °
5%	100.8	96.3
10%	103.7	96.9
15%	105.3	97.7
20%	106.6	99.4
25%	107.5	102.6
30%	108.0	104.3
35%	108.0	105.4
40%	109.1	106.7
45%	109.3	107.1
50%	109.8	107.8
55%	110.3	108.4
60%	110.9	109.3
65%	111.3	109.7
70%	112.8	110.7
75%	114.3	111.2
80%	115.3	112.1

85%	116.8	113.0
90%	117.3	113.9
95%	120.5	117.0

One of the objectives of this study was to establish if hip flexion range of motion and hip flexion strength values were influenced by playing position, kicking leg, or having a history of hip and groin pain. A linear regression analysis of data was used to determine correlation.

A multivariate regression analysis was used as the examiner did not allocate participants to groups, rather, they self-selected kicking leg, playing position and injury history.

Categorisation of players: Players were categorised in the tables below into either 'backs' or 'forwards'. Players in the 'backs' group are positions 9 to 15 on the field of play, typically lighter than the forwards and cover more running distance. The players in the 'forwards' group are numbers 1-8 on the pitch and are involved in scrummaging, line-out lifting and cover less overall running distance than the backs.

Tables 9-14 outline the findings.

Table 9: Influence of variables on hip flexion range of motion of the right leg.

	Mean	Std.error	t value	P value
Hip Flexion Right ROM ° (Dependent variable)	108.9	3.9	27.93	0.771

Positive history of hip and groin injury	1.28	2.26	0.57	0.57
Position 'Backs'	2.79	2.75	1.01	0.32
Position 'forwards'	1.78	3.09	0.58	0.57
Dominant Leg (R)	-1.05	2.57	-0.41	0.69

- Residual standard error: 5.83 on 39 degrees of freedom
Multiple R-squared: 0.0442, Adjusted R-squared: -0.0538
- F-statistic: 0.451 on 4 and 39 DF, p-value: 0.771

Playing position, leg dominance and having a history of hip and groin pain had no statistically significant influence on active hip flexion range of motion of the right leg in this cohort.

Table 10: Influence of variables on hip flexion range of motion of the left leg.

	Mean	Std.error	t value	P value
Hip Flexion Left ROM ° (Dependent variable)	107.384	4.63	23.19	0.742
Positive history of hip and groin injury	2.064	2.688	0.77	0.45
Position 'Backs'	-2.025	3.271	-0.62	0.54
Position 'forwards'	-2.701	3.669	-0.74	0.47
Dominant leg (R)	0.973	3.053	0.32	0.75

- Residual standard error: 6.92 on 39 degrees of freedom
Multiple R-squared: 0.0479, Adjusted R-squared: -0.0497
- F-statistic: 0.491 on 4 and 39 DF, p-value: 0.742.

Playing position, leg dominance and having a history of hip and groin pain had no statistically significant influence on active hip flexion range of motion of the left leg in this cohort.

Table 11: Influence of variables on peak hip flexion strength of the right leg at 90°.

	Mean	Std.error	t value	P value
Peak Hip Flexion strength @ 90° Right leg (Dependent variable)	330.307	40.381	8.18	0.701
Positive history of hip and groin injury	4.587	23.446	0.20	0.85
Position 'Backs'	-18.195	28.524	-0.64	0.53
Position 'forwards'	11.669	31.997	0.36	0.72
Dominant leg (R)	0.233	26.625	0.01	0.99

- Residual standard error: 60.4 on 39 degrees of freedom
Multiple R-squared: 0.0533, Adjusted R-squared: -0.0438
- F-statistic: 0.549 on 4 and 39 DF, p-value: 0.701

Playing position, leg dominance and having a history of hip and groin pain had no statistically significant influence on hip flexion strength at 90° of the right leg in this cohort.

Table 12: Influence of variables on peak hip flexion strength of the left leg at 90°.

	Mean	Std.error	t value	P value
Peak Hip Flexion strength @ 90° Left leg (Dependent variable)	299.671	32.609	9.19	0.48
Positive history of hip and groin injury	-4.476	18.933	-0.24	0.81
Position 'Backs'	-26.418	23.034	-1.15	0.26
Position 'forwards'	0.246	25.838	0.01	0.99
Dominant leg (R)	6.567	21.501	0.31	0.76

- Residual standard error: 48.8 on 39 degrees of freedom
Multiple R-squared: 0.0836, Adjusted R-squared: -0.0104
- F-statistic: 0.889 on 4 and 39 DF, p-value: 0.48

Playing position, leg dominance and having a history of hip and groin pain had no statistically significant influence on hip flexion strength at 90° of the left leg in this cohort.

Table 13: Influence of variables on peak hip flexion strength of the right leg at maximal available inner range (above 90°).

	Mean	Std.error	t value	P value
Peak Hip Flexion strength @ inner range hip flexion - right leg (Dependent variable)	289.53	58.24	4.97	0.372
Positive history of hip and groin injury	1.13	33.81	0.03	0.97
Position 'Backs'	-39.25	41.14	-0.95	0.35
Position 'forwards'	15.91	46.15	0.34	0.73
Dominant leg (R)	34.57	38.40	0.90	0.37

- Residual standard error: 87.1 on 39 degrees of freedom
Multiple R-squared: 0.101, Adjusted R-squared: -0.00888
- F-statistic: 1.1 on 4 and 39 DF, p-value: 0.372

Playing position, leg dominance and having a history of hip and groin pain had no statistically significant influence on hip flexion strength at maximal available inner range of the right leg in this cohort.

Table 14: Influence of variables on peak hip flexion strength of the left leg at maximal available inner range (above 90°).

	Mean	Std.error	t value	P value
Peak Hip Flexion strength @ inner range hip flexion - left leg (Dependent variable)	369.0	41.5	8.89	0.0424
Positive history of hip and groin injury	-34.9	24.1	-1.45	0.156
Position 'Backs'	-72.5	29.3	-2.47	0.018*

Position 'forwards'	-31.7	32.9	-0.96	0.341
Dominant leg (R)	-17.5	27.4	-0.64	0.525

- Residual standard error: 62.1 on 39 degrees of freedom
Multiple R-squared: 0.219, Adjusted R-squared: 0.139
- F-statistic: 2.74 on 4 and 39 DF, p-value: 0.0424

Leg dominance and having a history of hip and groin pain had no statistically significant influence on hip flexion strength at maximal available inner range of the left leg in this cohort.

If a player was a back, their inner range hip flexion strength score decreased by 72.5Nm when compared to a backrow forward, which is significant ($p = 0.018$).

A separate objective of this study was to examine the correlation (if any) between:

- hip flexion strength values and i-HOT 33 and HAGOS subsections.
- hip flexion range of motion values and i-HOT 33 and HAGOS subsections.

Regression models of analysis were used to establish if there were any correlations between the clinical measures of strength and range of motion with every sub-section of i-HOT 33 and HAGOS. No correlation was found between active hip flexion range of motion and the subsections of the i-HOT 33 or the subsections of HAGOS. The i-HOT 33 subsections were; 1) symptoms and functional limitations, 2) job-related concerns, 3) sports and recreational activities, and 4) social, emotional and lifestyle concerns. The subsections of HAGOS are; 1) pain, 2) symptoms, 3) activities of daily living, 4) sport and recreational activities, 5) participation in physical activities, and 6) quality of life. No significant correlations were found between either clinical measure of strength or range of motion and the PROM subsectional scores.

The output for all of this data is presented in appendices 5 and 6.

The final objective of this study was to establish if HAGOS and i-HOT 33 subsection scores were influenced by a player having a history of hip and groin pain, despite being injury and symptom free at the time of testing. Tables 15 and 16 below highlight the significant findings from this analysis. Please see appendix 7 for all raw data.

Please also note: playing position or kicking leg had no significant effect on the scores of the sub-sections of i-HOT 33 or HAGOS.

Table 15: Significant findings on the effect of having a history of hip and groin pain on the subsections the i-HOT 33.

	Effect of history of hip and groin pain on scores	p value	Adjusted R-squared
i-HOT 33 symptoms and functional limitations	-7.796	0.043	0.115 (11.5% variance)
i-HOT 33 Job related concerns	-15.07	0.0096	0.234 (23.4% variance)
i-HOT 33 Social, emotional and lifestyle concerns	-9.5	0.013	0.281 (28.1% variance)

The results showed that injury-free professional rugby players with a history of hip and groin pain experienced more symptoms, had more job-related concerns and also had more social, emotional and lifestyle concerns than their colleagues without a history of hip and groin pain. No correlation was found between having a history of hip and groin pain and the i-HOT 33 subsections of sports and recreational activities.

Table 16: Significant findings on the effect of having a history of hip and groin pain on the subsections of HAGOS.

	Effect of history of hip and groin pain on scores	p value	Adjusted R-squared
HAGOS symptoms	-13.72	0.0061	0.241 (24.1% variance)

HAGOS function, sports and recreational activities	-14.19	0.006	0.327 (32.7% variance)
HAGOS quality of life	-21.64	0.002	0.305 (30.5% variance)

The results showed that injury-free professional rugby players with a history of hip and groin pain experienced more symptoms, had a reduction in quality of life and functional and recreational activities than their history free colleagues. No correlation was found between having a history of hip and groin pain and the subsections of pain, activities of daily living and physical activities.

CHAPTER 4 - DISCUSSION

4.1 Introduction

The aim of this study was to address a gap in the literature surrounding hip flexion strength and kinematics in a sporting population, and their association (if any) with a risk of injury or a history of hip and groin injury.

The normative hip flexion strength ranges documented in this study are a valuable reference point for clinicians working in professional team sports as they recorded peak strength values. A like-for-like comparison with the normative values of hip strength as outlined by *Thorborg K, 2014* in professional soccer cannot be made due to methodological differences, however the methods of measurements used in this study are easily reproducible and should be applied by clinicians working in professional sport in order to make the data meaningful.

In analysing what influence the variables of playing position, history of hip and groin pain, and preferred kicking leg had on hip flexion ROM, it was found that there was no significant correlation between any of the variables and the clinical measures.

The same variables of playing position, kicking leg, and history of hip and groin pain were also analysed to determine their influence on hip flexion strength. The only significant finding was that if a player was a back, their inner range hip flexion strength decreased by 72.5 Nm ($p=0.018$), when compared to the playing position of back row forward. The reasons for this finding cannot be inferred from this study, so no cause and effect can be given, and as a result this finding only serves to provide us with a question as to why this was the case. Further research into examining strength differences by playing position may shed further light on this finding.

This thesis also highlighted that rugby union players who are injury free, but have a history of hip and groin pain, subjectively experience more symptoms, have more job related and social concerns, and have a decreased quality of life than their colleagues without a history of hip and groin pain. This finding is in line with other studies (*Thorborg et al, 2014*), and further sheds light on the difference between objective clinical measures and subjective PROM scores.

