

THE UNIVERSITY OF HULL

The Development and Implementation of a Hip Injury Screening Protocol
within Elite Ice Hockey.

being a Thesis submitted for the Degree of Doctor of Philosophy

in the University of Hull

by

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(December 2015)

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Acknowledgements

This thesis would not have been possible were it not for the kind friendship, support, generosity and hospitality of Chad Osgood and his family (Christine, Ethan and Maddie).

You are a truly amazing family and I cannot thank you all enough for what you have done for me and only wish to continue our friendship so I can somehow repay you all.

I would also like to thank Dr Rebecca Vince and Dr Hollie White who have helped me enormously since becoming my supervisors. You have both been motivating, realistic and supportive throughout the whole process and I am extremely grateful.

There are many other people from the Department who deserve a mention for their general support, especially Chris Towlson, James Bray and Steve Hayes who have all been excellent in offering their friendship and support throughout the project over many a coffee, although not always useful it is always entertaining. Colin Johnson and Sam Nabb have also helped keep me sane at many moments of the project with their friendship, support and guidance on many things. I must also thank all the girls in the Departmental office, Charlotte, Lola, Catherine, Andrea and Alicia, for your expertise but mainly your conversations that take my mind off all things PhD and work related! A special thanks goes to Liam Sykes who helped me complete testing during an experimental chapter of which I am extremely thankful. I must also offer thanks to all participants involved within the project as without you this would not have been possible.

I would like to thank my Mom, Dad, Brother, Laura and Grandad for the constant belief that I would eventually complete this project. Finally, I would like to thank my wife, Gemma, who has dealt with many bad moods and moments of doubt with support, love, baking and sometimes just a hug, biscuit and cup of tea, thank you!

Abstract

The primary aim of this project was to both investigate injury epidemiology and create methods to potentially reduce injuries within elite ice hockey athletes. Chapter Four assessed the injury problem within ice hockey by retrospectively collecting data from two National Collegiate Athletic Association (NCAA) division III teams across a four year period investigating the prevalence, location, severity and type of injuries sustained. Findings showed that contact injuries were more prevalent (58%) than non-contact injuries (42%), with the knee (15%), shoulder (12%) and hip (13%) being the most frequently injured locations when both contact and non-contact injuries were combined. When investigating only non-contact injuries the hip complex (hip, groin and thigh) (50%) was by far the most injured location with similar frequencies, in terms of injury severity, observed.

Chapter Five analysed intrinsic risk factors of the ice hockey athlete by investigating differences of hip range of motion (ROM), strength and functional tests between ice hockey athletes, soccer athletes and control participants. Results demonstrated that ice hockey athletes had significantly weaker hip adduction ($p = 0.023$) and flexion in sitting ($p = 0.001$) strength compared to soccer athletes and less external rotation strength compared to control participants ($p = 0.010$). Ice hockey athletes also displayed greater strength than control participants in flexion in sitting ($p = 0.005$). Ice hockey athletes exhibited greater ROM in abduction ($p = 0.001$) than control participants and greater adduction than both soccer athletes ($p = 0.003$) and control participants ($p = 0.004$). Ice hockey athletes exhibited less hip flexion in lying ($p = 0.001$) and external rotation ($p < 0.001$) when compared to control participants. Ice hockey athletes also presented with an increased number of positive flexion, abduction and external rotation (FABER) tests compared to both soccer athletes and control participants.

Chapter Six investigated the effectiveness of the newly created hip screen by comparing ice hockey athletes with and without a previous non-contact hip injury and their performance during the hip screen. Findings demonstrated that athletes who had no previous hip injury had greater internal ($p = 0.004$) and external rotation ROM ($p = 0.022$) on the dominant (Dom) limb and greater flexion in sitting ($p = 0.031$) and internal rotation ROM ($p = 0.050$) on the non-dominant (Ndom) limb. Although non-significant, previously injured athletes also displayed less ROM in all hip movements compared to previously uninjured athletes. Similar trends were found in strength measures with previously uninjured athletes showing significantly stronger abduction ($p = 0.012$) on the Dom limb and flexion in lying on both the Dom ($p = 0.008$) and Ndom limb ($p < 0.001$). Previously injured athletes displayed more positive FABER (Dom; 13% vs. 0%, Ndom; 13% vs. 5%), Trendelenburg (Dom; 75% vs. 58%, Ndom; 50% vs. 5%) and Ober's (Dom; 13% vs. 5%, Ndom; 75% vs. 68%) tests with higher scores on the overall screen than uninjured athletes.

Chapter Seven investigated the intra and inter-tester reliability of the hip screen finding that intra-class correlation coefficients (ICC) of intra-tester reliability of the ROM (0.49), strength (0.80) and overall screen (0.76) was moderate to near perfect. Inter-tester reliability again showed very large ICCs for ROM (0.71), strength (0.77) and overall screen scores (0.81). The minimum criterion change (MCC) (3.78 points) was also found to be small for the screen score change needed to be viewed as clinically worthwhile. These findings demonstrate that the screening procedure developed is useful, reliable and repeatable when assessing the ice hockey athlete's hip.

Chapter Eight demonstrated that all participants regardless of group improved their ROM and strength measures following the intervention period. However, it was demonstrated that the ice hockey intervention (IHI) group saw a decrease in the amount of positive FABER tests following the intervention compared to ice hockey control (IHC) and intervention control (IC) group (IHI: pre 15 vs. post 6; IHC: pre 15 vs. post 14; IC: pre 10 vs. post 9). It was also demonstrated that the IHI group improved above the MCC value presented within Chapter Seven with regards to the overall hip injury screen score (pre 48 vs. post 52) indicating that ice hockey athletes who participated in the intervention programme may be at a decreased risk of sustaining a non-contact hip injury due to the intervention exercises targeting weaknesses highlighted in the hip injury screen.

In summary, the current project achieved the stated aims by demonstrating that the hip complex was the most common location for injuries of a non-contact nature and the creation of a reliable and repeatable hip injury screen that allows clinicians to potentially highlight athletes considered as 'at risk'. To complete the injury prevention sequence, future work would be necessary to track athletes who scored low on the hip injury screen over time either following the intervention or as a control to assess if they were more or less likely to sustain a non-contact hip injury. Future work should also continue to optimise the intervention strategy to further develop and enhance its effectiveness in the prevention of non-contact hip injuries. This could be achieved either through a longer protocol that is incorporated into routine training or individualisation of the programme and as such provide a valuable tool for clinicians and medical teams wishing to reduce the risk of ice hockey athletes sustaining a non-contact hip injury.

List of Published Works and Works in Press

Wilcox, C. R. J., Osgood, C. T., White, H. S. F., Vince, R. V. Investigating Injury Susceptibility of the Hip Complex in Ice Hockey Players. *Poster presented at American College of Sports Medicine (ACSM) Conference 61st Annual Meeting and 5th World Congress on Exercise is Medicine, Orlando, USA, May 2014.*

Wilcox, C. R. J, Osgood, C. T., White, H. S. F., & Vince, R. V. (2015). Investigating Strength and Range of Motion of the Hip Complex in Ice Hockey Athletes. *Journal of Sport Rehabilitation*. 24(3), 300-306

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List of Abbreviations, Acronyms, and Symbols

°	Degrees
'	Feet
%	Percent
±	Plus or minus
AC	Acromioclavicular
ACL	Anterior Cruciate Ligament
AE	Athlete Exposure
AIIS	Anterior Inferior Iliac Spine
ASIS	Anterior Superior Iliac Spine
BPM	Beats per minute
CI	Confidence intervals
cm	Centimetre
CV	Coefficient of Variation
D	Defenseemen
Dom	Dominant
F	Forwards
FABER	Flexion abduction external rotation
FAI	Femoroacetabular impingement
F-MARC	Fédération Internationale de Football Association Medical Assessment and Research Center
FMS	Functional Movement Screen
G	Game

GT	Greater trochanter
H:Q	Hamstring to quadriceps ratio
IC	Intervention control
ICC	Intra-class coefficient correlation
IHC	Ice hockey control
IHI	Ice hockey intervention
kg	Kilogram
LSD	Least significant difference
MCC	Minimum criterion change
MCL	Medial collateral ligament
MIAC	Minnesota Intercollegiate Athletic Conference
min	minute
ml	millilitres
MRI	Magnetic resonance imaging
N	Newton's
n	Number
NCAA	National Collegiate Athletic Association
Ndom	Non-dominant
NHL	National Hockey League
Nm/kg	Newton meters per kilogram
P	Practice
p	Probability statistic
ROM	Range of motion
rpm	Repetitions per minute

SD	Standard deviation
SIJ	Sacroiliac joint
SPSS	Statistical package for social sciences
SWC	Smallest worthwhile change
UK	United Kingdom
USA	United States of America
vs.	Versus

Chapter One: General Introduction

1.1 Introduction

Sporting injuries can be classified as either contact (e.g. traumatic) or non-contact (e.g. overuse) in nature with contact injuries often caused by extrinsic risk factors out of the limits of control of the athlete in a single, identifiable incident (Collins & Raleigh, 2009; Fuller et al., 2006; Hreljac, 2004; Hreljac, Marshall, & Hume, 2000; Sharma & Maffulli, 2006). Non-contact injuries are typically less well defined by one single event and are often caused by an accumulation of many 'microtraumatic' repetitive movements controlled primarily by intrinsic risk factors (Collins & Raleigh, 2009; Fuller et al., 2006; Hreljac, 2004; Hreljac et al., 2000; Sharma & Maffulli, 2006). Non-contact injuries are typically multifaceted and difficult to predict due to many differing intrinsic risk factors playing an important role in the occurrence of an injury (Collins & Raleigh, 2009; Fuller et al., 2006; Hreljac, 2004; Hreljac et al., 2000; Kirkendall, 1990; Meeuwisse, 1994; Sharma & Maffulli, 2006). It is therefore important to consider the multiple intrinsic risk factors affecting non-contact injuries in order to appreciate the impact preventative measures can have upon injury occurrence. It has been suggested that lack of muscular strength, range of motion (ROM) and previous injury are all important internal risk factors upon non-contact injury occurrence/reoccurrence (Baumhauer, Alosa, Renström, Trevino, & Beynnon, 1995; Blackburn, Prentice, Guskiewicz, & Busby, 2000; Ekstrand & Gillquist, 1983; Hewett et al., 2005a; Holder-Powell & Rutherford, 2000; Murphy, Connolly, & Beynnon, 2003; Söderman, Alfredson, Pietilä, & Werner, 2001; Tyler, Nicholas, Campbell, & McHugh, 2001; Witvrouw, Danneels, Asselman, D'Have, & Cambier, 2003; Worrell & Perrin, 1992).

Due to the fast paced, highly physical nature of ice hockey, athletes are constantly relying upon high levels of muscular strength, power, ROM and balance to maximise

performance (Montgomery, 2006; Potteiger, Smith, Maier, & Foster, 2010; Quinney et al., 2008; Vescovi, Murray, Fiala, & VanHeest, 2006). This, therefore causes a high occurrence of injuries sustained by the ice hockey athlete with previous studies investigating injury prevalence reporting between 4.9 injuries/1000 athlete exposures (AE) (Flik, Lyman, & Marx, 2005) to 15.6 injuries/1000 AE (McKay, Tufts, Shaffer, & Meeuwisse, 2014). The majority of these injuries are classified as being contact injuries (Agel, Dompier, Dick, & Marshall, 2007b; Ferrara & Schurr, 1999; Flik et al., 2005; Kuzuhara, Shimamoto, & Mase, 2009; McKay et al., 2014; McKnight, Ferrara, & Czerwinska, 1992; Pettersson & Lorentzon, 1993; Pinto, Kuhn, Greenfield, & Hawkins, 1999; Schick & Meeuwisse, 2003; Tegner & Lorentzon, 1991). Although contact injuries are more prevalent than non-contact within ice hockey it is arguably more important, with regards to injury prevention, to focus upon the modifiable non-contact injuries, for the reasons outlined above, than contact injuries which by their very nature are more difficult to predict.

More specifically, evidence suggests that the hip is among the most common location of the ice hockey athlete's body to become injured, when both contact and non-contact injuries are considered (Agel et al., 2007b; Agel & Harvey, 2010; Flik et al., 2005; Jørgensen & Schmidt-Olsen, 1986; Kujala et al., 1995; Kuzuhara et al., 2009; McKay et al., 2014; McKnight et al., 1992; Pettersson & Lorentzon, 1993; Pinto et al., 1999; Schick & Meeuwisse, 2003; Tegner & Lorentzon, 1991). During the unique locomotion within the ice hockey skating pattern the hip is responsible for propulsion and stabilisation of the lower body allowing the upper body to complete complex skills integral with ice hockey performance (Chang, Turcotte, & Pearsall, 2009; McPherson, Wrigley, Montelpare, Pearsall, & Ashare, 2004; Upjohn, Turcotte, David, & Loh, 2008). Ice hockey skating requires combinations of hip abduction with external rotation during the push off phase and hip flexion combined with internal rotation during the recovery phase

placing high loads through the hip (Bizzini, Notzli, & Maffiuletti, 2007; Keogh & Batt, 2008; Philippon, Weiss, Koppersmith, Briggs, & Hay, 2010; Stull, Philippon, & LaPrade, 2011). These combinations of movements may increase the hips susceptibility to non-contact injuries by placing the hip in a vulnerable position (Bartlett, 2002; Bizzini et al., 2007; Keogh & Batt, 2008; Philippon et al., 2010; Upjohn et al., 2008).

In order to combat the rate of potentially preventable injuries, previous studies have used screening protocols aimed at highlighting ‘at risk’ athletes, such as the Functional Movement Screen (FMS), with many finding athletes who score lower during the screen to be more likely to sustain a subsequent injury (Kiesel, Plisky, & Butler, 2011; Kiesel, Plisky, & Voight, 2007; Peate, Bates, Lunda, Francis, & Bellamy, 2007). Previous studies have investigated injury prevention strategies within sports such as volleyball (Bahr, Lian, & Bahr, 1997; Verhagen et al., 2004), soccer (Askling, Karlsson, & Thorstensson, 2003; Junge, Rösch, Peterson, Graf-Baumann, & Dvorak, 2002) and handball (Myklebust et al., 2003) with many finding a decrease in injury occurrence following their injury prevention programme. Although there is limited research aimed at preventing non-contact injuries within ice hockey the decreases seen in other sports provides evidence that the same could be achieved within ice hockey.

Therefore the aims of this project were to investigate injury prevalence, location, severity and type sustained by elite ice hockey athletes. Following the injury audit a hip assessment was developed to analyse the ice hockey athlete’s hip ROM, strength and functional capabilities compared to soccer athletes and a normal population. This aimed to explore why ice hockey athletes are particularly susceptible to non-contact hip injuries compared to other sporting, and non-sporting populations. Subsequently, a screening protocol sensitive enough to detect previous hip injuries was developed aimed at identifying athletes ‘at risk’ of sustaining a non-contact hip injury. The final objective of

this project was to establish whether the athletes highlighted as ‘at risk’ by the screening protocol benefitted from a strength and ROM intervention programme in order to decrease the amount of non-contact hip injuries seen within ice hockey.

Chapter Two: Literature Review

2.1 Understanding injuries

Nicholl, Coleman, and Williams (1995) estimates that twenty-nine million injuries are sustained by the British public from sport and exercise annually. It is also estimated that in the United States of America (USA) three to five million injuries occur annually in both competitive and recreational sports (Murphy et al., 2003). Injury within all sport is commonplace (Agel et al., 2007b; Brooks, Fuller, Kemp, & Reddin, 2005a; Ferrara & Schurr, 1999; Flik et al., 2005; Hawkins, Hulse, Wilkinson, Hodson, & Gibson, 2001; Kujala et al., 1995; Kuzuhara et al., 2009; McKay et al., 2014; McKnight et al., 1992; Murphy et al., 2003; Nicholl et al., 1995; Pettersson & Lorentzon, 1993; Pinto et al., 1999; Schick & Meeuwisse, 2003; Tegner & Lorentzon, 1991) with ice hockey athletes being at a greater risk than other athletes in many other intermittent team sports such as soccer and rugby union (Hawkins et al., 2001; Kujala et al., 1995). Many common sporting injuries, particularly within ice hockey, are of a contact nature (Agel et al., 2007b; Ferrara & Schurr, 1999; Flik et al., 2005; Kuzuhara et al., 2009; McKay et al., 2014; McKnight et al., 1992; Pettersson & Lorentzon, 1993; Pinto et al., 1999; Schick & Meeuwisse, 2003; Tegner & Lorentzon, 1991) and the occurrence of this type of physical trauma can presumably be explained by the high impact/collision nature of sport (Warsh, Constantin, Howard, & Macpherson, 2009).

2.1.1 Injury occurrence

Injuries are typically of a multifactorial causation (Collins & Raleigh, 2009; Kirkendall, 1990; Meeuwisse, 1994). In Figure 2.1 Meeuwisse (1994) suggests that the direct mechanism of injury, or inciting event, is simply the final stage of a process of injury

occurrence with multiple intrinsic risk factors having an effect upon the athlete potentially increasing the likelihood of sustaining an injury. These increased risk factors do not solely control the injury occurrence or outcome for the athlete but may make the athlete more likely to receive an injury (Bahr & Krosshaug, 2005). In addition to these intrinsic risk factors, extrinsic risk factors (e.g. weather conditions, surface, opponents and game situation) may also potentially increase the athlete's susceptibility to injury (Meeuwisse, 1994). Therefore, it is suggested that injuries occur from a combination of both modifiable and non-modifiable risk factors that may or may not be controllable. Understanding injury as a process in this manner may be important to highlight potential opportunities for prevention.

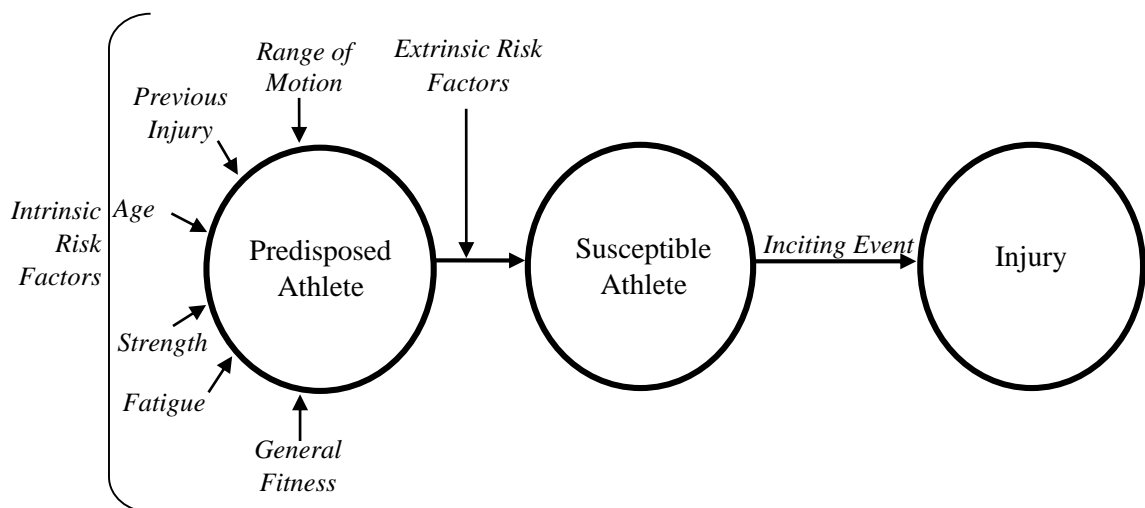


Figure 2.1 A multifactorial model of athletic injuries indicating their multifaceted nature (Adapted from Meeuwisse, 1994)

2.1.2 Classification of sporting injuries

It is important to recognise the potential causation of injuries, albeit possibly multifactorial in nature (as demonstrated in Figure 2.1), in order to appreciate the type of injury the athlete has sustained, and which injuries are therefore potentially controllable and/or preventable. For this, it is important to understand how the injury occurred, of

which there are two main mechanisms of injury: traumatic (contact) or overuse (non-contact) (Collins & Raleigh, 2009; Hreljac, 2004; Hreljac et al., 2000; Sharma & Maffulli, 2006). Contact injuries are often caused by extrinsic factors outside of the limits of control of the athlete in one specific, identifiable ‘macrotraumatic’ event such as contact with another athlete (Collins & Raleigh, 2009; Fuller et al., 2006; Sharma & Maffulli, 2006). Therefore, there is limited scope to decrease contact injuries with preventative measures alone due to the uncontrollable and unpredictable nature of the extrinsic risk factors (Aubry et al., 2002; Benson, Rose, & Meeuwisse, 2002).

Non-contact injuries, on the other hand, are less defined and occur due to a cumulative effect of a large number of ‘microtraumatic’ repetitive forces under the tensile limit that eventually cause the structure to fatigue and increase the risk of injury (Collins & Raleigh, 2009; Fuller et al., 2006; Hreljac, 2004; Hreljac et al., 2000). If enough time is allowed for the structure to fully recover from the fatigue of the repetitive loads then it is likely that no injury discernible will occur, however, when the structure is not given adequate recovery time the cumulative effect builds and can ultimately lead to injury (Collins & Raleigh, 2009; Hreljac, 2004; Hreljac et al., 2000). This therefore highlights the importance of being able to understand in more details the intrinsic, yet modifiable risk factors with the intention of being able to decrease the number of injuries sustained.

2.1.3 Intrinsic risk factors for injury

The majority of intrinsic risk factors to injury, such as general fitness levels, strength and ROM are modifiable and therefore important to understand in further detail to allow effective injury prevention (Bahr & Holme, 2003). However, it should also be considered that this process is somewhat limited because other important risk factors such as age and previous injury are by their nature non-modifiable (Bahr & Holme, 2003).

Lack of muscular strength is an intrinsic risk factor for injury (Baumhauer et al., 1995; Blackburn et al., 2000; Ekstrand & Gillquist, 1983; Murphy et al., 2003; Söderman et al., 2001). Ekstrand and Gillquist (1983) found that male soccer athletes who went on to sustain a lower limb injury presented with reduced isokinetic quadriceps strength pre injury compared to participants who remained uninjured (Ekstrand & Gillquist, 1983). Muscular strength is also a key component of joint stability with previous research by Tyler, Nicholas, Campbell, Donellan, and McHugh (2002) showing significant increases in hip adductor strength of ice hockey athletes following a six week strength based exercise program during pre-season. Although Tyler et al. (2002) found increases in hip adductor strength it must be noted that these increases were not seen until the following pre-season making direct links questionable. Additionally, previous work by Tyler et al. (2001) found ice hockey athletes who subsequently went on to sustain a hip musculature injury had a decrease in pre-injury hip adduction strength compared to athletes who did not sustain an injury. This is of particular importance because it offers possibilities for prevention. Muscle strength may be altered with an effective targeted exercise programme (Askling et al., 2003; Myklebust et al., 2003; Olsen, Myklebust, Engebretsen, Holme, & Bahr, 2005), therefore, possibly reducing the intrinsic risk of injury to the athlete (Croisier, Ganteaume, Binet, Genty, & Ferret, 2008).

A further intrinsic risk factor is a lack of flexibility or ROM (Bradley & Portas, 2007; Ekstrand & Gillquist, 1983; Hreljac et al., 2000; Tyler et al., 2001; Witvrouw et al., 2003; Worrell & Perrin, 1992). It has been suggested that a general decrease in ROM increases an athlete's risk of injury due to the hindrance limited ROM brings to complex skills integral within sport (Quinney et al., 2008; Witvrouw et al., 2003). Witvrouw et al. (2003) report that soccer athletes who displayed pre injury hamstring ROM below 90° were at a significant increase of sustaining a hamstring muscle strain compared to athletes who had pre injury hamstring ROM above 90°. However, it has been found by Tyler et al. (2001)

that ice hockey athletes who subsequently sustained a hip adductor muscle injury presented with no significant difference in hip adductor ROM to the subsequently uninjured athletes. Although the work of Tyler et al. (2001) is specifically looking at the hip adductor muscle group and its injuries it does further highlight the probable multifactorial nature of injuries providing clinicians with an insight into how all intrinsic risk factors of the athlete should be considered to fully appreciate injuries (Collins & Raleigh, 2009; Kirkendall, 1990; Meeuwisse, 1994).

Another intrinsic risk factor to injury is the presence of a previous injury sustained by the athlete (Bahr & Bahr, 1997; Holder-Powell & Rutherford, 2000; Murphy et al., 2003). It has been previously reported that of 234 ankle injuries sustained by volleyball athletes, ten were new injuries compared to a significantly higher figure of 38 injuries sustained by previously injured ankles (Bahr & Bahr, 1997). It is also suggested that the previous injury increases the athletes risk of future injury/re-injury due to compromise of the static and dynamic joint stabilisers surrounding the previously injured joint (Murphy et al., 2003). This compromise of the joint stabilisers alters the athletes ability to maintain and control their balance forcing the athlete into hazardous positions therefore increasing their risk of injury (Murphy et al., 2003). Further findings suggest that an athlete will suffer from joint laxity, decreased proprioception, flexibility and muscular strength with the presence of a previous injury which also may increase the athlete's susceptibility to further injury/re-injury (Bahr & Holme, 2003; Bahr & Krosshaug, 2005; Murphy et al., 2003). A final, and perhaps more pertinent associated consequence of previous injury is the quality of rehabilitation of the original injury. If the athlete has followed an appropriate rehabilitation programme the risk of further injury/re-injury should be reduced (Bahr et al., 1997; McKay, Goldie, Payne, & Oakes, 2001). However, this factor is often difficult to truly appreciate. Perhaps for this reason, in the literature to date previous injury is treated as a yes/no factor and is not considered modifiable. The

consequences of a previous injury such as altered ROM and strength may be subsequently modified as required.

An additional factor in the consideration of intrinsic injury risk is fatigue. Fatigue has been described as important because, when fatigued, the muscle can no longer produce the required power output therefore resulting in an increased risk of injury (Kirkendall, 1990). A possible cause for the lack of muscular control when a muscle is fatigued may be the decrease in joint proprioception and neuromuscular control impairing joint position sensibility (Lephart & Fu, 2000). Muscular fatigue can generally be described as an amalgamation of acute effects that impair performance, which in turn lead to the athlete to believe that the effort required to exert a desired force is higher than it actually is, eventually leading to the inability to produce the necessary force therefore increasing their risk of injury (Enoka, 1994). Not only is the force produced often perceived as higher than needed, but the ability to produce necessary protective reactive actions is often impaired when fatigued (Lephart & Fu, 2000). It has also been noted that overtraining can induce chronic fatigue and therefore underperformance and the associated increased risk of injury (Budgett, 1998). Fatigue, however, is a modifiable risk factor and correct exercise based programmes targeting other modifiable risk factors such as strength and flexibility can possibly delay or mitigate the onset of muscular fatigue therefore reducing injury risk (Enoka, 1994).

Poor or abnormal neuromuscular control is another important intrinsic risk factor to be considered as these factors increase an athlete's risk of injury, especially during dynamic joint stabilisation with muscles actively producing force whilst ligaments passively restrain the joint (Hewett et al., 2005a). Hewett et al. (2005a) suggest that nine of 196 athletes who went on to sustain an anterior cruciate ligament (ACL) injury displayed decreased neuromuscular control during biomechanical analysis of a drop jump compared

to athletes who remained uninjured placing them at a greater risk of additional injury/re-injury. With a decrease in neuromuscular control leading to the athlete utilising compensation mechanisms to overcome the weakness, athletes may potentially create further problems either up or down the kinetic chain, therefore further increasing their risk of injury (Lephart & Fu, 2000). In a study investigating the effects of a proprioception and neuromuscular control programme, consisting of strength, ROM, plyometrics and agility exercises, in female soccer athletes over a two year period reported a significant decrease in the occurrence of ACL injuries within the intervention group (Mandelbaum et al., 2005). This suggests that a prevention strategy to decrease injuries may need to include proprioception and neuromuscular control exercises as part of the injury prevention programme (Mandelbaum et al., 2005).

Finally, overall fitness is considered to be another important intrinsic risk factor for athletes in terms of injury risk as Knapik, Ang, Reynolds, and Jones (1993) found that soldiers with the presence of a previous musculoskeletal injury exhibited lower overall fitness levels than soldiers who had not suffered a previous injury. Although Knapik et al. (1993) suggest that previous injury leads to a decrease in overall fitness, they also acknowledge that as their work is retrospective with regards to injury data collection and therefore the opposite may be true that a decrease in overall fitness levels actually lead to injury. However it has been found that the higher the cardiovascular fitness, measured by a graded walking treadmill test in a general population, the greater the chance of injury with Hootman et al. (2001) reporting that men with high levels of cardiovascular fitness were four times more likely to sustain an injury compared to men with low levels of cardiovascular fitness. Although the study by Hootman et al. (2001) suggests that higher cardiovascular fitness levels increase the risk of injury, they used overall fitness as a measure of physical activity within a non-sporting population, and therefore, it can be surmised that an increase in physical activity, or sporting exposure, as opposed to higher

levels of cardiovascular fitness leads to an increased risk of injury. This further highlights the need for correct recovery time for athletes to avoid the occurrence of an overuse injury as previously discussed within section 2.1.2 (page 6).

Although many of these single internal risk factors may play a large role in the occurrence or susceptibility to injury on their own, it must be appreciated that injury and re-injury are likely to be multifaceted and therefore it is likely that all of these modifiable intrinsic risk factors are interlinked and interrelated (Collins & Raleigh, 2009). This connection between many of these internal risk factors is of extreme importance when looking to prevent injuries and create preventative measures. Additionally, this further highlights the inherent problems with identifying single risk factors when analysing injury occurrence and causation (Bahr & Holme, 2003; van Mechelen, Hlobil, & Kemper, 1992). Injuries must therefore be considered in relation to all of the modifiable intrinsic risk factors thus potentially allowing for a greater understanding of injury occurrence and possibilities for prevention.

2.1.4 Prevention of injuries

It is important to investigate in detail the ways in which injuries can be prevented and the likely sequence of identifying factors involved in injury prevention. Injury prevention has previously been described as a four-step process as demonstrated in Figure 2.2. To initiate any successful preventative model the first step is to understand the magnitude of the injury problem by analysing the incidence, severity, location and the type of injury within the chosen sport or activity (step one Figure 2.2 (Tyler et al., 2002; van Mechelen et al., 1992)). Step two then requires the clinician to begin to appreciate the risk factors associated with this type of injury and common mechanisms that cause the injury to gain a better understanding of how and why the injury is occurring (Bahr & Krosshaug, 2005;

Tyler et al., 2002). Once this process has been established within step two the next phase is to implement a preventative measure based upon information gained in step one and two aimed at reducing the likelihood of such recurrence (Figure 2.2). Following the implementation of the preventative measures within step three the clinician must then assess the effectiveness of the measures by returning to step one and beginning the process again within step four (Figure 2.2) (Bahr & Krosshaug, 2005; Tyler et al., 2002). It is also important to assess the efficacy of any proposed intervention protocol to ensure that it is likely to succeed before entering into step three of the van Mechelen et al. (1992) cycle shown in Figure 2.2 (Van Tiggelen, Wickes, Stevens, Roosen, & Witvrouw, 2008). The assessment of a proposed injury prevention protocol suggested by Van Tiggelen et al. (2008) is more effective in the prevention of injuries due to the correct development and optimisation of the protocols before entering them into step three of Figure 2.2. Thus, giving greater certainty of their success before implementation.

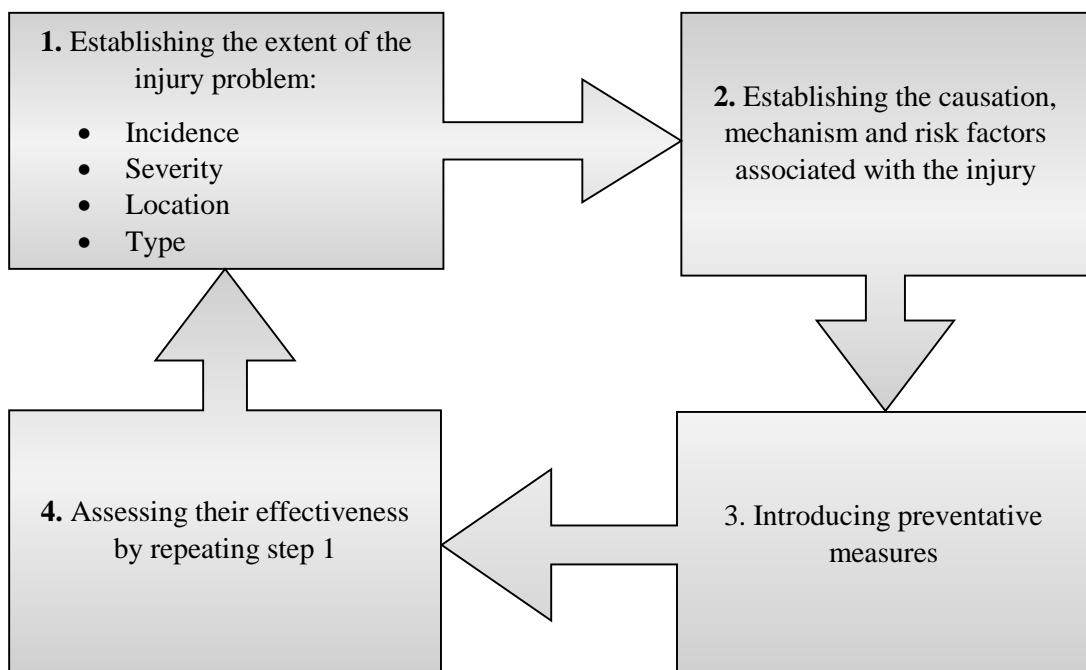


Figure 2.2 Sequence of injury recognition and prevention
(Adapted from van Mechelen et al., 1992)

2.1.5 Summary

In summary, injuries can be classified simply into two categories; contact or non-contact (Collins & Raleigh, 2009; Hreljac, 2004; Hreljac et al., 2000; Sharma & Maffulli, 2006), with non-contact injuries considered to be more easily preventable due to their intrinsic risk factors (Meeuwisse, 1994). Although many injuries are thought to be caused by a single factor they are often multifactorial and because of this many risk factors must be considered in synergy to fully appreciate injury causation (Collins & Raleigh, 2009; Kirkendall, 1990; Meeuwisse, 1994). The knowledge that many intrinsic risk factors are modifiable is important and consequently the focus must be centred on these as injury prevalence may be reduced by altering these modifiable intrinsic risk factors.

2.2 Injuries in ice hockey

2.2.1 Injury definition and reporting

Injury definitions and collection methods can have a huge influence on epidemiological studies by affecting the number/type of reported injuries (Orchard & Seward, 2002). Many studies define an injury as any event that required the attention of the team's medical staff or ones which prevented the athlete from participating in practices or a game (Agel & Harvey, 2010; Ferrara & Schurr, 1999; Kuzuhara et al., 2009; McKay et al., 2014; Pettersson & Lorentzon, 1993; Pinto et al., 1999; Schick & Meeuwisse, 2003; Tegner & Lorentzon, 1991; Tyler et al., 2001). However, others state that injuries should not only include ones that are reported to the medical staff but also injuries that go unreported (Fuller et al., 2006). Either method used to determine injury prevalence may bring about specific problems, with athletes' attitudes to injury having a differing impact upon results. For example, if an athlete has a high pain threshold they are less likely to report the injury to the medical staff and therefore less likely to miss any activity which

will then impact upon injury data collected (Fuller et al., 2006). On the other hand, athletes with a lower pain threshold may report injuries which are more of a nuisance injury that are not necessarily causing them to miss any activity but would still nonetheless classify as an injury. Whichever method is chosen within studies, this discrepancy highlights difficulties in data collection and comparisons between studies. If all injuries reported to the team's medical staff are included then it relies upon the willingness of the athlete to report an injury and also the medical staff to include it in their figures, this is especially true of minor, nuisance injuries (Fuller et al., 2006; Orchard & Seward, 2002). Whereas, if only injuries that cause an athlete to miss either a practice or a game are included then minor injuries, which do not cause the athlete to miss activity, will be excluded causing potential injuries, or the potential of subsequent serious injury, going unnoticed (Orchard & Seward, 2002).