4.2 Normative value of hip flexion strength.

The first aim of this study was to establish normative reference values for hip flexion strength for male professional rugby union players. This is the first known study to document these values. Having normative reference values of strength are an important component in attempting to identify limitations or deficits that can be addressed (*Bohannon et al, 2005*).

This study presents normative ranges as illustrated in table 7. The methods of recording these values are easily reproducible clinically. The values of hip flexion strength are normally distributed, and no significance in strength was identified between the participants' dominant and non-dominant legs. Strength was assessed at 90° of hip flexion and also at the participants maximal available inner range of hip flexion (above 90° in all cases). Mean hip flexion strength for this cohort when tested in 90° of hip flexion was 319.0 Nm (+/- SD 59.11) for the dominant kicking leg and 267.7 Nm (+/- SD 48.11) for the non-dominant leg.

The normative values outlined in this study cannot be compared to reference values for the general public as there is no published literature currently available to make such a comparison. There is only one other published study that collected normative hip flexion strength for a multi-directional team sport, (Hanna et al, 2010). This study recorded hip flexion strength in amateur football players from New Zealand using a HHD, however the authors chose an isometric make test, as opposed to a break test as used in this study. They also chose to measure strength in the modified 'Thomas Test' position, which places the hip in a position of hip extension, essentially outer range strength. As a consequence, a like-for-like comparison cannot be made.

Both this study and the study by *Hanna C, 2010* did however both use a calibrated HHD, and all strength tests were carried out on injury and symptom free participants at the time of testing. Table 17 below illustrates the comparisons of methods used in both studies.

Table 17: Comparison of methods between this study and Hanna C, 2010 for establishing normative hip flexion strength values.

	This study	<i>Hanna C, 2010</i>
Instrument used	HHD	HHD
Position of participant	Supine in 90° of hip flexion	Modified Thomas Test, in hip extension

Method of strength test used	Eccentric break test	Isometric make test
Participant	Professional rugby union player	Amateur football players

While table 17 highlights methodological differences between both studies, table 18 attempts to compare mean values between the two studies. The values outlined for this study in table 18, refer to hip flexion strength at 90° only.

Table 18: Differences of mean hip flexor strength values, between professional RU players and amateur footballers.

	This study	<i>Hanna C, 2010</i>
Mean strength Dominant leg	319.0 Nm	200.5 Nm
Mean strength non-dominant leg	296.7 Nm	180.1 Nm

It is difficult to infer anything meaningful from tables 17 and 18, other than come to the conclusion that:

1. There are no published studies currently with normative values for hip flexion strength in professional rugby union players, and a general paucity of publications for normative values for all team sports.
2. Methodology between this study and the study by Hanna C, 2010 differ greatly, making meaningful comparisons difficult and importantly, highlighting the need for a common methodological consensus going forward.

An interesting finding from this study was that there was no significant difference in strength values between playing position and dominant versus non-dominant leg. The study by Hanna C, 2010 found a significant strength difference of 10.2% ($p < .0001$) between the dominant and non-dominant legs of football players. This may be because football is a sport where every player kicks the ball throughout a match with mostly a dominant leg, whereas in rugby

union, kicking, while an important component in the game, is not the predominant skill throughout the team.

As this is the only available data outlining normative values for hip flexion strength in this unique population, it can potentially be used to serially monitor players throughout the cycle of a season. A professional rugby player could be assessed for any weakness relative to the predicted normal values. This information may help with off-season screening of players, and may also form a component of the multi-faceted return-to-play decision conundrum.

4.3 Normative values of active hip range of motion.

Another primary aim of this study was to establish normative reference values for active hip flexion range of motion in professional rugby union players. Table 8 illustrates these values. This study measured hip flexion range of motion using a commonly used and easily applied clinical method of assessment. There are currently no studies with normative data for hip flexion range of motion for any sport, making this the first known study to do so. The results revealed no significant difference in hip flexion range of motion between dominant and non-dominant legs, playing position or history of hip and groin pain.

There is very little published data detailing normal joint range of motion for the general population, again meaning comparisons cannot be made.

Of the limited literature available, one study in 2010 (Soucie et al, 2010) attempted to establish normative reference values for passive joint ranges of motion for the general population aged between two and sixty-nine. The study published mean values for difference age ranges and different sexes. The closest matched group to this study was the male group aged between twenty and forty-four. The mean passive hip flexion range of motion for this group was 130.4 ° (Soucie J, 2010), while the mean active hip flexion range of motion for the cohort examined in this study was 108.9° for the right leg, and 107.38° for the left leg. That is a difference of 21.5° and 23.02° for the right and left leg respectively, when comparing both studies.

It is reported that a reduction in hip flexion range of motion significantly increases a professional footballer's risk of incurring a hamstring injury (Henderson et al, 2010), ($p < 0.05$). While this is a different sporting population to the one examined in this study, it remains a relevant finding for all multi-directional team sports including rugby union.

The normative reference values for active hip flexion range of motion as outlined in this study may be used in conjunction with the normative strength values in monitoring, assessing and decision making in professional rugby union.

4.4 Influence of playing position, history of hip and groin pain and leg dominance on the clinical measures of hip flexion strength and hip flexion range of motion.

Another objective of this study was to establish if the clinical measures of hip flexion strength and hip flexion range of motion were influenced by having a history of hip and groin pain, playing position, or leg dominance. A linear regression analysis of data revealed that the only significant influencer of hip flexion strength was that if a player was a back, then their mean inner range hip flexion strength decreased by 72.5Nm, ($P < 0.018$) when compared to a backrow forward player.

An Australian study that profiled academy level rugby union players strength by leg preference and playing position, found that backs produced lower peak torque values than the forwards during hip flexion strength testing, however it was not significant ($p < 0.45$), (Brown et al, 2016). The study by *Brown, 2016* measured concentric isokinetic strength through mid-range hip flexion, as opposed to inner range testing using a HHD with an eccentric break test, as per the protocol in this study.

Forwards in rugby union require large force producing capabilities during situations such as scrums, mauls and wrestling, whereas backs need great velocity capabilities for evasion and high-speed running (Vaz et al, 2013). Backs are also responsible for the majority, if not all, of the kicking in Rugby Union, which places a large demand on the hip flexor musculature. The different demands on the hip flexor musculature may be a theoretical reason for the significant strength difference found between the backs and the backrow forwards, however this does not entirely make sense as there was no difference in the strength between the backs and the 'tight-five' forwards playing position. Further research may be beneficial to profile rugby union players strength by playing position, further breaking down the forward positional group into two separate groups for tight-five forwards, and backrow forwards. This may help with positional strength demands per playing group.

4.5 Influence of PROM subsection scores on the clinical measures of hip flexion strength and hip flexion range of motion.

This study also examined the correlation, if any between hip flexion strength and HAGOS and i-HOT 33 subsection scores, and the relationship between hip flexion range of motion and HAGOS and i-HOT 33 subsection scores. The results showed that there is no significant correlation between the clinical measures of hip flexion strength and range of motion and the i-HOT 33 and HAGOS scoring. It was hypothesised that a reduced sub-section score in either of the PROMs used, would correlate with a concomitant reduction in hip flexion strength and range of motion, however this was proven to not be the case, as no statistical correlation was found

This is an important finding of this study, as it highlights the difficulty in correlating a single outcome with injury or symptoms in a sporting population. It is said that the multifactorial and complex nature of sports injuries arises not from the linear combination of isolated and predictive factors, but from the interaction among what Philippe, 1998 called 'the web of determinants' (Philippe et al, 1998). Furthermore, a recent study that carried out a comprehensive strength testing protocol on over 400 professional footballers, came to the conclusion that the clinical value of isolated strength testing is limited, especially in its use to attempt to predict future injury (van Dyk et al, 2017). Hip extension strength was not measured in this study, and is acknowledged as a study limitation. This is not to say that isolated clinical tests, such as the ones carried out in this study have no value, or should be disregarded. Rather, it should be recognized that they should form part of a comprehensive assessment and measurement of many factors in the ongoing problematic pursuit of injury prediction.

A recent study evaluated lower extremity and trunk muscle strength and function in patients with long-standing hip and groin pain. The authors hypothesized that they would exhibit more deficient scores in functional performance measures (such as a parallel squat) and the HAGOS than healthy aged-matched controls. It found that while the patients with hip and groin pain scored significantly lower than the healthy controls in the HAGOS subsections, there was no statistically significant difference between the groups for any of the performance-based measures (Worner et al, 2017).

4.6 Influence of having a history of hip and groin pain on the PROM subsection scores.

The final objective of this study was to establish if the HAGOS and i-HOT 33 subsection scores were influenced by a player having a history of hip and groin pain, despite being injury free at the time of testing. The lead researcher had access to all of the participants injury history. They were deemed to have a history of hip and groin pain, once there was a record of them having an injury to this anatomical region. The results revealed that there was a significant reduction in scores for players with a history of hip and groin pain than those without for three of the four sections in the i-HOT 33 and three of the six sections in the HAGOS. The HAGOS findings are similar to a study on injury-free soccer players, (Thorborg et al, 2017). Injury-free professional rugby union players with a history of hip and groin pain experienced more symptoms ($p=0.0061$), decreased function ($p=0.006$) and a reduction in quality of life ($p = 0.002$) compared to players without, according to our HAGOS findings. The same players also experienced more symptoms ($p=0.043$), and had more job-related ($p=0.0096$), social, emotional and lifestyle concerns ($p=0.013$) to their history-free colleagues. There are no comparative i-HOT 33 studies in the literature.

Australian football players also had significantly lower HAGOS scores for the quality of life subscale if they had historical hip and groin pain (Krew et al, 2017).

It is acknowledged that finding a correlation between lower PROM subscale scores and a history of hip and groin pain is not a novel finding, however it is important to emphasize the important role PROMs can play in potentially identifying a player at risk of a future or recurring injury to the hip and groin (Thorborg et al, 2014). This becomes relevant when a player being is deemed fully fit, injury free and available to play based off strength markers alone. If that same player has a history of hip and groin injury but has not completed a relevant PROM such as HAGOS or i-HOT 33, then that players subjective markers will not be known or addressed appropriately. This study is not stating that having a lower PROM score is a risk factor for injury, rather, this paper is suggesting that being aware of a player's perception of their health is a vital component of the overall management and monitoring of the multiple variables that surround injury risk.