There are two main methods of recording injuries utilised by previous ice hockey epidemiology studies: self-reporting questionnaires and medical staff reporting injuries. Jørgensen and Schmidt-Olsen (1986) used self-reporting questionnaires completed by athletes from 14 teams over a two year period finding that only 76% of the total injuries were reported to the team medical staff, highlighting the complications and problems of potential over diagnosis of the self-reporting method. Although the self-reporting method seen with Jørgensen and Schmidt-Olsen (1986) suggests that it highlights more overall injuries compared to other studies using the medical team to report injuries, it also relies upon athletes to self-disclose injuries that they may not want the team, medical staff or a researcher to be aware of as they may want to play through the pain rather than miss a game (Orchard & Seward, 2002). This non-disclosure of injury has the potential to miss many minor injuries possibly reducing the number of total injuries reported. The majority of studies use a more structured method for injury reporting, relying upon the team's medical staff to report injuries with detailed information of mechanism, nature and

diagnosis of the injury (Agel et al., 2007b; Agel & Harvey, 2010; Ferrara & Schurr, 1999; Flik et al., 2005; Kuzuhara et al., 2009; McKay et al., 2014; McKnight et al., 1992; Pettersson & Lorentzon, 1993; Pinto et al., 1999; Schick & Meeuwisse, 2003; Tegner & Lorentzon, 1991; Tyler et al., 2001). However, this method again may not account for all injuries, in particular those injuries not reported to the team's medical staff, whilst also removing some amount of the effect athletes attitudes to injury may have on reporting injury data (Fuller et al., 2006). This further highlights the potential problem of sporting exposure by athletes with an injury that has not been reported to the team's medical staff. If the athlete does not disclose the injury but continues to practice/play this could potentially increase their risk of injury due to accumulation of 'microtrauma' discussed previously within section 2.1.2 (page 6).

Table 2.1 collates current information from studies investigating injury prevalence within elite male ice hockey, giving particular attention to injury incidence, severity, type and common locations. Due to the differing styles, rules and physicality of male to female ice hockey only male focused studies were included within Table 2.1 and only studies analysing elite level ice hockey injuries were included for the same reasons.

Table 2.1 Research papers showing injuries in ice hockey

Author (Date)	Study length	Population	Method of data collection	Injury incidence	Injury severity (as per study definition)	Most common type (%)	Most common location (%)	Mechanism of injury (%)
Jorgensen and Schmidt-Olsen (1986)	2 seasons	Danish Elite (14 teams)	Self-reported by athlete	189 4.7/1000 hours (P: 1.5/1000 hours, G: 38.0/1000 hours)	0-1 days: 19% 2-7 days: 19% 8-14 days: 22% 15-21 days: 8% 22-30 days: 15% 30+ days: 17%	Concussion: 26 Sprain: 20 Strain: 8 Unknown: 39 Fracture: 7	Head: 28 Upper extremity: 19 Lower extremity: 27 Other: 19	Data not presented
Tegner and Lorentzon (1991)	1 season	Swedish Elite (12 teams)	Reported by medical team	285	Minor: 61% Moderate: 22% Major: 9%	Strain/sprain: 24 Laceration: 24 Contusion: 18 Fracture: 9 Miscellaneous: 25	Head/face: 39 Knee: 13 Hip/thigh: 12 Back/trunk: 11 Shoulder: 9 Hand/finger/arm: 8	Contact: 85 Non-contact: 15
McKnight et al. (1992)	3 seasons	NCAA (7 teams)	Reported by medical team	280 10.22/1000 AE G: 14.73/1000 AE P: 2.52/1000 AE	0-7 days lost: 60% 8-21 days lost: 25% 22+ days lost: 15%	Contusion: 33 Sprain: 30 Strain: 15 Laceration: 9 Fracture: 6 Other : 7	Head/neck: 11 Shoulder: 18 Upper extremity: 12 Groin/Hip: 10 Thigh: 10 Knee: 16 Ankle: 8	Contact (person/ice): 41 Boards: 19 Puck: 10 Stick: 6 Goal: 1 Other: 13
Pettersson and Lorentzon (1993)	4 years	Swedish Elite League (1 team)	Reported by medical team	376 G: 74.1/1000 hours P: 2.6/1000 hours	No absence: 61% 1-7 days: 34% 8-30 days: 4% 30+ days: 1%	Contusions: 43 Laceration: 26 Sprain: 12.0 Strain: 10 Concussion: 4 Fracture: 3 Tooth: 2	Head, neck and face: 31 Shoulder: 6 Back and trunk: 5 Wrist: 5 Hand: 5 Hip: 3 Thigh: 7 Groin: 6 Knee: 13	Stick contact: 26 Player contact: 24 Puck contact: 16 Collision with boards: 7 Fall, no contact: 4 Skate contact: 2 Miscellaneous: 21

Ferrara et al. (1999)	3 seasons	NCAA (7 teams)	Reported by medical team	10.22/1000 AE G: 14.73/1000 AE P: 2.52/1000 AE	0-7 days: 60% 8-21 days: 26% 22 days +:14%	Fracture/dislocation: 7 Sprain: 31 Strain: 17 Laceration: 9 Contusion: 36	Leg/foot: 14 Knee: 16 Shoulder: 19 Hip/thigh: 23 Thorax: 7 Arm/hand: 12 Head/neck: 9	Contact: 81 Non-contact: 19
Pinto et al. (1999)	1 season	Junior A	Reported by medical team	74 (22 athletes)	Data not presented	Sprains/ strains/ dislocations: F: 32, D: 42 Contusions: F: 30, D: 29	Face: F: 23, D: 29 Thigh: F: 13, D: 13 Shoulder: F: 13, D: 13 Hip: F: 6, D: 4	Stick: 16 Overuse: 14 Contact: 12 Non-contact: 8
Tyler et al. (2001)	2 seasons	NHL (47 teams)	Reported by medical team	141 total : 17/1000 hours 3.2 adductor sprains/1000 AE	141 total: 17/ 1000 hrs 3.2 adductor sprains/ 1000 AE	2: second degree 9: First degree	Adductor Muscle group	Data not presented
Schick et al. (2003)	1 year	Canadian University	Reported by medical team	161, 9.19/1000 AE	1 session missed: 10% 2-7 sessions missed: 50% 8-14 sessions missed: 20% 14+ sessions missed: 20%	Concussion: 11 Adductor strain: 8 MCL strain: 7 Ankle Sprain: 6 AC sprain: 8 Thigh contusion: 4 Hip flexor strain: 2 Knee contusion: 2 SIJ dysfunction: 1	Thigh: 17 Knee: 15 Head: 14 Shoulder: 15 Lower back: 11 Ankle: 5 Wrist: 5 Hand: 6 Hip: 4 Arm: 2	Boards: 36 Opponent: 38 Stick: 13 Other: 13
Flik et al. (2005)	1 season: 2 teams	NCAA Division I	Reported by medical team	113 injuries 4.9/1000 AE G: 13.8/1000 AE P: 2.2/1000 AE	Data not presented	Concussion: 19	Knee/leg: 22 Head: 19 Shoulder: 15 Foot/Ankle: 12 Hip/Groin: 9 Back/Spine: 9 Wrist/Hand: 7 Other: 7	Collision with: Opponent: 33 Boards: 19 Overuse: 8 Other: 8

Agel et al. (2007b)	16 seasons	NCAA	Reported by medical team	4673 G: 16.27/1000 AE P: 1.96/1000 AE	10+ days: G: 27% P: 25%	Knee: Internal derangement: 14 Head: Concussion: 9 Shoulder: AC Joint: 9 Upper leg: Contusion: 6 Pelvis/hip: Muscle-tendon strain: 5	Head/neck: G: 16, P: 10 Upper extremity: G: 34, P: 25 Trunk/back: G: 14, P: 26 Lower extremity: G: 34, P: 36 Other: G: 2, P: 3	Other contact: G: 40, P: 34 Player contact: G: 50, P: 33 Non-contact: G: 10, P: 33
Kuzuhara et al. (2009)	3 seasons	Japanese Elite	Reported by medical team	319 G:74.3/1000 hours P:11.2/1000 hours	Nuisance: 86% Minor: 9% Moderate: 3% Major: 2%	Most Common: Contusions: 38 Strains: 26 Lacerations: 10 Sprains: 9	Most Common: Head/neck: 17 Upper limb: 28 Trunk and back: 13 Lower limb: 42	Contact: 67 Non-contact: 17 Unreported: 16
Agel and Harvey (2010)	7 seasons	NCAA	Reported by medical team	2828 5.95/1000 AE	Data not reported	Most Common: Concussion: 12 Shoulder: 10 Knee: 10 Hip/Groin: 2 Ankle: 1	Most Common: Head/Neck: 12 Shoulder: 10 Knee: 10 Hip/Groin: 2 Ankle: 1	Data not reported
McKay et al. (2014)	6 seasons	NHL	Reported by medical team	5184, 15.6/1000 AE	40943 man-games lost	Data not collected	Head: 17 Thigh: 14 Knee: 13 Shoulder: 12 Hand: 7 Ankle: 6 Foot: 6 Hip: 4	Body contact: 28.2 Non-contact: 14.8

Abbreviations: Acromioclavicular (AC), Athlete Exposure (AE), Defensemen (D), Forwards (F), Game (G), Medial Collateral Ligament (MCL), National Collegiate Athletic Association (NCAA), National Hockey League (NHL), Practice (P), Sacroiliac Joint (SIJ).

2.2.2 Injury incidence

Table 2.1 shows that the injury incidence in elite male ice hockey ranged from 4.9 injuries/1000 AE (Flik et al., 2005) to 15.6/1000 AE (McKay et al., 2014), with various studies reporting injury incidence between the two (Agel & Harvey, 2010; Ferrara & Schurr, 1999; Flik et al., 2005; McKnight et al., 1992; Schick & Meeuwisse, 2003). It is interesting to note that there may be differences in the way injury prevalence data is reported worldwide. For example, the majority of North American injury audits report injuries per 1000 AE (Agel et al., 2007b; Agel & Harvey, 2010; Ferrara & Schurr, 1999; Flik et al., 2005; McKay et al., 2014; McKnight et al., 1992; Schick & Meeuwisse, 2003) compared to injury audits from Denmark (Jørgensen & Schmidt-Olsen, 1986), Sweden (Pettersson & Lorentzon, 1993; Tegner & Lorentzon, 1991) and Japan (Kuzuhara et al., 2009) which report injuries per 1000 hours of ice hockey activity or total injuries. It is therefore difficult to make comparisons of injury data from North America to the rest of the world.

Although the majority of studies describe injury prevalence in a similar method, by reporting injuries/1000 AE in which each time an athlete participates in ice hockey activity is classed as an exposure (Agel et al., 2007b; Agel & Harvey, 2010; Ferrara & Schurr, 1999; Flik et al., 2005; McKay et al., 2014; McKnight et al., 1992; Schick & Meeuwisse, 2003; Tyler et al., 2001), there are some slight discrepancies within the literature. For example, Agel et al. (2007b) reported the difference between game and practice injuries and not the total number per 1000 AE. Additionally, two studies reported only the total number of injuries (Pinto et al., 1999; Tegner & Lorentzon, 1991). Furthermore, a number of studies (Jørgensen & Schmidt-Olsen, 1986; Kuzuhara et al., 2009; Tegner & Lorentzon, 1991; Tyler et al., 2001) reported injuries per 1000 hours of ice hockey activity which makes comparisons difficult due to the intermittent nature of

the sport and differing amounts of 'ice time' received by individual athletes during games (Green et al., 1976; Leone, Leger, Lariviere, & Comtois, 2007; Montgomery, 2006; Reilly & Secher, 1990). The study by McKay et al. (2014) did, however, try to account for the intermittent nature of the sport and calculated injuries per 1000 hours of ice hockey playing time using the individual athletes time on ice where the minutes and seconds played by the athlete were calculated to give a season total in hours, thus giving a more accurate injury rate for games. McKay et al. (2014) found that the injury rate of athletes using the injuries per 1000 hours (of time on ice) were much higher than that of the same figures calculated into injuries per 1000 AE but also acknowledged the difficulty in using this method on a large scale due to underreporting and inaccurate time on ice measures.

2.2.3 Contact vs. non-contact injuries

Table 2.1 also suggests that contact injuries were more prevalent within the game of ice hockey than non-contact injuries (Agel et al., 2007b; Ferrara & Schurr, 1999; Flik et al., 2005; Kuzuhara et al., 2009; McKay et al., 2014; McKnight et al., 1992; Pettersson & Lorentzon, 1993; Pinto et al., 1999; Schick & Meeuwisse, 2003; Tegner & Lorentzon, 1991) and especially higher in games compared to practice situations. Pettersson and Lorentzon (1993) found that of the 376 total injuries, 318 (85%) were caused by contact. Similar trends were found by Tegner and Lorentzon (1991) and Ferrara et al. (1999) who found 85% and 81% of injuries respectively were due to contact. McKnight et al. (1992) found that only 35 (13%) of a total 280 injuries were sustained in a non-contact manner, typically being overuse injuries, when analysing 15 teams over a three-year period. Pinto et al. (1999) established that one team of athletes sustained a total of 13% of non-contact injuries when analysing all injuries for the team over a one year period which also confirms the general trend found by McKnight et al. (1992). More recently it has been found that body contact alone accounted for 28% of the 5184 injuries sustained in the

National Hockey League (NHL) across a six year period (McKay et al., 2014). For reasons outlined previously within section 2.1.2 (page 6) it may be more important to consider non-contact injuries in more depth due to their greater preventability. Further investigation of non-contact injuries could potentially allow teams' medical staff to implement measures aimed at reducing injuries as opposed to the changing of rules or equipment that would be required to reduce the high number of contact injuries seen (Aubry et al., 2002; Benson et al., 2002; Brunelle, Goulet, & Arguin, 2005). Unfortunately many of the studies within Table 2.1 do not distinguish between contact and non-contact injuries in terms of location or severity, only giving information of either frequency or percentage of such injuries. This makes detailed comparison between injury types difficult to ascertain.

2.2.4 Injury severity

As can be seen in Table 2.1 the most widely used method of grading the severity of injuries in previous injury epidemiology studies is to record and categorise days missed from sport participation (Agel et al., 2007b; Ferrara & Schurr, 1999; Jørgensen & Schmidt-Olsen, 1986; McKnight et al., 1992; Pettersson & Lorentzon, 1993). In ice hockey the majority of injuries resulted in absence from practice or games for zero to seven days (Ferrara & Schurr, 1999; Jørgensen & Schmidt-Olsen, 1986; McKnight et al., 1992; Pettersson & Lorentzon, 1993; Pinto et al., 1999). It should be noted that only one study chose to grade injuries by counting sessions (practices or games) missed as opposed to days missed (Schick & Meeuwisse, 2003). Another graded injuries by accounting for total man games lost due to injury giving an estimation of games lost per athlete during one season (McKay et al., 2014). Assessing injury severity in sessions missed is potentially a more accurate method of indicating injury severity; it is however very subjective, being influenced by the team's schedule, practice timings, frequency and level

of play as well as the possibility that athletes may play through pain, thereby, affecting the injury data (Fuller et al., 2006; Orchard & Seward, 2002).

Other studies chose to report injury severity by grading injuries. Tyler et al. (2001) used a grading system as prescribed by the team's medical staff and relied heavily upon the correct analysis and diagnosis of the injury to measure accurately the injury rate and severity. Although using the team's medical staff to grade injuries measures severity clinically it depends heavily upon the assessor diagnosing and grading the injury correctly (Tyler et al., 2001). Flik et al. (2005) gave descriptive data on injury severity and focused on the most prevalent injuries, therefore not giving a full and thorough insight into the total severity of all injuries over a season. Two studies (Kuzuhara et al., 2009; Tegner & Lorentzon, 1991) organised injuries into minor, moderate and major categories but gave no distinction between the categories making comparison difficult due to the subjective and potentially differing opinions of the assessing medical staff. The studies by Petterson and Lorentzon (1993) and Kuzuhara et al. (2009) did however further categorise injuries into nuisance injuries or injuries which did not result in an athlete missing any sessions. This potentially allows total figures of injuries to be analysed more accurately and compared to injuries which caused athletes to miss ice hockey activity.

Any of these methods are useful in grading the severity of injuries but using total days missed, regardless of ice hockey activity, may be the most transferrable measure of severity, allowing medical teams to truly understand the risk and likelihood of time missed due to injury for their athletes. Although using days missed as a measure of severity may be the most appropriate and accurate, it cannot account for injuries that are not reported by athletes. One possible explanation for the non-reporting of injuries is due to the athlete not perceiving it to be a problem or planning to play regardless of the injury or pain (Fuller et al., 2006). Another potential problem with using days missed as a

measure of injury severity is external factors affecting return to play, with athletes returning from injury too quickly for a variety of reasons potentially being a major problem (Orchard & Seward, 2002; Podlog & Eklund, 2004, 2007). For example, such reasons may be due to coach or team mate pressure to return or the potential rewards for playing a part in an important game outweighing the possibility of worsening the injury, these factors may lead to a more hurried return and therefore a potential increased risk of further injury/re-injury (Orchard & Seward, 2002; Podlog & Eklund, 2004, 2007). Conversely, athletes may miss more time by feeling trepidation and nerves about the injury and risk of re-injury therefore lengthening the injury time and severity giving a false representation of the injury (Podlog & Eklund, 2007). Another consideration of using the days missed method to measure injury severity may be if the team has days off from ice hockey activity, for rest purposes. The injured athlete may then be classified as missing more time/days than actually needed, leading to the injury to be classified as more severe than it actually was. Therefore, it is important to understand that although injury severity using days missed is potentially the optimal and most transferrable method for severity assessment it must also be viewed with a certain amount of caution due to the many different and uncontrollable factors which can affect severity determination. It is therefore likely that the amount of days missed is a combination of athlete perception of the injury, team performance and schedule and practice timetable which all have an impact upon the measurement of severity.

2.2.5 Injury location

As can be seen in Table 2.1 the most common area of injury during ice hockey activity is the head and neck area accounting for 14%-31% of all injuries despite the use of helmets (Agel et al., 2007b; Agel & Harvey, 2010; Flik et al., 2005; Jørgensen & Schmidt-Olsen, 1986; Kujala et al., 1995; Kuzuhara et al., 2009; McKay et al., 2014; McKnight et al.,

1992; Pettersson & Lorentzon, 1993; Pinto et al., 1999; Schick & Meeuwisse, 2003; Tegner & Lorentzon, 1991). Another frequently injured area of the ice hockey athlete was the shoulder accounting for between 6% (Pettersson & Lorentzon, 1993) and 19% (Ferrara & Schurr, 1999) of total injuries observed. The high number of injuries to the head, neck and shoulder may be explained by the high body contact and physicality of ice hockey with injuries to these areas expected to be most prevalent due to the technique of body checking (Byers & Roberts, 2006). Other common areas of injury that can be seen in Table 2.1 were reported to be the knee ranging from 10% (Agel & Harvey, 2010) to 22% (Flik et al., 2005) and hip which ranges from 2% (Agel & Harvey, 2010) to 23% (Ferrara & Schurr, 1999).

A further problem when comparing studies in Table 2.2 is the method of reporting injury location. Some studies group all injuries to the lower limb, or multiple areas, together and report injuries to this area as one figure (Agel et al., 2007b; Agel & Harvey, 2010; Jørgensen & Schmidt-Olsen, 1986; Kuzuhara et al., 2009; Tegner & Lorentzon, 1991). Not only does this make comparison to other studies with differing methods of reporting injury location problematic, it makes the highlighting of a specific injury problem challenging. It may, therefore, be of benefit to group injuries, particularly of a non-contact nature, into location by joint allowing the injury problem to be clear enabling clinicians to target specific joints when looking to implement an injury prevention programme.

2.2.6 Comparison of injuries in ice hockey to other team sports

It was important to appreciate the similarities and differences between the injuries sustained within ice hockey in comparison to other team sports of an intermittent nature in order to set the context for the specific injury problem within ice hockey. Soccer was considered a comparable sport to ice hockey because of the intermittent nature shared by

both sports, along with the relatively high number of lower limb injuries seen within soccer (Di Salvo et al., 2007; Edwards, Macfadyen, & Clark, 2003; Montgomery, 2006; Witvrouw et al., 2003; Worrell & Perrin, 1992).

Injury incidence studies within soccer have ranged between 0.5 injuries/1000 hours (Sullivan, Gross, Grana, & Garcia-Moral, 1980) and 27.9 injuries/1000 hours (Junge, Cheung, Edwards, & Dvorak, 2004) of soccer activity, with many other studies between this range (Askling et al., 2003; Collins & Raleigh, 2009; Hewett et al., 2005b; Witvrouw et al., 2003). Comparison to ice hockey injury studies was difficult due to the majority of ice hockey studies reporting results in injuries/1000 AE as opposed to injuries/1000 hours of activity as can be seen within Table 2.1. Hawkins et al. (2001) state that each soccer athlete was likely to receive 1.3 injuries per season when investigating injuries from 92 English professional soccer clubs across a two year period. Although this is a good measure of injuries per athlete and adds a measure of 'real life' perspective, it does make comparison to other studies difficult due to being an alternative method of reporting injury frequency to that more commonly used in previous literature.

Comparison of injuries within ice hockey and rugby union is also useful due to the similarities in the high collision nature and injury frequency seen by both sports (Brooks et al., 2005a). Brooks et al. (2005a) found the injury rate to be 91 injuries/1000 hours of rugby activity during competitive matches when analysing 12 professional rugby union teams. Although this figure is very high, a further study by Brooks, Fuller, Kemp, and Reddin (2005b) demonstrated that practice injuries accounted for considerably less with 2 injuries/1000 hours of rugby activity. Even with the addition of the practice injuries lowering the total injury frequency it still remains relatively high when compared to ice hockey (Table 2.1). Although ice hockey displays high injury rates when compared to other comparable intermittent sports, such as soccer, and figures that are similar to rugby

union the tendency within ice hockey to report injuries/1000 AE makes detailed comparison to other studies and sports difficult.

The most common area of injury was the lower limb for both soccer (Collins & Raleigh, 2009; Hennessey & Watson, 1993; Witvrouw et al., 2003; Worrell & Perrin, 1992) and rugby union (Brooks et al., 2005a; Brooks et al., 2005b; Junge et al., 2004) compared to the head, neck, face and shoulder within ice hockey (Table 2.1). This may be due to the exposure of the head, neck and face compared to the rest of the body which is covered by protective equipment within ice hockey. This exposure coupled with the main mechanism of contact utilising the shoulder as the main point of contact during body checking (Byers & Roberts, 2006) may give the high number of injuries seen to these areas in Table 2.1. Although the sports differ in injury location they are consistent when investigating the method of reporting injury severity with days missed being the most common method in soccer (Ekstrand & Gillquist, 1983; Junge et al., 2004), rugby union (Junge et al., 2004) and ice hockey (Table 2.1). Similarly the most common amount of days for athletes to miss was zero to seven days due to the injury which was consistent across soccer (Ekstrand & Gillquist, 1983; Junge et al., 2004), rugby union (Junge et al., 2004) and ice hockey (Table 2.1).

One area of disagreement between sports is that contact injuries within soccer accounts for 38% of total injuries (Hawkins et al., 2001; Junge et al., 2004) compared to 71% of all injuries in rugby union (Brooks et al., 2005a) and similarly high figures from ice hockey injuries (Table 2.1). These high figures of contact injuries within rugby union and ice hockey may be explained due to the high contact nature of both sports, thus, accounting for a higher frequency of injuries, in particular those of a contact nature (Brooks et al., 2005a; Brooks et al., 2005b; Byers & Roberts, 2006; Warsh et al., 2009).

2.2.7 Summary

Injuries, particularly of a contact nature, are extremely common within ice hockey (Agel et al., 2007b; Agel & Harvey, 2010; Ferrara & Schurr, 1999; Flik et al., 2005; Jørgensen & Schmidt-Olsen, 1986; McKay et al., 2014; McKnight et al., 1992; Schick & Meeuwisse, 2003). However, difficulties arise in defining and assessing severity of injuries due to the differing methodologies used with previous literature, thus highlighting the need for a standardised definition and grading system. The majority of studies chose to grade the severity of injury in days missed as a result of the injury, with the most common amount of time missed being between zero and seven days (Ferrara & Schurr, 1999; Jørgensen & Schmidt-Olsen, 1986; McKnight et al., 1992; Pettersson & Lorentzon, 1993; Pinto et al., 1999). The most common area of the body to become injured were the head, shoulder, knee and hip when both contact and non-contact injuries are considered together (Agel et al., 2007b; Agel & Harvey, 2010; Flik et al., 2005; Jørgensen & Schmidt-Olsen, 1986; Kujala et al., 1995; Kuzuhara et al., 2009; McKay et al., 2014; McKnight et al., 1992; Pettersson & Lorentzon, 1993; Pinto et al., 1999; Schick & Meeuwisse, 2003; Tegner & Lorentzon, 1991). However, there exists a lack of previous literature reporting specifics of non-contact injuries within ice hockey. Although contact injuries are more prevalent than non-contact injuries within ice hockey (Agel et al., 2007b; Ferrara & Schurr, 1999; Flik et al., 2005; Kuzuhara et al., 2009; McKay et al., 2014; McKnight et al., 1992; Pettersson & Lorentzon, 1993; Pinto et al., 1999; Schick & Meeuwisse, 2003; Tegner & Lorentzon, 1991), the prevention of injuries should focus upon the modifiable factors common within non-contact injuries. Comparison of injuries in ice hockey to soccer and rugby union demonstrated that both ice hockey and rugby union athletes are more likely to sustain a contact injury, with the high majority of injuries across all three sports leaving athletes to miss 0-7 days of activity (Brooks et al., 2005a;

Brooks et al., 2005b; Collins & Raleigh, 2009; Ekstrand & Gillquist, 1983; Hawkins et al., 2001; Junge et al., 2004).

2.3 Understanding ice hockey

Understanding the demands placed upon the ice hockey athletes body is imperative to fully understand the injury problem present within the sport. Appreciating the biomechanical, physiological and psychological demands of the game will allow research to focus upon common movements, and problems specific to the sport and ice hockey athletes.

2.3.1 The game

Ice hockey is a fast paced, start-stop intermittent contact sport that places a high level of demand upon the body, with its requirement for athletes to generate both maximal speed and power whilst maintaining balance and reacting to other athletes (Montgomery, 2006; Potteiger et al., 2010; Quinney et al., 2008; Vescovi et al., 2006). Physiologically, ice hockey athletes rely on aerobic and anaerobic energy systems in order to maintain high levels of activity, muscular strength, power, flexibility and balance to maximise performance (Montgomery, 2006; Potteiger et al., 2010; Quinney et al., 2008). One of the primary aims in ice hockey is reaching a destination as quickly as possible (Behm, Wahl, Button, Power, & Anderson, 2005; Farlinger, Kruisselbrink, & Fowles, 2007). Additionally training specificity has been demonstrated to be of great importance: previous research has indicated that not replicating the predominant actions of ice hockey when practicing can lead to a decrease in 'on ice' performance (Behm et al., 2005).

Ice hockey is characterised by three 20 minute periods of play separated by an average 12-15 minute break between periods with athletes having approximately 18-26 shifts (a

shift is, the time which athletes spend on the ice before being substituted) for forwards and 20-32 shifts for defensemen (Green et al., 1976; Jørgensen & Schmidt-Olsen, 1986; Pollitt, 2003; Reilly & Secher, 1990). Each shift typically lasts 45-60 seconds, and consists of acceleration, coasting and deceleration interspersed with sprints typically lasting approximately 5-7 seconds (Green et al., 1976; Jørgensen & Schmidt-Olsen, 1986; Pollitt, 2003; Reilly & Secher, 1990). Little time is spent skating at full speed in a straight line, demonstrating that other aspects such as acceleration, stopping and changing direction are of equal importance to straight line speed (Farlinger et al., 2007). The majority of teams have four lines of forwards, three pairs of defensemen and two net minders with three forwards, two defensemen and one net minder on the ice during normal play (Reilly & Secher, 1990). Typically forwards have a work to rest ratio of 1:3 as opposed to defensemen who can have a work to rest ratio of between 1:1-1:3 dependent upon athlete ability, puck possession and game situation (Pollitt, 2003). Another important characteristic of ice hockey is 'body checking', in which an athlete deliberately uses force and body contact to remove the opposition athlete from the puck (Warsh et al., 2009). Although considered an important, indeed a vital part, of the game, body checking is also controversial, with a high number of injuries associated with it at all levels of the game (Warsh et al., 2009). Due to the high intermittent workload seen within ice hockey it is important to appreciate the biomechanical, physiological and psychological demands placed upon the ice hockey athlete during practice and game play.

2.3.2 Demands of ice hockey activity

2.3.2.1 Biomechanical demands

Ice hockey involves a unique style of locomotion: unlike normal gait, complex movements in both the frontal and sagittal planes allow athletes to utilise medio-lateral

movements of the body (Upjohn et al., 2008). A well-developed skating style and technique enables athletes to move accurately with speed on the ice, thereby allowing them to compete for puck possession, along with attending to the strategic tasks and movements demanded by the game (McPherson et al., 2004; Upjohn et al., 2008). Similarly to walking gait, the main skating stride consists of two phases of movement: support and swing phases (McPherson et al., 2004; Upjohn et al., 2008). The support phase can be separated further into the double and single support phase with propulsion taking place in both of these sub phases through the internal rotation of the hip along with extension of both the hip and knee (Upjohn et al., 2008).

There are many factors that contribute to an effective and efficient skating stride, both knee and hip abduction angle at push off and touchdown along with the degree of forward lean which must be taken into consideration (McPherson et al., 2004). In a recent study it was found that high calibre ice hockey athletes demonstrated increased hip flexion, knee extension and plantar flexion during skating leading to an increased speed and an increased stride length (Upjohn et al., 2008). Through this increase of joint motion it was found that high calibre skaters had less lateral movement and propulsion when compared to low calibre skaters, allowing more of their force and power to be applied in the correct direction of travel (Upjohn et al., 2008). Skating may therefore place a high load onto the hip joint when in flexion, abduction and lateral rotation. High loading rates in this joint position have been linked with increased pain, loss of movement and decreased power when consistently overloaded, which is often seen in ice skating (Bizzini et al., 2007; Philippon et al., 2010).

2.3.2.2 Physiological demands

As previously discussed ice hockey is a highly intermittent sport that requires athletes to travel at maximal speed for short periods of time (Green et al., 1976; Jørgensen & Schmidt-Olsen, 1986; Pollitt, 2003; Reilly & Secher, 1990). As previously stated there are differences in the physiological demands between playing positions in ice hockey with an average VO_2 max ranging from 52-63 ml/kg/min, suggesting that although ice hockey is an intermittent sprint sport, aerobic metabolism accounts for a high proportion of total energy requirements (Leone et al., 2007; Montgomery, 2006). Conversely, there is evidence that suggests that 'on-ice' VO_2 max is not indicative of fitness in ice hockey athletes as a high VO_2 max score suggests a lack of efficiency when skating as opposed to a high aerobic capacity and is therefore suggested to be a poor predictor of ice hockey fitness (Green et al., 1976). It has also been observed that the average 'on-ice' heart rate was 173 beats per minute (BPM) and an 'off-ice' heart rate of 120 BPM when analysing Canadian ice hockey athletes during a game situation, indicating that ice hockey athletes are working at around 80% of their maximal heart rate during their 'on-ice' shifts of play (Reilly & Secher, 1990). On average defensemen had a heart rate 10-15 BPM lower than that of forwards during game simulation which is consistent with a decrease in velocity during each shift when compared to forwards (Green et al., 1976). Due to the relationship previously discussed between sporting exposure and injury incidence (Hootman et al., 2001; Knapik et al., 1993), it was important to appreciate the physiological demands required of an ice hockey athlete to appreciate the loads placed upon their body.

2.3.2.3 Practice tendencies and styles of play

It is well described that injuries within games are higher than those sustained during practice (Agel, Dick, Nelson, Marshall, & Dompier, 2007a; Agel et al., 2007b; Agel &

Harvey, 2010; Ferrara & Schurr, 1999; Flik et al., 2005; Jørgensen & Schmidt-Olsen, 1986; Kuzuhara et al., 2009; McKay et al., 2014; McKnight et al., 1992; Pettersson & Lorentzon, 1993; Pinto et al., 1999; Schick & Meeuwisse, 2003; Tegner & Lorentzon, 1991) but it is important to appreciate the frequency, amount and length of practices that differing levels of ice hockey athletes perform. Although practice frequency and length vary from team to team, on average each team practices four times a week for two hour sessions (Pettersson & Lorentzon, 1993; Pinto et al., 1999). However, two studies found that the average practice time was 1.5 hours (Pinto et al., 1999) for four days a week and 5.5 hours per week (Jørgensen & Schmidt-Olsen, 1986) showing there is a range between teams and differing levels. It was found that within Women's National Collegiate Athletic Association (NCAA) division III teams they trained less than their more skilled counterparts, with an average of 64 practices a year compared to 77 for division II and 84 for division I teams over a four year period (Agel et al., 2007a). The findings in the women's game are also observed in the men's game by Agel et al. (2007b) who found that across a 16 year period the average that division III athletes practiced was 67 times, division II practiced 84 times and division I practiced 95 times per year. This increased practice time within the levels of NCAA divisions suggests that as quality and standard of play/athlete increases so does the practice time thus creating a greater risk of injury due to the higher exposure. In a study of Swedish Elite League athletes Pettersson and Lorentzon (1993) found they practice more than in North America reporting that over a four season period the average amount of practices was 176 per season (209 hours) in Sweden compared to the 95 times NCAA division I athletes practice in America (Agel et al., 2007b). This increased practice rate seen by Pettersson and Lorentzon (1993) may again lead to an increased injury incidence due to the exposure to the sport.

North American ice hockey is known to be more physical than that of European ice hockey due to the nature of tactics and strategy potentially explaining the increased injury

rate seen in Table 2.1. The typical North American style of ‘dump and chase’ (where the attacking athletes propel the puck into the opposing team’s defensive zone and use body contact to regain puck possession) is more physical and is believed to bring about a higher number of contact injuries (Flik et al., 2005). Another major difference between the European and North American style is the size of the playing surface: in Europe it is on an international sized ice rink (200’ x 100’) whereas the North American game is played on a narrower ice rink (200’ x 85’) adding to the physicality due to the decrease in space allowed per athlete (Gee & Leith, 2007; Wennberg, 2004).

2.3.2.4 Psychological demands

A further consideration for all analysis of the demands placed upon the ice hockey athlete is psychological. It was not within the scope of this project to perform a detailed review of literature in this topic, however, a brief overview was necessary.

Due to the high contact nature of ice hockey it is important to understand and appreciate the psychological demands placed upon the ice hockey athlete due to potential violence and physicality being relatively commonplace within all levels of ice hockey (Gee & Leith, 2007). It has been implied that athletes playing in differing positions in ice hockey have contrasting psychological profiles potentially leading to an increased risk of injury for certain playing positions (Park, Buunk, & Wieling, 2007). Forwards, for example, have been shown to have a higher injury rate compared to defenseman which may be explained by them being more likely to take risks to try and create a scoring opportunity, therefore increasing their risk of injury (Junge, 2000). It is also believed that athletes in general who have more psychological demands within their life (death in the family, marriage, children etc.) are more susceptible to injury than athletes who do not have such demands (Junge, 2000).

In a study of elite level youth hockey athletes it was found they were likely to use physical or psychological aggression towards opposing athletes to either intimidate them or help their team win (Dunn & Dunn, 1999; Gee & Leith, 2007). This type of behaviour shown by certain athletes increases the risk of injury as they may not appreciate or show concern towards the opposing athletes' welfare (Dunn & Dunn, 1999). Another major psychological factor within ice hockey is frustration; this can develop for a variety of reasons ranging from frustration from not being able to possess the puck within a game to losing a game overall (Gee & Leith, 2007). Athletes often associate aggressive behaviour in ice hockey with positive performance results and believe that displaying this behaviour has a positive outcome on their team and performance (Gee & Leith, 2007). These psychological aspects may link to the common under-reporting of injuries within ice hockey as athletes may not wish to show weakness or injury to teammates and opponents, believing this could negatively affect their team performance or place within the team (Wiese-Bjornstal, Smith, Shaffer, & Morrey, 1998).

2.3.3 Summary

The review of literature highlights the intermittent nature of ice hockey with athletes typically having a work to rest ratio of between 1:1 and 1:3 requiring them to produce high levels of power and speed during their time on the ice (Montgomery, 2006; Pollitt, 2003; Potteiger et al., 2010; Quinney et al., 2008; Vescovi et al., 2006). Due to these high levels of speed and power, ice hockey athletes need good levels of muscular strength, flexibility, power and balance to be able to play the game to the highest level (Montgomery, 2006; Potteiger et al., 2010; Quinney et al., 2008). Not only are these qualities important in ice skating and skill execution but with the high contact nature of the sport they are imperative to ensure the athlete's safety and ability to play the game successfully (Warsh et al., 2009). Ice hockey is played worldwide with injuries and

contact highest within North America, attributable to the style of play employed and the smaller size of ice rinks compared to the European style of play (Gee & Leith, 2007; Wennberg, 2004). The unique locomotion technique involved in ice skating places the athlete's hip in vulnerable positions, subjecting the hip under a great amount of stress and load (Bizzini et al., 2007; Philippon et al., 2010; Upjohn et al., 2008).