4.7 Interpretation of findings, and indications for future research

The normative values for hip flexion strength outlined in this study, reveal that this cohort of professional Rugby Union players are a heterogeneous population. The lowest percentile (5%) strength score in this group was 181.6 Nm, while the highest percentile (95%) was 425.4 Nm. This may be because, Rugby Union is different from other team-based field sports such as soccer for example, in that each positional group in rugby have markedly different physical demands to each other. Players who are forwards (at all levels, from amateur to professional) are also significantly taller, heavier and have a larger percentage of body fat than their playing colleagues who are backs (Fontana et al, 2015). A player who is a back for example, covers significantly more total distance and distance at high speed running than a forward ($p < 0.01$), while forwards are involved in more collisions, tackles and rucks compared to backs ($p < 0.001$), (Lyndsay et al, 2015). What these findings outline, is that future research should divide players into sub-groups from the outset, as essentially each playing position in Rugby Union are their own unique population with their own unique characteristics and playing responsibilities and demands. Measurement of hip extension strength as well as hip flexion strength is also recommended for future research to provide more insight into sagittal plane hip muscle imbalance and possible correlation with injury.

The normative values outlined in this study for active hip flexion range of motion do not compare favourably with what is often quoted as normal active hip flexion range of motion for the general public. Active hip flexion range of motion in the general population is said to range from 120° to 130° (Roach et al, 1991). The mean active ROM in this cohort for their dominant leg was 108.9°, as opposed to 130.4° in a male cohort aged between twenty-two and forty-four (albeit passive ROM), (Soucie et al, 2010). The normative values as revealed in this study, may lead to the question; is there a hip mobility issue in Rugby Union? While there are of course many variables that may restrict active hip flexion range of motion, all players in this study were injury free. Future research should also attempt to establish factors that may restrict hip mobility in this cohort.

This study also revealed that if a Rugby Union player is a back, then his inner range hip flexion strength is significantly weaker ($p=0.018$) than that of his playing colleague in the backrow position. Hypothetically, this ties in with the different running, kicking and tackling demands of each position, and how they affect hip flexion strength. This finding continues the theme mentioned previously, that Rugby Union is a unique game in that there are effectively at least three different games taking place within one game, in terms of the physical demands of each position. This also emphasises the message that future research in a professional Rugby Union population should treat each playing group separately when examining or measuring strength and range of motion, similar as to how the management group evaluate the performance of each playing position separately.

This study revealed that players who are injury free, but have a history of hip and groin pain score significantly lower in the HAGOS and i-HOT 33 when it comes to symptoms, quality of life and job and social and lifestyle concerns. This is an interesting finding, as the strength and ROM scores of the players with a history of hip and groin pain were not affected. This highlights the importance of using PROMs when monitoring players. If a clinician was only to monitor strength and ROM, and not use a PROM, then they are potentially missing an important component of player management; the players subjective perspective on their health. We already know that having a previous soft tissue injury is a major risk factor for a future soft tissue injury (Mendiguchia et al, 2013) (Bourne et al, 2015), however if a player is at full strength and ROM, then why is this the case? Should the use of PROMs be routinely used in injury free players with a historic hip and groin injury? An area for future research should attempt to examine the relationship between subjective outcome measures and subsequent injury. A hypothesis may be that a player who scores significantly lower on a PROM is more likely to re-injure than a player who does not.

4.8 Study Limitations

A sample of convenience was recruited for this study. All squad members, including academy players were invited to participate in this study, meaning the study sample size was an accurate reflection of the population of a professional rugby union club in Ireland.

Hip extension strength was not measured on this population. Hip extensor strength data may have allowed for further interpretation of results, in terms of muscle imbalance around the hip

in the sagittal plane. As players were tested in-season, the opportunity for further testing was not available due to their regular training and recovery time constraints.

Normative values presented in this study are that of an in-season professional rugby team, so are not indicative of other sporting populations or the general public. An arguable limitation of this study is the use of the Universal Goniometer for the measurement of hip range of motion. While the goniometer has been shown to have good intra-rater reliability, measurements of range of motion might be evaluated by different clinicians with varying levels of experience, meaning that utilisation of this tool may result in measurement error.

Another limitation of this study is that it is a cross-sectional design, capturing data at a specific point in time of the season for the participants, and as such provides a snapshot, rather than changes over time (or a season in this case). This study design also cannot determine cause and effect, however can reveal important correlations (or lack thereof).

A final limitation of this study is the marginally different methodology used in comparison to other studies that measured lower limb muscle strength. It was deemed important to use a break test for this population as opposed to an isometric make test, as a break test yields greater strength values than a break test (Bohannon, 2005), and this study was aiming to record peak strength values.

4.9 Implications for Practice

Evaluating hip range of motion is an important component of a physical examination in a sporting population, allowing the identification of joint and muscle limitations, as well as the potential risk of injury (Verrall et al, 2007). Additionally, range of motion and strength measurement can be used when evaluating the effects of a rehabilitation processes (Clarkson et al, 2012). Having normative reference values of strength are an important component in attempting to identify limitations or deficits that can be addressed (Bohannon et al, 2005). Members of the medical and rehabilitation team working in professional rugby can use these reference values as a guideline of strength and ROM markers when designing player-specific rehabilitation and strength programs.

The method of measuring ROM and strength in this study was chosen specifically with practicing clinicians in mind. Clinicians can easily replicate the protocol used in this study inexpensively.

CHAPTER 6 - CONCLUSION

This thesis set out to address a gap in the literature surrounding the clinical measurement of hip flexion ROM and strength in a professional sporting cohort. This study also examined what influence variables such as playing position, preferred kicking leg, and history of hip and groin pain would have on the clinical measures of hip flexion strength and ROM.

This will be the first study to document normative ranges for hip flexion ROM in a professional sporting population. There are currently no other published studies to compare this data to, making the normative ranges outlined in this study the only available reference point to date for professional rugby union, and indeed all multi-directional field sports.

In analysing what influence the variables of playing position, history of hip and groin pain, and preferred kicking leg had on hip flexion ROM, it was found that there was no significant correlation between any of the variables and the clinical measures.

The same variables of playing position, kicking leg, and history of hip and groin pain were also analysed to determine their influence on hip flexion strength. The only significant finding was that if a player was a back, their inner range hip flexion strength decreased by 72.5 Nm ($p=0.018$), when compared to the playing position of back row forward, emphasising the need for future research into professional Rugby Union players to sub-divide players by playing positional groups from the outset.

This thesis also highlighted that rugby union players who are injury free, but have a history of hip and groin pain, subjectively experience more symptoms, have more job related and social concerns, and have a decreased quality of life than their colleagues without a history of hip and groin pain.

In conclusion, this study provides normative values for hip flexion strength and range of motion for a professional rugby union playing population. While no clinical value can be taken in isolation when making return to play decisions or decisions regarding strength programs, having normative values for this unique population can provide meaningful reference points for all relevant stakeholders.

This study also revealed no correlation between strength and range of motion scores and lower PROM scores. This is important, as it highlights the need for research to move from looking at isolated risk factors to a new- concept of injury pattern recognition (Bittencourt et al, 2016).

CHAPTER 7 – REFERENCES

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CHAPTER 8 - APPENDICES

8.1 Appendix 1 : The Copenhagen Hip and Groin Outcome Score (HAGOS)

Questionnaire concerning hip and/or groin problems

Today's date: ____/____/____ Date of birth: ____/____/____

Name: _____

INSTRUCTIONS: This questionnaire asks for your view about your hip and/or groin problem. The questions should be answered considering your hip and/or groin function during the past week. This information will help us keep track of how you feel, and how well you are able to do your usual activities.

Answer every question by ticking the appropriate box. Tick only one box for each question. If a question does not pertain to you or you have not experienced it in the past week please make your “best guess” as to which response would be the most accurate.

Symptoms

These questions should be answered considering your hip and/or groin symptoms and difficulties during the past week.

S1 Do you feel discomfort in your hip and/or groin?

Never	Rarely	Sometimes	Often	Always
☐	☐	☐	☐	☐

S2 Do you hear clicking or any other type of noise from your hip and/or groin?

Never	Rarely	Sometimes	Often	All the time
☐	☐	☐	☐	☐

S3 Do you have difficulties stretching your legs far out to the side?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

S4 Do you have difficulties taking full strides when you walk?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

S5 Do you experience sudden twinging/stabbing sensations in your hip and/or groin?

Never	Rarely	Sometimes	Often	All the time
☐	☐	☐	☐	☐

Stiffness

The following questions concern the amount of stiffness you have experienced during the past week in your hip and/or groin. Stiffness is a sensation of restriction or slowness in the ease with which you move your hip and/or groin.

S6 How severe is your hip and/or groin stiffness after first awakening in the morning?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

S7 How severe is your hip and/or groin stiffness after sitting, lying or resting later in the day?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Pain

P1 How often is your hip and/or groin painful?

Never	Monthly	Weekly	Daily	Always
☐	☐	☐	☐	☐

P2 How often do you have pain in areas other than your hip and/or groin that you think may be related to your hip and/or groin problem?

Never	Monthly	Weekly	Daily	Always
☐	☐	☐	☐	☐

The following questions concern the amount of pain you have experienced during the past week in your hip and/or groin. What amount of hip and/or groin pain have you experienced during the following activities?

P3 Straightening your hip fully

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P4 Bending your hip fully

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P5 Walking up or down stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P6 At night while in bed (pain that disturbs your sleep)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P7 Sitting or lying

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

The following questions concern the amount of pain you have experienced during the past week in your hip and/or groin. What amount of hip and/or groin pain have you experienced during the following activities?

P8 Standing upright

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P9 Walking on a hard surface (asphalt, concrete, etc.)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P10 Walking on an uneven surface

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Physical function, daily living

The following questions concern your physical function. For each of the following activities please indicate the degree of difficulty you have experienced in the past week due to your hip and/or groin problem.

A1 Walking up stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A2 Bending down, e.g. to pick something up from the floor

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A3 Getting in/out of car

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A4 Lying in bed (turning over or maintaining the same hip position for a long time)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A5 Heavy domestic duties (scrubbing floors, vacuuming, moving heavy boxes etc)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Function, sports and recreational activities

The following questions concern your physical function when participating in higher-level activities. Answer every question by ticking the appropriate box. If a question does not pertain to you or you have not experienced it in the past

week please make your “best guess” as to which response would be the most accurate. The questions should be answered considering what degree of difficulty you have experienced during the following activities in the past week due to problems with your hip and/or groin.

SP1 Squatting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP2 Running

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP3 Twisting/pivoting on a weight bearing leg

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP4 Walking on an uneven surface

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP5 Running as fast as you can

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP6 Bringing the leg forcefully forward and/or out to the side, such as in kicking, skating etc.

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP7 Sudden explosive movements that involve quick footwork, such as accelerations, decelerations, change of directions etc.

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP8 Situations where the leg is stretched into an outer position

(such as when the leg is placed as far away from the body as possible)

None	Mild	Moderate	Severe	Extreme
------	------	----------	--------	---------

☐☐☐☐☐

Participation in physical activities

The following questions are about your ability to participate in your preferred physical activities. Physical activities include sporting activities as well as all other forms of activity where you become slightly out of breath. When you answer these questions consider to what degree your ability to participate in physical activities during the past week has been affected by your hip and/or groin problem.