2.4 The hip

2.4.1 Hip anatomy

The hip joint is a highly congruent ball and socket joint consisting of the acetabulum and the head of the femur (Anderson, Strickland, & Warren, 2001; Drake, Vogl, & Mitchell, 2009; Hughes, Hsu, & Matava, 2002). A fibrocartilagenous rim, the acetabular labrum, increases the joint congruency by deepening the acetabulum causing the head of the femur to be more secure (Anderson et al., 2001; Drake et al., 2009; Hughes et al., 2002; Palastanga & Soames, 2011). Although the acetabulum labrum deepens the socket and increases the congruency of the joint, in an erect position the femoral head is not completely covered by the acetabulum and therefore puts the joint in a potentially vulnerable position due to the instability caused (Palastanga & Soames, 2011). Although the hip joint is often classified as extremely congruent (Anderson et al., 2001; Drake et al., 2009; Hughes et al., 2002) the shape of the femoral head and acetabulum are actually incongruent therefore limiting the contact between the two (Palastanga & Soames, 2011). This limited contact between the femoral head and acetabulum is of benefit to the joint as the congruency increases with increasing loads, adding to the stability of the joint but also acting as a weight bearer and distributor limiting the forces passed through the joint (Palastanga & Soames, 2011). During weight-bearing activities the femur is under

extreme tensile and compression forces causing the joint to be of extreme importance in both stance and locomotion (Hughes et al., 2002; Palastanga & Soames, 2011).

Like the majority of joints the hip exhibits a joint capsule which is very strong and thick anteriorly and superiorly increasing the stability of the joint (Palastanga & Soames, 2011). The capsule is strengthened on the anteromedial aspect by the deep fibres of rectus femoris and laterally by the deep fibres of gluteus medius as well as inferiorly and anteriorly by the pubofemoral ligament (Drake et al., 2009; Hughes et al., 2002; Palastanga & Soames, 2011). The fibres that make up the joint capsule are extremely important with fibres holding the femoral head deeper into the acetabulum, increasing the congruency and stability of the joint (Drake et al., 2009; Palastanga & Soames, 2011).

Due to the incomplete nature of the acetabular rim the transverse ligament of the acetabulum plays a pivotal role in completing the acetabular rim, therefore, holding the femoral head in place (Drake et al., 2009; Palastanga & Soames, 2011). Within the hip joint lies the fibroelastic acetabular fat pad sitting within the fossa which during extension becomes extruded from the fossa below the transverse ligament allowing the femoral head to press deeper into the fossa, therefore gaining a greater ROM (Drake et al., 2009; Palastanga & Soames, 2011). During flexion the fat pad returns back into the fossa filling the gap left by the femoral head protecting the joint space of the hip (Drake et al., 2009; Palastanga & Soames, 2011).

The ligaments of the hip are known to be the strongest within the body and are well adapted to the high forces placed upon the hip (Anderson et al., 2001). The three capsular ligaments (iliofemoral, pubofemoral and ischiofemoral ligaments) not only help reinforce the joint capsule but also play the major role in the stability of the joint (Drake et al., 2009; Hughes et al., 2002; Palastanga & Soames, 2011). These three ligaments work together and are orientated in a spiral pattern around the hip joint becoming taught in

extension and most slack in a combination of flexion, abduction and external rotation (Drake et al., 2009; Hughes et al., 2002; Palastanga & Soames, 2011). These three major ligaments of the hip are extremely important in stability and are well adapted to the high forces placed through the hip. However, if these ligaments become lax, potentially from a previous injury, the stability and congruency of the joint may become compromised. If the joint stability does become compromised the musculature surrounding the hip must compensate to maintain joint stability.

2.4.2 Hip musculature

Understanding how the hip musculature is compiled is important to gain a broader understanding of how the hip is moved and supported, and therefore likely to become injured. Although the articular surfaces of the femur and acetabulum are congruent and the joint is fairly stable the surrounding musculature contributes to the continued stability of the joint (Palastanga & Soames, 2011). Many muscles aid with ensuring the head of the femur stays within the acetabulum, these muscles include psoas, iliacus, pectineus anteriorly, gluteus minimus superiorly, gluteus medius, obturator internus and externus, the gemelli, quadratus femoris and piriformis posteriorly (Palastanga & Soames, 2011). As the hip is a stable yet mobile joint there are many muscles that contribute to both movement and stability to the joint, therefore it is important to consider the muscles in terms of movements they control as can be seen within Table 2.2.

Table 2.2 Muscles acting upon the hip according to their movement

Action	Muscle	Origin	Insertion
Flexion	Psoas major	Bases of transverse processes of all lumbar vertebrae, bodies of T12 and 13 vertebrae, IV disks above each lumbar vertebrae	Lesser Trochanter of femur
	Iliacus	Upper 2/3 rd s of iliac fossa, AIIS	Psoas major tendon, lesser trochanter of femur
	Pectineus	Superior ramus of pubis	Lesser trochanter to linea aspera of femur
	Rectus Femoris	AIIS and ilium above acetabulum	Superior patella
	Sartorius	ASIS	Anteromedial surface of shaft of tibia
	Tensor fascia latae	ASIS and iliac crest	Iliotibial tract
Extension	Gluteus maximus	Outer surface of ilium behind posterior gluteal line, adjacent posterior sacrum and coccyx	Iliotibial tract of fascia latae, gluteal tuberosity
	Semitendinosus	Ischial tuberosity	Medial shaft of tibia
	Semimembranosus	Ischial tuberosity	Posterior medial condyle of tibia
	Biceps femoris	Ischial tuberosity	Fibula head and lateral condyle of tibia
Abduction	Gluteus maximus		As above
	Gluteus medius	Anterior gluteal line	Lateral surface of GT
	Gluteus minimus	Outer surface of ilium	Anterior surface of GT
	Tensor fascia latae		As above
Adduction	Adductor magnus	Inferior ramus of pubis and tuberosity of ischium	Linea aspera and adductor tubercle of femur
	Adductor longus	Anterior body of pubis	Medial lip of linea aspera
	Adductor brevis	Outer surface of inferior ramus of pubis	Below lesser trochanter to linea aspera
	Gracilis	Inferior ramus of pubis	Upper medial surface of shaft of tibia
	Pectineus		As above

Internal	Gluteus medius		As above
Rotation	Gluteus minimus		As above
	Tensor fascia latae		As above
	Psoas major		As above
	Iliacus		As above
External	Gluteus maximus		As above
Rotation	Piriformis	Internal surface of sacrum, sacrotuberous ligament	Upper border of GT
	Obturator internus	Pelvic surface of obturator membrane and ilium, ischium and pubis	Common tendon with superior and inferior gemelli to medial surface of upper border of GT
	Obturator externus	Outer surface of superior and inferior rami of pubis and ramus of ischium surrounding obturator foramen	Trochanteric fossa of femur
	Gemellus superior	Spine of ischium	With tendon on obturator internus into medial surface of upper border of GT
	Gemellus inferior	Upper margin of ischial tuberosity	With tendon on obturator internus into medial surface of upper border of GT
	Quadratus femoris	Lateral border of ischial tuberosity	Below intertrochanteric line

Abbreviations: Anterior Inferior Iliac Spine (AIIS), Anterior Superior Iliac Spine (ASIS), Greater Trochanter (GT), Intervertebral (IV), Lumber (L), Thoracic (T)

2.4.3 Purpose of the joint

The hip joints main purpose is to propel the body during locomotion along with disseminating weight throughout the body. Within gait the hip plays a pivotal role in allowing the lower, more distal, limb to extend further forward allowing greater and more economical advancement of the body (Hughes et al., 2002). Within ice hockey the hip plays an integral role in both locomotion and balance (Bracko, Fellingham, Hall, Fisher, & Cryer, 1998; Chang et al., 2009). During quiet stance each hip joint is subject to between one third and one half of body weight: this figure increases from two and a half to four times body weight when stood on one limb (Hughes et al., 2002; Maquet, 1985; Palastanga & Soames, 2011). This high force therefore places the hip at an increased risk of injury.

2.4.4 Ice hockey movements

During propulsion of the ice skating stride the hip is responsible for explosive extension, abduction and external rotation (Chang et al., 2009). As previously discussed the hip plays a pivotal role in propulsion of the body and allows the upper body to complete the complex skills seen within ice hockey (McPherson et al., 2004; Upjohn et al., 2008). The primary muscles involved for movement are the hip abductors and extensors whilst the hip flexors and adductors are predominantly stabilisers and decelerators of the lower limb (Tyler et al., 2001). It has been observed that high calibre ice hockey athletes display a greater rate of hip flexion, during weight acceptance, compared to low calibre ice hockey athletes (Upjohn et al., 2008). This greater rate of hip flexion during loading is suggestive of a higher eccentric contraction of the anterior thigh muscles, therefore allowing a greater concentric contraction during the propulsive phase (Upjohn et al., 2008). Due to the greater rate and range of hip flexion that high calibre athletes achieve they also exhibit

greater force during propulsion leading to a greater speed of ice skating (Upjohn et al., 2008). The increased speed achieved from the greater amount of hip flexion seen, should therefore result in an increased amount of hip abduction allowing the hip to maintain the propulsive angle needed for efficient forward movement (De Koning, Thomas, Berger, de Groot, & van Ingen, 1995). Although an increase in ROM of hip abduction and flexion is a desired objective to increase speed, it can lead to an increase of hip injuries due to the higher eccentric load placed upon the hip flexors and adductors associated with the increased ROM (Chang et al., 2009; Stull et al., 2011). Athletes are also reported to be at a greater risk of non-contact injury with the existence of hip flexor and adductor muscular weakness thus limiting the eccentric muscle control needed for successful skating along with a compromise of stability throughout the skating pattern (Chang et al., 2009; Stull et al., 2011; Tyler et al., 2001). Due to the movements and role of the hip musculature associated with ice skating it is therefore possible that the same risk of injury can be said for the extensors, abductors and internal and external rotators of the hip. However, there is a lack of research on the impact and extent to which the hip internally and externally rotates, as well as the magnitude of abduction and adduction the hip is subjected to during the stance and propulsion phase of ice skating (Upjohn et al., 2008).

Along with the increase in speed associated with higher calibre athletes, Upjohn et al. (2008) state that higher calibre ice hockey athletes also exhibit an increased stride length and width whilst maintaining the same stride rate suggesting that as the force and power production increases that this may further increase the risk of injury. The medio-lateral hip musculature is under high amounts of stress during ice skating due to the small base of support offered by the ice skate; this small base of support offers little side to side stability instead requiring stability from the medio-lateral musculature of the hip, knee and ankle particularly when an athlete is competing in physical battles for puck possession with opposition athletes (Chang et al., 2009). The movements associated with ice hockey

specific movements are not only important in terms of injury analysis but a greater knowledge of the implications of the load transmitted through the hip is necessary to fully understand the potential risk of injury to the hip.

2.4.5 Pathology of the hip joint

Previous literature has categorised pathology and injury of the hip to either the joint (Bizzini et al., 2007; Leunig, Beck, Dora, & Ganz, 2005; Mitchell et al., 2003; Philippon & Schenker, 2006; Philippon et al., 2010), the individual structure surrounding the joint (Tyler et al., 2002; Tyler et al., 2001) or grouped pathology by a number of structures surrounding the hip joint and soft tissues associated with the joint (Larson, Pierce, & Giveans, 2011). While this approach has merit in that it allows for either specific or multifaceted investigation into injuries and injury prevention it also presents a problem with regard to differing definitions of injury pathology and size of the injury problem found in the literature.

The hip joint has previously been demonstrated to be frequently injured within ice hockey (Ferrara & Schurr, 1999; Flik et al., 2005; McKay et al., 2014; McKnight et al., 1992; Pettersson & Lorentzon, 1993; Pinto et al., 1999; Tegner & Lorentzon, 1991) and although hip injuries occur less often when compared to the extremities (e.g head, knee), hip injuries still require extensive rehabilitation and can become problematic issues for athletes (Anderson et al., 2001). Common causes of hip pain are adductor muscle pathology, osteitis pubis, athletic pubalgia, femoroacetabular impingement (FAI) and trochanteric bursitis with some less common injuries including psoas bursitis or strains along with neurological complaints (Mitchell et al., 2003; Philippon & Schenker, 2006; Philippon et al., 2010; Tyler et al., 2001). It has previously been suggested that a decrease in hip ROM or muscular strength leads to not only a decrease in athletic performance, but

also an increased risk of injury (Hughes et al., 2002; Larson et al., 2011; Philippon & Schenker, 2006).

FAI is an emerging injury within the aging and, increasingly in sporting populations, in particular ice hockey athletes due to the abnormal loading of the hip during the skating stride (Bizzini et al., 2007; Larson et al., 2011; Leunig et al., 2005; Philippon & Schenker, 2006; Philippon et al., 2010). A believed cause of FAI is the occurrence of one of two major factors: 1.) the acetabulum opening facing too posteriorly causing the femoral head to impinge upon the acetabulum or labrum, or 2.) deviation of the proximal femur causing the same outcome (Larson, Guanche, Kelly, Clohisy, & Ranawat, 2009; Larson et al., 2011; Leunig et al., 2005; Philippon & Schenker, 2006). If either of the above occur the coverage of the acetabulum on the anterolateral aspect of the femoral head is too great, causing a dysfunction of internal rotation and flexion potentially leading to the FAI (Larson et al., 2009; Leunig et al., 2005; Philippon & Schenker, 2006). This abnormal contact between the proximal femur and the acetabulum is worsened due to repetition of movements or forceful loading of movements, both of which are found in many athletic movements, particularly within ice hockey (Larson et al., 2009; Leunig et al., 2005; Philippon & Schenker, 2006). Athletes who present with FAI often have pain, strength and ROM deficits (Larson et al., 2011; Philippon & Schenker, 2006).

FAI can be classified as two types: cam or pincer impingement (Larson et al., 2009; Leunig et al., 2005; Philippon & Schenker, 2006). Cam FAI presents as an enlargement of the femoral head/neck junction causing an outside-in impingement of the acetabulum due to the shear forces placed upon the acetabulum during movements, in particular flexion (Larson et al., 2009; Leunig et al., 2005; Philippon & Schenker, 2006). Pincer FAI is caused by the abnormality of the acetabulum, as opposed to the femoral head, and is often due to the acetabulum being too deep or, as previously mentioned, over covering

the anterolateral aspect of the femoral head causing a linear impingement of the acetabular labrum (Larson et al., 2009; Leunig et al., 2005; Philippon & Schenker, 2006). Although both the cam and pincer FAI are common possible causations of hip pathology; pincer FAI is much more common within the elderly population as opposed to the cam FAI which is found more within the athletic population (Leunig et al., 2005; Philippon & Schenker, 2006; Philippon et al., 2010). Either type of FAI can cause not only degeneration of the acetabular labrum but also tearing and avulsion from the acetabulum causing pain and blockages in movements (Larson et al., 2009; Leunig et al., 2005; Philippon & Schenker, 2006).

Another common cause of FAI within the athletic population is the occurrence of a combination of abduction and external rotation of the femur or flexion combined with internal rotation of the femur which puts an increased force through the hip joint in a vulnerable position potentially leading to FAI (Bizzini et al., 2007; Keogh & Batt, 2008; Philippon et al., 2010; Stull et al., 2011). These combinations of movements are commonly seen within ice skating with a combination of abduction with external rotation seen during the push off phase and flexion with internal rotation seen during the recovery phase of the skating pattern coupled with the high loads being placed through the hip (Bizzini et al., 2007; Keogh & Batt, 2008; Philippon et al., 2010; Stull et al., 2011). The occurrence of this high load through the hip is not only a predictor of injury but with the constant, repetitive nature of ice skating the hip is highly susceptible to an overuse or FAI injury (Bartlett, 2002; Bizzini et al., 2007; Keogh & Batt, 2008; Philippon et al., 2010; Stull et al., 2011). A recent study conducted by Stull (2011) suggests that youth ice hockey athletes display similar patterns of abduction with external rotation during the push off phase and flexion with internal rotation during the recovery phase of the skating pattern as their adult counterparts. This finding of the kinematics of the youth ice hockey athlete suggests they are increasing their risk of developing a cam FAI due to the

repetitive nature of the ‘at risk’ movements associated with ice hockey. Once the cam FAI has developed and established asymptotically in the youth ice hockey athlete, the increase seen in strength and speed associated with maturation generates higher forces through the hip along with a higher rate of rotation which could potentially increase their risk of a labral injury (Bizzini et al., 2007; Philippon, Schenker, Briggs, & Kuppersmith, 2007a; Stull et al., 2011). This implies that although the labral injuries are commonly seen later in an ice hockey athlete’s development the fundamental movements learned by the youth ice hockey athlete potentially increases the risk of future injury due to the repetitive predisposition to the ‘at risk’ movements (Stull et al., 2011). An emerging combination of injuries presented by athletes is athletic pubalgia accompanied with FAI, however, it is unclear which may be present first in the symptomatic hip (Larson et al., 2011). What is clear is a lack of ROM in internal rotation and flexion of the hip with both FAI and athletic pubalgia (Larson et al., 2011).

2.4.6 Summary

The major anatomy of the hip was considered and although it is a highly congruent and stable joint it also offers a large amount of mobility to the lower limb (Anderson et al., 2001; Drake et al., 2009; Hughes et al., 2002; Palastanga & Soames, 2011). This allows the hip to play a major role within the unique locomotion of ice skating with high forces passing through the joint (Bracko et al., 1998; Chang et al., 2009). Although ligaments and muscles hold the femoral head into the acetabulum securely it is still susceptible to overuse injuries, in particular FAI and athletic pubalgia due to the large ROM allowed (Bizzini et al., 2007; Drake et al., 2009; Larson et al., 2011; Leunig et al., 2005; Palastanga & Soames, 2011; Philippon & Schenker, 2006; Philippon et al., 2010).

Ice skating is a very complex skill that places a high demand upon the hip adductors along with the majority of other hip musculature (Chang et al., 2009; Tyler et al., 2001; Upjohn et al., 2008). The hip abductors and extensors are the primary mobilisers whilst the flexors and adductors act as the primary stabilisers of the hip during the unique and complex ice skating technique (Tyler et al., 2001). Previous research states that higher calibre ice hockey athletes reach greater skating speed by achieving greater hip flexion ROM during weight acceptance leading to greater eccentric forces transmitted from the anterior thigh muscles allowing a greater concentric force giving the greater propulsion (Upjohn et al., 2008). This greater concentric force, whilst achieving the desired increase in propulsion, potentially increases the risk of injury to higher calibre ice hockey athletes due to the higher forces within the hip during inner range hip flexion (Chang et al., 2009; Stull et al., 2011). The increased ROM seen within higher calibre athletes potentially increases the risk of injury to an athlete, especially if they exhibit decreases in the muscular strength required to control the limb at the end of the increased range (Chang et al., 2009; Stull et al., 2011; Tyler et al., 2002; Tyler et al., 2001).

2.5 Prevention of hip injury in ice hockey

Prevention of injuries in ice hockey may be difficult because of the high degree of unpredictable physical contact and extrinsic factors (Byers & Roberts, 2006; Gee & Leith, 2007) with many prevention strategies trying to address, or reduce, the amount of contact injuries, in particular concussions due to the prevalence and seriousness, sustained by athletes (Benson et al., 2002; Benson, Hamilton, Meeuwisse, McCrory, & Dvorak, 2009; Biasca, Wirth, & Tegner, 2002; Cook, Cusimano, Tator, & Chipman, 2003; Marchie & Cusimano, 2003). However, the majority have been unsuccessful requiring the modification of the rules of the sport or equipment to find success (Aubry et al., 2002; Benson et al., 2002). It may be argued therefore that the greatest scope for prevention of

injury lies in focusing on modifiable risk factors and non-contact injuries if exercise based injury prevention strategies are to be utilised and successful (Askling et al., 2003; Collins & Raleigh, 2009; van Mechelen et al., 1992).

2.5.1 Evaluation of previous prevention strategies

Little research exists into injury prevention strategies for intrinsic risk factors within ice hockey; however, there is a plethora within other sports. Bahr et al. (1997) found that ankle injuries were reduced by 47% (0.9 – 0.5 injuries/1000 hours) in 719 volleyball athletes following an educational and proprioception intervention programme completed over one season. Although the authors found a large decrease in ankle injuries following the intervention programme it was aimed at targeting how athletes should be completing complex sporting tasks, such as landing and taking off as opposed to an exercise based intervention (Bahr et al., 1997). In another study investigating ankle injuries within 1127 volleyball athletes Verhagen et al. (2004) found a significant decrease in acute ankle injuries (0.5 injuries/1000 hours) in the 641 athletes who completed a balance board intervention programme lasting one season, aimed at increasing their proprioception and balance strategies, compared to the 486 control athletes (0.9 injuries/1000 hours). Although Verhagen et al. (2004) found a decrease in the occurrence of acute ankle injuries, they did, however, find a significant increase in knee overuse injuries in the intervention group (0.3 injuries/1000 hours) compared to the control group (0.1 injuries/1000 hours) therefore questioning the efficacy of this particular intervention strategy whilst also suggesting that researches may wish consider the athlete as a whole and not try and focus too closely on one commonly injured area of the body.

Myklebust et al. (2003) found that ACL injuries decreased when utilising an exercise based injury prevention programme targeting the neuromuscular control system along

with education on landing techniques within female handball athletes. Myklebust et al. (2003) reported that ACL injuries reduced from 29 during the control year (n = 942), to 23 during the first year of the injury prevention programme (n = 855) further reducing to 17 injuries in the second year of the programme (n = 850). In further work which considered a cohort of 30 professional soccer athletes it was found that those who took part in a strength exercise program over a ten week period targetting the hamstring muscles did significantly decrease the amount of hamstring injuries sustained (n = 15, 3 hamstring injuries) compared to the control group (n = 15, 10 injuries) (Askling et al., 2003). Askling et al. (2003) also reported significant increases in concentric and eccentric isokinetic hamstring muscle strength in those athletes in the intervention group following the programme as well as a quicker 30 metre (m) sprint time when compared to the control group. Olsen et al. (2005) investigated the effects of a season long intervention programme consisting of warm up, technique, balance and strength and power exercises on 1837 handball athletes (intervention n = 958, control n = 879) finding a significant decrease in number of injuries sustained to athletes in the intervention group (9.9% of total injuries) compared to the control (19% of total injuries) when all injuries were combined. These results appear to suggest that if the right programme or strategy is employed the prevention of non-contact injuries within ice hockey are possible.

Further work has been completed by implementing a structured prescribed injury prevention programme, the Fédération Internationale de Football Association Medical Assessment and Research Center (F-MARC) developed an intervention programme designed to improve ankle and knee stability, ROM and strength of the leg, hip and trunk muscles as well as improving co-ordination, reaction time and endurance (Junge et al., 2002). Junge et al. (2002) examined 194 amateur youth soccer athletes over a two year period finding that athletes who completed the F-MARC intervention programme (n = 101) sustained significantly less injuries (0.76 injuries/ athlete/ year) compared to the

control group (1.18 injuries/ athlete/ year) when all injuries were combined suggesting that a global intervention programme targeting multiple intrinsic risk factors can reduce injuries in athletes. Not only does the work of Junge et al. (2002) provide evidence that the F-MARC decreases injury but the findings of Brito et al. (2010) also demonstrate that when the F-MARC was completed three times a week for ten weeks by 18 athletes they had a significant increase in isokinetic strength of both the hamstrings and quadriceps muscles following the F-MARC intervention. Further work by Kilding, Tunstall, and Kuzmic (2008) investigated the effects of the F-MARC upon performance measures of 20 m sprint time, horizontal and vertical jump height, core strength and agility finding that the intervention group athletes who showed significant increases in horizontal jump (3.4% increase) and vertical jump (6.0% increase) measures compared to their pre-intervention scores with the control group showing no increase from the pre-intervention testing. Similar results were found for 20 m sprint times with the intervention group significantly improving by 2% following the intervention test with the control group showing no increase (Kilding et al., 2008). Although increases were seen in vertical and horizontal jumps and 20 m sprint tests no significant increases were seen in agility or core stability measures (Kilding et al., 2008). Conversely many studies have found the F-MARC intervention programme to be of no benefit to athletes who completed it (Steffen, Bakka, Myklebust, & Bahr, 2008a; Steffen, Myklebust, Olsen, Holme, & Bahr, 2008b; van Beijsterveldt et al., 2012). Van Beijsterveldt et al. (2012) reported that injuries did not decrease following the season long implementation of the F-MARC intervention programme with the control group (n = 246) sustaining 9.7 injuries/1000 hours compared to the intervention group (n = 241) who sustained 9.6 injuries/1000 hours of sporting activity. When investigating performance measures of lower limb strength, jumping ability, 40 m sprint time, speed dribbling and shooting distance Steffen et al. (2008a) found no increase in 18 female players who completed the F-MARC intervention

programme over a ten week period. Further work by Steffen et al. (2008b) investigated the effects of the F-MARC intervention upon injury finding no significant injury within the intervention group (n = 1091) who displayed 3.6 injuries/1000 hours of activity compared to the control group (n = 1001) who sustained 3.7 injuries/1000 hours of activity following the implementation of the programme over an eight month period. The contrasting results found when utilising the F-MARC intervention programme further highlights the need for an intervention programme to not only be specific to an individual sport but also potentially to individual athletes providing evidence that a global intervention programme aimed at a large group of uninjured athletes may not reduce non-contact injuries.

A problem within previous literature is the differing lengths of intervention programmes employed within studies. These differ vastly with many completing an intervention programme over one sporting season (Bahr & Bahr, 1997; Olsen et al., 2005; Steffen et al., 2008b; van Beijsterveldt et al., 2012; Verhagen et al., 2004), a number of weeks ranging from six to ten (Askling et al., 2003; Brito et al., 2010; Kilding et al., 2008; Steffen et al., 2008a) and few lasting more than one sporting season (Anderson, Hall, & Martin, 2004; Junge et al., 2002; Myklebust et al., 2003). This makes comparison between studies somewhat difficult due to the possible impact of time upon the participants and intervention programme.

Another potential problem is the way in which previous studies consider the intervention programme to be a success. Previous studies judge success of their programme by the reduction in injuries (Bahr et al., 1997; Junge et al., 2002; Myklebust et al., 2003; Olsen et al., 2005; Steffen et al., 2008b; van Beijsterveldt et al., 2012; Verhagen et al., 2004), the increase in performance measures (Brito et al., 2010; Kilding et al., 2008; Steffen et al., 2008a) or a combination of both (Askling et al., 2003). Judging the success of an

intervention programme by the decrease in injuries and increase in performance measures is ideal but often time consuming and difficult to track participants. Therefore, measuring the effect of an intervention programme upon a participant's intrinsic risk factors may be both beneficial and more useful to clinicians than reporting injury occurrence alone. As previously discussed an intervention that has a positive effect upon an athlete's intrinsic risk factors leads to a decreased risk of injury (Baumhauer et al., 1995; Blackburn et al., 2000; Bradley & Portas, 2007; Ekstrand & Gillquist, 1983; Green et al., 1976; Hreljac et al., 2000; Söderman et al., 2001; Tyler et al., 2001; Witvrouw et al., 2003; Worrell & Perrin, 1992), and therefore, provides a better indicator of success than a decrease in the occurrence of injuries which are impacted by many differing factors (Bahr & Krosshaug, 2005; Collins & Raleigh, 2009; Kirkendall, 1990; Meeuwisse, 1994).

2.5.2 Importance of a screening protocol

A successful screening protocol or tool should be sensitive enough to highlight athletes who are 'at risk' of sustaining a non-contact injury allowing clinicians to implement an informed injury prevention programme. There is a range of differing whole body screening protocols aiming to decrease injuries by highlighting 'at risk' athletes that already exist (Kiesel et al., 2011; Kiesel et al., 2007; Peate et al., 2007), but currently limited screening tools for specific injuries or populations exist. Therefore, it is important to create bespoke screening protocols for individual sports targeting both common and problematic injuries thus, creating a useful, informed screening protocol.

The FMS has previously been used to assess the impact of a screening tool upon injury occurrence with authors finding that athletes who went on to sustain an injury presented, pre injury, with lower scores than athletes who did not receive an injury (Kiesel et al., 2011; Kiesel et al., 2007; Peate et al., 2007). Kiesel et al. (2011) found that of 62

professional American football athletes, those with a lower than average FMS score improved their score following a personalised strength and conditioning intervention programme targeting the weaknesses highlighted in the FMS. The increase seen in FMS score implies they were at a decreased risk of sustaining an injury due to the intervention programme (Kiesel et al., 2011). Peate et al. (2007) investigated the FMS from an alternative perspective investigating if previous injury affected the FMS scores and found that fire fighters who had sustained a previous injury scored significantly lower on the FMS than their colleagues who had not sustained a previous injury. This suggests that a screening protocol is important in understanding an athlete's weaknesses and potential for sustaining an injury throughout the season or their career. The findings of Peate et al. (2007) also highlight the importance of correct rehabilitation of previous injuries to minimise any weaknesses within an athlete. Although it is unlikely that anything can be done about the treatment received retrospectively, a screening protocol ensures athletes who have received a previous injury are fully recovered and not suffering from the effects of the injury, thus making a medical teams return to play procedures more robust and effective (Bahr et al., 1997; McKay et al., 2001). Although the FMS is a global screening protocol comprising of seven movements it is aimed to highlight athletes who lack the mobility or stability to perform essential movement, such as the deep squat or in line lunge (Cook, Burton, & Hoogenboom, 2006a, 2006b) providing potential evidence that a more global screening protocol can be successfully employed.

2.5.3 Injury prevention in ice hockey

Few studies have investigated an exercise based injury prevention strategy specifically within ice hockey, such as through modification of intrinsic risk factors, for example strength or ROM. Tyler et al. (2002) found that a functional strength programme targeted at 33 professional ice hockey athletes classified as 'at risk' due to adduction:abduction

strength deficits of less than 80% significantly decreased the number of hip adductor strain injuries with a reduction from eight of 21 athletes (3.2 injuries/1000 hours of ice hockey) sustaining an injury to three of 33 athletes (0.71 injuries/1000 hours of ice hockey) receiving an injury following their intervention programme. Although Tyler et al. (2002) found a significant decrease in adductor injuries following their intervention programme they did not report pre and post intervention strength scores of the athletes leaving the explanation for their findings difficult to fully explain due to the unpredictable and multifaceted nature of injuries. Although research into exercise based interventions within ice hockey is limited, assumptions can be made by analysing pre-season measures linked to injury occurrence from other sporting populations. One such measure frequently investigated is strength, with many studies analysing the association between strength and subsequent injury. Blackburn et al. (2000) found dynamic balance and stability to be higher in athletes who exhibited more muscular strength, potentially reducing their risk of injury. In a study of female soccer athletes it was found that having a decreased hamstring to quadriceps strength ratio increased the risk of traumatic injury whereas an increased hamstring to quadriceps ratio led to an increase in the risk of sustaining an overuse injury (Murphy et al., 2003; Söderman et al., 2001). Similarly, in a study of male soccer athletes it was found that all non-contact injury participants had a reduced isokinetic quadriceps strength when compared to participants who remained uninjured (Ekstrand & Gillquist, 1983). As previously discussed the higher calibre ice hockey athletes produce more force and therefore speed leaving athletes with decreased muscular strength at a disadvantage and increased risk of injury (Tyler et al., 2001; Upjohn et al., 2008).

A decreased ROM in athletes has also been shown to have a negative effect upon injury occurrence with studies finding that a reduced ROM is common within athletes who subsequently go on to suffer an injury (Bradley & Portas, 2007; Hreljac et al., 2000; Tyler

et al., 2001). It was reported that recreational running athletes with a history of muscular injury presented with decreased hamstring ROM via the sit and reach test compared to a similar group of runners who had no history of muscular injury suggesting that the presence of a previous injury has a negative effect upon ROM, thus, increasing the athletes risk of injury or re-injury (Hreljac et al., 2000). Confirming the findings of Hreljac et al. (2000) is a more recent study of professional soccer athletes finding a significantly decreased pre season hip and knee flexion ROM in athletes who subsequently sustained a hip or knee flexor injury compared to athletes who did not (Bradley & Portas, 2007). However, within ice hockey, the work of Tyler et al. (2001) shows that no significant difference was observed in hip adductor ROM between athletes who subsequently went on to sustain a hip musculature injury and those who did not suggesting that if clinicians are to reduce or prevent injuries multiple intrinsic risk factors must be considered (Collins & Raleigh, 2009; Kirkendall, 1990; Meeuwisse, 1994). Due to the strong relationship observed between lack of strength and ROM with injury susceptibility these are, therefore, two important aspects which are imperative to include within a pre-season/injury screening protocol alongside functional movement screening in order to gain an appreciation of 'at risk' athletes with the view of implementing an injury prevention protocol aiming to reduce injuries. Although previous work suggests that limited ROM increases an athlete's risk of injury, as previously discussed athletes with greater ROM may also be at an increased risk of injury if they do not possess the strength needed to control the limb when placed in the outer ranges of motion.

2.5.4 Summary

There is limited research attempting to prevent injuries within ice hockey exhibiting some success when implementing a strength and ROM programme finding significantly lower injuries following the intervention (Tyler et al., 2002). There is, however, much more

research around injury prevention in other sports (Askling et al., 2003; Bahr et al., 1997; Junge et al., 2002; Myklebust et al., 2003; Verhagen et al., 2004). Previous literature investigating injury prevention protocols found a decrease in injury occurrence following a specific injury prevention programme (Askling et al., 2003; Bahr et al., 1997; Myklebust et al., 2003; Verhagen et al., 2004). Other research investigated the effects of a structured warm up protocol aimed at injury prevention with some finding a decrease in injuries and increase in performance measures in athletes who participated in the programme (Brito et al., 2010; Junge et al., 2002; Kilding et al., 2008).

Many previous studies use a screening protocol, such as the FMS, to identify athletes at risk of sustaining an injury with the majority finding athletes who score lower more likely to receive a subsequent injury (Kiesel et al., 2011; Kiesel et al., 2007; Peate et al., 2007). Due to the current limited research around injury screening and prevention protocols surrounding the hip in ice hockey, it is, therefore, important that a reliable screening protocol is developed and combined with a successful intervention programme aiming to highlight ‘at risk’ athletes and decrease the amount of non-contact hip injuries seen.

2.6 Measurement of the ice hockey athlete’s hip

Strength and ROM testing of a joint are paramount in the creation of a successful screening protocol and currently there exists a multitude of differing options to assess the strength and ROM of participants. To create such protocols it is also imperative to measure both strength and ROM using standardised, valid and reliable methods to allow the correct interpretation of results gained and the subsequent response (Awan, Smith, & Boon, 2002; Bierma-Zeinstra et al., 1998; MacDermid, Chesworth, Patterson, & Roth, 1999; Roach, San Juan, Suprak, & Lyda, 2013; van de Pol, van Trijffel, & Lucas, 2010).

Therefore, the following sections will address the reliability, validity, sensitivity, accuracy and error associated with the testing options to measure strength and ROM.

2.6.1 Range of motion

In a clinical setting clinicians are limited to two main methods of assessing ROM; goniometry and inclinometry both of which can be conducted manually or electronically. Measurements using a standard goniometer are often preferred by clinicians to gather baseline information of a person's ROM highlighting limitations in movements quickly and effectively (Armstrong, MacDermid, Chinchalkar, Stevens, & King, 1998; Gajdosik & Bohannon, 1987; Nussbaumer et al., 2010; Unver, Nalbant, & Karatosun, 2015). Nussbaumer et al. (2010) indicate that the ease of use, low cost, accessibility and direct measurement of ROM are the key advantages for the use of standard goniometry. Standard goniometry however, poses some disadvantages in that the starting position, centre of rotation and long axis of the movement segment all require visual estimation from the clinician thus giving the potential for error (Nussbaumer et al., 2010).

In a study comparing standard goniometry results to that of an electronic goniometer in 15 participants with confirmed FAI and 15 control participants it was found that the standard goniometer produced significantly higher values of hip ROM compared to the electronic goniometer and suggest that the visual estimation of the alignment of the goniometer as the reasoning for the larger ROM values gained (Nussbaumer et al., 2010). Although the study by Nussbaumer et al. (2010) demonstrated significantly larger ROM in the standard goniometer results for assessing hip ROM they do, however, present that the standard goniometer provided intra-class correlation coefficient (ICC) figures of above 0.84 for the test-retest of the standard goniometer. Similarly, in a study investigating the differences between a standard goniometer and digital inclinometer it

was reported that again there were significant differences between the two devices' measurements of hip ROM when the same tester assessed 30 healthy participants three times using the two devices (Roach et al., 2013). Although there existed significantly different results between the standard goniometer and the digital inclinometer the intra-tester ICC values for both the standard goniometer (0.8) and the digital inclinometer (0.9) were both high, again suggesting that either device is valid and reliable (Roach et al., 2013). In a study comparing standard goniometer, manual inclinometer and electronic goniometer measurements of cervical ROM in 27 healthy participants taken by four testers the electronic goniometer was found to be most reliable in three of the four ROM measures taken (Pringle, 2003). While Pringle (2003) reports that the electronic goniometer was the most valid in terms of accuracy the ICC values gained for inter-tester reliability for the standard goniometer were found to be more reliable than either of the other methods used suggesting it is indeed a useful and meaningful method to assess ROM.