PA1 Are you able to participate in your preferred physical activities for as long as you would like?

Always

Often

Sometimes

Rarely

Never

☐☐☐☐☐

PA2 Are you able to participate in your preferred physical activities at your normal performance level?

Always

Often

Sometimes

Rarely

Never

☐☐☐☐☐

Quality of Life

Q1 How often are you aware of your hip and/or groin problem?

Never

Monthly

Weekly

Daily

Constantly

☐☐☐☐☐

Q2 Have you modified your life style to avoid activities potentially damaging to your hip and/or groin?

Not at all	Mildly	Moderately	Severely	Totally
☐	☐	☐	☐	☐

Q3 In general, how much difficulty do you have with your hip and/or groin?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Q4 Does your hip and/or groin problem affect your mood in a negative way?

Not at all	Rarely	Sometimes	Often	All the time
☐	☐	☐	☐	☐

Q5 Do you feel restricted due to your hip and/or groin problem?

Not at all	Rarely	Sometimes	Often	All the time
☐	☐	☐	☐	☐

Thank you very much for completing all the questions in this questionnaire.

8.2 Appendix 2: Internation Hip Outcome Tool (i-HOT 33)

Quality of Life Questionnaire for Young, Active Patients with Hip Problems

Instructions:

These questions ask about the problems you may be experiencing in your hip, how these problems affect your life, and the emotions you may feel because of these problems.

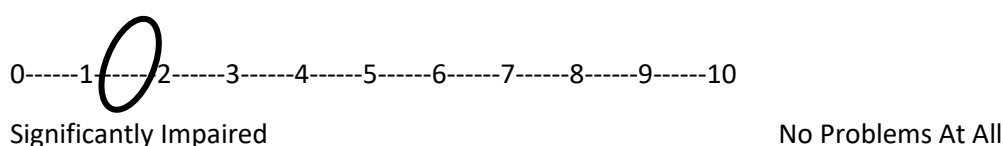
Please answer each question with respect to the current status, function, circumstances and beliefs related to your hip.

Consider the last month.

The questions are formatted so that you can indicate the severity of the problem by circling a number below the question.

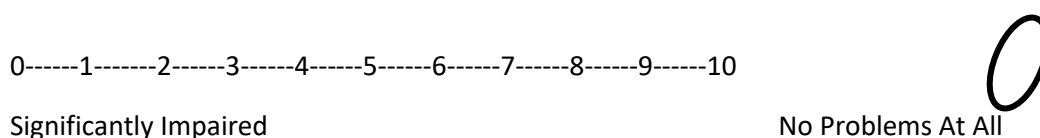
Please note:

Please circle the number which most closely represents your situation. If you circle a number on the far left, it means that you feel you are significantly impaired. *For example:*



- If you circle a number on the far right, it means that you do not think that you have any problems with your hip.

For example:



If a number is circled in the middle of the line, this indicates that you are moderately disabled, or in other words, between the extremes of 'significantly impaired' and 'no problems at all'. It is important to circle a number at the appropriate end of the line if the extreme descriptions accurately reflect your situation.

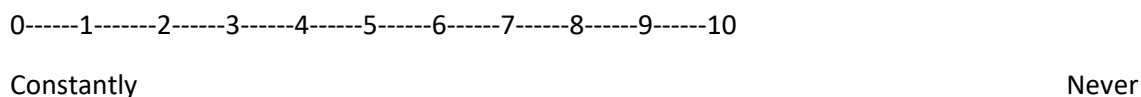
If the question asks about something that you do not experience, please mark the option:

I do not do this action in my activities, where this is appropriate.

I: SYMPTOMS AND FUNCTIONAL LIMITATIONS

The following questions ask about symptoms that you may experience in your hip and about the function of your hip with respect to daily activities. Please think about how you have felt most of the time over the past month and answer accordingly.

1. How often does your hip/groin ache?



2. How stiff is your hip as a result of sitting/resting during the day?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extremely Stiff

Not Stiff At All

3. How difficult is it for you to walk long distances?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extremely Difficult

Not Difficult At All

4. How much pain do you have in your hip while sitting?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extreme Pain

No Pain At All

5. How much trouble do you have standing on your feet for long period of time?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Severe Trouble

No Trouble At All

6. How difficult is it for you to get up and down off the floor/ground?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extremely Difficult

Not Difficult At All

7. How difficult is it for you to walk on uneven surfaces?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extremely Difficult

Not Difficult At All

8. How difficult is it for you to lie on your affected hip side?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extremely Difficult

Not Difficult At All

9. How much trouble do you have with stepping over obstacles?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Severe Trouble

No Trouble At All

10. How much trouble do you have climbing up/downstairs?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Severe Trouble

No Trouble At All

11. How much trouble do you have with rising from a sitting position?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Severe Trouble

No Trouble At All

12. How much discomfort do you have with taking long strides?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extreme Discomfort

No Discomfort At All

13. How much difficulty do you have with getting into and/or out of a car?

0 -----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extreme Difficulty

No Difficulty At All

14. How much trouble do you have with grinding, catching, or clicking in your hip?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Severe Trouble

No Trouble At All

15. How much difficulty do you have with putting on/taking off socks, stockings, or shoes?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extreme Difficulty

No Difficulty At All

14. Overall, how much pain do you have in your hip/groin?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extreme Pain

No Pain At All

—

II: SPORTS AND RECREATIONAL ACTIVITIES

The following questions ask about your hip when you participate in sports and recreational activities. Please think about how you have felt most of the time over the past month and answer accordingly.

17. How concerned are you about your ability to maintain your desired fitness level?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extremely Concerned

Not Concerned At All

18. How much pain do you experience in your hip after activity?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extreme Pain

No Pain At All

19. How concerned are you that the pain in your hip will increase if you participate in sports or recreational activities?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extremely Concerned

Not Concerned At All

20. How much was your quality of life deteriorated because you cannot participate in sport/recreational activities?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extremely Deteriorated

Not Deteriorated At All

21. How concerned are you about cutting/changing directions during your sports or recreational activities?

☐ I do not do this action in my activities.

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extremely Concerned

Not Concerned At All

22. How much has your performance level decreased in your sport or recreational activities?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extremely Decreased

Not Decreased At All

III: JOB RELATED CONCERNS

The following questions relate to your hip with respect to your work or occupational activities. Please think about how you have felt most of the time over the past month and answer accordingly.

I am retired ☐ (please skip section)

I do not work ☐ for reasons other than my hip condition (please skip section)

23. How much trouble do you have pushing, pulling, lifting, or carrying heavy objects at work?

☐ I do not do these actions in my work.

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Severe Trouble

No Trouble At All

24. How much trouble do you have with crouching/squatting?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Severe Trouble

No Trouble At All

25. How concerned are you that your job will make your hip worse?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extremely Concerned

Not Concerned At All

26. How much trouble do you have at work because of reduced hip mobility?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extreme Difficulty

No Difficulty At All

IV: SOCIAL, EMOTIONAL AND LIFESTYLE CONCERNS

The following questions ask about social, emotional and lifestyle concerns that you may feel with respect to your hip problem. Please think about how you have felt most of the time over the past month and answer accordingly.

27. How frustrated are you because of your hip problem?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extremely Frustrated

Not Frustrated At All

28. How much trouble do you have with sexual activity because of your hip?

☐ This is not relevant to me.

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Severe Trouble

No Trouble At All

29. How much of a distraction is your hip problem?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extreme Distraction

No Distraction At All

30. How difficult is it for you to release tension and stress because of your hip problem?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extremely Difficult

Not Difficult At All

31. How discouraged are you because of your hip problem?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extremely Discouraged

Not Discouraged At All

32. How concerned are you about picking up or carrying children because of your hip?

☐ I do not do this action in my activities.

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Extremely Concerned

Not Concerned At All

33. How much of the time are you aware of the disability in your hip?

0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

8.3 Appendix 3: Ethical Approval



Coláiste na Tríonóide, Baile Átha Cliath
Trinity College Dublin
Ollscoil Átha Cliath | The University of Dublin

David O'Regan

21 Ardbeg Park

Artane

Dublin 5

22nd March 2016

Ref: 20160101

Title of Study: Sagittal plane hip strength and Kinematics and their correlation with hip symptoms in professional rugby union players.

Dear Mr O'Regan,

Further to a meeting of the School of Medicine Research Ethics Committee held in January 2016, we are pleased to inform you that the above project has been approved.

Yours sincerely,

Professor Thomas Rogers

Chairperson

School of Medicine Research Ethics Committee

An tOllamh Paul Browne MB, FRCP, FRCPath
Ceann Scoil an Leighis

Ms. Orla Bannon
Riarthóir na Scoile

Scoil an Leighis
An Institiúid Eolaíochtaí Bithleighis
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Professor Paul Browne MB, FRCP, FRCPath
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8.3 Appendix 4: Participant Information Leaflet



Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

Title of Study: Saggital plane hip strength and kinematics and their correlation with hip symptoms in professional rugby union players.

Introduction

It is widely acknowledged that hip muscle weakness is a contributing factor to lower limb extremity injuries in athletes. That said, to date there has been limited research establishing normative values of strength about the hip, particularly amongst athletic populations.

Professional rugby union is a game that requires multiplanar hip movements. All of the available hip strength measurements research has centred on hip external and internal rotation and frontal plane movements of abduction and adduction. There is currently no available research on saggital hip plane strength (flexion and extension) in rugby union players. As such, this study aims to address this gap in the literature by measuring saggital plane hip strength and kinematics in professional rugby union players.

By exploring this and establishing any relationship between muscle weakness and injury, it will enable clinicians to provide a better screening and treatment programme for players presenting with hip symptoms.

Procedures

To be eligible for this study you must:

- Be an adult of 18 years or older
- Contracted to Leinster rugby senior or academy squad.
- Be able to read and understand the English language
- Not have had hip, lumbar spine or groin surgery in the past 2 years

We will assess your hip flexion and extension strength and range of movement at a time and date that is convenient to you. We will also get you to complete the Internation Hip Outcome Tool (iHOT 33) questionnaire, as well as the Copenhagen Hip

and Groin Outcome Score (HAGOS) questionnaire, which will inform us of any hip symptoms you may have.

Benefits

There are no immediate benefits but by participating in this study you will be informed of your strength scores on the day of testing. This will help identify any side to side differences and may assist in addressing any deficits.

Risks

There are no anticipated risks associated with participation in this study.

Confidentiality

Your identity will remain confidential. Your name will not be published and will not be disclosed to anyone outside of the research team.

Insurance

This study is covered by insurance policies organised by the institution.

Voluntary contribution

You have volunteered to participate in this study. You may withdraw at any time. If you decide not to participate, or if you quit, you will not be penalised.

Permission

This study has School of Medicine Research Ethics Committee approval.

Further information

You can get more information or answers to your questions about this study, your participation in this study, and your rights, from David O'Regan who can be telephoned at 087-660 4396 or emailed at daoregan@tcd.ie.

8.4 Appendix 5: Informed Consent



Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

Title of Study: Sagittal plane hip strength and kinematics and their correlation with hip symptoms in professional rugby union players.

This study and this consent form have been explained to me. David O'Regan has answered all my questions to my satisfaction. I believe I understand what will happen if I agree to be part of this study.

I have read, or had read to me, this consent form. I have had the opportunity to ask questions and all my questions have been answered to my satisfaction. I freely and voluntarily agree to be part of this research study, though without prejudice to my legal and ethical rights. I have received a copy of this agreement.

PARTICIPANT'S NAME: _____

PARTICIPANT'S SIGNATURE: _____

Date:

Date on which the participant was first furnished with this form:

Statement of investigator's responsibility: I have explained the nature, purpose, procedures, benefits, risks of, or alternatives to, this research study. I have offered to answer any questions and fully answered such questions. I believe that the participant understands my explanation and has freely given informed consent.

Principal Investigator's signature: _____

Principal Investigator's name: David O'Regan

Contact details: daoregan@tcd.ie

Date:

8.5 Appendix 6: Raw data output: iHOT subsections vs strength and range of motion

iHot Symptoms

```
model18<-lm(IhotSymp~HipFlexR_M)
```

```
summary(model18)
```

```
##
## Call:
## lm(formula = IhotSymp ~ HipFlexR_M)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -24.57  -4.01   2.61   6.62  13.48
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)   99.778     31.105   3.21  0.0027 **
## HipFlexR_M    -0.110     0.282  -0.39  0.6988
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.1 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared:  0.00388,    Adjusted R-squared:  -0.0217
## F-statistic: 0.152 on 1 and 39 DF,  p-value: 0.699
```

```
model19<-lm(IhotSymp~HipFlexL_M)
```

```
summary(model19)
```

```
##
## Call:
## lm(formula = IhotSymp ~ HipFlexL_M)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -23.42  -4.42   2.04   6.39  14.95
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  122.353     24.816   4.93 1.6e-05 ***
## HipFlexL_M   -0.326     0.233  -1.40  0.17
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
```

```
## Residual standard error: 9.86 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared: 0.0479, Adjusted R-squared: 0.0235
## F-statistic: 1.96 on 1 and 39 DF, p-value: 0.169

model20<-lm(IhotSymp~STR_R_Peak)
summary(model20)

##
## Call:
## lm(formula = IhotSymp ~ STR_R_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -25.39  -3.91   2.59   6.81  12.44
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  86.25760    8.85516   9.74 5.4e-12 ***
## STR_R_Peak    0.00432    0.02666   0.16  0.87
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.1 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared: 0.000673, Adjusted R-squared: -0.025
## F-statistic: 0.0263 on 1 and 39 DF, p-value: 0.872

model21<-lm(IhotSymp~STR_L_Peak)
summary(model21)

##
## Call:
## lm(formula = IhotSymp ~ STR_L_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -25.42  -3.88   2.66   6.32  13.34
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)   79.286     9.365    8.47 2.3e-10 ***
## STR_L_Peak     0.029     0.032    0.91  0.37
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared: 0.0207, Adjusted R-squared: -0.00441
## F-statistic: 0.824 on 1 and 39 DF, p-value: 0.369
```

```

model122<-lm(IhotSymp~IR_R_Peak)
summary(model122)

##
## Call:
## lm(formula = IhotSymp ~ IR_R_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -25.88  -3.53   1.88   6.81  12.42
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  85.88682    5.66206   15.17  <2e-16 ***
## IR_R_Peak     0.00584    0.01781    0.33    0.74
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.1 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared:  0.00275, Adjusted R-squared: -0.0228
## F-statistic: 0.107 on 1 and 39 DF, p-value: 0.745

model123<-lm(IhotSymp~IR_L_Peak)
summary(model123)

##
## Call:
## lm(formula = IhotSymp ~ IR_L_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -25.75  -3.31   1.32   6.67  13.45
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  77.5815    7.2458   10.71 3.6e-13 ***
## IR_L_Peak     0.0335    0.0235    1.42    0.16
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 9.85 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared:  0.0495, Adjusted R-squared: 0.0251
## F-statistic: 2.03 on 1 and 39 DF, p-value: 0.162

iHot Sports

model124<-lm(IhotSports~HipFlexR_M)
summary(model124)

```

```
##
## Call:
## lm(formula = IhotSports ~ HipFlexR_M)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -33.25  -5.45   1.80   8.39  13.79
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  112.019     33.031   3.39  0.0016 **
## HipFlexR_M    -0.214     0.299  -0.71  0.4793
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.7 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared:  0.0129, Adjusted R-squared:  -0.0124
## F-statistic: 0.51 on 1 and 39 DF,  p-value: 0.479

model25<-lm(IhotSports~HipFlexL_M)
summary(model25)

##
## Call:
## lm(formula = IhotSports ~ HipFlexL_M)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -32.62  -6.36   2.17   8.61  12.90
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  106.363     26.978   3.94  0.00032 ***
## HipFlexL_M    -0.168     0.253  -0.67  0.50991
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.7 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared:  0.0112, Adjusted R-squared:  -0.0141
## F-statistic: 0.442 on 1 and 39 DF,  p-value: 0.51

model26<-lm(IhotSports~STR_R_Peak)
summary(model26)

##
## Call:
## lm(formula = IhotSports ~ STR_R_Peak)
##
## Residuals:
```

```
## -31.41 -6.55 1.50 7.96 13.26
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 96.1331      9.3666  10.26 1.2e-12 ***
## STR_R_Peak  -0.0235      0.0282  -0.83  0.41
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.7 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared:  0.0175, Adjusted R-squared: -0.00771
## F-statistic: 0.694 on 1 and 39 DF, p-value: 0.41

model27<-lm(IhotSports~STR_L_Peak)
summary(model27)

##
## Call:
## lm(formula = IhotSports ~ STR_L_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -31.78  -5.25   1.56    8.27   11.62
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 8.82e+01  1.01e+01   8.73  1e-10 ***
## STR_L_Peak  9.77e-04  3.45e-02   0.03  0.98
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.8 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared:  2.06e-05, Adjusted R-squared: -0.0256
## F-statistic: 0.000803 on 1 and 39 DF, p-value: 0.978

model28<-lm(IhotSports~IR_R_Peak)
summary(model28)

##
## Call:
## lm(formula = IhotSports ~ IR_R_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -31.84  -5.75   1.68    7.93   11.93
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 89.47083    6.04607  14.80 <2e-16 ***
## IR_R_Peak   -0.00333    0.01902  -0.17  0.86
```

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.8 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared:  0.000783, Adjusted R-squared:  -0.0248
## F-statistic: 0.0306 on 1 and 39 DF, p-value: 0.862

model29<-lm(IhotSports~IR_L_Peak)
summary(model29)

##
## Call:
## lm(formula = IhotSports ~ IR_L_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -30.61  -6.19   1.07   8.94  13.18
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  81.4902     7.8456   10.39 8.6e-13 ***
## IR_L_Peak     0.0232     0.0255    0.91  0.37
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.7 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared:  0.0207, Adjusted R-squared:  -0.00439
## F-statistic: 0.825 on 1 and 39 DF, p-value: 0.369

## iHot IhotJob_Rel

model30<-lm(IhotJob_Rel~HipFlexR_M)
summary(model30)

##
## Call:
## lm(formula = IhotJob_Rel ~ HipFlexR_M)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -50.68  -4.14   4.27  12.77  15.02
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  104.539     49.534    2.11  0.041 *
## HipFlexR_M    -0.161     0.449   -0.36  0.722
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
##
## Residual standard error: 16.1 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared: 0.00328, Adjusted R-squared: -0.0223
## F-statistic: 0.128 on 1 and 39 DF, p-value: 0.722

model31<-lm(IhotJob_Rel~HipFlexL_M)
summary(model31)

##
## Call:
## lm(formula = IhotJob_Rel ~ HipFlexL_M)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -47.54  -3.09   3.11  12.05  16.46
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  130.483     39.877   3.27  0.0022 **
## HipFlexL_M    -0.411      0.374  -1.10  0.2794
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 15.8 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared: 0.0299, Adjusted R-squared: 0.00505
## F-statistic: 1.2 on 1 and 39 DF, p-value: 0.279

model32<-lm(IhotJob_Rel~STR_R_Peak)
summary(model32)

## Call: lm(formula = IhotJob_Rel ~ STR_R_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -51.33  -4.88   4.53  12.08  14.53
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  92.8834     14.0674   6.60 7.6e-08 ***
## STR_R_Peak   -0.0185      0.0423  -0.44  0.66
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 16 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared: 0.00488, Adjusted R-squared: -0.0206
## F-statistic: 0.191 on 1 and 39 DF, p-value: 0.664

model33<-lm(IhotJob_Rel~STR_L_Peak)
summary(model33)
```

```
##
## Call:
## lm(formula = IhotJob_Rel ~ STR_L_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -51.76  -4.37   3.25  13.08  13.44
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  87.47023    15.06485   5.81  9.6e-07 ***
## STR_L_Peak   -0.00222     0.05146  -0.04   0.97
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 16.1 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared:  4.77e-05,    Adjusted R-squared:  -0.0256
## F-statistic: 0.00186 on 1 and 39 DF,  p-value: 0.966

model34<-lm(IhotJob_Rel~IR_R_Peak)
summary(model34)

##
## Call:
## lm(formula = IhotJob_Rel ~ IR_R_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -50.85  -4.23   4.28  12.24  14.67
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  83.2260     9.0062   9.24  2.3e-11 ***
## IR_R_Peak     0.0118     0.0283   0.42   0.68
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 16 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared:  0.00443,    Adjusted R-squared:  -0.0211
## F-statistic: 0.174 on 1 and 39 DF,  p-value: 0.679

model35<-lm(IhotJob_Rel~IR_L_Peak)
summary(model35)

##
## Call:
## lm(formula = IhotJob_Rel ~ IR_L_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
```

```
## -53.53 -5.11 6.32 9.17 18.58
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  71.4576    11.5602    6.18 2.9e-07 ***
## IR_L_Peak    0.0511     0.0376    1.36  0.18
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 15.7 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared:  0.0453, Adjusted R-squared:  0.0208
## F-statistic: 1.85 on 1 and 39 DF, p-value: 0.181
## iHot Social
```