While the work of Roach et al. (2013), Nussbaumer et al. (2010) and Pringle (2003) suggest that both the electronic goniometer and inclinometer may be a more valid and reliable method of assessing ROM the work of Clapper and Wolf (1988) showed the standard goniometer to exhibit significantly less variation between five measurements taken within a three week period compared to an electronic goniometer when assessing twenty healthy participants. Clapper and Wolf (1988) reported that the standard goniometer not only displayed higher ICCs than the electronic goniometer but also smaller degrees of variance than the electronic goniometer when assessing lower limb ROM. Whilst the findings of Clapper and Wolf (1988) suggest that the standard goniometer is more reliable and repeatable than the electronic goniometer when assessing ROM in the lower extremity the electronic goniometer may have improved since the testing with newer technology and versions of electronic goniometry available today. It

is however, noted more recently by Roach et al. (2013) that due to the similarity of results found between the standard goniometer and the electronic inclinometer that the choice of device to measure ROM is based upon clinical skill, ease of use and availability.

In works examining the measurement of passive shoulder ROM in 34 participants with shoulder pathology using a standard goniometer completed by two testers it was found that intra-tester reliability was high for both testers (ranging from 0.89 to 0.94) and also inter-tester reliability (ranging from 0.85 to 0.86) providing further evidence that using a standard goniometer is both reliable when completing longitudinal testing but also when differing testers complete the assessments (MacDermid et al., 1999). Although the study by MacDermid et al. (1999) reported good intra and inter-tester reliability they suggest that the majority of error between testers was created by the differing pressures applied by the testers to move the limb passively. It is therefore assumed that when using a goniometer to complete active ROM assessments this error would be reduced making measurements more accurate, reliable and valid (MacDermid et al., 1999). The work of MacDermid et al. (1999) is also supported by Armstrong et al. (1998) who report that intra-tester ICC values were above 0.89 with an error of below 5° when analysing the results of 5 testers who assessed 38 participants in ROM of their elbow and wrist using a standard and electronic goniometer. Inter-tester reliability was moderate for the goniometer (ICCs = 0.58 – 0.87) and high for the electronic goniometer (ICCs = 0.89 – 0.95), with the standard goniometer exhibiting higher error scores than the electronic goniometer (6.2° – 7.3° and 3.2° – 5.4° respectively) for elbow flexion and extension (Armstrong et al., 1998). Hayes, Walton, Szomor, and Murrell (2001) reported results of shoulder ROM of injured participants when assessed using a standard goniometer, finding a range of ICCs from 0.49 to 0.67 when one tester assessed participants three times over a 48 hour period. However, it should be noted that although the study completed by Hayes et al. (2001) found lower ICC figures than that of MacDermid et al. (1999), they

investigated the test-retest abilities of only one tester using three measurement sessions carried out within a 48 hour period which is suggested to increase the accuracy and therefore produce more accurate results when compared to studies which separate testing procedures by days or weeks (Gajdosik & Bohannon, 1987). MacDermid et al. (1999) also state that although reliability is not a measure of validity nor accuracy, the occurrence of similar results for both the electronic and standard goniometer suggest that both of the instruments results are valid due to the ICC being similar and the unlikely event that both measures are equally inaccurate.

With the error and repeatability of the electronic and standard goniometer similar in previous studies it is important to consider the measurements compared to the 'gold standard' technique. It is commonly assumed that the gold standard method of measuring ROM is radiography and it is therefore frequently used as a guide or reference for the validity of ROM measurements (Ålund & Larsson, 1990; Bush, Collins, Portman, & Tillett, 2000; Hermann & Reese, 2001; Mayer, Brady, Bovasso, Pope, & Gatchel, 1993; Strimpakos et al., 2005; Tousignant, de Bellefeuille, O'Donoghue, & Grahovac, 2000; Tousignant et al., 2002; Wolfenberger, Bui, & Batenchuk, 2002). In work by Ålund and Larsson (1990) investigating cervical ROM with an electronic goniometer they reported that the electronic goniometer readings were reliable with ICCs ranging from 0.76-0.85 when compared to the gold standard of radiography readings. This finding is confirmed in a study of 60 participants with knee pathologies who completed knee ROM assessments by two testers using a standard goniometer compared to radiographic results, reporting that there was no significant difference between the measurements of the standard goniometer or radiography results (Brosseau et al., 2001). Brosseau et al. (2001) also reported that ICC values for both the testers was high when using a standard goniometer giving further merit to the use of a standard goniometer in not only clinical settings but also giving accurate and reliable measurements across time and multiple

testers. Thus, when clinicians or researchers are deciding upon a method to measure ROM it is important that whichever method is chosen that all measurements are taken using the same instrument as switching between instruments has been reported to give an unacceptable error (MacDermid et al., 1999; Roach et al., 2013).

2.6.2 Strength

Analysis of strength can also be performed using various methodologies by both clinicians and researchers. Assessments of strength are commonly measured against the gold standard of isokinetic dynamometry due to this methodology providing the most accurate and reliable measurements (Drouin, Valovich-mcLeod, Shultz, Gansneder, & Perrin, 2004; Feiring, Ellenbecker, & Derscheid, 1990; Maffiuletti, Bizzini, Desbrosses, Babault, & Munzinger, 2007; Martin et al., 2006a). Drouin et al. (2004) investigated the reliability and validity of an isokinetic dynamometer by analysing measurements of position, torque and velocity of the equipment six times over two consecutive days. Drouin et al. (2004) reported that the isokinetic dynamometer was indeed extremely reliable and valid reporting ICC values for all variables of either 0.99 or 1.00 across all trials and days. Similar results have been reported by Feiring et al. (1990) when analysing the test-retest reliability of an isokinetic dynamometer, demonstrating ICCs ranging from 0.82 to 0.99 when measuring flexion and extension of the knee in 19 healthy participants. In an intra-tester reliability study of 15 males and 15 females using an isokinetic dynamometer to measure various variables (peak torque, average work, average power and angle of peak torque) of knee extension and flexion seven days apart it was reported that the reliability of the isokinetic dynamometer was very high for all variables of knee flexion and extension measured (Maffiuletti et al., 2007). These results show that not only is the isokinetic dynamometer accurate, reliable and valid but any other methods of

assessing strength should be measured against it to assess their reliability, validity and accuracy.

Perhaps a more clinically relevant method of measuring strength is that of the hand-held dynamometer due to its substantially lower cost, portability and lower time required for a full strength assessment (Deones, Wiley, & Worrell, 1994; Stratford & Balsor, 1994; Thorborg, Petersen, Magnusson, & Hölmich, 2010). In a study comparing the results of a hand-held dynamometer to an isokinetic dynamometer when assessing 21 participants being treated for knee injuries it was reported that the hand-held dynamometer was in fact more reliable and accurate than the isokinetic dynamometer in testing quadriceps strength giving an ICC value of 0.93 compared to the isokinetic dynamometer which recorded an ICC value of 0.87 when the knee was in 60° of flexion (Deones et al., 1994). Deones et al. (1994) further reported that the percentage difference between the participants injured and uninjured limbs with the hand-held dynamometer was 0.7% but with the isokinetic dynamometer it was much higher at 18.1% when tested again at 60° flexion making the isokinetic dynamometer more sensitive to any potential changes. One potential reason for the larger deficit noted by Deones et al. (1994) may be the strength of the assessor as it has previously been shown that weaker assessors have a poorer intra-tester reliability (ICC = 0.229) compared to stronger assessors (ICC = 0.781) when completing shoulder external rotation, elbow flexion and knee extension muscle tests with the hand-held dynamometer (Wikholm & Bohannon, 1991). The strength of the assessor completing the assessment is therefore important if valuable, reliable and valid results are to be gained using a hand-held dynamometer.

There are two ways to manually assess a participant's strength using a hand-held dynamometer: 1.) The make force method where the assessor does not move the dynamometer and requires maximum force from the participant into the equipment and

2.) The break force method where the assessor pushes against the participant until the participants maximal force is broken, characterised by movement at the joint (Bohannon, 1988). The strength of the assessor is even more important when utilising the break force method, which is often employed when completing hand-held dynamometer assessments, as if the assessor is unable to generate enough force to break the participants force then the measurements will be inaccurate and unreliable. In a study comparing the make and the break force techniques of the hand-held dynamometer in 32 healthy participants completing elbow flexion it was reported that there was no difference in reliability (both ICCs = 0.89) but interestingly slightly larger, but not statistically different, forces reported from the break force method (Stratford & Balsor, 1994). These findings are confirmed by Bohannon (1988) who also reported higher measurements of strength for the break force method compared to the make force method when assessing 27 female participants who completed elbow flexor and extensor strength.

In work examining the intra and inter-session reliability of the hand-held dynamometer in 200 healthy participants who completed multiple upper and lower limb strength assessments using the break force method it was reported that the intra-session ICC values were high, ranging from 0.88 to 0.99, when three consecutive tests were performed (Phillips, Lo, & Mastaglia, 2000). Phillips et al. (2000) also reported that the inter-session reliability was high, with ICCs ranging from 0.54 to 0.98, when the testing sessions were separated by two weeks. Phillips et al. (2000) compared their results to that of Bohannon (1997) who reported normative values in various age ranges and confirmed previous findings (Bohannon, 1988; Stratford & Balsor, 1994) in that the break force method consistently gave higher, but equally reliable, values than that of the make force method. Therefore, due to the general reliability of the hand-held dynamometer in both the make and break force techniques it is deemed the clinician/researchers decision as to which method is employed often based upon experience, measurement techniques and strength

(Bohannon, 1988). It is, however, important to ensure that the tester completing the strength assessment is both competent and experienced in the measurement techniques employed to gain more reliable and valid results thereby reducing the potential error associated with this methodology, which is often created by the testers inexperience (Bohannon, 1986; Scott, Bond, Sisto, & Nadler, 2004).

It is also of importance to consider the accuracy and associated error with the hand-held dynamometer to fully understand and interpret any results gained. In a study investigating the accuracy of the hand-held dynamometer compared to a spring loaded transducer programmed to 'give way' at specific forces of 19 participants with motor neurone disease and 22 healthy participants who completed various upper and lower body strength assessments it was reported that the hand-held dynamometer had an average of 3% error (Goonetilleke, Modarres-Sadeghi, & Guiloff, 1994). The reported 3% error was averaged across three testers who completed the assessments, one of which was experienced and the other two novices at hand-held dynamometry, and it was described that the experienced tester had 0% error compared to 5.4% and 3.6% of the two novice testers respectively (Goonetilleke et al., 1994). The finding that error decreases with experience provides further evidence that to obtain reliable, accurate and valid results of strength using a hand-held dynamometer it must be conducted by an experienced clinician/researcher. It has further been reported that the hand-held dynamometer is not only reliable but also that changes of muscular strength above 10% of a participants normal can be interpreted as a clinical difference when 12 movements of the hip were analysed in nine healthy participants (Thorborg et al., 2010).

Stark, Walker, Phillips, Fejer, and Beck (2011) highlight that another potential problem with the use of hand-held dynamometers is that many of the previous studies investigating the reliability and validity use differing patient populations and hand-held dynamometer

positions for the same movements making comparisons problematic. In work analysing the placement of the hand-held dynamometer upon the reliability and torque production of the hip abductors and adductors it was determined that using a long lever (placing the dynamometer furthest away from the pivot point) yielded more reliable results of muscular strength (Krause, Schlagel, Stember, Zoetewey, & Hollman, 2007). Although this is a potential problem in using all hand-held dynamometers (regardless of manufacturer or method) when compared to the gold standard of isokinetic dynamometry, provided assessments of strength utilise the same standardised procedures using the same participant positioning this limitation can be reduced (Krause et al., 2007; Stark et al., 2011). This further provides evidence that although there is no standardised method of completing hand-held dynamometer assessments, with various techniques being suggested as reliable and valid, it is the clinician/researchers choice and preference as to which position to place the participant to gain the measurements.

2.6.3 Functional testing

Functional testing must also be reliable and valid, as with any test, and in ideal practice this can be achieved by using x-ray or magnetic resonance imaging (MRI) results to confirm the findings of a functional test, however this is not always possible within clinical practice or research (Altman & Bland, 1994). It is perhaps of interest to consider the sensitivity and specificity of the functional test to determine whether the tests are both reliable and valid when used within clinical practice and research (Altman & Bland, 1994). It is suggested that sensitivity is the ability of the test to correctly identify true positives whereas specificity is the ability of the test to correctly identify true negatives (Altman & Bland, 1994; Bird, Oakley, Shnier, & Kirkham, 2001; Stuber, 2007).

The flexion, abduction and external rotation (FABER) test is commonly used within the assessment of the hip as it assesses for the presence of general hip joint pathology including SIJ pain, FAI or psoas pain (Philippon et al., 2010). In a study of 25 participants who presented with hip pain and pathology it was reported that the FABER test was 88% sensitive when assessed using MRI to confirm intra-articular hip joint pathology (Mitchell et al., 2003). Although the findings of Mitchell et al. (2003) suggest that the FABER test can correctly identify intra-articular hip joint pathologies they also state that it cannot be used to successfully highlight any one specific joint pathology. Although Mitchell et al. (2003) explains that the FABER test is more of a general hip pathology test and not specific to one injury or pathology the work of Margo, Drezner, and Motzkin (2003) suggest that the FABER test is more specific to SIJ injuries. However, the study by Margo et al. (2003) did not assess the sensitivity nor specificity of the FABER test and their work is based upon clinical opinions as opposed to the MRI confirmation as gained by Mitchell et al. (2003). Similarly another study investigated the link of the FABER test and positive diagnosis of SIJ pathology and found the sensitivity of the test to be 69% and the specificity at 16% when assessing 72 participants with hip pathology (Dreyfuss, Michaelsen, Pauza, McLarty, & Bogduk, 1996). This further highlights the findings of Mitchell et al. (2003) who suggest that the FABER test is extremely sensitive when investigating general intra-articular hip pathology but potentially not as reliable when considering specific pathologies as seen in the work of Dreyfuss et al. (1996) and Margo et al. (2003). In a more recent study investigating both the specificity and sensitivity of the FABER test by conducting MRI scans of 30 participants it was reported that the FABER test was only 41% sensitive but 100% specific when used to assess for labral tears of the hip (Troelsen et al., 2009). Although Troelsen et al. (2009) found a lower value of sensitivity this may be explained as they were again only assessing the successfulness of the FABER test in correctly identifying participants who presented with

a labral tear following an MRI investigation, further emphasising that the FABER test may be a good measure of correctly identifying intra-articular joint pathology but not specific pathologies (Martin, Enseki, Draovitch, Trapuzzano, & Philippon, 2006b; Mitchell et al., 2003).

The Trendelenburg test is a further functional test of the hip which assesses the function of the participant's gluteus medius muscle and general hip abductors (Bird et al., 2001; Clohisy & McClure, 2005a; Woodley et al., 2008). There currently exists less research into the sensitivity and specificity of the Trendelenburg test with Bird et al. (2001) describing the test to be the most accurate, sensitive, specific and reliable test in assessing for gluteus medius injuries in 24 participants who reported to a rheumatologists. Bird et al. (2001) suggested that the sensitivity of the Trendelenburg test was 72.7% and the specificity 76.9% with the results being confirmed by MRI. In more recent works it has been reported that the Trendelenburg test is only 23% sensitive and 94% specific when again compared to MRI results of 40 participants with unilateral hip pain (Woodley et al., 2008). Confirming these findings is Bewyer and Chen (2005) who report that the Trendelenburg test is the most sensitive and specific test in finding gluteus medius pathologies. The Trendelenburg test has however been confirmed as reliable when assessing the test-retest measures of one assessor who completed the test on 36 participants finding ICC values of 0.83 for the left side and 0.75 for the right side providing evidence that the test is reliable when the same assessor completes multiple tests on the same participant (Roussel, Nijs, Truijen, Smeuninx, & Stassijns, 2007). The work of Bewyer and Chen (2005); Bird et al. (2001) and Woodley et al. (2008) were investigating the successfulness of the Trendelenburg test in confirming a specific pathology of the hip which may suggest that, like the FABER test, Trendelenburg's test may be more successful in confirming a more general hip pathology.

The Ober's test is a further functional test of the hip which aims to identify those participants with iliotibial band tightness. Similarly to the Trendelenburg test little research specifically detailing the specificity and sensitivity of the standard (where the knee is flexed to 90°) or modified (where the knee remains extended) Ober's test exists (Hattam & Smeatham, 2010). However in a study of 36 healthy participants who completed both the standard and modified Ober's test whilst also being assessed using ultrasound to investigate the potential narrowing of the iliotibial tract it was described that both the standard and modified Ober's test successfully narrowed the iliotibial tract which, if symptomatic, would create pain and therefore a positive test (Wang, Jan, Lin, & Wang, 2006). Although the study by Wang et al. (2006) does not measure sensitivity or specificity of the Ober's test they do note that the modified Ober's test may be more clinically useful as it narrows the iliotibial tract more so than the standard Ober's test and would, therefore, reproduce symptoms more successfully in the symptomatic hip. In work examining the amount of hip adduction ROM allowed by 49 healthy participants who completed both the standard and modified Ober's test it was described that the modified Ober's test achieved significantly more hip adduction (Gajdosik, Sandler, & Marr, 2003). The standard Ober's test is suggested to not only stretch and therefore assess the iliotibial band but also apply tension to the tensor fascia latae and vastus lateralis due to the flexion of the knee potentially giving false positives (Gajdosik et al., 2003). Thus, making the modified Ober's test more specific to only the iliotibial band. Therefore due to the more successful narrowing of the iliotibial tract (Wang et al., 2006) along with more hip adduction allowed (Gajdosik et al., 2003) during the modified Ober's test this is often preferred with clinicians and in research.

2.6.4 Summary

It is of importance when testing the strength and ROM of the ice hockey athlete's hip joint to employ a standardised method offering valid and reliable measures allowing the correct understanding of any results gained (Awan et al., 2002; Bierma-Zeinstra et al., 1998; MacDermid et al., 1999; Roach et al., 2013; van de Pol et al., 2010). There are various methods of assessing both the ROM and strength of the ice hockey athlete's hip with the majority being valid and reliable making it the clinicians/researchers choice as to which method they utilise. Whichever method is employed it is imperative to ensure that the tester is adequately trained in using the equipment and standardised methods are used. Although the gold standard may be the obvious choice when completing both strength and ROM assessments using a more accessible, cheaper and portable option, such as the standard goniometer and hand-held dynamometer, may have the potential to offer more generalisability of any results gained.

2.7 Objectives of the project

The first objective of this project is to investigate the frequency, type (contact or non-contact) severity and location of injuries sustained by elite ice hockey athletes in order to gain a greater understanding and knowledge of injuries within this group.

The second objective of this project was to analyse the ice hockey athlete's hip ROM and strength when compared to soccer athletes and a normal active population to observe any differences between the populations to evaluate why ice hockey athletes are particularly susceptible to non-contact hip injuries.

The third objective was to develop a screening protocol sensitive enough to detect previous injuries alongside the potential to evaluate the risk of future injury/re-injury due to weakness in ROM and strength measures of ice hockey athletes.

The fourth objective of this project was to ensure the hip screen was both valid and reliable by reproducing the results using the same participants both over time and between investigators. This would allow the screening protocol to be used more widely if proved reliable.

The fifth objective of this project was to establish whether the ROM, strength and functional test performance increased, in individual measures and the overall screen, in participants who completed the season long strength and ROM based intervention programme.

Chapter Three: General Methodology

3.1 Definition of the hip complex

For the purposes of this project and for reasons outlined within section 2.2.5 (page 24) and 2.4.2 (page 38) the hip complex was defined as the hip joint, sacroiliac joint (SIJ), adductors (groin), abductors, internal and external rotators, hip flexors and extensors.

3.2 Design and participants

The design of the experimental chapters included in this project is outlined in Table 3.1. Participant number, demographics, inclusion/exclusion criteria and other relevant information is also outlined in Table 3.1. Participant suitability for inclusion was assessed using a pre-exercise medical questionnaire (Appendix E). Throughout the project participant information was anonymised and kept strictly confidential on a password encrypted computer in a locked office. All participants were made aware of the reason of each study as well as all testing procedures and written informed consent was gained from each participant (Appendices B to D). Ethical approval was sought from the appropriate ethical committees for each chapter and participants were treated according to the declaration of Helsinki.

Table 3.1 Participant number, demographics, inclusion/exclusion criteria and other relevant information for each chapter

Chapter	n =	Design	Inclusion Criteria	Exclusion Criteria	Demographics (Mean \pm SD)	Other Information	Ethics
4	107	Retrospective four year analysis (2008-2012) of electronic medical records which was completed by the principle investigator and head Athletic Trainer of each selected college.	Male NCAA division III ice hockey athlete from two colleges in the MIAC. Medical care provided by the college appointed medical team.	Multi-sport athlete. Ice hockey athletes not registered to play for the selected college, MIAC or NCAA.	Age 24 ± 2 years, height 181.4 ± 5.0 cm, body mass 83.4 ± 7.1 kg.	The MIAC consists of 13 colleges in the state of Minnesota competing in the second tier of University level ice hockey in the USA. Consent to access medical records was given by the head Athletic Trainer of each selected college.	Approved by Bethel University and University of Hull ethics committees.
5	24	Comparison of ROM, strength and functional testing of ice hockey, soccer and control participants.	Male NCAA division III ice hockey or soccer athlete recruited from Bethel University in the MIAC. Clear medical screening (Appendix A).	Multi-sport athlete. Ice hockey or soccer athletes not registered to play for the selected college, MIAC or NCAA. Failed medical screening (Appendix A). Sustained an injury in the past three months.	Ice hockey athletes: n = 16, age 22 ± 1 year, height 183.3 ± 7.3 cm, body mass 84.9 ± 7.7 kg. Soccer athletes: n = 8, age 20 ± 1 year, height 181.3 ± 7.3 cm, body mass 74.9 ± 5.2 kg.	Testing took place at Bethel University, USA.	Approved by Bethel University and University of Hull ethics committees.
5	8	Comparison of ROM, strength and functional testing of ice hockey, soccer and control participants.	Male apparently healthy active non-sport specific individuals. Clear medical screening (Appendix A).	Failed medical screening (Appendix A). Sustained an injury in the past three months.	n = 8, age 32 ± 6 years, height 179.7 ± 6.0 cm, body mass 82.4 ± 10.2 kg.	Testing took place at the University of Hull.	Approved by Bethel University and University of Hull ethics committees.

6	19	Implementation of the screening procedure to investigate if ice hockey athletes who had a history of hip injury scored lower on the overall screen.	Male NCAA division III ice hockey athlete recruited from Bethel University in the MIAC. Clear medical screening (Appendix A). Free from past hip complex injury.	Multi-sport athlete. Ice hockey athletes not registered to play for the selected college, MIAC or NCAA. Failed medical screening (Appendix A). Sustained an injury in the past three months. Sustained a hip complex injury in the past	Age 22 ± 1 year, height 182.8 ± 7.6 cm, body mass 85.5 ± 6.6 kg.	All testing took place at Bethel University, USA.	Approved by Bethel University and University of Hull ethics committees.
6	8	Implementation of the screening procedure to investigate if ice hockey athletes who had a history of hip injury scored lower on the overall screen.	Male NCAA division III ice hockey athlete recruited from Bethel University in the MIAC. Clear medical screening (Appendix A). Previously sustained a non-contact hip complex injury.	Multi-sport athlete. Ice hockey athletes not registered to play for the selected college, MIAC or NCAA. Sustained an injury in the past three months. Failed medical screening (Appendix A).	Age 21 ± 2 years, height 180.0 ± 5.9 cm, body mass 86.5 ± 11.5 kg.	Four athletes sustained the previous non-contact hip injury to the Dom limb and four sustained the injury to the Ndom limb.	Approved by Bethel University and University of Hull ethics committees.
7	9	Intra and inter-tester reliability of the screening procedures.	Male apparently healthy active non-sport specific individuals. Clear medical screening (Appendix A).	Sustained an injury in the past three months. Failed medical screening (Appendix A).	Age 32 ± 7 years, height 179.2 ± 6.2 cm, body mass 80.7 ± 9.6 kg.	Testing took place at the University of Hull.	Approved by the University of Hull ethics committees.

8	23	Analysis of the effects of a season long intervention programme upon performance in the screening procedures.	Male NCAA division III ice hockey athlete recruited from Bethel University in the MIAC. Clear medical screening (Appendix A).	Multi-sport athlete. Ice hockey athletes not registered to play for the selected college, MIAC or NCAA. Sustained an injury in the past three months. Failed medical screening (Appendix A).	Age 22 ± 1 year, height 182.0 ± 7.2 cm, body mass 85.8 ± 8.1 kg.	Testing took place at Bethel University, USA. Intervention was completed over an eight month period (October 2013 – May 2014). Exercises completed in the presence of a student Athletic Trainer.	Approved by Bethel University and University of Hull ethics committees.
8	9	Analysis of the effects of a six week long intervention programme upon performance in the screening procedures.	Male apparently healthy active non-sport specific individuals. Clear medical screening (Appendix A).	Sustained an injury in the past three months. Failed medical screening (Appendix A).	Age 30 ± 7 years, height 178.1 ± 7.0 cm, body mass 80.0 ± 12.4 kg.	Testing took place at the University of Hull. Intervention was completed over a six week period. Exercises completed in the presence of the principle investigator.	Approved by Bethel University and University of Hull ethics committees.

Abbreviations: *Minnesota Intercollegiate Athletic Conference (MIAC), National Collegiate Athletic Association (NCAA), United States of America (USA)*

3.3 Injury reporting (Chapter Four)

Analysis of the teams' medical records databases were completed by the principle investigator and the head Athletic Trainer of each team. The relevant information (occurrence, type (contact or non-contact), location and severity) was retrospectively gathered for each athlete injury and entered into the injury audit form (Appendix A) by the investigator to allow for appropriate comparisons between studies (Agel et al., 2007a; Agel et al., 2007b; Flik et al., 2005; McKnight et al., 1992; Pettersson & Lorentzon, 1993; Pinto et al., 1999; Schick & Meeuwisse, 2003).

Only injuries that occurred during ice hockey activity, either on or off ice, in either practice or competition were included, and all injuries reported to the medical staff were included in the data. Self-reported injuries that were not brought to the attention of the medical staff were not included. The injury audit form took into account how many days the athlete missed which was representative of the severity of the injury in accordance with previous research (Agel et al., 2007a; Agel et al., 2007b; Jørgensen & Schmidt-Olsen, 1986; McKnight et al., 1992; Pettersson & Lorentzon, 1993; Pinto et al., 1999).

3.4 General procedures for Chapter Five, Six, Seven and Eight

Throughout all testing for this project participants were asked to arrive in a fully hydrated state, having consumed no food within one hour before testing, and were asked to abstain from alcohol and strenuous exercise in the 24 hours preceding each visit. During the visit, each participant was given a full briefing regarding the testing procedure and provided with an opportunity to ask questions. Participants were deemed eligible to participate in the study once they successfully completed the pre-exercise medical questionnaire (Appendix A) and were free from all of the exclusion criteria, fulfilled the criteria for

inclusion and were willing to provide written informed consent once they were satisfied with all that was expected of them and were happy to participate.

Measures of height (Seca 217, Seca, Hanover, MD, USA) and mass (Seca 700, Seca) were taken as part of the screening process along with limb length. These were measured from the Anterior Superior Iliac Spine (ASIS) to one inch above the lateral malleolus, head of fibula to one inch above the lateral malleolus and ASIS to one inch above the knee joint line for manual muscle testing. Participants began with a five-minute warm up on a cycle ergometer (Monark 824E, Monark Exercise AB, Varberg, Sweden) cycling at 50 rpm prior to testing. Participants were randomly assigned to either begin with their dominant (Dom) or non-dominant (Ndom) limb first by being assigned a participant number, odd numbers began with their Dom limb and even numbers began with their Ndom limb. Once all testing had been completed participants cooled down on the cycle ergometer for five minutes again at 50 rpm.

3.4.1 Range of motion (Chapters Five, Six, Seven and Eight)

While, as discussed in section 2.6.1, significantly different values of ROM have been found for the standard goniometer when compared to the electronic goniometer and inclinometer it has been demonstrated that using a standard goniometer gives good test-retest reliability and therefore is a valid and useful method of assessing ROM (Armstrong et al., 1998; Clapper & Wolf, 1988; MacDermid et al., 1999; Nussbaumer et al., 2010; Roach et al., 2013). Although a limitation of standard goniometry is that it measures ROM in only two dimensions this is reduced when considering measurements of the hip due to all movements being in-plane (Nussbaumer et al., 2010). Participants were asked to complete hip adduction and abduction followed by flexion (in both sitting and lying), extension and internal and external rotation. ROM assessment comprised of one

familiarisation movement and three experimental movements, with a one minute rest allowed between each movement. ROM tests were measured in degrees (°) using a standard goniometer (Golleshon extendable goniometer, Lafayette Instruments, Lafayette, IN, USA) by the investigator. Table 3.2 shows the placement of the goniometer arms and axis according to Reiman and Manske (2009):

Table 3.2 Placement of the goniometer arms and axis for all ROM assessments

Movement	Position of Participant	Placement of Goniometer		
		Axis	Movement arm	Stationary arm
Hip Abduction	Supine lying	Ipsilateral ASIS	Anterior midline of the femur pointing towards the patella	Toward the contralateral ASIS
Hip Adduction	Supine lying	Ipsilateral ASIS	Anterior midline of the femur pointing towards the patella	Toward the contralateral ASIS
Hip Flexion (Sitting and lying)	Supine lying and sitting	GT of the femur	Lateral midline of the femur toward the lateral femoral epicondyle.	Lateral midline of the pelvis and trunk
Hip Extension	Prone lying	GT of the femur	Lateral midline of the femur toward the lateral femoral epicondyle.	Lateral midline of the pelvis and trunk
Hip Internal Rotation	Seated with knees flexed at 90°	Midpoint of the patella	Anterior midline of the tibia along the tibial crest	Vertical to the floor
Hip External Rotation	Seated with knees flexed at 90°	Midpoint of the patella	Anterior midline of the tibia along the tibial crest	Vertical to the floor

Abbreviations: Anterior Superior Iliac Spine (ASIS), Greater Trochanter (GT)

3.4.2 Strength (Chapters Five, Six, Seven and Eight)

As discussed in section 2.6.2 hand-held dynamometers offer a reliable, valid and accurate measure of strength when compared to the gold standard of isokinetic dynamometry making them a viable option of accurately assessing strength of participants. It was therefore decided to use a hand-held dynamometer within the current project thereby making the screen and testing more realistic and accessible for teams and clinicians working with ice hockey athletes due to the vast cost difference, ease of use and

portability of the hand-held dynamometer compared to the isokinetic dynamometer (Deones et al., 1994; Stark et al., 2011; Stratford & Balsor, 1994; Thorborg et al., 2010). Following the ROM measures the participant completed strength measures testing hip musculature strength using a hand-held dynamometer (Datalink DLK900, Biometrics Ltd, Newport, UK). Participants completed one familiarisation and five maximal strength tests for hip abduction, adduction, extension, hip flexion (in sitting and lying) and internal and external rotation with one minute rest between each test. The break force method was used to assess participants' strength by asking the participant to push as maximally as possible until the principal investigator moved their limb in the opposite direction by approximately one inch indicating that the maximal force had been broken (Tyler et al., 2001). All data was measured in Newton's (N) and converted into Newton metres per kilogram (Nm/kg) by using participant's limb length and total body weight. Nm/kg was calculated both for adduction/abduction and external/internal rotation strength ratios to evaluate any imbalances between opposing muscle groups.

3.4.3 Functional testing (Chapters Five, Six, Seven and Eight)

Functional testing, aimed to measure the functional capabilities of the hip and the lower extremity, were measured by a positive/negative response with a positive test given if the participant experienced pain or tightness within the hip along with the positive signs outlined specifically below. The participants completed a modified Ober's test to assess for iliotibial band tightness or pain; this test involved the participant being in a side lying position with the tested limb uppermost and passively moved from hip flexion and abduction into hip extension and adduction by the investigator whilst the knee remained extended (Herrington, Rivett, & Munro, 2006). The FABER test was completed with the participant in supine lying assessing for the presence of general hip joint pathology including SIJ pain, FAI or psoas pain (Philippon et al., 2010). The Trendelenburg test

was also completed assessing the function of the participant's gluteus medius muscle and general hip abductors (Bird et al., 2001; Clohisy & McClure, 2005a; Woodley et al., 2008). This test measured for any discrepancies between the participant's SIJ lines along with anterior hip impingement (Clohisy & McClure, 2005a). The test was completed by asking the participant to stand on one limb and lift the other off the floor flexing at the knee whilst remaining stood upright, a positive test was indicated if the hip dropped below the standing limb hip (Trendelenburg, 1998). All functional testing were carried out bilaterally starting with the pre-determined limb and consisted of only one test per limb without the use of familiarisation due to the passive nature of the tests.

3.5 Screening procedures (Chapter Six)

ROM (hip adduction, flexion in sitting and lying and internal and external rotation), strength measures (hip abduction, adduction and flexion in both sitting and lying) and functional tests (Ober's, FABER and Trendelenburg tests) were concentrated upon during the screening procedures due to the ice skating technique utilised by ice hockey athletes (Tyler et al., 2001; Upjohn et al., 2008). Focusing on the above movements allowed for the optimisation of methods permitting the screen to analyse and highlight weaknesses surrounding the ice hockey athlete's hip. Individual assessment scores for the screening procedure were calculated using the group's mean \pm standard deviation (SD). This method of scoring was adapted from the FMS whereby a score of one represents below average, a score of two represents average, a three if above average and a score of zero if they reported pain at any point during a measure (Cook et al., 2006a, 2006b). Participants were therefore given a score of one if they fell below the group mean minus the SD, two if they scored between the group mean plus/minus the SD and three if they scored above the group mean plus the SD. Functional tests were scored as one if the athlete displayed a positive test or pain and three if the athlete displayed a negative test and no pain.

Following the approach of Cook et al. (2006a, 2006b) participant's cumulative screening score was calculated by adding all assessment results together. A high score indicated that the athlete was above average in the majority of assessments and therefore potentially less likely to sustain an injury (Cook et al., 2006a, 2006b).



3.6 Intra and inter-tester reliability procedures (Chapter Seven)



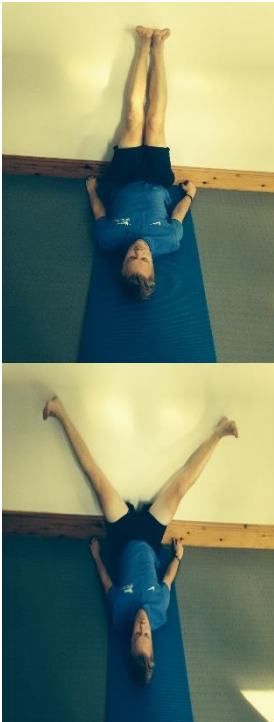
Intra and inter-tester reliability procedures were based upon measures included within the screening procedures detailed in section 3.5 which were repeated three times within a one week period at the same time of day, with a minimum of 48 hours rest between testing. Each testing day participants completed the screening procedure twice, once with the principle investigator and once with a Physiotherapist (kindly performed by Liam Sykes, Physiotherapist, University of Hull), alternating which tester they began with throughout testing to avoid the occurrence of bias. Investigators were blinded to each other's scores. Analysis of inter and intra-tester reliability was completed on the cumulative score of the strength, ROM and overall screen scores across both tester one and two. The scores collated from the functional testing were not analysed for inter and intra-tester reliability due to the yes/no nature of the answers making analysis difficult.

3.7 Intervention procedures (Chapter Eight)

Intervention groups (demographics given in Table 3.1) were determined by numbering participants one or two descending down the ranked order according to their screen results with odd numbered participants completing the intervention. Participants in the intervention group were given a series of exercises outlined in Table 3.3 (Appendix F) to increase their hip musculature strength and ROM throughout one season (October 2013 – May 2014).