```
model36<-lm(Social~HipFlexR_M)
summary(model36)
```

```
##
## Call:
## lm(formula = Social ~ HipFlexR_M)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -34.55  -1.94   2.27   7.39  11.51
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  119.230     33.421    3.57 0.00097 ***
## HipFlexR_M   -0.253      0.303   -0.83 0.40937
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.8 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared:  0.0175, Adjusted R-squared: -0.00767
## F-statistic: 0.696 on 1 and 39 DF, p-value: 0.409
```

```
model37<-lm(Social~HipFlexL_M)
summary(model37)
```

```
##
## Call:
## lm(formula = Social ~ HipFlexL_M)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -34.38  -1.66   2.69   7.57  11.12
##
```

```
## Coefficients:
##           Estimate Std. Error t value Pr(>|t|)
## (Intercept) 124.701      26.991   4.62 4.1e-05 ***
## HipFlexL_M  -0.313       0.253  -1.24  0.22
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.7 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared:  0.0377, Adjusted R-squared:  0.013
## F-statistic: 1.53 on 1 and 39 DF, p-value: 0.224
```

```
model38<-lm(Social~STR_R_Peak)
summary(model38)
```

```
##
## Call:
## lm(formula = Social ~ STR_R_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -32.39  -2.14   3.46   7.37  10.57
##
## Coefficients:
##           Estimate Std. Error t value Pr(>|t|)
## (Intercept) 100.1931      9.4758  10.57 5.2e-13 ***
## STR_R_Peak  -0.0269      0.0285  -0.94  0.35
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.8 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared:  0.0223, Adjusted R-squared: -0.00274
## F-statistic: 0.891 on 1 and 39 DF, p-value: 0.351
```

```
model39<-lm(Social~STR_L_Peak)
summary(model39)
```

```
##
## Call:
## lm(formula = Social ~ STR_L_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -32.82  -2.51   3.12   7.59   9.18
##
## Coefficients:
##           Estimate Std. Error t value Pr(>|t|)
## (Intercept) 89.25948    10.23219   8.72 1.1e-10 ***
## STR_L_Peak   0.00739     0.03495   0.21  0.83
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
##
## Residual standard error: 10.9 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared: 0.00115, Adjusted R-squared: -0.0245
## F-statistic: 0.0447 on 1 and 39 DF, p-value: 0.834

model40<-lm(Social~IR_R_Peak)
summary(model40)

##
## Call:
## lm(formula = Social ~ IR_R_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -32.83  -2.78   2.94   7.23   8.64
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  91.52076   6.134040   14.92  <2e-16 ***
## IR_R_Peak    -0.000414   0.019299   -0.02    0.98
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.9 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared: 1.18e-05, Adjusted R-squared: -0.0256
## F-statistic: 0.00046 on 1 and 39 DF, p-value: 0.983

model41<-lm(Social~IR_L_Peak)
summary(model41)

##
## Call:
## lm(formula = Social ~ IR_L_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -31.81  -3.31   3.65   7.19  10.34
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  84.2155   7.9539   10.59  5e-13 ***
## IR_L_Peak     0.0239   0.0258    0.92   0.36
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.8 on 39 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared: 0.0214, Adjusted R-squared: -0.00369
## F-statistic: 0.853 on 1 and 39 DF, p-value: 0.361
```

8.6 Appendix 6: Raw data - HAGOS subsections vs strength and range of motion

```
## HAGOSSymp
```

```
model42<-lm(HAGOSSymp~HipFlexR_M)
```

```
summary(model42)
```

```
##
## Call:
## lm(formula = HAGOSSymp ~ HipFlexR_M)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -33.09  -8.08   0.84   9.78  20.49
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  7.94e+01   4.21e+01   1.89    0.067 .
## HipFlexR_M   6.55e-04   3.81e-01   0.00    0.999
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 12.9 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  8.22e-08, Adjusted R-squared: -0.0278
## F-statistic: 2.96e-06 on 1 and 36 DF, p-value: 0.999
```

```
model43<-lm(HAGOSSymp~HipFlexL_M)
```

```
summary(model43)
```

```
##
## Call:
## lm(formula = HAGOSSymp ~ HipFlexL_M)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -32.51  -7.83   0.93   9.27  20.90
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  85.2718   35.1449   2.43    0.02 *
## HipFlexL_M   -0.0539    0.3285  -0.16    0.87
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
```

```
## Residual standard error: 12.9 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared: 0.000748, Adjusted R-squared: -0.027
## F-statistic: 0.027 on 1 and 36 DF, p-value: 0.87

model144<-lm(HAGOSSymp~STR_R_Peak)
summary(model144)

##
## Call:
## lm(formula = HAGOSSymp ~ STR_R_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -33.51  -7.19   1.09   9.85  21.14
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  72.7097    12.8390   5.66   2e-06 ***
## STR_R_Peak    0.0204     0.0380   0.54   0.59
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 12.9 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared: 0.00794, Adjusted R-squared: -0.0196
## F-statistic: 0.288 on 1 and 36 DF, p-value: 0.595

model145<-lm(HAGOSSymp~STR_L_Peak)
summary(model145)

##
## Call:
## lm(formula = HAGOSSymp ~ STR_L_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -35.46  -5.20   2.18   8.58  20.91
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  54.0485    11.9656   4.52 6.5e-05 ***
## STR_L_Peak    0.0873     0.0404   2.16  0.038 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 12.2 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared: 0.114, Adjusted R-squared: 0.0899
## F-statistic: 4.65 on 1 and 36 DF, p-value: 0.0377
```

```

model46<-lm(HAGOSSymp~IR_R_Peak)
summary(model46)

##
## Call:
## lm(formula = HAGOSSymp ~ IR_R_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -31.518  -7.077   0.782   9.537  20.883
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  74.1319     7.9447    9.33 3.8e-11 ***
## IR_R_Peak     0.0172     0.0245    0.70  0.49
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 12.8 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.0135, Adjusted R-squared:  -0.0139
## F-statistic: 0.492 on 1 and 36 DF,  p-value: 0.487

model47<-lm(HAGOSSymp~IR_L_Peak)
summary(model47)

##
## Call:
## lm(formula = HAGOSSymp ~ IR_L_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -34.84  -6.26  -0.57   9.20  19.33
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  62.9637     9.2856    6.78 6.4e-08 ***
## IR_L_Peak     0.0548     0.0300    1.83  0.076 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 12.4 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.0847, Adjusted R-squared:  0.0593
## F-statistic: 3.33 on 1 and 36 DF,  p-value: 0.0763

## HAGOSPain

```

```

model48<-lm(HAGOSPain~HipFlexR_M)
summary(model48)

##
## Call:
## lm(formula = HAGOSPain ~ HipFlexR_M)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -31.22  -6.87   4.54   8.03   9.35
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  102.2379     34.1086   3.00  0.0049 **
## HipFlexR_M    -0.0953      0.3083  -0.31  0.7591
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.5 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.00265, Adjusted R-squared:  -0.0251
## F-statistic: 0.0955 on 1 and 36 DF, p-value: 0.759

model48<-lm(HAGOSPain~HipFlexL_M)
summary(model48)

##
## Call:
## lm(formula = HAGOSPain ~ HipFlexL_M)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -30.80  -6.65   4.12   7.43   9.69
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  111.520     28.307   3.94  0.00036 ***
## HipFlexL_M    -0.186      0.265  -0.70  0.48779
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.4 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.0135, Adjusted R-squared:  -0.0139
## F-statistic: 0.491 on 1 and 36 DF, p-value: 0.488

model49<-lm(HAGOSPain~STR_R_Peak)
summary(model49)

##
## Call:
## lm(formula = HAGOSPain ~ STR_R_Peak)

```

```
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -31.63   -6.25    4.53    8.23    8.41
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  92.31400    10.44870     8.83 1.5e-10 ***
## STR_R_Peak   -0.00181     0.03096    -0.06   0.95
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.5 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  9.52e-05, Adjusted R-squared: -0.0277
## F-statistic: 0.00343 on 1 and 36 DF, p-value: 0.954
```

```
model50<-lm(HAGOSPain~STR_L_Peak)
```

```
summary(model50)
```

```
##
## Call:
## lm(formula = HAGOSPain ~ STR_L_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -30.50   -6.59    3.85    7.29    9.91
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)   78.4908    10.0627     7.80 3e-09 ***
## STR_L_Peak     0.0453     0.0340     1.33  0.19
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.2 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.047, Adjusted R-squared:  0.0205
## F-statistic: 1.77 on 1 and 36 DF, p-value: 0.191
```

```
model51<-lm(HAGOSPain~IR_R_Peak)
```

```
summary(model51)
```

```
##
## Call:
## lm(formula = HAGOSPain ~ IR_R_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -32.75   -5.60    3.97    7.61    9.31
##
## Coefficients:
```

```
##           Estimate Std. Error t value Pr(>|t|)
## (Intercept) 88.82331    6.46484   13.74 6.9e-16 ***
## IR_R_Peak   0.00923    0.01994    0.46  0.65
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.4 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.00591, Adjusted R-squared: -0.0217
## F-statistic: 0.214 on 1 and 36 DF, p-value: 0.646
```

```
model52<-lm(HAGOSPain~IR_L_Peak)
```

```
summary(model52)
```

```
##
## Call:
## lm(formula = HAGOSPain ~ IR_L_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -32.30  -6.55   4.08   7.25  11.00
##
## Coefficients:
##           Estimate Std. Error t value Pr(>|t|)
## (Intercept)  80.6437    7.6375   10.56 1.4e-12 ***
## IR_L_Peak     0.0367    0.0247    1.48  0.15
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.2 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.0577, Adjusted R-squared:  0.0315
## F-statistic:  2.2 on 1 and 36 DF, p-value: 0.147
## HAGOSADL
```

```
model53<-lm(HAGOSADL~HipFlexR_M)
```

```
summary(model53)
```

```
##
## Call:
## lm(formula = HAGOSADL ~ HipFlexR_M)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -27.51  -2.54   2.69   7.56   8.02
##
## Coefficients:
##           Estimate Std. Error t value Pr(>|t|)
```

```
## (Intercept) 89.4063 30.9082 2.89 0.0064 **
## HipFlexR_M 0.0268 0.2793 0.10 0.9241
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 9.48 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared: 0.000256, Adjusted R-squared: -0.0275
## F-statistic: 0.00921 on 1 and 36 DF, p-value: 0.924
```

```
model54<-lm(HAGOSADL~HipFlexL_M)
summary(model54)
```

```
##
## Call:
## lm(formula = HAGOSADL ~ HipFlexL_M)
##
## Residuals:
```

	Min	1Q	Median	3Q	Max
	-26.72	-2.30	2.33	7.63	8.63