Table 3.3 Intervention exercises completed by participants

Exercise	Repetitions and sets	Control	Instructions
Walking lunges	15 on each leg (30 total)	Participants had to ensure their knee touched the floor for each rep. Participants must keep a good core position. Participants must drive their leg up as far as possible.	Participants were asked to take one step forward and touch back knee to the floor, keeping a good core position. Then flex their torso forward towards their front knee. In one movement participants were asked to lift leg back up and drive back leg up into hip flexion in standing. This was one repetition.
	Laying knee to chest	Hold for 25s x 3 on both limbs	Straight leg to remain on the floor. Hold behind the knee. Head to remain on the floor.
	Laying on their back, participants were asked to pull their knee towards their chest.		

Knees in feet out.	Hold for 25s x 3 on both limbs	Knees must remain touching. Feet must remain on the floor. Head must remain on the floor.	Participants were asked to place their knees together and walk their feet outwards whilst maintaining knee contact.	
	Foot to knee	Hold for 25s x 3 on both limbs	Uninvolved limb must be at 90 degrees of flexion in the hip and knee. Head must remain on the floor.	Participants to place involved foot on the knee of the opposite leg and push involved knee to the floor.
	Leg fall out	Hold for 25s then complete 15 reps (without holding the end position) and hold for a further 25s.	Legs must remain straight. Participant to be as close to the wall as possible Head to remain on the floor.	Participants were asked to sit as close to a wall as possible with their legs straight at all times. They were then asked to drop their legs as far down as possible.
				

Ice hockey participants were instructed to complete the exercises twice a week with a register being taken every session of the regular season. The exercises were not completed on specific days with the participant deciding on when to complete the task so as to make the intervention more accessible and easy to implement, thus increasing compliance. The intervention exercises were completed in the presence of a student Athletic Trainer to ensure compliance and correct technique (kindly performed by Jackson Schmidt). The hip screening procedure was again completed following the season long intervention (post season) as outlined above (section 3.5, page 79).

Following the initial intervention procedures outlined above, an additional control intervention group was recruited from the University of Hull and completed the intervention programme twice a week for a six week period. The introduction of the control intervention group aimed to guarantee the intervention programme was being completed correctly with the investigator checking for correct technique and timings of exercises, whereas this was unfortunately not possible in the ice hockey intervention group. Due to the differing success of previous intervention studies where interventions lasted between six weeks to multiple sporting seasons (section 2.5.1, page 48) it was deemed that six weeks was a sufficient time to see any benefits or changes in participant's measures. All exercises were completed in the presence of the principle investigator to ensure correct technique, timing of the intervention exercises and compliance to the programme. Once the six week intervention period had been completed participants again completed the screening protocol used for analysis. This testing and intervention was completed at a different time and location to the initial testing but using the same equipment to ensure comparability.

3.8 Statistical analysis

All statistical analysis was conducted using Microsoft Excel (2011 version, Microsoft Inc., USA) and statistical package for social sciences (SPSS) version 19 (Chicago, IL, USA). Significance was accepted as $p \leq 0.05$ throughout this project. Specific details of data reduction and statistical analysis performed can be found throughout the experimental chapters (Chapters Five to Eight).

Chapter Four: Injury Evaluation in Men's NCAA Ice Hockey across a Four Year Period: Prevalence, Type, Location and Severity

4.1 Introduction

Injury rates within ice hockey are relatively high, with previous research reporting a range of between 4.9 injuries/1000 AE (Flik et al., 2005) to 10.22 injuries/1000 AE (McKnight et al., 1992). It has been reported that ice hockey had the highest injury rate when compared to soccer, volleyball, karate, judo and basketball (Kujala et al., 1995). However, in sports similar to ice hockey with regard to its intermittent nature and number of lower limb injuries, soccer for example, comparison can be problematic due to the differing methods of reporting injury occurrence. The majority of injury incidence studies within soccer report injuries per 1000 hours of activity (Askling et al., 2003; Collins & Raleigh, 2009; Hewett et al., 2005a; Junge et al., 2004; Sullivan et al., 1980; Witvrouw et al., 2003) as opposed to injuries per 1000 AE commonly seen in ice hockey studies (Agel et al., 2007b; Agel & Harvey, 2010; Ferrara & Schurr, 1999; Flik et al., 2005; McKay et al., 2014; McKnight et al., 1992; Schick & Meeuwisse, 2003).

Current understanding of injury incidence in ice hockey is complicated by the varied methods employed during injury data collection. For example, many studies define an injury as any event that required the attention of the team's medical staff or prevented the athlete from participating in training or a game (Agel et al., 2007b; Agel & Harvey, 2010; Ferrara & Schurr, 1999; Flik et al., 2005; Kuzuhara et al., 2009; McKay et al., 2014; McKnight et al., 1992; Pettersson & Lorentzon, 1993; Pinto et al., 1999; Schick & Meeuwisse, 2003; Tegner & Lorentzon, 1991; Tyler et al., 2001), however, others state that injuries should not only include ones that are reported to the medical staff but also injuries that go unreported (Fuller et al., 2006; Jørgensen & Schmidt-Olsen, 1986).

Therefore whichever method of injury reporting is used there may be unavoidable discrepancies leading to erroneous assumptions about the injury problem present in the sport. A further problem with many injury audits is that the reporting of severity differs greatly between studies. The most common method of grading severity is to measure the amount of days missed irrespective of ice hockey activity (Agel et al., 2007b; Ferrara & Schurr, 1999; Jørgensen & Schmidt-Olsen, 1986; McKnight et al., 1992; Pettersson & Lorentzon, 1993; Pinto et al., 1999) whereas others use games or sessions missed as the marker of severity (Agel & Harvey, 2010; Flik et al., 2005; Kuzuhara et al., 2009; McKay et al., 2014; Pinto et al., 1999; Schick & Meeuwisse, 2003). Thus, the injury problem present in the sport may be easily over or underestimated.

Previous research suggests that the most common area of injury during ice hockey activity is the head and neck area accounting for 14% - 31% of all injuries sustained (Agel et al., 2007a; Agel et al., 2007b; Flik et al., 2005; Jørgensen & Schmidt-Olsen, 1986; Kujala et al., 1995; McKnight et al., 1992; Pettersson & Lorentzon, 1993; Pinto et al., 1999; Schick & Meeuwisse, 2003). Other common areas of injury are reported to be the shoulder, knee and hip, especially injuries occurring through contact with either the boards, other athletes or the ice (Agel et al., 2007b; Jørgensen & Schmidt-Olsen, 1986; McKnight et al., 1992; Pettersson & Lorentzon, 1993).

Due to the differing methods of measuring injury occurrence and severity in previous research this study aimed to investigate the occurrence, type (contact or non-contact), location and severity of injury sustained during ice hockey activity for two teams over a four season period. A key outcome of this analysis was to compare these variables in both contact and non-contact injuries, as well as provide a detailed analysis of the non-contact injuries. This data can be used to ascertain the injury problem present for the group of ice hockey athletes who may then be targeted for a preventative intervention.

4.2 Methodology

4.2.1 Participants

Participant demographics are outlined in detail in Chapter Three (section 3.2; Table 3.1, page 72). Each team competed in the Minnesota Intercollegiate Athletic Conference (MIAC) and played 25 regular season games with an additional maximum of three playoff games each season. There was no maximum squad size for the conference however only 20 athletes were allowed to dress for competitive games. These 20 athletes include a maximum of 18 out skaters and two net minders. Data within the audit was retrospectively collected and compiled using the injury report form (Appendix A) by the principle investigator and the head Athletic Trainer of the selected Colleges. Due to time constraints of the current project the data collected within this study is of a retrospective nature and therefore some information was not gathered for all injuries due to incomplete medical notes from the Colleges selected. Hence some details, such as when the injury occurred during the game and exact details of the injury mechanism, were missing and therefore not included within the current study.

4.2.2 Analysis

The procedure for this study has been outlined in detail in Chapter Three (section 3.3, page 75). In brief the principle investigator collated injury data retrospectively from two NCAA division III ice hockey teams. Descriptive statistics consisted of frequency and percentages of injury type (contact and non-contact), severity (days missed) and location. Injury rates are described by giving injuries/1000 AE and also injuries/1000 hours of ice hockey activity.

4.3 Results

4.3.1 Injury frequency

Of the 107 athletes, 73 (68%) sustained injuries over the four seasons, with 171 injuries reported. Injury incidence was 10.15 injuries/1000 AE or 5.68 injuries/1000 hours of ice hockey activity. Contact injuries, through contact from the boards, ice, other athletes or equipment numbered 99 (58%) and accounted for 5.88 injuries/1000 AE or 3.29 injuries/1000 hours of ice hockey activity. Non-contact injuries numbered 72 (42%) which equated to 4.27 injuries/1000 AE or 2.39 injuries/1000 hours of ice hockey activity.

4.3.2 Injury location

Figure 4.1 displays the total amount of injuries sustained by location not distinguishing between contact and non-contact injuries. The knee accounted for the majority of all injuries to a single area with a total of 26 (15%), whilst the hip totalled 23 (13%) and the shoulder totalled 22 (12%) injuries (Figure 4.1). When the hip, thigh and groin were combined into the hip complex this became the most injured area of the body with a total of 46 injuries, amounting to 27% of all injuries sustained through both contact and non-contact.

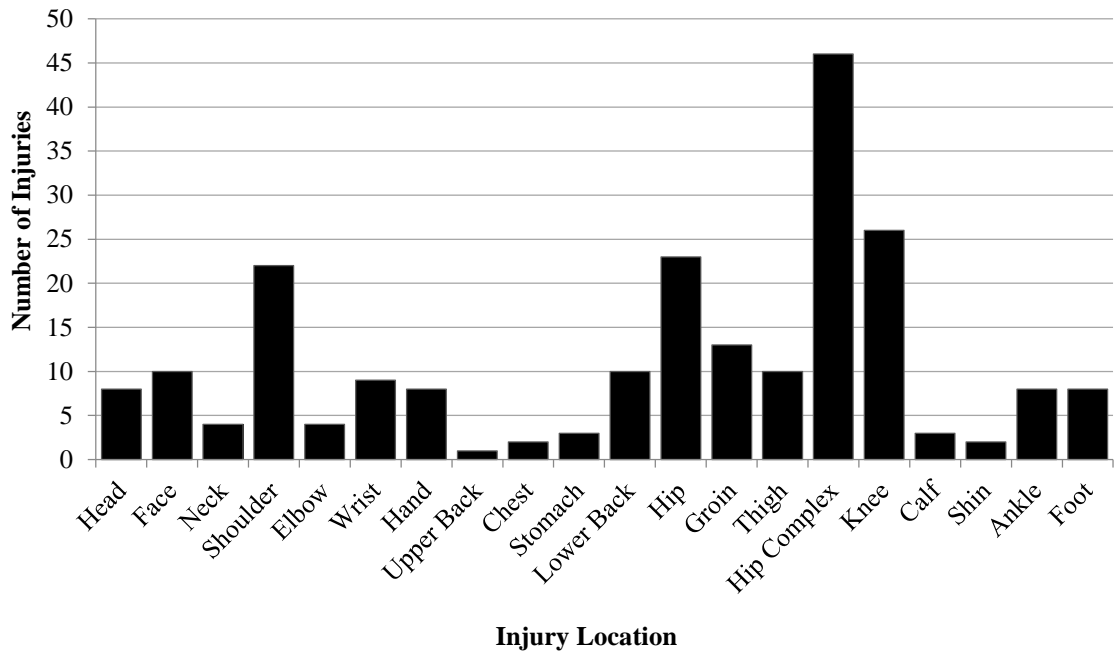


Figure 4.1 Analysis of total injuries by location by both contact and non-contact mechanisms

Figure 4.2 shows the amount of injuries per location separated into either contact or non-contact injuries. When considering non-contact injuries specifically, the hip complex was the most frequently injured area of the body with a total of 36 of the total 72 non-contact injuries (50%), followed by the hip with 20 (14%) and groin totalling 13 (9%). The 13 injuries (18%) sustained to the groin were all of a non-contact nature. Conversely, contact accounted for all nine facial injuries (9%), the majority of the 18 (18%) injuries to the shoulder and the majority of the 17 injuries to the knee (17%).

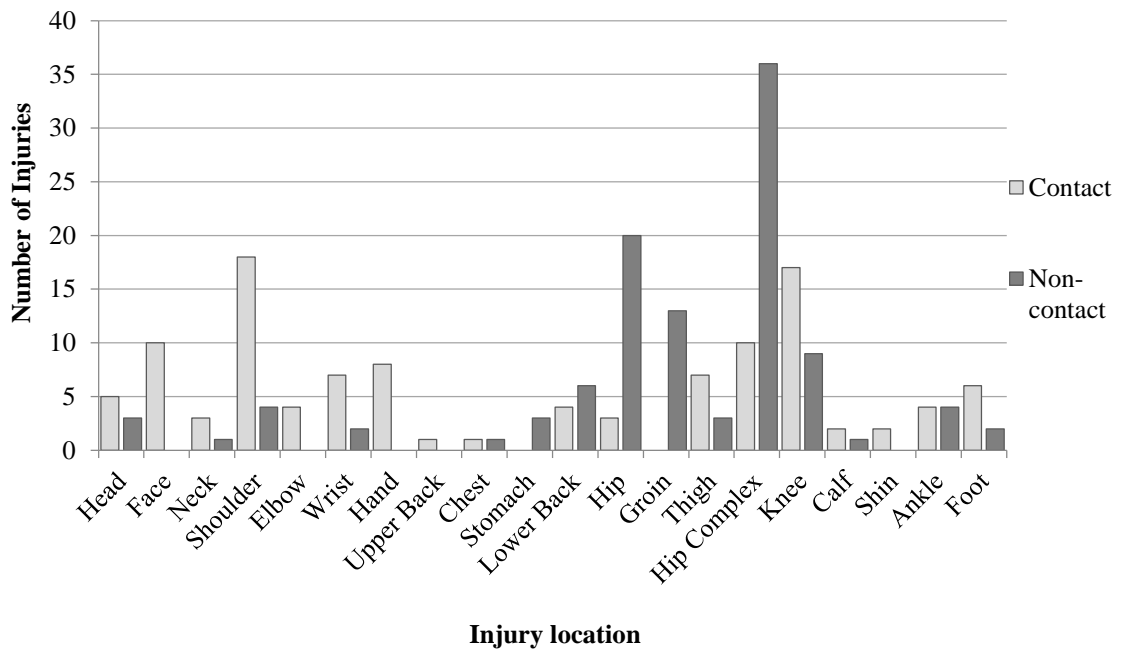


Figure 4.2 Classification of contact and non-contact injuries by location

4.3.3 Injury severity

When assessing total injury severity, 82 of the 171 total injuries caused athletes to miss zero days (48%), with 49 (29%) injuries causing the athlete to miss between one to seven days (Figure 4.3). At the time of data collection there were a total of six injuries (4%) that were on going.

Similar trends were seen when analysing non-contact injuries, with 48 (67%) of 72 non-contact injuries causing the athlete to miss zero days of activity, decreasing to 11 injuries (8%) leaving the athlete to miss between one and seven days with only 13 (9%) injuries causing athletes to miss more than eight days (Figure 4.3). There were two (1%) injuries that lasted longer than 91 days which were both acetabulum tears requiring surgery (Figure 4.3).

Contact injury frequencies alone show slight differences to those of a non-contact nature in that 38 (38%) of the 99 contact injuries caused the athlete to miss between one and seven days and 34 (34%) left the athlete missing zero days which is less than non-contact

(Figure 4.3). Similar frequencies were observed, when analysing injuries that caused the athlete to miss more than eight days, to non-contact injuries with 27 (27%) of all contact injuries causing the athlete to miss more than eight days.

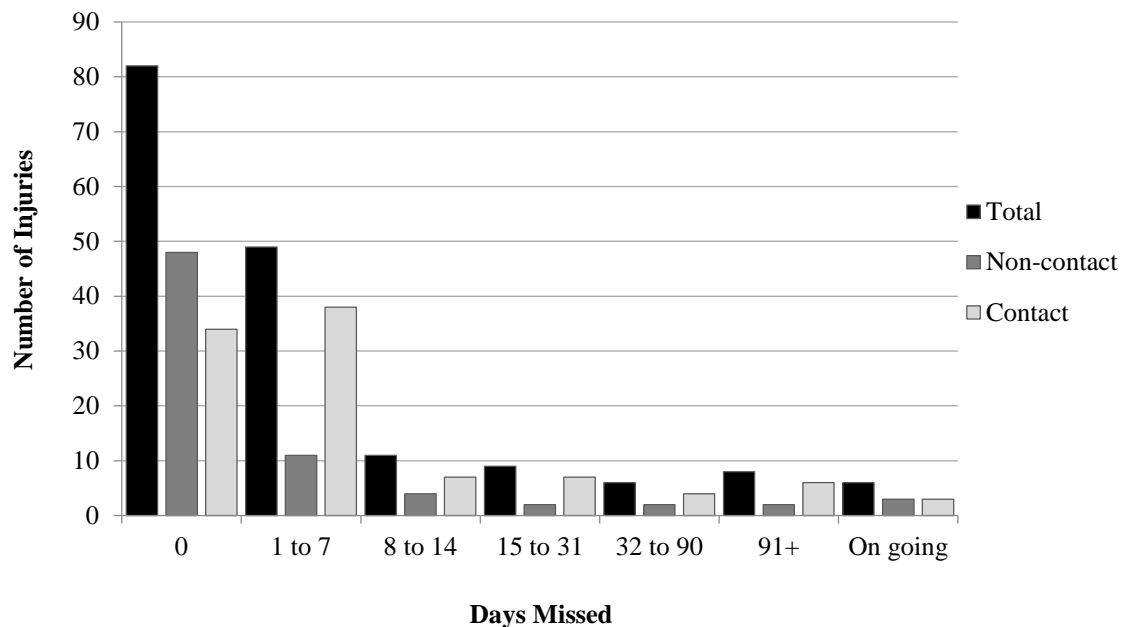


Figure 4.3 Number of days missed due to both contact and non-contact injuries

4.4 Discussion

This study aimed to investigate the occurrence, type (contact or non-contact), location and severity of injury sustained during ice hockey activity for two teams over a four season period ranging from 2008 to 2012. The main findings were that contact injuries were slightly more prevalent than non-contact injuries (58% vs. 42% respectively) in ice hockey with the majority of all injuries (48%) causing athletes to miss zero days. A further finding was that the hip complex was the most commonly injured body location accounting for the majority of both total (27%) and non-contact injuries (50%).

4.4.1 Injury frequency/type

A major finding of the current study was that the injury prevalence observed was similar to that seen in previous studies investigating injuries in ice hockey (Ferrara & Schurr, 1999; Jørgensen & Schmidt-Olsen, 1986; McKay et al., 2014; McKnight et al., 1992; Schick & Meeuwisse, 2003). The current study reports that injury occurrence was 10.15 injuries/1000 AE which is similar to the work of McKnight et al. (1992) (10.22 injuries/1000 AE), Ferrara and Schurr (1999) (10.22 injuries/1000 AE), Schick and Meeuwisse (2003) (9.19 injuries/1000 AE) and McKay et al. (2014) (15.6 injuries/1000 AE). However, Flik et al. (2005) and Agel and Harvey (2010) reported a smaller injury rate finding 4.9 injuries/1000 AE and 5.95 injuries/1000 AE respectively. Only the work of Jørgensen and Schmidt-Olsen (1986) report total injuries per 1000 hours of ice hockey activity finding a total of 4.7 injuries/1000 hours which is similar to the findings of the current study which reports 5.68 injuries/1000 hours of ice hockey activity. Although other studies (Agel et al., 2007b; Kuzuhara et al., 2009; Pettersson & Lorentzon, 1993) report injuries per 1000 hours and AE they do not give a single figure of total injuries and instead choose to report injuries sustained during practice and competitive games separately making comparison to the current study difficult.

A further finding was that contact injuries (n = 99, 58%) were only slightly more prevalent than non-contact injuries (n = 72, 42%). Whilst contact injuries within the current study were more prevalent than non-contact injuries this finding is in disagreement with many previous studies which have previously demonstrated a much higher percentage of contact injuries (Agel et al., 2007b; Ferrara & Schurr, 1999; Flik et al., 2005; Pettersson & Lorentzon, 1993; Schick & Meeuwisse, 2003; Tegner & Lorentzon, 1991). Pettersson and Lorentzon (1993) reported that of a total 376 injuries sustained by one Swedish ice hockey team over a four year period, 318 (85%) were of a contact nature. Similarly

Tegner and Lorentzon (1991) reported that 85% of total injuries were caused by contact from one team over one season of Swedish ice hockey. The lower amount of contact injuries found in the current study may suggest that the league, or University level, may not be as physical as teams/leagues previously studied or the size of the current study was not large enough. Perhaps then a more suitable comparison for the current study would be to analyse studies which investigated injuries from NCAA ice hockey athletes due to their similar playing ability and practice/league schedules. McKnight et al. (1992) report that of a total 280 injuries, only 35 (13%) were sustained in a non-contact manner, with the majority being overuse injuries, when investigating 15 NCAA teams over a three year period. Similarly Ferrara et al. (1999) found that contact injuries accounted for 81% when investigating injuries over three seasons collected from seven NCAA division I teams. Although the study by Flik et al. (2005) doesn't provide clear classification between contact and non-contact injuries they do suggest that overuse injuries accounted for 8% of a total 113 injuries collected from two NCAA division I teams over one season. Similarly Agel et al. (2007b) report that non-contact injuries accounted for only 10% of injuries sustained during competitive games and a higher figure of 33% were sustained during ice hockey practice. The results of this study, whilst similar in the general trend seen in previously cited work, do differ slightly in that the differences between contact and non-contact are not as large with contact injuries only 16% more prevalent than non-contact injuries. However, many of the previous studies have collected injury data from more teams over a longer period of time. If the data collected within the current study were expanded to include more teams, over a longer period of time, a larger difference may have been observed between the occurrence of contact and non-contact injuries.

4.4.2 Injury location

The most common injury locations were the hip complex (27%), knee (15%), hip (13%) and the shoulder (12%) when both contact and non-contact injuries combined were analysed (Figure 4.1). These injury frequencies show similarity to the work of Agel et al. (2007b) who reported that 14% of injuries were sustained to the knee and 9% sustained by the shoulder in an investigation of contact and non-contact injuries sustained by a similar cohort of NCAA ice hockey athletes from all divisions across a 16 year period. In further NCAA based work, Agel and Harvey (2010) also reported that the head was the most common location to be injured, accounting for 12% of all injuries with the shoulder and knee both accounting for 10% of injuries in 24% of NCAA teams over seven seasons. Although the results of Agel and Harvey (2010) are similar to the current study in certain aspects of injury location they do, however, report that hip/groin injuries accounted for only 2% of injuries which is very different to the current study which found a total of 22% of injuries being sustained to the hip complex (Figure 4.1). The work of Ferrara et al. (1999) who investigated injuries from seven NCAA teams across a three year period found the most similar results to the current study in terms of injury location reporting that the hip/thigh accounted for 23% of all injuries, with the shoulder (19%) and knee (16%) also accounting for high percentages of total injuries. McKnight et al. (1992) demonstrated that the shoulder was the most frequently injured location of NCAA athletes from seven teams during three seasons with 18% of the total injuries with the knee accounting for 16% and the groin, hip and thigh combined accounting for 20%. Comparable results to the current study were reported by Flik et al. (2005) when analysing injuries compiled from two NCAA teams over one season with knee injuries representing 22% of total injuries, the shoulder accounting for 15% and the hip and groin combined only accounting for 9%. McKay et al. (2014) report that the head was the most commonly injured location (17%) with the thigh (14%), knee (13%) and shoulder (12%) also being

frequently injured when analysing injuries from all eligible NHL athletes during a six year period. Similar results have been reported within the Swedish Elite ice hockey league as Tegner and Lorentzon (1991) reported that 39% of all injuries were sustained to the head and face over a one year period. Although the study by McKay et al. (2014) and Tegner and Lorentzon (1991) reports the head and face to be the most commonly injured location it may be surmised that this is due to athletes in the NHL and Swedish Elite League not enforced to wear a face shield, as they are mandated to in the NCAA, leaving this area exposed potentially explaining the high number of injuries sustained to this area.

None of the previously mentioned research investigated non-contact injuries specifically, however with regard to future injury prevention possibilities it was essential to distinguish between the location and severity of non-contact injuries sustained by the ice hockey athlete. The current study presented that the most common location for non-contact injury was the hip complex representing 36 (50%) of a total of 72 injuries. This high amount of non-contact injuries sustained by the hip complex could be attributable to the locomotion of ice skating. This unique locomotion, as previously discussed, places the hip in vulnerable combinations of abduction with external rotation during the push off phase and flexion with internal rotation during the recovery phase which may have an impact upon non-contact injury occurrence (Bizzini et al., 2007; Keogh & Batt, 2008; Philippon et al., 2010; Stull et al., 2011). These problematic positions may be further exacerbated by the potential overloading through the hip, in particular the abductors and external rotators at the terminal phase of the skating stride. This overloading requires the abductors and external rotators to be extremely strong at their end range which may potentially place the athlete at further risk if weaknesses, in either strength or ROM, are present. However, without completing further works into the aetiology of injuries linking to skating mechanics this link is speculative. Injuries to the knee (15%) and shoulder (12%), which are commonly injured when contact and non-contact injuries are combined (Figure 4.1),

recorded far fewer non-contact injuries with nine (13%) and four injuries (5%) respectively (Figure 4.2). These frequencies, particularly the low frequencies seen in Figure 4.2 to the shoulder, are significantly different to the results of previous literature mentioned above who report injury frequencies to these locations to be much higher when both contact and non-contact injuries are combined (Agel et al., 2007b; Agel & Harvey, 2010; Ferrara & Schurr, 1999; Flik et al., 2005; McKay et al., 2014; McKnight et al., 1992). The lower figures of non-contact injuries sustained to the shoulder reported in the current study may be explained due to the high contact nature of sport, and in particular, the way in which body contact is initiated in ice hockey with athletes ideally using the shoulder as the principle point of contact placing it at a greater risk of sustaining a contact injury (Byers & Roberts, 2006). Similar patterns are seen with injuries sustained to the head, face and neck as these three areas account for a combined 22 (13%) of total injuries, however, when analysing only non-contact injuries this figure is reduced to just four injuries (3%). This finding that the head, neck and face were commonly injured via a contact mechanism may again potentially be explained due to the high contact nature of ice hockey (Montgomery, 2006; Potteiger et al., 2010; Quinney et al., 2008; Vescovi et al., 2006; Warsh et al., 2009). In a study by Emery et al. (2010) comparing ice hockey leagues allowing contact and leagues that do not it was displayed that the contact league had over double the amount of injuries (241 injuries from 85,077 exposure hours) compared to the non-contact league (91 injuries from 82,099 exposure hours) which is consistent with the higher number of contact injuries seen within previous literature and the current study. This does, however, highlight the need for further investigation into non-contact injuries sustained by ice hockey athletes as there is potential to reduce these injuries without changing the rules or equipment required to reduce the incidence of contact injuries (Aubry et al., 2002; Benson et al., 2002).

4.4.3 Injury severity

The current study reported that the most common amount of time for athletes to miss was zero days (82 (48%) of the 171 injuries). The next most common severity category was one to seven days missed (n = 49, 29%) (Figure 4.3). As previously discussed, it may be of benefit to compare the current study to that of previous works investigating injuries in the NCAA for similarity. The previous work of McKnight et al. (1992) reported that 60% of total injuries sustained by athletes from seven teams over a three year period left athletes missing between zero and seven days with 25% causing athletes to miss between eight and 21 days. Very similar results to the current study were reported by Ferrara et al. (1999) who identified that 60% of injuries caused athletes to miss between zero and seven days and 26% of injuries left the athlete missing between eight and 21 days. Both the results of McKnight et al. (1992) and Ferrara et al. (1999) are similar to the results of the current study which found that 77% of total injuries resulted in athletes missing between zero and seven days and only 23% caused the athlete to miss more than eight days due to the injury (Figure 4.3). The higher number of injuries resulting in the athlete missing zero days (48%) seen within the current study may be explained due to the athletes wanting to report the injury to the medical staff to ensure they will not exacerbate the injury if they continue with ice hockey activity. However, specific reasons into injury reporting were not measured within the current study and warrant further investigation in order to gain an insight and understanding of athlete's views and expectations of injury.

As previously discussed the study by Schick and Meeuwisse (2003) counted severity in terms of number of sessions missed making comparisons to the current, and other, studies difficult due to the differing measures of severity. However, Schick and Meeuwisse (2003) did report that 80 (50%) of the 161 injuries resulted in between two and seven sessions missed with 32 (20%) injuries leaving athletes missing between eight and 14 sessions and

33 (20%) injuries forcing athletes to miss more than 14 sessions. There are advantages and disadvantages to this method of grading severity as it counts only ice hockey activity that is missed (games, practices or gym sessions) and therefore can give an insight into the amount of ice hockey activity missed potentially giving a true reflection of time the athlete will have missed due to the injury. The method utilised by Schick and Meeuwisse (2003) would also avoid counting days where the athlete has completed no ice hockey specific training, for example rest days enforced by the team, further enhancing their method of grading severity. However, a major disadvantage to this method is that if the team had only one game a week, as opposed to the normal two, the data may become skewed and disproportionate, particularly as different teams/levels may have different schedules of practice/competition. As such, it would be useful to report both days and sessions missed in future research allowing both easier comparisons and more detailed information to be analysed.

In comparison to injuries collected from differing levels and leagues the results of the current study are consistent with the work of Petterson and Lorentzon (1993) who demonstrated that 61% of a total 376 injuries sustained across a four year period left athletes missing zero days and 34% left athletes to miss between one and seven days due to the injury. Although the studies are similar in terms of results reported, it must be considered that the work of Petterson and Lorentzon (1993) only analysed injuries collated from one team of ice hockey athletes across a four year period which may have increased, or decreased, the injury figures dependent upon league position, team injuries and schedule (Phillips, 2000) as opposed to using multiple teams making direct comparison a little more difficult. The study by Jørgensen and Schmidt-Olsen (1986), of 14 teams over two seasons of Danish ice hockey, differ from the current study as they report injuries causing the athlete to miss between zero and one day to be much lower (19%) as opposed to the current studies higher 48% (Figure 4.3). The work of Jørgensen

and Schmidt-Olsen (1986) also presented that the most common amount of days to be missed by athletes due to injury is between eight and 14 accounting for 22% of total injuries, which again is significantly different to the current study which suggests only 6% of injuries caused athletes to miss between eight and 14 days. Although the current study and the work of Jørgensen and Schmidt-Olsen (1986) differ significantly it may be due to the style of play employed within the North American game as opposed to the less physical game seen in the larger ice rinks of Europe (Gee & Leith, 2007; Wennberg, 2004). A further potential reason for the differing results reported by Jørgensen and Schmidt-Olsen (1986) may be due to the change in tactics and style of play in the modern game which has changed since their collection of data.

4.5 Conclusion

The findings of the current study demonstrate that ice hockey athletes are more susceptible to sustaining a contact injury than a non-contact injury. Although the current study is in some agreement with previous literature that contact injuries are more prevalent it is perhaps more important to concentrate on those injuries of a non-contact nature to potentially begin to reduce the number of non-contact injuries sustained by ice hockey athletes. The hip complex, knee and shoulder are the most commonly injured locations of an ice hockey athlete when all injuries are considered. However, when investigating only non-contact injuries the hip complex is clearly the most commonly injured location.

It is, therefore, of major importance to investigate potential reasons as to why the hip complex is commonly injured in terms of non-contact injuries alone. Thus, future research should investigate why the hip complex may be vulnerable to non-contact injuries allowing the development of screening procedures and subsequent intervention

programmes aimed at preventing/reducing these injuries or highlighting those athletes possibly 'at risk'.

Chapter Five: Investigating Injury Susceptibility of the Hip in Ice Hockey Athletes

5.1 Introduction

Many studies demonstrate strength as an important risk factor for lower limb injuries and in particular overuse injuries, especially to the hip and groin (Askling et al., 2003; Baumhauer et al., 1995; Ekstrand & Gillquist, 1983; Mohammadi, Kazemi, Sazvar, Rahimi, & Khademi, 2013; Murphy et al., 2003; Söderman et al., 2001). Muscular strength and proprioception are described as key components in joint stability, with significant differences in dynamic balance observed following a six week protocol aimed at increasing strength and proprioception leading to a reduced risk of injury (Blackburn et al., 2000). In a study of female soccer athletes it was displayed that a decreased hamstring to quadriceps strength ratio increased the risk of contact injury, whereas an increased hamstring to quadriceps ratio led to an increase in the risk of sustaining a non-contact injury providing evidence that a balance between muscle groups is beneficial (Murphy et al., 2003; Söderman et al., 2001). Similarly, in a study of male soccer athletes, those who sustained a non-contact injury exhibited reduced isokinetic quadriceps strength when compared to athletes who remained uninjured (Ekstrand & Gillquist, 1983).

In professional ice hockey Tyler et al. (2001) demonstrated that athletes with weaker hip adductor muscles were at a significant increase in receiving a hip adductor muscle strain. Additionally, athletes who exhibited a significant weakness in their hip adductor muscles compared to their abductor muscles were also at an increased risk of sustaining a hip adductor muscle strain, providing evidence that athletes with hip adduction strength less than 80% of their hip abduction score were at much greater risk of sustaining an injury (Tyler et al., 2001). In further work it was found that a six week combined strength and dynamic exercise program, targetting ice hockey athletes with hip adduction strength less

than 80% of their hip abductors, significantly decreased the amount of hip adductor injuries sustained finding a reduction from eight of 21 athletes (3.2 injuries/1000 hours of ice hockey) sustaining an injury to three of 33 athletes (0.71 injuries/1000 hours of ice hockey) receiving an injury following their intervention programme (Tyler et al., 2002).

A further factor for consideration is that limited ROM increases the potential risk of injury to athletes in both soccer and ice hockey (Ekstrand & Gillquist, 1983; Orchard, Marsden, Lord, & Garlick, 1997; Quinney et al., 2008; Tyler et al., 2001). Ekstrand and Gillquist (1983) identified muscular tightness to be the biggest risk factor for adductor strains in professional soccer. It has also been described that professional soccer athletes with a decreased hamstring or quadriceps muscle ROM were significantly more likely to sustain a hamstring or quadriceps muscle injury (Witvrouw et al., 2003). In a more recent study of English professional soccer athletes Bradley and Portas (2007) demonstrated significantly decreased pre season ROM in the hip and knee flexors in athletes who subsequently sustained a hip or knee flexor injury compared to athletes who did not. Conversely, it has been found that a stretching and flexibility intervention program implemented over two seasons did not reduce the incidence of hamstring injuries sustained by elite soccer athletes (Arnason, Andersen, Holme, Engebretsen, & Bahr, 2008). Arnason et al. (2008) reported that injury occurrence was not significantly affected by the flexibility programme alone with athletes suffering from similar injury rates compared to those that did not complete the programme (0.54 injuries/1000 hours and 0.35 injuries/1000 hours respectively). However, athletes who completed a combined strength and ROM programme did display a decrease in injury occurrence following the programme compared to those that did not complete the intervention programme (0.22 injuries/1000 hours and 0.62 injuries/1000 hours respectively) (Arnason et al., 2008).

Within professional ice hockey athletes, Tyler et al. (2001) demonstrated there was no significant difference in pre season hip adductor ROM between athletes who subsequently went on to sustain a hip musculature injury and athletes who did not. It was also found that athletes who did suffer an injury had no difference between their Dom and Ndom limb showing that both limbs were equally susceptible to an injury (Tyler et al., 2001).

The purpose of this study was to compare the differences in ROM, strength and functional testing of the hip for both Dom and Ndom limbs in ice hockey athletes, soccer athletes and control participants. Control participants were healthy adult males whom were not single sport athletes giving a greater comparison to the single sport athletes from both soccer and ice hockey. Soccer athletes were chosen for comparison to ice hockey athletes due to similarities between the two sports with regards to the intermittent nature of the sports (Di Salvo et al., 2007; Edwards et al., 2003; Montgomery, 2006) and the relatively similar high number of lower limb injuries observed in soccer (Agel et al., 2007b; Jørgensen & Schmidt-Olsen, 1986; McKnight et al., 1992; Pettersson & Lorentzon, 1993; Witvrouw et al., 2003; Worrell & Perrin, 1992). A key outcome of this analysis was to determine why the ice hockey athletes' hip is possibly 'at risk' from non-contact injuries.

5.2 Methodology

5.2.1 Participants

Participant demographics are outlined in detail in Chapter Three (section 3.2; Table 3.1, page 72). All 24 participants recruited from Bethel University were either members of the soccer or ice hockey team and had been on the respective team for at least one season. The nine participants recruited from the University of Hull acted as a control group to the

specifically trained athletes and were tested at a different time and in a different location but using the same experimental equipment.

5.2.2 General procedures

The procedure for the current study, including the comparison between ice hockey, soccer and control participants, has been outlined in detail in Chapter Three (section 3.4, page 75). In brief, participants completed ROM and strength measures of all hip movements (abduction, adduction, flexion in lying and sitting, extension and internal and external rotation) along with functional testing of Ober's, Trendelenburg and FABER tests.

5.2.3 Analysis

Data were analysed using SPSS version 19. A mixed model ANOVA was used to investigate interactions (sport (ice hockey/soccer/control) x limb (Dom/Ndom)) and main effects (limb differences or sport differences) for the ROM variables abduction, adduction, flexion in sitting, flexion in lying, extension, internal rotation, external rotation and for the strength variables abduction, adduction, flexion in sitting, flexion in lying, extension, internal rotation and external rotation. In the instance of a significant interaction, post-hoc analysis was completed using least significance difference (LSD). One participant from the control group was removed due to anomalous results for both ROM and strength measurements seen during data analysis.

5.3 Results

5.3.1 Range of motion

Mean hip ROM for ice hockey, soccer and control participants are displayed in Table 5.1. There was a significant interaction for group and limb dominance for ROM in adduction

($F(2, 31) = 5.806, p = 0.007, \eta^2 = 0.266$). Ice hockey athletes had greater hip adduction ROM on their Dom limb compared to soccer athletes ($p < 0.001$) and control participants ($p < 0.001$) (Table 5.1).

Table 5.1 Mean and standard deviation for hip ROM in ice hockey athletes, soccer athletes and control participants

Hip ROM measured (°)	Limb Dominance	Ice Hockey (Mean ± SD) n = 16	Soccer (Mean ± SD) n = 8	Control (Mean ± SD) n = 8
Abduction	Dom	46.31 ± 8.90	38.25 ± 4.33	33.45 ± 10.03
	Ndom	42.88 ± 12.68	39.63 ± 9.96	30.91 ± 9.29
Adduction	Dom	29.25 ± 8.28*	19.38 ± 3.74	20.18 ± 3.49
	Ndom	25.13 ± 4.29	20.75 ± 4.43	21.64 ± 5.18
Flexion in Lying	Dom	97.94 ± 18.43	103.88 ± 17.96	116.82 ± 7.72
	Ndom	102.00 ± 14.50	110.63 ± 15.49	118.18 ± 7.77
Flexion in Sitting	Dom	42.19 ± 9.56	39.88 ± 9.67	40.09 ± 7.40
	Ndom	45.56 ± 8.45	35.25 ± 7.11	39.27 ± 5.39
Extension	Dom	24.44 ± 10.60	22.13 ± 5.74	20.64 ± 5.54
	Ndom	24.25 ± 12.90	20.50 ± 8.25	19.82 ± 8.05
Internal Rotation	Dom	27.25 ± 8.34	23.13 ± 6.36	29.18 ± 6.63
	Ndom	29.19 ± 11.15	30.13 ± 12.16	29.64 ± 7.59
External Rotation	Dom	29.36 ± 8.04	37.25 ± 7.87	45.36 ± 8.77
	Ndom	28.56 ± 14.24	36.75 ± 13.71	45.72 ± 7.24

* Ice hockey athletes had greater ROM on Dom limb compared to both soccer athletes ($p < 0.001$) and control participants ($p < 0.001$)

There were main effect differences between groups for hip abduction ($F(2, 31) = 7.351, p = 0.002, \eta^2 = 0.315$), adduction ($F(1, 31) = 7.192, p = 0.003, \eta^2 = 0.310$) flexion in lying ($F(1, 31) = 6.277, p = 0.005, \eta^2 = 0.282$) and external rotation ($F(1, 31) = 8.920, p = 0.001, \eta^2 = 0.358$) on both limbs. Ice hockey athletes displayed significantly greater ROM hip abduction compared to control participants ($p = 0.001$) and adduction compared to both soccer athletes ($p = 0.003$) and control participants ($p = 0.004$) (Figure

5.1). Ice hockey athletes also displayed significantly less ROM in hip flexion in lying ($p = 0.001$) and external rotation ($p < 0.001$) when compared to control participants (Figure 5.1).

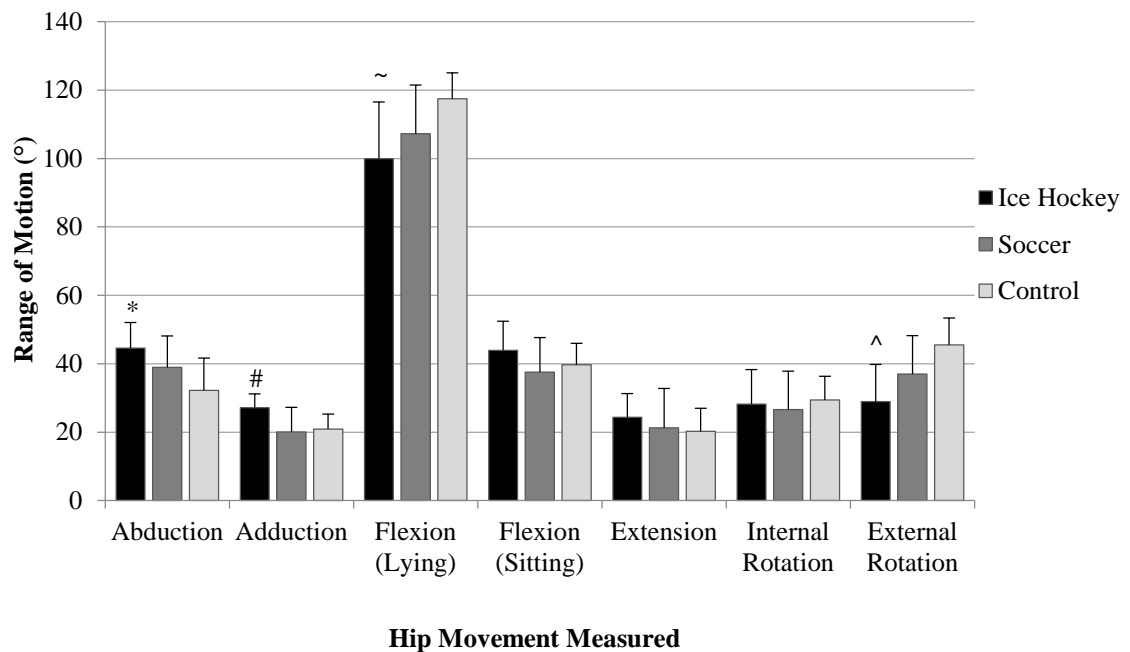


Figure 5.1 Mean and standard deviation ROM differences between groups for both limbs combined

* Ice hockey athletes had significantly greater hip abduction than control participants ($p = 0.001$). # Ice hockey athletes had significantly greater hip adduction than soccer athletes ($p = 0.003$) and control participants ($p = 0.004$). ~ Ice hockey athletes had significantly less hip flexion in lying than control participants ($p = 0.001$). ^ Ice hockey athletes had significantly less external rotation than control participants ($p < 0.001$).

No significant differences were observed between the Dom and Ndom limb between groups, however, there were also main effect differences between the limbs of participants for all groups. The Ndom limb displayed greater ROM in flexion in lying ($F(2, 31) = 7.652, p = 0.009, \text{Peta}^2 = 0.193$) and internal rotation ($F(2, 31) = 5.260, p = 0.029, \text{Peta}^2 = 0.141$) (Figure 5.2). When all groups were combined the Dom limb displayed greater ROM in flexion in sitting ($F(2, 31) = 8.121, p = 0.008, \text{Peta}^2 = 0.202$) when analysing Dom versus Ndom limbs when all groups were combined (Figure 5.2).

There were no other significant interactions between group and limb, nor main effect differences between limb or group for the remaining ROM variables measured.

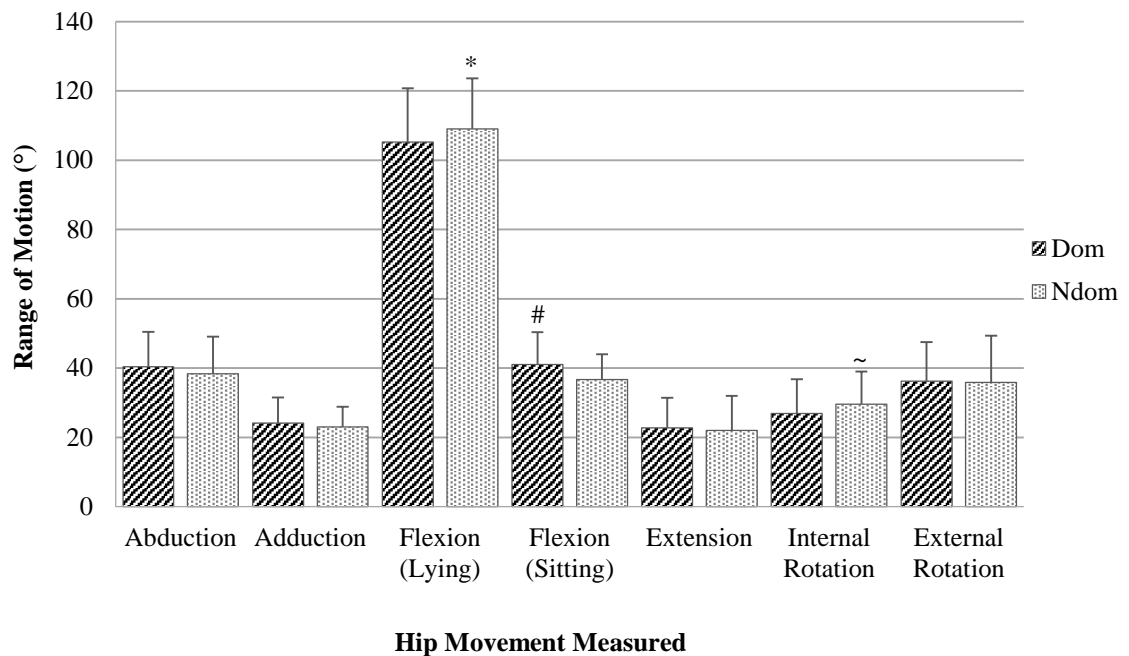


Figure 5.2 Mean and standard deviation ROM differences between limbs for all participants

* Ndom limb had significantly greater hip flexion in lying ($p = 0.009$). # Dom limb had significantly greater hip flexion in sitting ($p = 0.008$). ~ Ndom limb had significantly greater internal rotation ($p = 0.029$)

5.3.2 Strength

Mean strength for ice hockey, soccer and control participants is displayed in Table 5.2.

There were no significant interaction effects for group and limb dominance for strength in any of the hip movements.

Table 5.2 Mean and standard deviation for hip strength in ice hockey athletes, soccer athletes and control participants

Hip Strength measured (Nm/kg)	Limb Dominance	Ice Hockey (Mean \pm SD) n = 16	Soccer (Mean \pm SD) n = 8	Control (Mean \pm SD) n = 8
Abduction	Dom	2.26 \pm 0.21	2.45 \pm 0.31	2.22 \pm 0.32
	Ndom	2.27 \pm 0.23	2.35 \pm 0.28	2.07 \pm 0.22
Adduction	Dom	2.64 \pm 0.28	2.90 \pm 0.33	2.46 \pm 0.31
	Ndom	2.39 \pm 0.25	2.68 \pm 0.36	2.28 \pm 0.24
Flexion in Lying	Dom	1.44 \pm 0.19	1.61 \pm 0.14	1.51 \pm 0.18
	Ndom	1.45 \pm 0.18	1.63 \pm 0.17	1.49 \pm 0.20
Flexion in Sitting	Dom	1.85 \pm 0.15	2.01 \pm 0.27	1.57 \pm 0.26
	Ndom	1.82 \pm 0.23	2.11 \pm 0.25	1.61 \pm 0.21
Extension	Dom	1.39 \pm 0.27	1.63 \pm 0.38	1.45 \pm 0.10
	Ndom	1.49 \pm 0.37	1.78 \pm 0.47	1.46 \pm 0.08
Internal Rotation	Dom	1.03 \pm 0.18	1.24 \pm 0.28	1.10 \pm 0.21
	Ndom	1.08 \pm 0.19	1.19 \pm 0.28	1.11 \pm 0.21
External Rotation	Dom	0.83 \pm 0.10	0.92 \pm 0.21	1.04 \pm 0.18
	Ndom	0.86 \pm 0.13	0.95 \pm 0.24	1.00 \pm 0.20

There were main effect differences between groups for hip adduction ($F(2, 31) = 6.156$, $p = 0.006$, $\eta^2 = 0.284$), hip flexion in sitting ($F(1, 31) = 12.042$, $p < 0.001$, $\eta^2 = 0.437$) and external rotation ($F(1, 31) = 3.755$, $p = 0.035$, $\eta^2 = 0.195$) when analysing the average of both limbs. Soccer athletes displayed significantly greater strength in hip adduction compared to ice hockey athletes ($p = 0.023$) and control participants ($p = 0.001$) (Figure 5.3). Ice hockey athletes displayed significantly less hip flexion in sitting strength compared to soccer athletes ($p = 0.021$) but significantly more compared to control participants ($p = 0.005$). Soccer athletes displayed significantly greater strength in hip flexion in sitting compared to control participants ($p < 0.001$). Ice hockey athletes displayed significantly less strength in external rotation when compared to control participants ($p = 0.010$) (Figure 5.3).

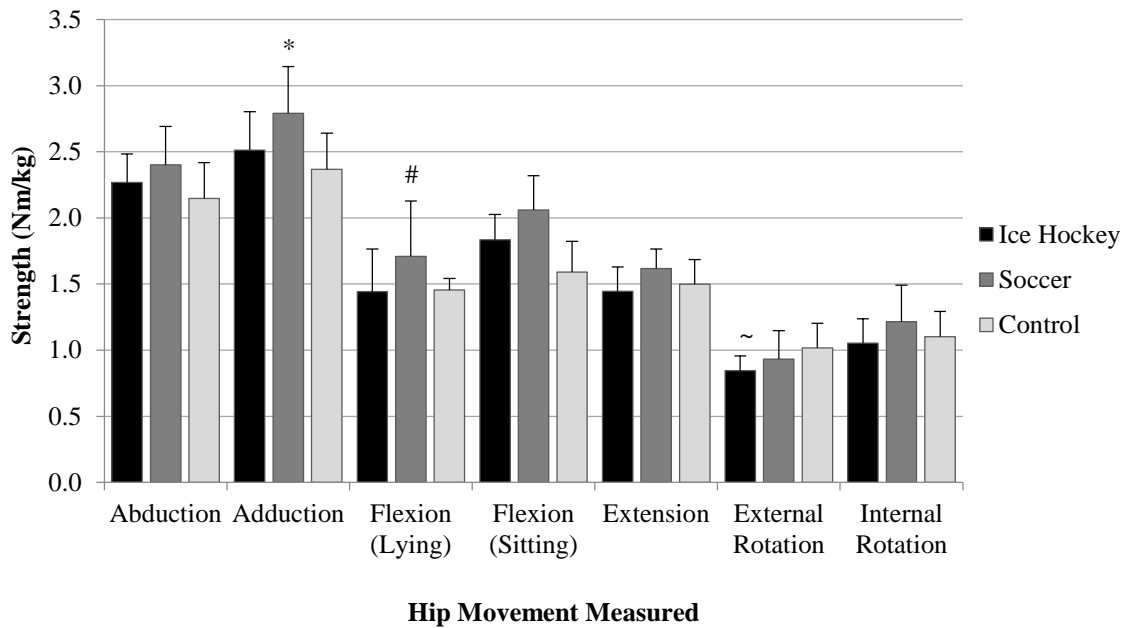


Figure 5.3 Mean and standard deviation strength differences between groups for both limbs combined

* Soccer athletes had significantly greater hip adduction than ice hockey athletes ($p = 0.023$) and control participants ($p = 0.001$). # Ice hockey athletes had significantly less hip flexion in sitting compared to soccer athletes ($p = 0.021$) but more than control participants ($p = 0.005$). # Soccer athletes displayed significantly more hip flexion in sitting compared to control participants ($p = 0.001$). ~ Ice hockey athletes had significantly less hip external rotation ($p = 0.010$)

No significant differences were observed between the Dom and Ndom limb between groups, however, there were main effect differences between the limbs of participants when all groups were combined. The Dom limb displayed greater strength in both abduction ($F(2, 31) = 4.608, p = 0.040, \eta^2 = 0.129$) and adduction ($F(2, 31) = 20.880, p < 0.001, \eta^2 = 0.402$) when analysing Dom vs. Ndom limbs regardless of group (Figure 5.4). There was a main effect difference for the adduction/abduction ratio between the limbs of all athletes, regardless of sport, with the Dom limb showing a higher ratio than the Ndom limb ($F(2, 31) = 5.255, p = 0.029, \eta^2 = 0.145$) (Figure 5.5). There were no other significant interactions between group and limb, nor main effect differences between limb or group for the variables measured.

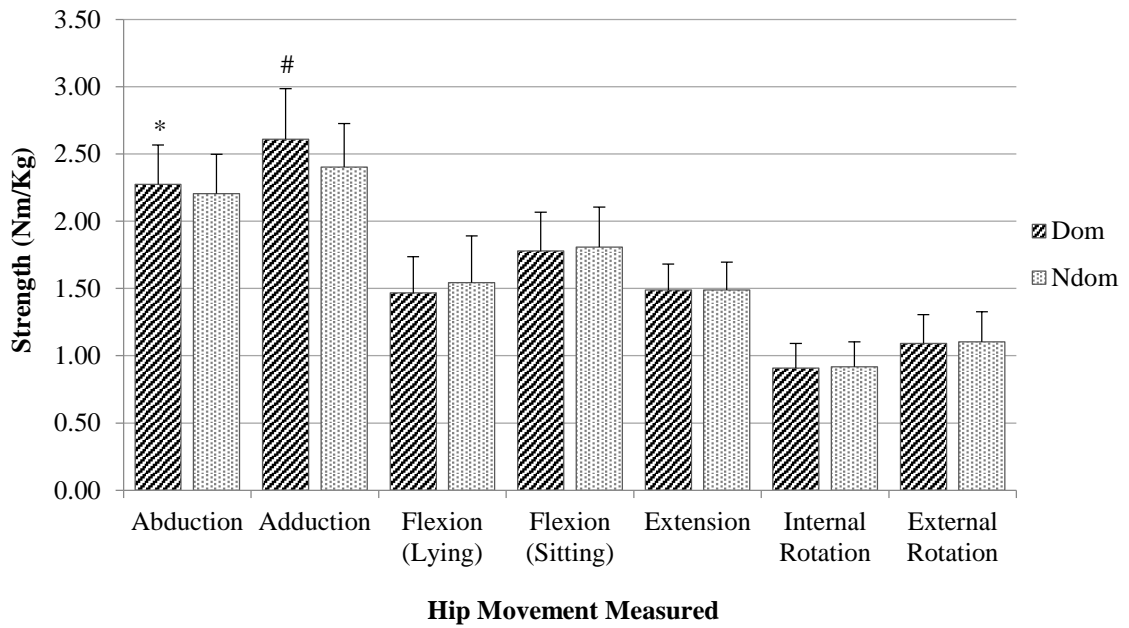


Figure 5.4 Mean and standard deviation strength differences between limbs for all groups combined

* The Dom limb displayed greater abduction strength compared to the Ndom limb ($p = 0.040$). # The Dom limb displayed greater adduction strength compared to the Ndom limb ($p < 0.001$)

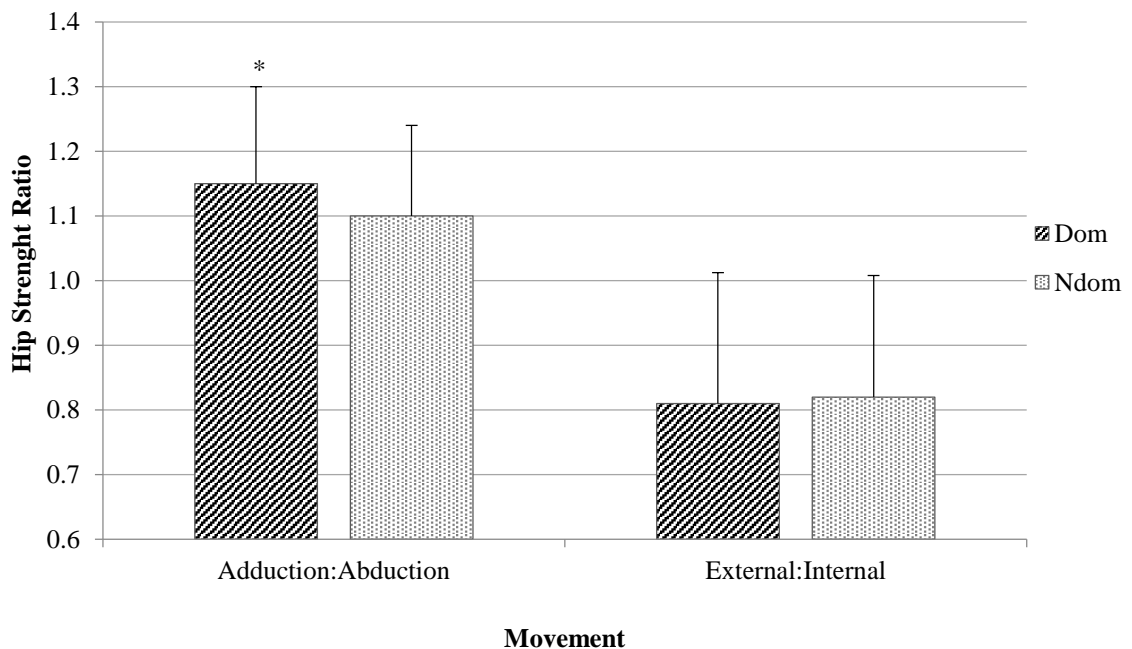


Figure 5.5 Mean and standard deviation strength ratio differences between Dom and Ndom limbs for adduction:abduction and external:internal rotation with all groups combined

* Dom limb showed significantly higher ratio than Ndom ($p = 0.029$)

5.3.3 Functional testing

Ice hockey athletes showed a greater percentage of positive FABER tests (Dom 56%, Ndom 75%) compared to soccer athletes (Dom 38%, Ndom 25%) on both limbs but less than control participants (Dom 82%, Ndom 55%) on the Dom limb (Figure 5.6). Ice hockey athletes displayed fewer positive Trendelenburg tests on the Dom limb compared to both soccer athletes and control participants (ice hockey 38%, soccer 63%, control 64%) but more than both groups on the Ndom limb (ice hockey 44%, soccer 38%, control 9%) (Figure 5.6). Control participants exhibited more positive Ober's tests than both ice hockey and soccer athletes (Figure 5.6).

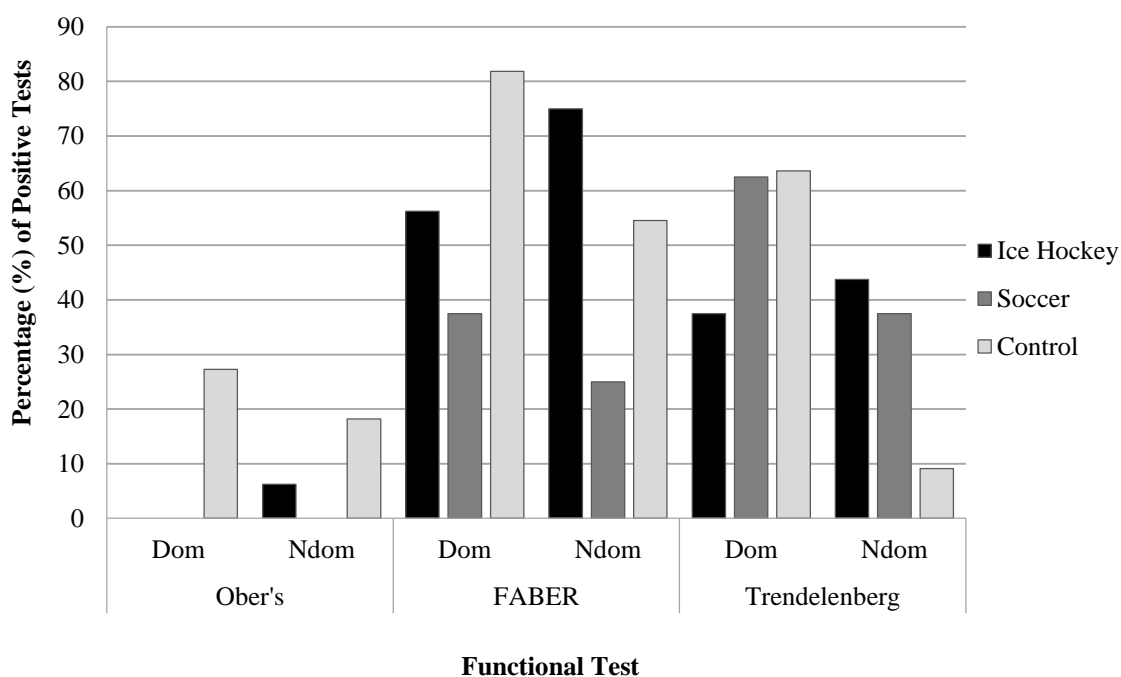


Figure 5.6 Total number of positive functional tests between ice hockey athletes, soccer athletes and control participants on both the Dom and Ndom limbs

5.4 Discussion

The purpose of this study was to compare the differences in ROM, strength and functional testing of the hip for both Dom and Ndom limbs in ice hockey athletes, soccer athletes

and control participants. A key outcome of this analysis was to determine why the ice hockey athletes' hip is possibly 'at risk' from non-contact injuries. The main findings were that ice hockey athletes displayed decreased strength overall compared to both soccer athletes and control participants in hip adduction, flexion in sitting and external rotation. A further finding was the Dom limb, when all participants were combined, exhibited greater strength in abduction, adduction and adduction:abduction strength ratio compared to the Ndom limb. Further findings were that ice hockey athletes displayed greater ROM in abduction and adduction but less ROM in hip flexion in lying and external rotation when compared to both soccer athletes and control participants. The Dom limb displayed greater ROM in hip flexion in sitting but less in flexion in lying and internal rotation when compared to the Ndom limb.

5.4.1 Strength

Tyler et al. (2001) displayed that ice hockey athletes who subsequently went on to sustain a hip injury had a decrease in pre injury hip adduction strength compared to athletes who did not sustain an injury. When this information is considered alongside the findings of the current study, that ice hockey athletes had a significant adduction strength deficit when compared to soccer athletes (Figure 5.3; ice hockey 2.51 Nm/kg vs. soccer 2.79 Nm/kg vs. control 2.37 Nm/kg), it may suggest that ice hockey athletes are at an increased risk of sustaining a non-contact hip injury. Although similarities between the work of Tyler et al. (2001) and the current study, particularly in hip adduction strength deficits, can be observed, direct comparisons are difficult to make due to the lack of injury data presented in the current study and the lack of strength measures reported by Tyler et al. (2001). Hip adduction weakness is also of particular importance as ice hockey athletes have previously been reported to be at a greater risk of injury with the existence of hip adductor weakness limiting the eccentric control needed for successful skating, along

with compromising stability throughout the skating pattern (Chang et al., 2009; Stull et al., 2011; Tyler et al., 2001). The knowledge that an ice hockey athlete who exhibits decreased hip adductor strength is at a greater risk of injury may hold interest for coaches, clinicians and trainers with an interest in performance enhancement and injury risk mitigation.

A further finding of the current study was that ice hockey athletes exhibited lower strength than soccer athletes in flexion in sitting (Figure 5.3; ice hockey 1.84 Nm/kg vs. soccer 2.06 Nm/kg) but more than control participants in the same movement (Figure 5.3; ice hockey 1.84 Nm/kg vs. control 1.59 Nm/kg). Although not significant ice hockey athletes also displayed lower strength in flexion in lying when compared to both soccer athletes and control participants (Figure 5.3; ice hockey 1.44 Nm/kg vs. soccer 1.71 Nm/kg vs. control 1.45 Nm/kg). This may be important because the hip flexors and adductors act as stabilisers during ice skating (Tyler et al., 2001), thus apparent weakness perhaps suggests some rationale for the incidence of non-contact hip musculature injuries in ice hockey. In comparison to the soccer specific literature this argument does seem to have merit. Studies such as those conducted by Askling et al. (2003) and Orchard et al. (1997) have reported that decreased knee flexor strength predisposes soccer athletes to hamstring muscle injury, theorising that this muscle has a role in stabilising the joint (Orchard et al., 1997). Conversely, it has also been previously displayed by Tyler et al. (2001) that there were no differences between injured and uninjured ice hockey athletes' flexion in sitting or lying strength which may suggest that hip musculature injury risk is dependent upon a pattern of muscle weakness across multiple movements within susceptible individuals.

A further finding of the current study was that ice hockey athletes displayed significantly weaker external rotation when compared to control participants, but not soccer athletes (Figure 5.3; ice hockey 0.84 Nm/kg vs. soccer 0.93 Nm/kg vs. control 1.02 Nm/kg). This

finding may have an impact upon non-contact injuries within ice hockey athletes due to the ice skating style employed. The ice hockey athlete's hip is repetitively loaded in a combination of external rotation and abduction during the explosive push off phase of the skating stride that has previously been linked to an increase of FAI injuries (Bizzini et al., 2007; Chang et al., 2009; Keogh & Batt, 2008; Philippon et al., 2010; Stull et al., 2011). Therefore, the demands of the ice hockey skating stride must be discussed in detail alongside the current study's findings to discern areas of possible causation for hip musculature injury.

During the skating stride in ice hockey the hip abductors, extensors and external rotators are the primary mobilisers whilst the hip flexors and adductors act predominantly as stabilisers of the hip joint and also act to decelerate the lower limb (Chang et al., 2009; Tyler et al., 2001). A weakness in strength of the above muscles in the ice hockey athlete compared to the soccer athlete (as seen in Figure 5.3) may therefore lead to an increased risk of injury due to the high strength required of the adductors when slowing the limb down across the hip, along with the high external forces placed upon the hip during the skating stride (Bizzini et al., 2007; Philippon et al., 2010; Tyler et al., 2001). Since higher calibre athletes generally achieve a faster skating speed whilst maintaining the same stride rate as lower calibre athletes (Upjohn et al., 2008), it may be assumed that the aforementioned loading patterns and forces are greater, meaning the strength deficit may be relative but also more damaging and pre-disposing to injury in high calibre ice hockey athletes. Indeed, work by Chang et al. (2009) and Stull et al. (2011) has suggested that increased skating speed is associated with higher eccentric muscle loading patterns and increased hip musculature injury rates. Additionally, increased skating speed is a desirable factor in ice hockey performance (Chang et al., 2009; Stull et al., 2011) which will likely be coached and practiced regularly, potentially further increasing predisposition to injury in athletes with strength deficit patterns due to the repetitive

nature and loading of ice skating. Although it can be suggested that weaknesses in strength may negatively affect the skating mechanics and therefore increase an athletes risk of sustaining a non-contact hip injury this has not been analysed within the current study and therefore can only be a speculative suggestion. Thus, further work to identify skating mechanics in athletes that go on to sustain a non-contact hip injury must be completed to solidify this suggestion.

The current study also demonstrated that the Ndom limb had a decreased adduction:abduction strength ratio compared to that of the Dom limb when all groups were combined (Figure 5.5; Dom 1.15 Nm/kg vs. Ndom 1.10 Nm/kg). Although the current study found that ice hockey athletes displayed greater strength in their adductors compared to their abductors (Figure 5.3 & 5.5), which contradicts the work of Tyler et al. (2001) who reported that professional ice hockey athletes had greater strength in their abductors compared to their adductors, it may be suggested that the Ndom limb is at a greater risk of injury due to the lower strength ratio observed. Tyler et al. (2001) found that ice hockey athletes who displayed a decreased adduction:abduction strength ratio were at a higher risk of sustaining a hip adductor injury when investigating injured versus uninjured ice hockey athletes suggesting that the same can be said of the Ndom limb within the current study. However, the study by Tyler et al. (2001) also reported no difference between the Dom and Ndom limb in athletes who went on to sustain a hip injury and although their work is suggestive that either limb is susceptible to injury, the current study suggests that the Ndom limb may be at an increased risk due to the decreased strength ratio seen in Figure 5.5. Unfortunately it was beyond the scope of the current study to analyse athletes who subsequently went on to sustain a hip injury due to difficulties in longitudinally tracking athletes once they left the medical support of the College team. Further research is necessary to investigate this further, particularly with respect to injury/re-injury risk. The current study also reported that the Dom limb had

significantly more strength in both abduction (Figure 5.4; Dom 2.28 Nm/kg vs. Ndom 2.20 Nm/kg) and adduction (Figure 5.4; Dom 2.61 Nm/kg vs. Ndom 2.40 Nm/kg) compared to the Ndom limb when all groups were combined. The lower abduction and adduction strength exhibited by the Ndom limb may further suggest that the Ndom is at a greater risk of injury due to such strength deficits (Figure 5.4).

5.4.2 Range of motion

With regard to ROM, ice hockey athletes displayed less flexion in lying (Figure 5.1; ice hockey 99.97° vs. soccer 107.25° vs. control 117.50°) and external rotation (Figure 5.1; ice hockey 28.97° vs. soccer 37.00° vs. control 45.55°) when compared to control participants and soccer athletes. The decrease in flexion in lying and external rotation displayed by ice hockey athletes may be important for injury risk as professional soccer athletes with decreased ROM have been shown to be more likely to sustain a muscular injury (Engebretsen, Myklebust, Holme, Engebretsen, & Bahr, 2010; Witvrouw et al., 2003). The findings of the current study, that ice hockey athletes have a decreased ROM in flexion in lying and external rotation (Figure 5.1), may imply they are at a greater risk of hip injury compared to soccer athletes as it has been noted that a decrease in general hip ROM leads to an increased risk of injury as performance of complex ice hockey skills, such as skating, is hindered (Quinney et al., 2008). This decrease in ROM of external rotation seen within ice hockey athletes may also begin to explain the increasing amount of FAI injuries observed in ice hockey (Bizzini et al., 2007; Keogh & Batt, 2008; Stull et al., 2011) as external rotation has been seen to decrease in athletes with FAI symptoms (Philippon, Maxwell, Johnston, Schenker, & Briggs, 2007b). A further finding of the current study was that ice hockey athletes displayed greater ROM in both abduction (ice hockey 44.59° vs. soccer 38.94° vs. control 32.18°) and adduction (ice hockey 27.19° vs. soccer 20.06° vs. control 20.91°) when compared to soccer athletes and control

participants (Figure 5.1). This observed increase in abduction and adduction ROM seen within ice hockey athletes may be attributable to the skating style employed, as it has previously been suggested that higher calibre ice skaters will achieve larger ROM within abduction permitting more successful forward propulsion and adduction enabling quicker recovery of the limb (De Koning et al., 1995; Upjohn et al., 2008). However, Upjohn et al. (2008) suggest that further work must be carried out upon the impact and extent to which the magnitude of abduction and adduction ROM the hip is subject to during the stance and propulsion phase of ice skating to fully understand the impact of the increases seen within Figure 5.1. However, as mentioned in section 5.4.1 the mechanics of skating have not been investigated within the current study and therefore this suggestion remains speculative.

All participants in the current study showed greater ROM in Dom hip flexion in sitting compared to the Ndom limb (Dom 40.43° vs. Ndom 38.37°), but conversely had less than the Ndom in flexion in lying (Dom 105.23° vs. Ndom 109.06°) and internal rotation (Dom 26.91° vs. Ndom 29.54°) (Figure 5.2). However, as previously mentioned measures of strength may be a greater determinant for injury as opposed to ROM alone and therefore both strength and ROM measures should be taken into account (Arnason et al., 2008; Askling et al., 2003; Baumhauer et al., 1995; Ekstrand & Gillquist, 1983; Mohammadi et al., 2013; Murphy et al., 2003; Söderman et al., 2001).