```
##
## Coefficients:
```

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	106.570	25.686	4.15	0.00019 ***
HipFlexL_M	-0.133	0.240	-0.55	0.58308

```
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 9.44 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared: 0.00845, Adjusted R-squared: -0.0191
## F-statistic: 0.307 on 1 and 36 DF, p-value: 0.583
```

```
model55<-lm(HAGOSADL~STR_R_Peak)
summary(model55)
```

```
##
## Call:
## lm(formula = HAGOSADL ~ STR_R_Peak)
##
## Residuals:
```

	Min	1Q	Median	3Q	Max
	-27.06	-2.48	2.50	7.54	8.17

```
##
## Coefficients:
```

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	94.62235	9.44975	10.01	6e-12 ***
STR_R_Peak	-0.00677	0.02800	-0.24	0.81

```
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 9.47 on 36 degrees of freedom
```

```
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.00162,    Adjusted R-squared:  -0.0261
## F-statistic: 0.0584 on 1 and 36 DF,  p-value: 0.81

model156<-lm(HAGOSADL~STR_L_Peak)
summary(model156)

##
## Call:
## lm(formula = HAGOSADL ~ STR_L_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -26.59  -2.95   3.35   7.15   9.16
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  83.9162     9.2194   9.10 7.2e-11 ***
## STR_L_Peak    0.0290     0.0312   0.93  0.36
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 9.37 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.0234, Adjusted R-squared:  -0.00369
## F-statistic: 0.864 on 1 and 36 DF,  p-value: 0.359

model157<-lm(HAGOSADL~IR_R_Peak)
summary(model157)

##
## Call:
## lm(formula = HAGOSADL ~ IR_R_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -27.53  -2.51   2.73   7.53   7.79
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  91.92142     5.86811  15.66 <2e-16 ***
## IR_R_Peak    0.00143     0.01810   0.08  0.94
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 9.48 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.000173, Adjusted R-squared:  -0.0276
## F-statistic: 0.00623 on 1 and 36 DF,  p-value: 0.938

model158<-lm(HAGOSADL~IR_L_Peak)
summary(model158)
```

```
##
## Call:
## lm(formula = HAGOSADL ~ IR_L_Peak)
##
## Residuals:
```

	Min	1Q	Median	3Q	Max
	-27.79	-4.61	4.05	6.90	9.56

```
##
## Coefficients:
```

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	84.5017	6.9932	12.08	3.1e-14 ***
IR_L_Peak	0.0261	0.0226	1.15	0.26

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 9.31 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.0356, Adjusted R-squared:  0.00877
## F-statistic: 1.33 on 1 and 36 DF, p-value: 0.257

## HAGOSSPORT_REC
```

```
model59<-lm(HAGOSSport_Rec~HipFlexR_M)
summary(model59)
```

```
##
## Call:
## lm(formula = HAGOSSport_Rec ~ HipFlexR_M)
##
## Residuals:
```

	Min	1Q	Median	3Q	Max
	-30.60	-7.25	5.56	10.89	14.86

```
##
## Coefficients:
```

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	119.829	45.804	2.62	0.013 *
HipFlexR_M	-0.285	0.414	-0.69	0.495

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 14.1 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.013, Adjusted R-squared:  -0.0144
## F-statistic: 0.474 on 1 and 36 DF, p-value: 0.495
```

```
model60<-lm(HAGOSSport_Rec~HipFlexL_M)
summary(model60)
```

```
##
## Call:
## lm(formula = HAGOSSport_Rec ~ HipFlexL_M)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -29.80  -7.49   4.46  11.31  15.19
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  138.069      37.565   3.68  0.00077 ***
## HipFlexL_M    -0.466       0.351  -1.33  0.19299
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 13.8 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.0466, Adjusted R-squared:  0.0201
## F-statistic: 1.76 on 1 and 36 DF, p-value: 0.193

model61<-lm(HAGOSSport_Rec~STR_R_Peak)
summary(model61)

##
## Call:
## lm(formula = HAGOSSport_Rec ~ STR_R_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -32.44  -8.52   6.84  11.26  12.23
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  85.58007    14.09785   6.07 5.6e-07 ***
## STR_R_Peak    0.00824     0.04177   0.20   0.84
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 14.1 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.00108, Adjusted R-squared: -0.0267
## F-statistic: 0.0389 on 1 and 36 DF, p-value: 0.845

model62<-lm(HAGOSSport_Rec~STR_L_Peak)
summary(model62)

##
## Call:
## lm(formula = HAGOSSport_Rec ~ STR_L_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
```

```
## -30.59 -6.00 5.75 9.49 14.22
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  72.1163    13.6422   5.29 6.2e-06 ***
## STR_L_Peak   0.0555     0.0461   1.20  0.24
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 13.9 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.0387, Adjusted R-squared:  0.012
## F-statistic: 1.45 on 1 and 36 DF, p-value: 0.236

model63<-lm(HAGOSSport_Rec~IR_R_Peak)
summary(model63)

##
## Call:
## lm(formula = HAGOSSport_Rec ~ IR_R_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -33.85  -8.07   7.29  10.52  13.25
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  83.4101     8.7116   9.57  2e-11 ***
## IR_R_Peak    0.0157     0.0269   0.58  0.56
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 14.1 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.0094, Adjusted R-squared: -0.0181
## F-statistic: 0.342 on 1 and 36 DF, p-value: 0.563

model64<-lm(HAGOSSport_Rec~IR_L_Peak)
summary(model64)

##
## Call:
## lm(formula = HAGOSSport_Rec ~ IR_L_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -32.86  -5.66   5.38  10.34  15.55
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  73.6350    10.3204   7.13 2.2e-08 ***
## IR_L_Peak    0.0487     0.0334   1.46  0.15
```

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 13.7 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.0557, Adjusted R-squared:  0.0295
## F-statistic: 2.12 on 1 and 36 DF, p-value: 0.154
## HAGOSPHYS_ACT
```

```
model65<-lm(HAGOSPhys_Act~HipFlexR_M)
summary(model65)
```

```
##
## Call:
## lm(formula = HAGOSPhys_Act ~ HipFlexR_M)
##
## Residuals:
```

##	Min	1Q	Median	3Q	Max
##	-19.63	-6.78	5.54	5.60	5.81

```
##
## Coefficients:
```

##		Estimate	Std. Error	t value	Pr(> t)
##	(Intercept)	96.8272	31.4120	3.08	0.0039 **
##	HipFlexR_M	-0.0219	0.2839	-0.08	0.9390

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 9.64 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.000165, Adjusted R-squared: -0.0276
## F-statistic: 0.00595 on 1 and 36 DF, p-value: 0.939
```

```
model66<-lm(HAGOSPhys_Act~HipFlexL_M)
summary(model66)
```

```
##
## Call:
## lm(formula = HAGOSPhys_Act ~ HipFlexL_M)
##
## Residuals:
```

##	Min	1Q	Median	3Q	Max
##	-23.22	-6.65	4.31	5.61	9.37

```
##
## Coefficients:
```

##		Estimate	Std. Error	t value	Pr(> t)
##	(Intercept)	55.841	25.411	2.20	0.035 *
##	HipFlexL_M	0.361	0.238	1.52	0.137

```
## ---
```

```
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 9.34 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.0603, Adjusted R-squared:  0.0342
## F-statistic: 2.31 on 1 and 36 DF,  p-value: 0.137
```

```
model67<-lm(HAGOSPhys_Act~STR_R_Peak)
summary(model67)
```

```
##
## Call:
## lm(formula = HAGOSPhys_Act ~ STR_R_Peak)
##
## Residuals:
```

	Min	1Q	Median	3Q	Max
	-20.52	-3.99	3.10	6.23	10.42

```
##
## Coefficients:
```

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	76.7400	9.1361	8.40	5.3e-10 ***
STR_R_Peak	0.0531	0.0271	1.96	0.058 .

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 9.16 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.0964, Adjusted R-squared:  0.0713
## F-statistic: 3.84 on 1 and 36 DF,  p-value: 0.0578
```

```
model68<-lm(HAGOSPhys_Act~STR_L_Peak)
summary(model68)
```

```
##
## Call:
## lm(formula = HAGOSPhys_Act ~ STR_L_Peak)
##
## Residuals:
```

	Min	1Q	Median	3Q	Max
	-20.30	-5.87	4.65	6.32	8.59

```
##
## Coefficients:
```

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	84.7896	9.3406	9.08	7.7e-11 ***
STR_L_Peak	0.0330	0.0316	1.04	0.3

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 9.49 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.0294, Adjusted R-squared:  0.00243
## F-statistic: 1.09 on 1 and 36 DF,  p-value: 0.303
```

```

model69<-lm(HAGOSPhys_Act~IR_R_Peak)
summary(model69)

##
## Call:
## lm(formula = HAGOSPhys_Act ~ IR_R_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -20.40  -6.45   4.79   5.99   7.13
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  90.8360     5.9320   15.31  <2e-16 ***
## IR_R_Peak     0.0114     0.0183    0.62    0.54
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 9.58 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.0107, Adjusted R-squared:  -0.0168
## F-statistic: 0.389 on 1 and 36 DF,  p-value: 0.537

model70<-lm(HAGOSPhys_Act~IR_L_Peak)
summary(model70)

##
## Call:
## lm(formula = HAGOSPhys_Act ~ IR_L_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -20.69  -5.96   4.57   5.33  11.05
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  82.3686     6.9387   11.87 5.3e-14 ***
## IR_L_Peak     0.0399     0.0224    1.78  0.084 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 9.24 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.0806, Adjusted R-squared:  0.0551
## F-statistic: 3.16 on 1 and 36 DF,  p-value: 0.084

## HAGOSSQOL

```

```

model71<-lm(HAGOSQOL~HipFlexR_M)
summary(model71)

##
## Call:
## lm(formula = HAGOSQOL ~ HipFlexR_M)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -56.91  -2.54   6.74  13.64  14.84
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)   97.334     60.650   1.60    0.12
## HipFlexR_M    -0.101     0.548  -0.18    0.85
##
## Residual standard error: 18.6 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.00094,    Adjusted R-squared:  -0.0268
## F-statistic: 0.0339 on 1 and 36 DF,  p-value: 0.855

model72<-lm(HAGOSQOL~HipFlexL_M)
summary(model72)

##
## Call:
## lm(formula = HAGOSQOL ~ HipFlexL_M)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -57.71  -4.94   6.75  13.85  15.92
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  116.016     50.388   2.30   0.027 *
## HipFlexL_M   -0.279     0.471  -0.59   0.557
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 18.5 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.00968,    Adjusted R-squared:  -0.0178
## F-statistic: 0.352 on 1 and 36 DF,  p-value: 0.557

model73<-lm(HAGOSQOL~STR_R_Peak)
summary(model73)