5.4.3 Functional testing

Figure 5.6 displays that ice hockey athletes had a greater percentage of positive FABER tests on both the Dom and Ndom limb (56% & 75% respectively) in comparison to soccer athletes (38% & 25% respectively) but not control participants (82% & 55% respectively) who exhibited a higher percentage of positive tests on the Dom limb. This finding, when

linked to the ice skating stride utilised by ice hockey athletes may explain the high number of positive tests as the ice hockey athlete is repetitively placing their hip into external rotation, abduction and flexion in the loading phase of the skating stride which increases the risk of sustaining a FAI injury due to those combinations of movements (Bizzini et al., 2007; Keogh & Batt, 2008; Philippon et al., 2010; Stull et al., 2011). The high number of positive FABER tests seen within both the control participants and ice hockey athletes in the current study may suggest they are at an increased risk of developing FAI with previous work indicating that a positive FABER test is potentially indicative of FAI within athletes (Martin et al., 2006b; Philippon et al., 2007a; Philippon et al., 2007b; Philippon et al., 2010). Ice hockey athletes displayed fewer positive Trendelenburg tests on the Dom limb compared to both soccer athletes and control participants (Figure 5.6; ice hockey 38%, soccer 63%, control 64%) but more than both groups on the Ndom limb (Figure 5.6; ice hockey 44%, soccer 38%, control 9%). This finding, that ice hockey athletes have fewer positive Trendelenburg tests on the Dom limb, is suggestive that both soccer and control participants have a weakness in hip abduction and therefore the potential to develop FAI injuries on their Dom limb compared to their Ndom limb as it has previously been described that a positive Trendelenburg test is often associated with the occurrence of FAI (Zebala, Schoenecker, & Clohisy, 2007). The difference observed between the amount of positive Trendelenburg tests in the Dom limb compared to the Ndom limb in both soccer and control participants may potentially be explained due to both populations having a strong preferred, or dominant, limb, which may not be experienced within ice hockey athletes. Soccer athletes in general will have a preferred kicking limb which will place differing demands upon their lower extremities, one such demand is that the Ndom limb is required to stabilise the body whilst the Dom limb kicks the ball (Brophy, Silvers, Gonzales, & Mandelbaum, 2010; Brophy, Backus, Pansy, Lyman, & Williams, 2007). This stability required from the Ndom limb whilst kicking a

ball may explain the low number of positive Trendelenburg tests seen in Figure 5.6 as the Ndom hip abductors may be more adapted to providing the hips and body with stability, which cannot be said of the Dom limb (Brophy et al., 2010; Brophy et al., 2007). A further finding was that control participants displayed a greater number of positive Ober's tests on both the Dom (Figure 5.6; ice hockey 0%, soccer 0%, control 27%) and the Ndom limb (Figure 5.6; ice hockey 6%, soccer 0%, control 18%). This larger number of positive Ober's tests within control participants may possibly be explained by the amount of specific sport training both the soccer and ice hockey athletes undertake, which may increase the amount of stretching of the iliotibial band, which may have a positive effect upon the tightness of their iliotibial band therefore presenting with a negative Ober's test (Herrington et al., 2006).

5.5 Conclusion

The findings of the current study suggest that ice hockey athletes may present an 'at risk' profile for non-contact hip injuries due to weaknesses in strength and ROM around the hip in comparison with soccer athletes and control participants. When discussed in relation to the specific demands of the ice hockey stride the results of this study give an insight to hip musculature injury causation which may aid in the recognition of ice hockey athletes who may benefit from strategies for injury prevention and performance enhancement. Future research should employ detailed biomechanical analysis of the loading of the hip in ice hockey, particularly in athletes who display an 'at risk' profile. High quality prospective studies are also required in this population to clarify the usefulness of the 'at risk' profile as a predictor of injury. Additionally, the efficacy of training and strength intervention studies aimed specifically at the hip of the ice hockey athlete should be investigated.

Chapter Six: Development of a Hip Injury Screen for Investigating Range of Motion, Strength and Functional Differences in Athletes with and Without Previous Injury

6.1 Introduction

Ice hockey athletes are often frequently injured as a result of both contact and non-contact injuries, with previous audits citing injury prevalence ranging from 4.7 injuries/1000 hours of ice hockey activity (Jørgensen & Schmidt-Olsen, 1986) to 10.22 injuries/1000 hours (McKnight et al., 1992), with the vast majority of these injuries being of a contact nature (Agel et al., 2007b; Flik et al., 2005; McKnight et al., 1992; Pettersson & Lorentzon, 1993; Pinto et al., 1999; Schick & Meeuwisse, 2003). As previously discussed in Chapter Four, many of these contact injuries are difficult to reduce in terms of incidence/severity without changing the rules of the game or equipment used, and as such these types of injuries are situations that medical teams do not have significant control over (Aubry et al., 2002; Benson et al., 2002). Therefore, it is imperative that an understanding of the frequently injured areas of the body under non-contact conditions is gained, as it may be possible to reduce the incidence/severity of these types of injuries.

Non-contact injuries of the hip have been identified as the most prevalent injury type and therefore potentially preventable within ice hockey athletes (Chapter Four). A notional suggestion as to the reasoning explaining the high number of non-contact hip injuries may be due to the nature of ice hockey and the skating pattern employed by high calibre athletes. The skating pattern involves loading of the hip in flexion, abduction and external rotation with constant repetitive loading of the joint, potentially bringing about pain, loss of ROM and strength deficits (Bizzini et al., 2007; Philippon et al., 2010). Therefore, an

athlete who presents with pain, weakness or a decrease in ROM of the hip may potentially be more susceptible to a non-contact hip injury.

As previously highlighted, the presence of a previous injury is also a major risk factor for subsequent re-injury for any athlete (Hewett et al., 2005a; Holder-Powell & Rutherford, 2000; Murphy et al., 2003). The existence of a previous injury alters the neuromuscular control of the previously injured joint placing the athlete at a greater risk of re-injury due to the compromised static and dynamic joint stabilisers (Hewett et al., 2005a; Murphy et al., 2003). Further to the reduced neuromuscular control and compromised joint stabilisers, the joint will also become more unstable having a decrease in proprioception, flexibility and muscular strength promoting the occurrence of a re-injury to the affected joint (Bahr & Holme, 2003; Bahr & Krosshaug, 2005; Murphy et al., 2003).

Although a major risk factor of injury occurrence is the presence of a previous injury to the joint, if rehabilitated correctly the joint should not be compromised with any instability or lack of muscular strength which can further expose it to a re-injury (Bahr et al., 1997; McKay et al., 2001). The risk of re-injury significantly increases when the previously injured joint exhibits other risk factors, such as joint instability, decreased ROM and decreased strength, due to poor rehabilitation of the previous injury (Bahr et al., 1997; McKay et al., 2001). In addition, it has been suggested that, not only is the re-occurrence of the previous injury problematic in terms of future performance but that the re-injury can also lead to an increase in absence compared to the initial injury (Le Gall et al., 2006). Furthermore, if an athlete has suffered from poor rehabilitation of a previous injury, for whatever reason, it is something that medical teams must also take into consideration in subsequent treatment regimens.

Creation of a screening protocol that not only highlights athletes who are at risk of injury due to weaknesses, loss of ROM or pain within the hip, but also allows medical teams to

highlight athletes who have suffered from an incomplete or unsuccessful rehabilitation process of a previous injury is of extreme importance in reducing the occurrence, or reoccurrence, of non-contact injuries of the hip. Additionally, an athlete who suffers from re-injury of a structure or joint may represent the beginning of a chronic problem which may become more problematic in terms of both performance and treatment. This study aimed to investigate the relationship between previous hip injury and strength, ROM and functional testing scores upon the sensitivity of the newly created hip screen. The newly created hip screen may help in identification of athletes who are ‘at risk’ of sustaining a hip injury due to weaknesses in strength, ROM and functional tests.

6.2 Methodology

6.2.1 Participants

Participant demographics are outlined in detail in Chapter Three (section 3.2; Table 3.1, page 73). All participants were recruited from Bethel University and were members of the ice hockey team and had been on the respective team for at least one season. Previously injured athletes had sustained a non-contact injury that resulted in pain within the hip that was currently considered, by the athlete, to be healed, pain and symptom free in their opinion.

6.2.2 Screening procedure

The detailed methodology for this study, including the screening procedure, has been outlined in Chapter Three (section 3.4, page 75 & 3.5, page 79). In brief, participants were divided into athletes who had received a previous non-contact hip injury and athletes who had no hip injury history. Four previously injured athletes sustained the injury to their Dom limb and four athletes sustained the previous injury to their Ndom limb.

Participants completed: 1.) ROM assessment (of hip adduction, flexion in sitting and lying, internal and external rotation), 2.) Strength assessment (of hip abduction, adduction and flexion in sitting and lying) and 3.) Functional testing involving Ober's test, FABER and Trendelenburg test. Individual assessment scores were calculated using the group's mean \pm SD as according to section 3.5 (page 79). In brief participants were given a score of one if they fell below the mean minus the SD for the group, two if they fell between the mean minus the SD and the mean plus the SD and given three if they scored above the mean plus the SD for all ROM and strength measures. Participants were given a score of zero if they experienced pain at any point during the tests. Functional testing was scored as one if the athlete displayed a positive test or pain and three if the athletes displayed a negative test and no pain. These scores were added together to give a total overall score for each participant.

6.2.3 Analysis

Data were analysed using SPSS version 19. A one way ANOVA was used to investigate interactions (group (injured/uninjured) x limb (Dom/Ndom)) and main effects (limb differences or group differences) for the ROM variables (adduction, flexion in sitting, flexion in lying, extension, internal rotation, external rotation) and for the strength variables (abduction, adduction, flexion in sitting, flexion in lying, extension, internal rotation and external rotation). Only significant findings are reported with their associated F values and effect size.

6.3 Results

6.3.1 Range of motion

ROM differences between previously injured and uninjured athletes for the Dom and Ndom limbs are shown in Table 6.1. Athletes who had not sustained a previous hip injury had significantly higher ROM on the Dom limb in internal rotation ($F(1, 26) = 9.928$, $p = 0.004$, $\text{Peta}^2 = 0.284$) and external rotation ($F(1, 26) = 5.196$, $p = 0.022$, $\text{Peta}^2 = 0.191$) compared to athletes who had sustained a previous hip injury, regardless of the previously injured limb dominance (Table 6.1). Athletes with no previous history of hip injuries displayed significantly greater ROM on the Ndom limb in flexion in sitting ($F(1, 26) = 5.193$, $p = 0.031$, $\text{Peta}^2 = 0.172$) and internal rotation ($F(1, 26) = 4.257$, $p = 0.050$, $\text{Peta}^2 = 0.145$) compared to athletes who had sustained a previous hip injury (Table 6.1). ROM scores for hip flexion in lying were higher in uninjured athletes compared to previously injured athletes, although this was not significant (Dom; 108.50° vs. 109.16° , $p = 0.821$, Ndom; 109.13° vs. 111.42° , $p = 0.549$). The uninjured athletes also displayed greater flexion in sitting on the Dom limb compared to previously injured athletes (32.00° vs. 36.63° respectively, $p = 0.194$) and external rotation of the Ndom limb (36.63° vs. 41.58° respectively, $p = 0.107$) (Table 6.1).

Table 6.1 ROM mean and standard deviation for previously injured (n = 8) and uninjured (n = 19) athletes for all hip movements

Hip ROM measured (°)	Limb Dominance	Previously injured (Mean ± SD)	Uninjured (Mean ± SD)
Adduction	Dom	24.00 ± 5.10	22.47 ± 4.91
	Ndom	21.25 ± 4.17	21.37 ± 4.68
Flexion in Lying	Dom	108.50 ± 8.14	109.16 ± 6.25
	Ndom	109.13 ± 9.16	111.42 ± 8.89
Flexion in Sitting	Dom	32.00 ± 4.93	36.63 ± 9.21
	Ndom	29.00 ± 8.30	36.16 ± 7.10 #
Internal Rotation	Dom	23.38 ± 6.30	30.84 ± 5.34 *
	Ndom	24.38 ± 6.93	30.11 ± 6.45 #
External Rotation	Dom	32.75 ± 7.29	39.26 ± 7.29 *
	Ndom	36.63 ± 5.73	41.58 ± 7.48

* Uninjured athletes displayed greater internal rotation (p = 0.004) and external rotation (p = 0.022).

Uninjured athletes displayed greater hip flexion in sitting (p = 0.031) and internal rotation (p = 0.050).

6.3.2 Range of motion in previously injured athletes

Athletes who had sustained the previous injury to the Dom limb showed a decrease in ROM scores compared to athletes who sustained the previous injury to the Ndom limb in flexion, sitting (p = 0.082) and lying (p = 0.253), internal (p = 0.716) and external rotation (p = 0.178), although these decreases were not significant (Table 6.2). Table 6.2 also highlights that the majority of previously injured athletes did not exhibit differences between their injured and uninjured limb regardless of the injured limb dominance.

Table 6.2 Comparison of ROM mean and standard deviation between athletes with previous injury to either the Dom limb (n = 4) or Ndom limb (n = 4)

Hip ROM measured (°)	Previously injured limb	Injured limb (Mean ± SD)	Uninjured limb (Mean ± SD)
Adduction	Dom	25.25 ± 3.51	19.75 ± 4.79
	Ndom	22.75 ± 3.40	23.50 ± 2.06
Flexion in Lying	Dom	104.25 ± 6.60	105.00 ± 6.60
	Ndom	113.25 ± 10.33	112.75 ± 7.93
Flexion in Sitting	Dom	30.75 ± 2.63	23.75 ± 3.30
	Ndom	34.25 ± 8.73	33.25 ± 6.75
Internal Rotation	Dom	22.25 ± 8.35	22.75 ± 9.52
	Ndom	26.00 ± 3.77	24.50 ± 4.43
External Rotation	Dom	34.75 ± 7.09	36.75 ± 8.06
	Ndom	36.50 ± 3.40	30.75 ± 7.93

6.3.3 Strength

Athletes who had not sustained a previous hip injury were significantly stronger on the Dom limb in abduction ($F(1, 26) = 7.295$, $p = 0.012$, $\eta^2 = 0.226$) and flexion in lying ($F(1, 26) = 8.457$, $p = 0.008$, $\eta^2 = 0.253$) compared to previously injured athletes (Table 6.3). Uninjured athletes had significantly greater strength on the Ndom limb in flexion in lying ($F(1, 26) = 16.325$, $p < 0.001$, $\eta^2 = 0.395$) compared to previously injured athletes (Table 6.3). Uninjured athletes were stronger than previously injured athletes across all other measures of hip strength: Abduction (Ndom; 2.05 Nm/kg vs. 1.83 Nm/kg respectively, $p = 0.072$), Adduction (Dom; 2.48 Nm/kg vs. 2.25 Nm/kg respectively, $p = 0.094$, Ndom; 2.31 Nm/kg vs. 2.08 Nm/kg respectively, $p = 0.105$) and flexion in sitting (Dom; 1.53 Nm/kg vs. 1.30 Nm/kg respectively, $p = 0.071$, Ndom; 1.55 Nm/kg vs. 1.27 Nm/kg respectively, $p = 0.078$) although these were not significant (Table 6.3).

Table 6.3 Mean and standard deviation strength between previously injured and uninjured athletes for all hip movements

Hip strength measured (Nm/kg)	Limb Dominance	Previously injured (Mean \pm SD)	Uninjured (Mean \pm SD)
Abduction	Dom	1.68 \pm 0.22	2.00 \pm 0.31 *
	Ndom	1.83 \pm 0.20	2.05 \pm 0.33
Adduction	Dom	2.25 \pm 0.23	2.48 \pm 0.28
	Ndom	2.08 \pm 0.28	2.31 \pm 0.33
Flexion in Lying	Dom	1.59 \pm 0.17	1.80 \pm 0.35 *
	Ndom	1.55 \pm 0.18	1.75 \pm 0.16 #
Flexion in Sitting	Dom	1.30 \pm 0.17	1.53 \pm 0.19
	Ndom	1.27 \pm 0.23	1.55 \pm 0.28

* Uninjured athletes displayed greater abduction ($p = 0.012$) and hip flexion in lying ($p = 0.008$). # Uninjured athletes displayed greater hip flexion in lying ($p < 0.001$).

6.3.4 Strength in previously injured athletes

Athletes with a previously injured Dom limb were weaker in flexion in lying in the injured limb compared to athletes with a previous Ndom injury ($F(1, 7) = 5.780$, $p = 0.053$, $Peta^2 = 0.289$) (Table 6.4). The uninjured limb of athletes with a previously injured Dom limb was weaker in hip abduction compared to the uninjured limb of athletes with a previously injured Ndom limb ($F(1, 7) = 12.790$, $p = 0.012$, $Peta^2 = 0.681$). Although not significant, athletes who had sustained the previous injury to the Dom limb showed decreased strength compared to athletes who had sustained the previous injury to the Ndom limb in flexion in sitting ($p = 0.168$) and abduction ($p = 0.633$) (Table 6.4).

Table 6.4 Mean and standard deviation strength differences between athletes with previous injury to either the Dom or Ndom limb

Hip strength measured (Nm/kg)	Previously injured limb	Injured limb (Mean ± SD)	Uninjured limb (Mean ± SD)
Abduction	Dom	1.58 ± 0.24	1.70 ± 0.12 [#]
	Ndom	1.96 ± 0.18	1.78 ± 0.17
Adduction	Dom	2.26 ± 0.21	2.04 ± 0.32
	Ndom	2.11 ± 0.28	2.25 ± 0.14
Flexion in Lying	Dom	1.22 ± 0.17 [*]	1.15 ± 0.16
	Ndom	1.40 ± 0.08	1.38 ± 0.13
Flexion in Sitting	Dom	1.54 ± 0.30	1.40 ± 0.23
	Ndom	1.69 ± 0.09	1.64 ± 0.16

* Athletes with a previously injured Dom limb displayed less strength in flexion in lying in the injured limb compared to athletes with a previous Ndom injury ($p = 0.053$). [#] The uninjured limb of athletes with a previously injured Dom limb displayed less strength of hip abduction compared to the uninjured limb of athletes with an previously injured Ndom limb ($p = 0.012$).

6.3.5 Functional testing

Figure 6.1 represents the percentage of positive functional tests seen within both injured and uninjured athletes on both the Dom and Ndom limbs. As can be seen in Figure 6.1, injured athletes had consistently higher percentages of positive tests on all functional tests. Percentages were higher on the Trendelenburg test for the Dom limb (Figure 6.1; previously injured 75% vs. uninjured 58%) compared to that of the Ndom limb (Figure 6.1; previously injured 50% vs. uninjured 5%) within both injured and uninjured athletes. However, the Ndom limb showed a higher percentage of positive Ober's tests (Figure 6.1; previously injured 75% vs. uninjured 68%) on the Ndom limb compared to the Dom limb (Figure 6.1; previously injured 13% vs. uninjured 5%) across both injured and uninjured athletes. Positive FABER tests were more common in the previously injured athletes compared to the uninjured athletes on both the Dom (Figure 6.1; previously injured 13% vs. uninjured 0%) and Ndom limbs (Figure 6.1; previously injured 13% vs. uninjured 5%).

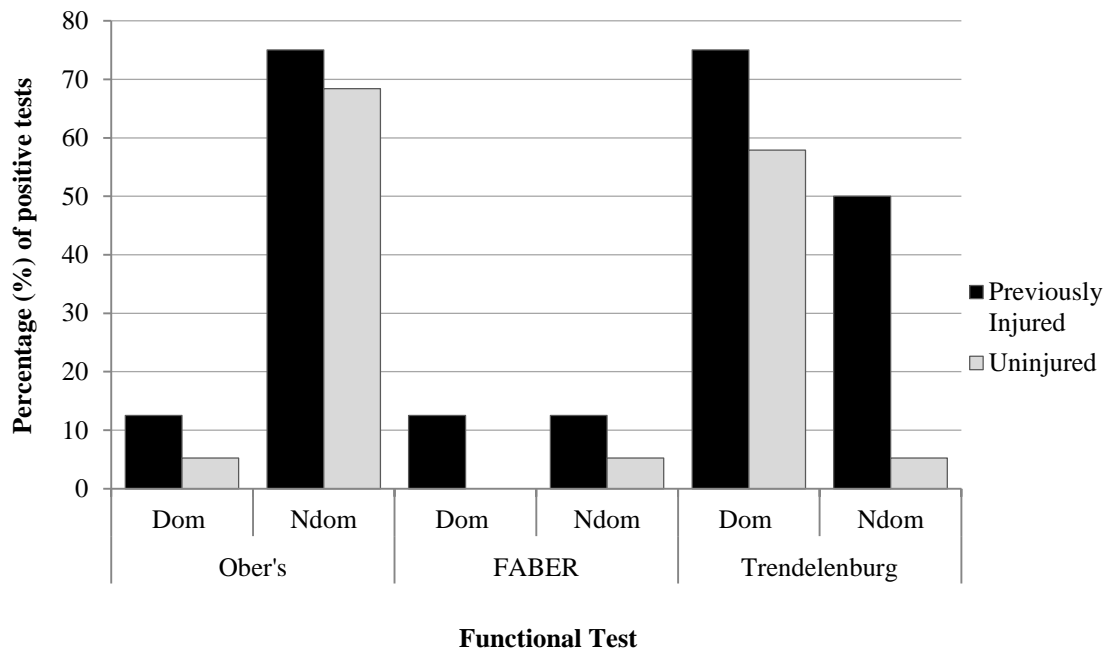


Figure 6.1 Positive functional tests as a percentage for both injured and uninjured athletes across the Dom and Ndom limb

6.3.6 Overall screen

Athletes who had not sustained a previous hip injury showed significantly higher overall screen scores than athletes who had sustained a previous hip injury (Figure 6.2; previously injured 42 vs. uninjured 51) ($F(1, 26) = 16.039, p < 0.001, \text{Peta}^2 = 0.391$) along with significantly higher strength screen scores (Figure 6.2; previously injured 17 vs. uninjured 21) ($F(1, 26) = 10.815, p = 0.003, \text{Peta}^2 = 0.302$), ROM screen scores (Figure 6.2; previously injured 18 vs. uninjured 20) ($F(1, 26) = 5.604, p = 0.026, \text{Peta}^2 = 0.183$) and functional test scores (Figure 6.2; previously injured 7 vs. uninjured 9) ($F(1, 26) = 4.198, p = 0.051, \text{Peta}^2 = 0.144$).

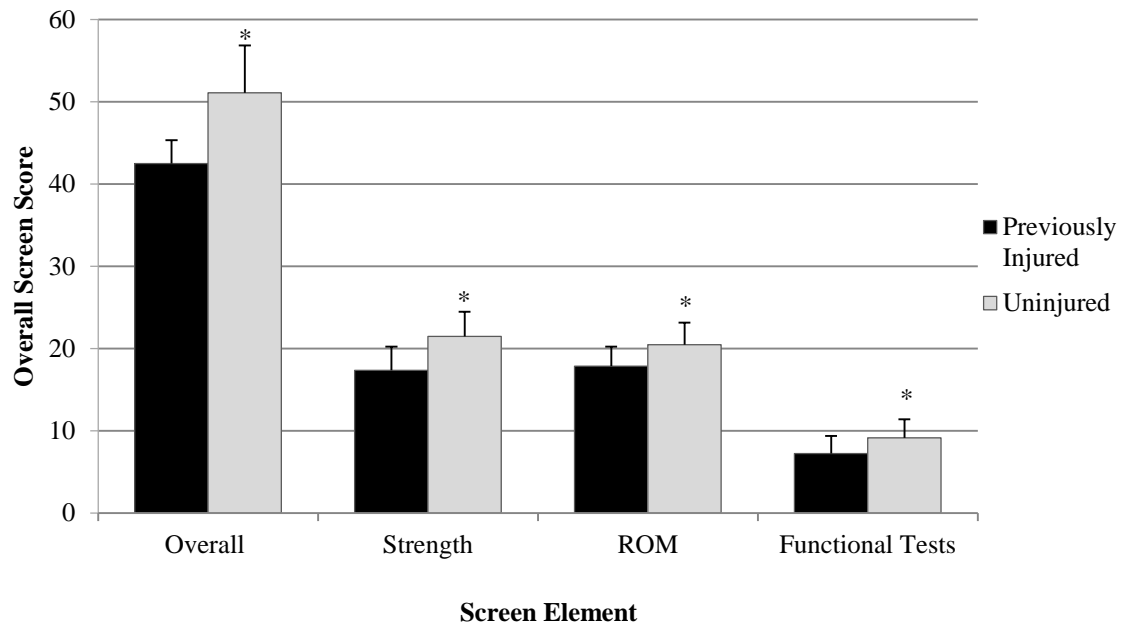


Figure 6.2 Overall screen score for athletes with a previous hip injury and uninjured athletes

* Uninjured athletes displayed greater overall screen score ($p < 0.001$), strength screen score ($p = 0.003$), ROM screen score ($p = 0.026$) and functional test score ($p = 0.051$).

6.4 Discussion

The current study aimed to investigate the effect of previous hip injury upon the sensitivity of a newly created hip screen potentially aiding the identification of athletes who are ‘at risk’ of sustaining a hip injury due to weaknesses in strength, ROM and functional tests and therefore a lower screen score. The current study also investigated the relationship between previous hip injury and strength, ROM, functional and overall screen scores around the hip. The main findings were that uninjured athletes presented higher scores for all strength and ROM measures (excluding Dom adduction) than athletes who had suffered from a previous hip injury (Tables 6.1 and 6.3). A further finding was that the overall screen, strength, ROM and functional test scores were significantly higher in the uninjured athletes compared to the previously injured athletes (Figure 6.2).

6.4.1 Range of motion

The findings of the current study provide evidence that uninjured athletes have significantly greater ROM in hip internal rotation (uninjured 30.84° vs. previously injured 23.38°, $p = 0.004$) and external rotation (uninjured 39.26° vs. previously injured 32.75°, $p = 0.022$) (Table 6.1) both on the Dom limb and significantly greater flexion in sitting (uninjured 36.16° vs. previously injured 29.00°, $p = 0.031$) and internal rotation (uninjured 30.11° vs. previously injured 24.38° $p = 0.050$) (Table 6.1) on the Ndom limb. This finding suggests that a previous injury will therefore further increase the risk of sustaining a future injury due to the lack of ROM, which is in agreement with previous literature by Holder-Powell and Rutherford (2000) who demonstrated that healthy participants who had sustained a lower limb injury in the past displayed significantly worse balance scores on their injured limb compared to their uninjured limb. Additionally, Hewett et al. (2005a) present that female soccer, basketball and volleyball athletes who went on to sustain an ACL injury displayed significantly worse knee posture and loading during a drop jump compared to uninjured athletes. Although both Holder-Powell and Rutherford (2000) and Hewett et al. (2005a) investigated the balance and landing strategies upon injury or previous injury, links can be made to the current study as athletes who display lower ROM around the hip are more likely to need to change their balance strategies, therefore, increasing their risk of injury. These findings suggest that the tools utilised within the current study are sensitive enough to highlight athletes who have sustained a previous injury but also to potentially identify those ‘at risk’ of sustaining an injury in the future. The general decrease in ROM around the hip seen within athletes who had previously sustained a hip injury compared to uninjured athletes (Table 6.1) may be explained due to the presence of scar tissue inhibiting the normal function of the muscle, particularly the method in which the tendon glides, reducing the ROM displayed in the previously injured limb (Heiderscheit, Sherry, Silder, Chumanov,

& Thelen, 2010; Lin, Cardenas, & Soslowsky, 2004). Philippon et al. (2007) discuss how high level athletes, such as those within the current study, are intrinsically motivated to return to sport quicker and therefore risk further complications, or injury, due to this motivation. This speed in return to play may be a potential explanation for the decrease in ROM seen within previously injured athletes.

Although non-significant the current study also found that athletes who sustained the previous injury to their Dom limb displayed lower scores for ROM of the previously injured limb in flexion, both sitting (previous Dom injury 30.75° vs. previous Ndom injury 34.25°) and lying (previous Dom injury 104.25° vs. previous Ndom injury 113.25°), internal rotation (previous Dom injury 22.25° vs. previous Ndom injury 26.00°) and external rotation (previous Dom injury 34.75° vs. previous Ndom injury 36.50°) (Table 6.2). This finding, that athletes who sustained a previous injury to the Dom limb had decreased ROM compared to athletes who sustained the injury to the Ndom limb, suggests that athletes who have sustained a previous injury to their Dom limb are potentially at a further risk of injury due to the decreased ROM seen within the current study. However, when analysing the previously injured to uninjured limb across previously injured athletes it becomes clear that there are no significant differences between the two suggesting that athletes with weakness in ROM around the hip are at a greater risk of injury on both their uninjured and previously injured limb (Table 6.2).

6.4.2 Strength

Strength measures of uninjured athletes were significantly stronger in abduction (uninjured 2.00 Nm/kg vs. previously injured 1.68 Nm/kg, $p = 0.012$) and flexion in lying (uninjured 1.53 Nm/kg vs. previously injured 1.30 Nm/kg, $p = 0.008$) (Table 6.3) for the Dom limb. It was also observed that uninjured athletes were significantly stronger in

flexion in lying (uninjured 1.56 Nm/kg vs. previously injured 1.27 Nm/kg, $p < 0.001$) on the Ndom limb (Table 6.3). This finding, that uninjured athletes were stronger than previously injured athletes, was confirmed by Tyler et al. (2001) who found that eight, of a total 47 NHL ice hockey athletes, went on to subsequently sustain a hip injury and had pre-injury hip adduction strength 18% lower than athletes who did not sustain an injury. This observation that athletes who went on to sustain a hip adductor injury displayed weaker strength is suggestive that the athletes within the current study who exhibited lower strength scores are potentially at an increased risk of injury, although this was not measured within the current study.

A further finding of note was that hip flexion strength in lying on both limbs was greater in the uninjured group compared to the injured group (Table 6.3). The strength deficit seen by previously injured athletes potentially increases their risk of a further injury, due to the hip flexors being a major stabiliser of the hip joint during skating, making a deficit of strength in this area a risk for athletes due to the high load placed through the limb (Bizzini et al., 2007; Philippon et al., 2010; Tyler et al., 2001). Although a weakness in strength may be highlighted as a risk area and potential problem for re-injury, comparison of the current studies finding that hip flexion in previously injured athletes was weaker than uninjured athletes cannot be made to previous work by Tyler et al. (2001) as they did not find sufficient athletes who sustained a hip flexor injury.

However, there is currently a large amount of research surrounding the role that muscular strength plays in the prevention of injury (Baumhauer et al., 1995; Blackburn et al., 2000; Ekstrand & Gillquist, 1983; Murphy et al., 2003; Söderman et al., 2001) and as can be seen in Table 6.3 the uninjured athletes were stronger in every hip movement on both the Dom and Ndom limb compared to the previous injured group. This finding, that uninjured athletes were stronger than previously injured athletes, is in agreement with similar

studies (Baumhauer et al., 1995; Blackburn et al., 2000; Ekstrand & Gillquist, 1983; Murphy et al., 2003; Söderman et al., 2001) that suggest that athletes with higher strength scores are at a decreased risk of sustaining a non-contact injury due to the strength needed to successfully control and stabilise a joint during sporting movements.

The current study also displays that athletes who had sustained a previous injury to the Dom limb exhibited less strength in flexion in lying on the injured limb compared to athletes with a previous Ndom injury (previous Dom injury 1.22 Nm/kg vs. previous Ndom injury 1.40 Nm/kg, $p = 0.053$) (Table 6.4). Although not significant the current study also found that athletes who sustained the previous injury to their Dom limb displayed lower scores for strength of the injured limb in flexion in sitting (previous Dom injury 1.54 Nm/kg vs. previous Ndom injury 1.69 Nm/kg) and abduction (previous Dom injury 1.58 Nm/kg vs. previous Ndom injury 1.96 Nm/kg) (Table 6.4). Although comparisons to previous studies are difficult to make this finding is consistent with that of Holder-Powell and Rutherford (2000) who, as previously mentioned, found athletes with a previous Dom injury had significantly lower balances scores than participants with a Ndom injury. This finding suggests that athletes who have sustained a previous injury to the Dom limb are at a greater risk of re-injury and therefore, may need to be monitored more closely.

6.4.3 Functional testing

The percentage of positive responses of previously injured athletes on the Ober's tests are consistently higher than those presented for uninjured athletes (Figure 6.1; previously injured; Dom 12.5%, Ndom 75.0%, uninjured; Dom 5.3%, Ndom 68.4%). In a study of 53 female NCAA field hockey, soccer and basketball athletes Devan, Pescatello, Faghri, and Anderson (2004) found that a positive Ober's test did not predict future knee injury

in the athletes over the course of one season. However, Devan et al. (2004) did find that athletes who exhibited a positive Ober's test had a significantly lower concentric hamstring to quadriceps (H:Q) muscle ratio which has been previously reported to increase an athlete's risk of injury (Croisier et al., 2008; Orchard et al., 1997). Although Orchard et al. (1997); Devan et al. (2004) and Croisier et al. (2008) report that a decrease in H:Q ratio to be associated with athletes who go on to sustain an injury many other authors present no significant decrease in H:Q ratios following injury (Bennell et al., 1998; Brockett, Morgan, & Proske, 2004; Croisier, Forthomme, Namurois, Vanderthommen, & Crielaard, 2002). While previous research is inconclusive it does suggest that a muscle imbalance associated with positive functional tests creates a potential risk of injury for athletes (Bennell et al., 1998; Brockett et al., 2004; Croisier et al., 2002; Croisier et al., 2008; Orchard et al., 1997). Interestingly the Ndom limb (Figure 6.1; previously injured 75%, uninjured 68%) displayed a much higher percentage of positive Ober's tests compared to the Dom limb (Figure 6.1; previously injured 13%, uninjured 5%) in both previously injured and uninjured athletes which is suggestive that the Ndom limb may be at an increased risk of injury due to the weakness/tightness of the iliotibial band.

Positive FABER tests displayed similar results to those found using Ober's test in that previously injured athletes had a higher percentage of positive tests (Figure 6.1; Dom 13%, Ndom 13%) compared to uninjured athletes (Figure 6.1; Dom 0%, Ndom 5%). Although the results are lower than that found with Ober's test, previous work suggests that the presence of a positive FABER test is indicative of FAI injuries due to the combination of abduction and external rotation within the test (Martin et al., 2006b; Philippon et al., 2007a; Philippon et al., 2007b). This combination of abduction and external rotation is a common cause of FAI injuries and coupled with the mechanics of ice skating, discussed previously (sections 2.3.2, page 30 & 2.4.4, page 41), further

exposes the athletes to the combination of movements suggesting that the previously injured athletes are at a greater risk of sustaining a hip injury (Bizzini et al., 2007; Keogh & Batt, 2008; Philippon et al., 2010; Stull et al., 2011).

The positive Trendelenburg test has previously been reported to denote a weakness or lack of function within the hip abductors (Hardcastle & Nade, 1985; Trendelenburg, 1998) with the results of the current study suggesting that injured athletes suffer from such a weakness, or lack of function, following injury with previously injured athletes displaying a higher percentage of positive tests (Figure 6.1; Dom 75%, Ndom 50%) compared to uninjured athletes (Figure 6.1; Dom 57.9%, Ndom 5.3%). This higher proportion of positive tests is indicative that athletes who have sustained a previous injury suffer from a decrease in strength, or function, compared to uninjured athletes making them potentially at a greater risk of re-injury or future injury. As previously stated within section 2.4.4 (page 41) the hip abductors are important in mobility in ice hockey athletes with their primary role being mobilisation during ice skating (Tyler et al., 2001). Therefore, a weakness of these muscles may cause an increased risk of injury due to the high forces transmitted by the hip abductors and the repetitive nature of ice skating (De Koning et al., 1995; Tyler et al., 2001; Upjohn et al., 2008).

6.4.4 Overall screen

The overall screen score of athletes was significantly higher in uninjured athletes compared to athletes who had previously received a hip injury (Figure 6.2; uninjured 51 vs. previously injured 42, $p < 0.001$), indicating that the screen created within the current study was sensitive enough to highlight athletes who have not only sustained a previous hip injury but also the athletes who may be at an increased risk of injury due to accumulation of weaknesses tested within the screen. The current study also presented

that the strength screen score (Figure 6.2; uninjured = 21 vs. previously injured = 17, $p = 0.003$), ROM screen score (Figure 6.2; uninjured = 20 vs. previously injured = 18, $p = 0.026$) and functional testing score (uninjured = 9 vs. previously injured = 7, $p = 0.051$) were all significantly higher in previously injured athletes compared to uninjured athletes suggesting that the screen highlights those athletes who have the presence of a previous injury or potentially those 'at risk' of sustaining a non-contact hip injury due to the athletes poor performance of the screen elements, however this was not measured within the current study. The findings of the current study and Kiesel et al. (2007) are similar as they reported that the FMS successfully highlighted professional American Football athletes who went on to sustain an injury with those athletes presenting lower scores than athletes who did not sustain an injury (Kiesel et al., 2007). However, the study by Kiesel et al. (2007) classed an injured athlete as one who had been injured for three weeks or more potentially missing many injured athletes. Although the current study investigated the effects of a previous injury and Kiesel et al. (2007) investigated participants who went on to sustain an injury both agree that athletes with a lower score are potentially at a greater risk of injury or re-injury. Peate et al. (2007) investigated the effects of previous injury upon the FMS score of 433 fire fighters presenting that uninjured fire fighters scored significantly higher than those who had sustained a previous injury confirming the findings of the current study. It must, however, be noted that the FMS utilised by Kiesel et al. (2007) and Peate et al. (2007) is a more functional movement assessment as opposed to the current study which analysed more basic movements. The findings of current study highlight the importance of correct rehabilitation of previous injuries to minimise any weaknesses an athlete exhibits and although it is unlikely that anything can be done about the treatment received retrospectively, the screening protocol within the current study may present evidence that previously injured athletes are still seen as 'at risk' due to the low scores provided within the screen. Thus making a medical

teams return to play procedures more robust and effective (Bahr et al., 1997; McKay et al., 2001).