##
## Call:
## lm(formula = HAGOSQOL ~ STR_R_Peak)
##
## Residuals:

```

```
##      Min      1Q Median      3Q      Max
## -56.19  -1.23   6.29  13.77  13.91
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)   85.850     18.564    4.62 4.7e-05 ***
## STR_R_Peak     0.001      0.055    0.02  0.99
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 18.6 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  9.26e-06, Adjusted R-squared: -0.0278
## F-statistic: 0.000333 on 1 and 36 DF, p-value: 0.986
```

```
model174<-lm(HAGOSQOL~STR_L_Peak)
summary(model174)
```

```
##
## Call:
## lm(formula = HAGOSQOL ~ STR_L_Peak)
##
## Residuals:
##      Min      1Q Median      3Q      Max
## -56.03  -2.26   4.63  13.48  17.57
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)   74.1319     18.1991    4.07 0.00024 ***
## STR_L_Peak     0.0413      0.0615    0.67 0.50623
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 18.5 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.0124, Adjusted R-squared: -0.0151
## F-statistic: 0.451 on 1 and 36 DF, p-value: 0.506
```

```
model175<-lm(HAGOSQOL~IR_R_Peak)
summary(model175)
```

```
##
## Call:
## lm(formula = HAGOSQOL ~ IR_R_Peak)
##
## Residuals:
##      Min      1Q Median      3Q      Max
## -55.90  -2.25   5.41  13.31  15.84
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)   82.3269     11.5003    7.16 2e-08 ***
```

```
## IR_R_Peak      0.0123      0.0355      0.35      0.73
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 18.6 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.00334,    Adjusted R-squared:  -0.0243
## F-statistic: 0.121 on 1 and 36 DF,  p-value: 0.73

model76<-lm(HAGOSQOL~IR_L_Peak)
summary(model76)

##
## Call:
## lm(formula = HAGOSQOL ~ IR_L_Peak)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -53.15  -4.90   5.82  12.17  22.25
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  68.4965    13.6478     5.02 1.4e-05 ***
## IR_L_Peak     0.0586     0.0441     1.33  0.19
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 18.2 on 36 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.0467, Adjusted R-squared:  0.0202
## F-statistic: 1.76 o
```

8.7 Appendix 7: Data: iHOT & HAGOS subsections vs history of hip and groin pain

IHot Data

```
model7<-lm(IhotSymp~Hx+Position+KICKING.LEG)
summary(model7)

##
## Call:
## lm(formula = IhotSymp ~ Hx + Position + KICKING.LEG)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -28.43  -4.68   0.32   5.05  17.85
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)      84.651      6.523   12.98 3.8e-15 ***
## HxY              -7.796      3.720   -2.10  0.043 *
## PositionBacks      0.524      4.478    0.12  0.907
## PositionTight5     2.139      4.978    0.43  0.670
## KICKING.LEGRight   4.770      4.418    1.08  0.288
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 9.38 on 36 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared:  0.203, Adjusted R-squared:  0.115
## F-statistic: 2.3 on 4 and 36 DF, p-value: 0.0778

model8<-lm(IhotSports~Hx+Position+KICKING.LEG)
summary(model8)

##
## Call:
## lm(formula = IhotSports ~ Hx + Position + KICKING.LEG)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -27.177  -8.386   0.406   7.076  16.153
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)      83.33      7.11   11.73 7.4e-14 ***
## HxY              -6.21      4.05   -1.53  0.13
## PositionBacks      0.84      4.88    0.17  0.86
## PositionTight5     3.71      5.42    0.68  0.50
## KICKING.LEGRight   5.89      4.81    1.22  0.23
## ---
```

```
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.2 on 36 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared:  0.17,    Adjusted R-squared:  0.0773
## F-statistic: 1.84 on 4 and 36 DF,  p-value: 0.143

model9<-lm(IhotJob_Rel~Hx+Position+KICKING.LEG)
summary(model9)

##
## Call:
## lm(formula = IhotJob_Rel ~ Hx + Position + KICKING.LEG)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -37.47  -6.87  -1.80    5.63   27.53
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)      78.57      9.66   8.13 1.1e-09 ***
## HxY             -15.07      5.51  -2.74 0.0096 **
## PositionBacks      4.33      6.63   0.65 0.5174
## PositionTight5      6.93      7.37   0.94 0.3533
## KICKING.LEGRight    8.97      6.54   1.37 0.1790
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 13.9 on 36 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared:  0.311,    Adjusted R-squared:  0.234
## F-statistic: 4.06 on 4 and 36 DF,  p-value: 0.00808

model10<-lm(Social~Hx+Position+KICKING.LEG)
summary(model10)

##
## Call:
## lm(formula = Social ~ Hx + Position + KICKING.LEG)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -25.85  -5.35   0.37    6.08   15.58
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)      86.73      6.36  13.63 8.7e-16 ***
## HxY             -9.50      3.63  -2.62 0.013 *
## PositionBacks     -2.50      4.37  -0.57 0.571
## PositionTight5      0.44      4.85   0.09 0.928
## KICKING.LEGRight    9.69      4.31   2.25 0.031 *
## ---
```

```
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 9.15 on 36 degrees of freedom
## (3 observations deleted due to missingness)
## Multiple R-squared:  0.353, Adjusted R-squared:  0.281
## F-statistic: 4.91 on 4 and 36 DF, p-value: 0.00292
```

HAGOS Data

```
model11<-lm(HAGOSSymp~Hx+Position+KICKING.LEG)
summary(model11)
```

```
##
## Call:
## lm(formula = HAGOSSymp ~ Hx + Position + KICKING.LEG)
##
## Residuals:
```

	Min	1Q	Median	3Q	Max
	-21.115	-6.624	0.078	5.427	28.411

```
##
## Coefficients:
```

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	75.57	8.43	8.97	2.3e-10 ***
HxY	-13.72	4.69	-2.93	0.0061 **
PositionBacks	4.04	5.36	0.76	0.4555
PositionTight5	2.93	6.01	0.49	0.6292
KICKING.LEGRight	5.70	5.88	0.97	0.3396

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 11.1 on 33 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.323, Adjusted R-squared:  0.241
## F-statistic: 3.94 on 4 and 33 DF, p-value: 0.0101
```

```
model12<-lm(HAGOSPain~Hx+Position+KICKING.LEG)
summary(model12)
```

```
##
## Call:
## lm(formula = HAGOSPain ~ Hx + Position + KICKING.LEG)
##
## Residuals:
```

	Min	1Q	Median	3Q	Max
	-21.38	-2.35	2.35	5.78	13.75

```
##
## Coefficients:
```

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	86.42	7.16	12.07	1.2e-13 ***
HxY	-7.97	3.98	-2.00	0.054 .
PositionBacks	1.07	4.55	0.24	0.816
PositionTight5	3.23	5.10	0.63	0.532

```
## KICKING.LEGRight      6.73      4.99      1.35      0.187
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 9.43 on 33 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.257, Adjusted R-squared:  0.167
## F-statistic: 2.85 on 4 and 33 DF, p-value: 0.0392

model13<-lm(HAGOSADL~Hx+Position+KICKING.LEG)
summary(model13)

##
## Call:
## lm(formula = HAGOSADL ~ Hx + Position + KICKING.LEG)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -21.10  -4.90   1.97   5.05  10.55
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)      84.91       6.71  12.65  3.3e-14 ***
## HxY              -5.50       3.73  -1.47   0.15
## PositionBacks     4.70       4.26   1.10   0.28
## PositionTight5     5.85       4.78   1.22   0.23
## KICKING.LEGRight   5.34       4.68   1.14   0.26
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 8.84 on 33 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.203, Adjusted R-squared:  0.106
## F-statistic:  2.1 on 4 and 33 DF, p-value: 0.103

model14<-lm(HAGOSSport_Rec~Hx+Position+KICKING.LEG)
summary(model14)

##
## Call:
## lm(formula = HAGOSSport_Rec ~ Hx + Position + KICKING.LEG)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -25.58  -5.96   3.41   5.67  22.98
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)      84.08       8.69   9.68  3.6e-11 ***
## HxY             -14.19       4.83  -2.94   0.006 **
## PositionBacks    -1.30       5.52  -0.24   0.815
## PositionTight5     4.08       6.19   0.66   0.514
```

```
## KICKING.LEGRight      8.42      6.06      1.39      0.174
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 11.4 on 33 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.4,   Adjusted R-squared:  0.327
## F-statistic: 5.49 on 4 and 33 DF,  p-value: 0.00167

model15<-lm(HAGOSPhys_Act~Hx+Position+KICKING.LEG)
summary(model15)

##
## Call:
## lm(formula = HAGOSPhys_Act ~ Hx + Position + KICKING.LEG)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -19.202  -4.304   0.697   5.798  13.383
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)      93.85       6.67   14.07 1.7e-15 ***
## HxY              -5.93       3.71   -1.60  0.12
## PositionBacks     1.65       4.24    0.39  0.70
## PositionTight5     6.75       4.76    1.42  0.16
## KICKING.LEGRight  -1.30       4.65   -0.28  0.78
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 8.79 on 33 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.237, Adjusted R-squared:  0.145
## F-statistic: 2.56 on 4 and 33 DF,  p-value: 0.0566

model16<-lm(HAGOSSport_Rec~Hx+Position+KICKING.LEG)
summary(model16)

##
## Call:
## lm(formula = HAGOSSport_Rec ~ Hx + Position + KICKING.LEG)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -25.58  -5.96   3.41   5.67  22.98
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)      84.08       8.69    9.68 3.6e-11 ***
## HxY             -14.19       4.83   -2.94  0.006 **
## PositionBacks    -1.30       5.52   -0.24  0.815
## PositionTight5     4.08       6.19    0.66  0.514
```

```
## KICKING.LEGRight      8.42      6.06      1.39      0.174
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 11.4 on 33 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.4,   Adjusted R-squared:  0.327
## F-statistic: 5.49 on 4 and 33 DF,  p-value: 0.00167

model17<-lm(HAGOSQOL~Hx+Position+KICKING.LEG)
summary(model17)

##
## Call:
## lm(formula = HAGOSQOL ~ Hx + Position + KICKING.LEG)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -41.94  -4.93   5.46   6.59  28.06
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)      82.81      11.62   7.13 3.7e-08 ***
## HxY              -21.64       6.46  -3.35  0.002 **
## PositionBacks     3.59       7.38   0.49  0.630
## PositionTight5    4.56       8.28   0.55  0.586
## KICKING.LEGRight  7.17       8.10   0.89  0.382
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 15.3 on 33 degrees of freedom
## (6 observations deleted due to missingness)
## Multiple R-squared:  0.38,   Adjusted R-squared:  0.305
## F-statistic: 5.05 on 4 and 33 DF,  p-value: 0.00274
```