A limitation of this study was the small previously injured participant size ($n = 8$), whereby an increase in injured participants may have brought about greater power and statistical significance. Another consideration would have been to use a psychological assessment investigating if the athlete believed the injury was healed correctly and completely to gain an understanding of how the athlete views the injury and their own body. Due to the small participant numbers, a further limitation was that all injuries were grouped together without consideration of severity or number of injuries/re-injuries and this may have had an impact upon the data. Potentially the largest limitation of the current study was the lack of longitudinal tracking of athletes following the screening procedures. This longitudinal tracking would have allowed the success of the screen to be assessed if those athletes that scored lower on the screen did indeed go onto suffer a hip injury/re-injury. This would also allow the screen to be more accurate in terms of highlighting those athletes classed as 'at risk' giving larger clinical relevance to medical teams.

6.5 Conclusion

The findings of the current study suggest that ice hockey athletes who have sustained a previous hip injury are at an increased risk of injury/re-injury compared to athletes who have not sustained a hip injury due to decreased ROM and strength measures of the hip. The creation of the hip screen within the current chapter allows coaches and medical teams to highlight athletes who are potentially 'at risk' of a non-contact hip injury and also assess those who have suffered a previous injury and who may still be impeded due to the injury. Future research should investigate the implementation of an intervention

programme for athletes who have been highlighted as 'at risk' with the aim of lowering their risk of sustaining a non-contact hip injury.

Chapter Seven: Determining the Intra and Inter-Tester Reliability of the Hip Injury Screen

7.1 Introduction

Clinical screening should be sufficiently reliable and reproducible to allow clinicians to make evidence based conclusions and meaningful observations in athletes/clinical populations. It is important that screening procedures are able to differentiate between a measurements actual score (minus testing error) and error score (including testing error) in various populations to allow interpretation to be accurate (Baumgartner, 1989). Establishing intra and inter-tester measures allows clinicians/researchers to systematically discriminate if an athlete has benefited from an intervention programme or the increases seen are a product of systematic or random error associated with the procedures (Atkinson & Nevill, 1998). Page (2014) stated that statistically significant differences between measures may not always represent an appropriate change within clinical settings with the correct interpretation essential to allow clinicians to make informed, clinically useful decisions. Whilst most research focuses upon significant differences, clinical research should instead focus upon the potential of clinically significant changes to correctly interpret results (Page, 2014). Therefore, the measure of smallest worthwhile change (SWC) has been suggested to be a useful measure of change (either positive or negative) in measures of equally matched groups of participants (Hopkins, Hawley, & Burke, 1999). To correctly analyse clinical SWC using the units of measurements for specific clinical tests it has been suggested that clinicians should use the spread of the raw data scores of the cohort by multiplying the between-participant SD by an arbitrary 0.2 (Cohen, 1977).

Although SWC is a useful measure, showing the smallest value of a potential clinically worthwhile change, it has been suggested a more robust measure may be the minimum criterion change (MCC) which is the sum of the coefficient of variation (CV) as a percentage (CV%) and the SWC showing the smallest value of change including measurement error (Kempton, Sirotic, & Coutts, 2013). This allows changes in values above the MCC to be seen as a causation of the intervention as opposed to random error, either in the testing or statistically (Kempton et al., 2013). Therefore, changes larger than the SWC figure suggest the change is worthwhile with figures above the MCC suggesting a probable significant change has been seen due to the intervention programme as opposed to any increase or decrease due to the measurement error associated with the testing procedures. This is useful because it allows researchers/clinicians to see that athletes have improved in measures with high certainty that the change seen is due to the intervention as opposed to any error, regardless of the potential lack of significance that may occur with traditional statistics.

Along with SWCs and MCCs, the effect size or typical error is important to report within clinical studies allowing an understanding of the magnitude of the difference in results between groups, with larger effect or error scores representing a larger difference between groups. As well as giving effect size it is important to report the confidence intervals (CI) within results, these CIs are useful within clinical testing as they focus upon the confidence that an outcome will be probable in future testing showing the level of confidence that the true value in a population is within the intervals (Page, 2014).

Seemingly, the use of such statistical methodology during ROM and strength measures may provide clinicians with accurate estimations of increases seen within athletes during an intervention or other measure that are potentially more useful than normal significance statistics. Therefore, this study aimed to investigate the reliability of intra and inter-tester

measures of ROM, strength and the overall hip screen aiming to ensure the measurements gained within the hip screen are repeatable between differing testers.

7.2 Methodology

7.2.1 Participants

Participant demographics are outlined in detail in Chapter Three (section 3.2; Table 3.1, page 73). All nine participants recruited from the University of Hull were apparently healthy and were not single sport athletes.

7.2.2 General procedures

The procedure for this study has been outlined fully within Chapter Three (section 3.6, page 80). Briefly, participants completed the hip screen protocol outlined within section 3.5 (page 79). To test intra and inter-tester reliability, the screening procedure was completed three times during one week with a minimum of 48 hours between testing. Each testing day participants completed the screening procedure twice, once with tester one and once with tester two, alternating which tester they began with throughout testing to randomise the order of testing to try to avoid the occurrence of bias.

7.2.3 Analysis

All intra and inter-tester differences for the ROM, strength and overall screen score were assessed for normality by the Shapiro-Wilk test (Razali & Wah, 2011) using SPSS Statistics 19. All data were presented as the mean \pm SD. CV were calculated using \log_{10} transformed data by dividing the SD of the differences between the participants results collected in session one and session two by the square root of two, then dividing the result by the grand mean of session one and session two. The same method was also completed

investigating session two and three. The calculations were performed using a customised spreadsheet (Hopkins, 2000) and the results are reported as a percentage. Magnitude of ICCs were described as trivial ($ICC < 0.1$), small ($0.1 < ICC < 0.3$), moderate ($0.3 < ICC < 0.5$), large ($0.5 < ICC < 0.7$), very large ($0.7 < ICC < 0.9$), nearly perfect ($ICC > 0.9$) and perfect ($ICC = 1$) (Hopkins, Marshall, Batterham, & Hanin, 2009). The CV% was multiplied by an arbitrary 0.2 to determine a relative smallest worthwhile percentage change ($SWC\%^{relative}$) (Hopkins et al., 2009; Kempton et al., 2013). The sum of CV% and SWC% was used to establish a relative percentage minimum criterion change ($MCC\%^{relative}$) required to elicit a probable significant change in either ROM, strength or the overall screen scores (Kempton et al., 2013). To establish an absolute smallest worthwhile change ($SWC^{absolute}$), the between participant SD was multiplied by an arbitrary 0.2 (Hopkins et al., 2009; Kempton et al., 2013) and added to the typical error to produce the minimum absolute criterion change ($MCC^{absolute}$) required to elicit a probable significant change in ROM, strength or the overall screen score (Kempton et al., 2013). $SWC^{absolute}$ and $MCC^{absolute}$ were calculated to give specific values relative to the units of measurement given in strength, ROM and the overall screen. $SWC\%^{relative}$ and $MCC\%^{relative}$ were calculated to give relative percentage increases in ROM, strength and the overall screen.

For the purposes of data analysis all ROM and strength measures were collated and a mean score for both tester one and two were created allowing comparison between visits and testers as a whole as opposed to individual measures. Using the screening procedure scoring previously outlined (section 3.5, page 79) participants were given an overall screen score, averaged across the three visits, to allow comparison in intra and inter-tester reliability.

7.3 Results

7.3.1 Intra-tester reliability

Intra-tester reliability for strength, ROM and overall screen score are shown in Table 7.1. Intra-tester reliability was high for both strength and overall screen score with results varying between large (ICC between 0.5-0.7) and near perfect (ICC > 0.9) for both tester one and tester two. ROM scores were not as high for either tester one or tester two ranging between moderate (ICC between 0.3-0.5) for tester one to very large (ICC between 0.7-0.9) for tester two.

Table 7.1. Mean and standard deviation of intra-tester reliability statistics across three trials for both tester one and tester two

	Tester 1			Tester 2		
	ROM (°)	Strength (Nm/kg)	Overall Screen Score	ROM (°)	Strength (Nm/kg)	Overall Screen Score
Visit 1 mean ± SD	50.89 ± 6.33	1.85 ± 0.33	48.25 ± 4.65	53.08 ± 8.24	1.93 ± 0.46	49.38 ± 6.09
Visit 2 mean ± SD	49.24 ± 6.38	1.82 ± 0.30	48.71 ± 5.19	55.55 ± 8.04	1.92 ± 0.43	47.71 ± 6.10
Visit 3 mean ± SD	49.00 ± 5.93	1.80 ± 0.30	46.11 ± 4.65	54.92 ± 7.63	1.94 ± 0.36	47.33 ± 5.94
ICC visit 1-2 (CI)	0.49 (-0.05 - 0.92)	0.80 (0.30 - 0.96)	0.76 (-0.03 - 0.96)	0.64 (-0.05 - 0.87)	0.89 (0.49 - 0.98)	0.91 (0.48 - 0.99)
ICC Descriptor visit 1-2	Moderate	Very large	Very large	Large	Very large	Near Perfect
ICC visit 2-3 (CI)	0.47 (-0.35 - 0.93)	0.70 (-0.01 - 0.94)	0.68 (0.00 - 0.92)	0.70 (-0.06 - 0.96)	0.88 (0.40 - 0.98)	0.85 (0.42 - 0.97)
ICC Descriptor visit 2-3	Moderate	Very large	Large	Very large	Very large	Very large
Mean Change % (CI) visit 1-2	-3.10 (-14.32 - 10.44)	-1.68 (-9.59 - 7.11)	0.25 (-6.34 - 7.30)	4.20 (-8.53 - 19.70)	0.31 (-7.77 - 9.57)	-4.27 (-9.00 - 0.89)
Typical error % as CV (CI) visit 1-2	12.45 (8.90 - 28.14)	8.17 (5.68 - 17.02)	-5.49 (-10.94 - 0.62)	12.23 (8.52 - 29.87)	6.96 (4.62 - 17.28)	4.02 (2.63 - 9.27)
Mean Change % (CI) visit 2-3	1.40 (-12.44 - 19.58)	-1.12 (-11.84 - 11.35)	5.78 (3.98 - 11.70)	-2.67 (-14.31 - 11.56)	-1.21 (-9.33 - 8.01)	-5.00 (-9.47 - 0.05)
Typical error % as CV (CI) visit 2-3	10.82 (7.03-33.15)	9.44 (6.31 - 23.93)	5.96 (4.11 - 12.09)	9.35 (6.69 - 26.79)	6.99 (4.64 - 16.99)	4.66 (3.20 - 9.34)
SWC ^{absolute}	1.10	0.03	0.83	1.02	0.04	0.56
MCC ^{absolute}	5.11	0.18	3.78	5.13	0.17	2.53
SWC ^{%relative}	3.59	3.84	2.00	4.88	5.45	2.74
MCC ^{%relative}	16.04	11.88	7.96	15.43	12.41	6.77

Abbreviations: Coefficient of variation (CV), Confidence intervals (CI), Intra-class correlation coefficients (ICC), Minimum criterion change (MCC), Range of Motion (ROM), Smallest worthwhile change (SWC), Standard deviation (SD).

7.3.2 Inter-tester reliability

Results from both testers one and two are consistent when assessing the reliability of their repeated measurements across the three trials (Table 7.1). Both testers were reliable when compared to one another with ROM, strength and the overall screen score scoring very large on the ICC descriptor (Table 7.2).

Table 7.2. Mean and standard deviation of inter-tester reliability between tester one and two with all three trials combined

	ROM (°)	Strength (Nm/kg)	Overall Screen Score
Tester 1 mean ± SD	49.40 ± 3.91	1.67 ± 0.19	48.02 ± 4.89
Tester 2 mean ± SD	54.57 ± 5.75	1.81 ± 0.25	48.28 ± 5.87
ICC (CI)	0.71 (0.12 - 0.93)	0.77 (0.18 – 0.95)	0.81 (0.31 – 0.96)
ICC Descriptor	Very large	Very large	Very large
Mean Change % (CI)	10.29 (5.12 – 17.03)	7.72 (0.39 – 16.33)	0.36 (-4.89 -5.94)
Typical error % (CI)	4.90 (3.34 – 10.16)	6.54 (4.44 – 14.22)	4.85 (3.30 – 10.10)
SWC ^{absolute}	0.77	0.03	0.65
MCC ^{absolute}	3.48	0.14	2.94
SWC ^{% relative}	1.95	2.83	2.38
MCC ^{% relative}	6.85	9.36	7.23

Abbreviations: Coefficient of variation (CV), Confidence intervals (CI), Intra-class correlation coefficients (ICC), Minimum criterion change (MCC), Range of Motion (ROM), Smallest worthwhile change (SWC), Standard deviation (SD).

7.4 Discussion

The current study aimed to investigate the reliability of intra and inter-tester measures of ROM, strength and the overall hip screen between two testers over three time points. The main findings were that both tester one and tester two showed moderate to near perfect intra-tester reliability across strength, ROM and overall screen measures (Table 7.1).

Inter-tester reliability was very large for strength, ROM and the overall screen measures when comparing tester one to tester two (Table 7.2).

7.4.1 Intra-tester reliability

The ICCs displayed within the current study were high when analysing intra-tester reliability for both tester one and tester two for the overall screen (Table 7.1; tester 1: 0.76 & 0.68; tester 2: 0.91 & 0.85). This was probably due to the experience levels of both testers along with the simplicity of the measures that form the hip screen. Although no similar screen for the hip exists, particularly for ice hockey athletes, the FMS is scored in a similar way and is therefore useful for comparison. The high ICC figures reported within the current study are similar to those found by Teyhen et al. (2012) who reported test-retest reliability to be high when analysing four Physical Therapy students completing the FMS at 48 to 72 hour intervals with ICC values of 0.74 within the testers. Gribble, Brigle, Pietrosimone, Pfile, and Webster (2013) describe that Athletic Trainers with experience in assessing the FMS scored highly on intra-tester reliability with an ICC of 0.95 compared to an ICC of 0.77 for Athletic Trainers with no experience, but knowledge of using the FMS, which is comparable to the findings of the current study (Table 7.1). However, the same study by Gribble et al. (2013) found that student Athletic Trainers who had no experience or knowledge of the FMS scored poorly on the reliability tests with ICCs of 0.37, potentially highlighting the need for experienced clinicians to be used within the hip screen for greater reliability. The findings of Gribble et al. (2013) are also in agreement with Shultz, Anderson, Matheson, Marcello, and Besier (2013) who found ICCs of 0.60 when six testers were analysed across two visits. Although Shultz et al. (2013) found slightly lower ICCs than that of Gribble et al. (2013) they analysed testers from differing backgrounds (one student, one Physical Therapist, two Athletic Trainers and two strength and conditioning coaches) with less experience of completing the FMS

which may account for the lower ICC values reported. Interestingly, the study conducted by Smith et al. (2013) found ICC values were largest (0.91) for testers who were experienced but not trained with the FMS and lowest (0.81) for certified FMS testers suggesting that specific training to the FMS, or any screen, is not essential as long as the tester is a qualified clinician. This is consistent with the results found within the current study as both tester one and tester two were repeatable throughout the three trials (Table 7.1; ICC 0.68 – 0.91).

Although the ICCs from the current study are similar to previous work (Gribble et al., 2013; Shultz et al., 2013; Smith, Chimera, Wright, & Warren, 2013; Teyhen et al., 2012), it must be noted that the 95% CIs for the ICCs (Table 7.1; tester 1: visit 1-2; 0.03% – 0.96% & visit 2-3; 0.00% – 0.92%; tester 2: 0.48% – 0.99% & 0.42% – 0.97% respectively) differ from previous work as Teyhen et al. (2012) reported 0.60% - 0.83%, Gribble et al. (2013) reported their lowest values of -0.798% - 0.780, Smith et al. (2013) reported their lowest value of 0.57% - 0.92% and Shultz et al. (2013) reported between 0.35% - 0.77%. The wider ICC figures reported within the current study may be due to the larger scoring system, ranging from zero to 72, increasing the range of possible scores achievable whereas the FMS used by Teyhen et al. (2012), Shultz et al. (2013) and Smith et al. (2013) only reaches a maximum of 21 allowing the range of error to be smaller within those studies.

The work by Teyhen et al. (2012) reported the absolute minimal detectable change for intra-tester reliability of the FMS to be 2.07 points whereas the current study found tester one to have a $SWC^{absolute}$ of 0.83 points and tester two to have a value of 0.56 points (Table 7.1). These lower figures of $SWC^{absolute}$ seen by both tester one and tester two is suggestive that intra-tester repeatability is potentially more sensitive within the current study allowing smaller increases to be viewed as clinically significant. One factor that

requires consideration that was omitted by the work of Teyhen et al. (2012) is the $MCC^{absolute}$ figures. The current study demonstrates a $MCC^{absolute}$ figure of 3.78 points for tester one and 2.53 points for tester 2. The use of $MCC^{absolute}$, as opposed to the $SWC^{absolute}$, figures is potentially more accurate for clinicians due to the inclusion of testing procedure error within the calculation. This gives more likelihood that increases above the $MCC^{absolute}$ figure are a clinically significant change which have taken place due to the intervention and not any error within the testing procedures (Kempton et al., 2013).

Intra-tester reliability was high for measures of hip ROM for both tester one (ICC visit 1-2: 0.49; visit 2-3 0.47) and tester two (ICC visit 1-2: 0.64; visit 2-3 0.70) (Table 7.1). Again, the high ICCs displayed was probably due to the experience levels of both testers along with the simplicity of the ROM measures used in the hip screen. Similar results have been found when analysing shoulder ROM of injured participants when assessed using a goniometer with Hayes et al. (2001) finding a range of ICCs from 0.49 to 0.67 when one tester assessed participants three times over a 48 hour period. It must be considered that the study of Hayes et al. (2001) investigated the test-retest abilities of one tester using three measurement sessions carried out within a 48 hour period which is suggested to increase the accuracy and produce differing results when compared to studies which separate testing procedures by days or weeks (Gajdosik & Bohannon, 1987). More specifically to hip ROM it has been found that all hip movements measured by standard goniometry, similar to methods of the current study, demonstrated ICC figures of above 0.84 (Nussbaumer et al., 2010). While the study by Nussbaumer et al. (2010) found slightly higher ICC results for ROM around the hip than the current study (Table 7.1), they reported larger typical error ranging from 6.6° – 11.2° compared to the current study (Table 7.1). Although the current study reports typical error as a CV%, when expressed as an absolute value smaller and more accurate results are displayed

compared to Nussbaumer et al. (2010) (tester 1; visit 1-2: 6.19°, visit 2-3: 5.38°; tester 2: visit 1-2, 6.67°, visit 2-3: 5.09° respectively).

Tester one and two had high repeatability for strength data across all three of the experimental tests (tester 1; visit 1-2 ICC 0.80, visit 2-3 ICC 0.70; tester 2; visit 1-2 ICC 0.89, visit 2-3 ICC 0.88) (Table 7.1). Similar findings have been found in a study of 30 participants with Bohannon (1986) finding a range of ICC figures between 0.84 and 0.99 when assessing multiple upper and lower body movements. Although these figures are slightly higher than the current study, the study by Bohannon (1986) analysed the test-retest reliability using only one test session analysing consecutive strength measures with only a 30 second rest between testing which may yield more reliable results due to the limitation of variables when assessing measurements in a short period of time (Gajdosik & Bohannon, 1987).

7.4.2 Inter-tester reliability

The current study found that inter-tester reliability was very high with an ICC of 0.81 (95% CI 0.31% – 0.96%) for the overall screen score (Table 7.2). Again, this may be due to the accuracy and experience of both testers in completing the components which form the hip screen. These findings are similar to the study conducted by Teyhen et al. (2012) who report that inter-tester ICCs were 0.76 when comparing two novice Physical Therapy students observing the same participant at the same time when completing the FMS. Smith et al. (2013) also reported similar results with ICCs of 0.89 and 0.87 for differing sessions when four testers measured the FMS twice each, seven days apart. However, previous work by Shultz et al. (2013) contradicts the findings of the current study reporting that inter-tester reliability of the FMS across six testers completing two measurements separated by a seven day period was poor with an ICC value of 0.38 for

all testers. The results of Shultz et al. (2013) may be suggestive of the lack of diversity allowed by the small scoring criteria and maximum score achievable when using the FMS as opposed to the current study which has a larger scoring system, therefore, allowing more diversity and reliability of results if scoring is consistent across testers. Another finding from the current study was that 95% CIs for the ICC values were 0.31% - 0.96% (Table 7.2) which is larger than that found by Teyhen et al. (2012), who reported CIs of 0.63-0.85, and Smith et al. (2013) who reported CIs of 0.80-0.95 and 0.76-0.94 suggesting that the precision of testing within the current study is less than previous work potentially owing to the hip screen having a larger scoring system (21 vs. 72 respectively).

The current study also found a $SWC^{absolute}$ figure of 0.65 points (Table 7.2) when analysing inter-tester reliability of the overall screen which is smaller than the figure found by Teyhen et al. (2012) who reported that 2.54 points was the minimum amount a participant must change by when completing the FMS for the change to be considered worthwhile and because of the intervention put in place as opposed to error. As with intra-tester reliability the lower $SWC^{absolute}$ figure suggests that the newly created screen within the current study is potentially more sensitive than the FMS potentially due to the lack of subjectivity within the scoring system. The current study also reported a $MCC^{absolute}$ figure of 2.94 points suggesting that if a change seen between 0.65 and 2.94 points ($SWC^{absolute}$ and $MCC^{absolute}$ respectively), for the overall screen, then the likelihood of change being due to error is extremely small making the change worthwhile and clinically meaningful (Kempton et al., 2013).

The current study reported ROM ICCs to be 0.71 (Table 7.2; 95% CI 0.12 – 0.93) which is more reliable and transferable between testers than the results of Hayes et al. (2001) who found ICCs ranging between 0.26 and 0.74 when analysing the inter-tester reliability of four testers who completed five ROM movements on eight participants. However, the

study by Hayes et al. (2001) reports individual ICC values for specific ROM movements as opposed to the current study which uses a mean of all ROM movements which may explain the lower results. When the findings of Hayes et al. (2001) are calculated into a mean figure for all ROM movements the ICC value is more reliable at 0.62 which is similar to that found by the current study (Table 7.2; ICC 0.71). The current study found ICC results of 0.77 (Table 7.2; 95% CI 0.18 – 0.95) for strength measures suggesting that reliability was very large between the two testers. This finding is confirmed by the previous work of Bohannon and Andrews (1987) who reported an average ICC of 0.90 when assessing hand-held dynamometry in 30 participants who had suffered cerebrovascular accidents. Although the current study found similar ICC values it must be appreciated that the work of Bohannon and Andrews (1987) only assessed one strength measurement per participant allowing the error measurement to be potentially larger than the current study so comparisons must be viewed with a certain level of caution.

As can be seen within Table 7.2 the $SWC^{absolute}$ and $MCC^{absolute}$ figures are 0.65 and 2.94 points respectively which is very low for inter-tester reliability considering the overall screen is scored out of a maximum 72 points. This may have been due to the combination of accuracy shown by both testers in the intra and inter-tester reliability providing evidence that the screen is both accurate and transferable between testers. Links to previous work are difficult to make as there exists a limited amount of research investigating the $SWC^{absolute}$ and $MCC^{absolute}$ of a screening procedure such as the one used within the current study. However, the low $SWC^{absolute}$ and $MCC^{absolute}$ figures for the overall screen reported within the current study suggest that if the overall screen is completed by differing testers across the time frame of the intervention programme, a change above 0.65 points is seen as a worthwhile change (although not potentially significant) with an increase of above 2.94 points deemed to be a probable significant change caused by the intervention as opposed to testing or measurement error.

7.5 Conclusion

The current study has demonstrated through analysis of ICC values that the newly created hip injury screen offers both reliability and repeatability of its component measures. The findings are valuable because they indicate consistency of intra and inter-tester measures. The current study also offers further value to clinical practice and research by providing results for both SWC and MCC in both absolute and relative values. Therefore, clinicians and researchers can now make informed decisions regarding further investigations of intervention studies using the hip injury screen. A figure above the SWC indicating a potential worthwhile change and a figure above the MCC showing a probable significant change giving certainty that any increase or decrease in measured value is due to the intervention as opposed to the error associated with the testing procedures.

Chapter Eight: Investigating the Effects of a Season Long Strength and Range of Motion Intervention Programme in Ice Hockey Athletes

8.1 Introduction

It is widely accepted that contact and non-contact injuries are common in ice hockey (Agel et al., 2007a; Agel et al., 2007b; Flik et al., 2005; McKnight et al., 1992; Pettersson & Lorentzon, 1993; Pinto et al., 1999; Schick & Meeuwisse, 2003) with the shoulder, knee and hip frequently injured by both contact and non-contact mechanisms (Agel et al., 2007b; Jørgensen & Schmidt-Olsen, 1986; McKnight et al., 1992; Pettersson & Lorentzon, 1993). Contact injuries are often caused by extrinsic factors outside of the limits of control of the athlete in one specific, identifiable ‘macrotraumatic’ event and as such are difficult to prevent due to their uncontrollable and unpredictable nature (Aubry et al., 2002; Benson et al., 2002; Collins & Raleigh, 2009; Fuller et al., 2006; Sharma & Maffulli, 2006). Overuse injuries on the other hand may be more easily prevented due to the changeability of the intrinsic risk factors of the athlete (Aubry et al., 2002; Collins & Raleigh, 2009; Fuller et al., 2006; Hreljac, 2004; Hreljac et al., 2000).

As found in Chapter Four the hip complex was the most likely body location to be injured during non-contact injuries (50%; 36 out of 72 injuries). Although this was not assessed within Chapter Four this may potentially be due to the nature of ice skating and high load placed upon the vulnerable hip (Bizzini et al., 2007; Philippon et al., 2010). Due to the high number of hip injuries it is predictable that an athlete with a weakness in ROM or strength coupled with the repetitive nature of ice skating is exposed to the potential risk of sustaining a non-contact injury (Bizzini et al., 2007; Philippon et al., 2010).

Although weaknesses in internal risk factors are often suggested as the cause of an injury, it must be appreciated that there are often many other impacting factors leading to the

injury making it a multifactorial event with difficulty in assigning causation to one single risk factor (Collins & Raleigh, 2009; Kirkendall, 1990; Meeuwisse, 1994). It is therefore reasonable to suggest that an athlete with multiple intrinsic risk factors (e.g. lack of strength, ROM, fitness or previous injury) may be at a greater risk of sustaining an injury or re-injury via a non-contact mechanism (Bahr & Krosshaug, 2005).

This study aimed to investigate the effect of a year-long multifaceted intervention programme in ice hockey athletes and six week intervention programme in control participants. The intervention programme aimed to increase the strength, ROM and functional test performance of the participant's hip whilst being tested using the previously created hip screen.

8.2 Methodology

8.2.1 Participants

Participant demographics are outlined in detail in Chapter Three (section 3.2; Table 3.1, page 74). All 23 participants recruited from Bethel University were members of the ice hockey team and had been on the team for at least one season. The nine participants recruited from the University of Hull acted as a control group to the ice hockey athletes and were tested at a different time and in a different location but using the same experimental equipment.

8.2.2 General procedures

The procedure for this study, including the screening method and intervention programme, have been outlined in detail in Chapter Three (section 3.7, page 80). In brief, participants first completed the hip injury screen (Chapter Three; section 3.5, page 79) to give base line measurements and were then either entered into the ice hockey intervention

(IHI) (n = 11), ice hockey control (IHC) (n = 12) or intervention control (IC) (n = 9) group. The IHI group were required to complete the intervention programme (Appendix F) twice a week for the entirety of the eight month season (October 2013 – May 2014) with the IC group completing the intervention programme twice a week for a six week period. Following the successful completion of the intervention programme participants again completed the hip injury screen.

8.2.3 Analysis

Data were analysed using SPSS version 19. A mixed model ANOVA was used to investigate interactions (group (IHC/IHI/IC) x time (pre/post) x limb (Dom/Ndom)) and main effects (limb or group or time differences) for the ROM variables: adduction, flexion in sitting, flexion in lying, internal rotation and external rotation, and for the strength variables of: abduction, adduction, flexion in sitting and flexion in lying. In the instance of a significant interaction post-hoc analysis was completed using LSD. Only significant findings were reported with their associated F values and effect size. Along with the traditional statistics outlined above, reliability data, in particular $SWC^{absolute}$ and $MCC^{absolute}$ values, calculated within Chapter Seven (Table 8.1) were used to evaluate if the changes seen in the post-intervention overall screen scores were clinically meaningful. Values above the $SWC^{absolute}$ figure can be viewed as a clinically worthwhile change with values above the $MCC^{absolute}$ figure being considered a clinically significant change and probably caused by the intervention programme taking into account experimental error.

Table 8.1 Reliability of the hip screen (adapted from Chapter Seven results, Table 7.1, section 7.3.1, page 145)

	Overall Screen Score
ICC visit 1-2 (CI)	0.76 (-0.03 – 0.96)
ICC Descriptor visit 1-2	Very large
ICC visit 2-3 (CI)	0.68 (0.00 – 0.92)
ICC Descriptor visit 2-3	Large
SWC ^{absolute}	0.83
MCC ^{absolute}	3.78

8.3 Results

8.3.1 Range of motion

Mean hip ROM for pre and post-intervention for all groups are displayed in Table 8.2 (page 160).

8.3.1.1 Pre-intervention differences

There was a significant interaction for group, limb dominance and time for external rotation ($F(1, 29) = 4.645, p = 0.018, \eta^2 = 0.243$). IC participants showed significantly greater external rotation ROM on the Dom limb in pre-intervention testing compared to the IHC group ($p = 0.05$) and the IHI group ($p = 0.012$) (Table 8.2, page 160). There were also significant interactions for group and time for external rotation ($F(1, 29) = 7.066, p = 0.003, \eta^2 = 0.328$) with the IC group displaying greater external rotation ROM compared to the IHC group ($p = 0.045$) when both pre and post-intervention scores were combined (Figure 8.1, page 161).

8.3.1.2 Effect of the intervention

The post-intervention testing showed significant increases for hip adduction ($F(1, 29) = 7.361, p = 0.011, \text{Peta}^2 = 0.202$), hip flexion in lying ($F(1, 29) = 12.881, p = 0.001, \text{Peta}^2 = 0.308$), hip flexion in sitting ($F(1, 29) = 17.216, p < 0.001, \text{Peta}^2 = 0.373$), internal rotation ($F(1, 29) = 10.468, p = 0.003, \text{Peta}^2 = 0.265$) and external rotation ($F(1, 29) = 39.952, p < 0.001, \text{Peta}^2 = 0.579$) when compared to that of the pre-intervention testing results regardless of group or limb (Table 8.2, page 160).

Main effect differences were observed between groups when both Dom and Ndom limbs were combined for hip adduction ($F(2, 31) = 7.351, p = 0.002, \text{Peta}^2 = 0.315$) showing that the IC group significantly increased from pre to post-intervention testing compared to the IHC ($p = 0.002$) and IHI ($p = 0.018$) groups respectively (Figure 8.1, page 161).

Table 8.3 (page 162) demonstrates the intervention effects as percentage change in order to easily compare the changes seen between groups and suggests that all variables, excluding hip flexion in both sitting and lying, increased more in the IHI group over the intervention period than the IHC group. Of particular note is the changes seen in internal rotation scores as the IHI group increased pre to post-intervention on the Dom and Ndom limbs by over 17.7% and 22.0% respectively, compared to only 5.1% and 7.6% respectively of the IHC group and 5.7% and 14.2% respectively of the IC group. The IHI group also displayed much greater percentage increases in adduction, internal and external rotation on the Ndom limb compared to the IHC group following the intervention (Table 8.3, page 162). The IC group showed a much larger increase in adduction (40.3% on the Dom limb and 50.3% on the Ndom limb) compared to the IHI (-4.0% on the Dom limb and 7.5% on the Ndom limb) and IHC groups (-0.7% on the Dom limb and -3.6% on the Ndom limb) following the intervention period (Table 8.3, page 162).

8.3.1.3 Post-intervention differences

There were significant interactions for group and time for adduction ($F(1, 29) = 7.080$, $p = 0.003$, $\text{Peta}^2 = 0.328$) with IC participants showing significantly greater adduction ROM at post-intervention testing compared to both the IHC group ($p < 0.001$) and the IHI group ($p < 0.001$) when both limbs were combined (Figure 8.1, page 161). The IHI group displayed greater external rotation ROM in post-intervention testing on the Ndom limb compared to IHC participants ($p = 0.44$) (Table 8.2, page 160).

8.3.1.4 Group and limb differences

Significant interactions were also displayed for limb and group for hip adduction ($F(1, 29) = 8.157$, $p = 0.002$, $\text{Peta}^2 = 0.360$) with the IC group showing significantly greater ROM on the Ndom limb compared to both the IHC ($p < 0.001$) and IHI group ($p = 0.012$) regardless of time (Table 8.2, page 160). The Dom limb showed greater ROM in hip flexion in lying ($F(1, 29) = 5.563$, $p = 0.025$, $\text{Peta}^2 = 0.161$) but less ROM in hip flexion in sitting ($F(1, 29) = 6.180$, $p = 0.019$, $\text{Peta}^2 = 0.176$) when all groups and limbs were combined (Table 8.2, page 160).

Table 8.2 Mean and standard deviation ROM for all groups across pre and post-intervention programme on both limbs

Hip movement measured (°)	IHC (Mean ± SD) n = 12				IHI (Mean ± SD) n = 11				IC (Mean ± SD) n = 9			
	Dom		Ndom		Dom		Ndom		Dom		Ndom	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Adduction	22.92 ± 5.52	22.75 ± 3.44	20.75 ± 4.83	20.00 ± 3.05	22.73 ± 5.26	21.82 ± 4.81	21.82 ± 4.49	23.45 ± 4.27	21.78 ± 6.20	30.56 ± 5.05 ~	19.44 ± 3.57	29.22 ± 5.56 ~
Hip flexion in lying	110.00 ± 7.87	112.75 ± 5.79	110.25 ± 10.28	118.42 ± 7.70	108.64 ± 6.05	111.36 ± 10.55	111.00 ± 8.33	116.09 ± 8.31	117.78 ± 6.65	120.11 ± 6.66	116.89 ± 6.64	119.22 ± 6.69
Hip flexion in sitting	36.92 ± 10.26	44.75 ± 8.41	33.75 ± 7.58	37.67 ± 6.39	34.45 ± 6.55	43.27 ± 7.90	34.82 ± 8.36	37.45 ± 8.94	38.44 ± 3.61	40.89 ± 6.29	37.67 ± 5.45	37.78 ± 6.39
Internal Rotation	29.67 ± 6.49	31.17 ± 10.21	29.58 ± 7.74	31.83 ± 7.72	26.18 ± 6.63	30.82 ± 10.30	25.18 ± 5.23	30.73 ± 7.10	31.22 ± 5.09	33.00 ± 4.87	28.22 ± 5.85 ^	32.22 ± 5.56 ^
External Rotation	36.08 ± 7.56	44.33 ± 6.65	40.00 ± 8.02	43.08 ± 6.08	37.09 ± 6.91	46.36 ± 6.19	40.64 ± 7.62	48.64 ± 7.51	44.67 ± 9.79 *	47.56 ± 4.82	45.89 ± 7.56	43.89 ± 6.47 #

* The IC group showed significantly higher pre-intervention external rotation on the Dom limb compared to the IHC (p = 0.05) and IHI group (p = 0.012). # The IHI group displayed greater external rotation in post-intervention testing on the Ndom limb compared to IHC athletes (p = 0.44). ~ The IC group showed significantly greater adduction at post-intervention testing compared to both the IHC (p < 0.001) and IHI group (p < 0.001) along with greater external rotation in the pre-intervention testing compared to the IHC group (p = 0.045). ^ The IC group showed significantly greater ROM on the Ndom limb compared to both the IHC (p < 0.001) and IHI group (p = 0.012).

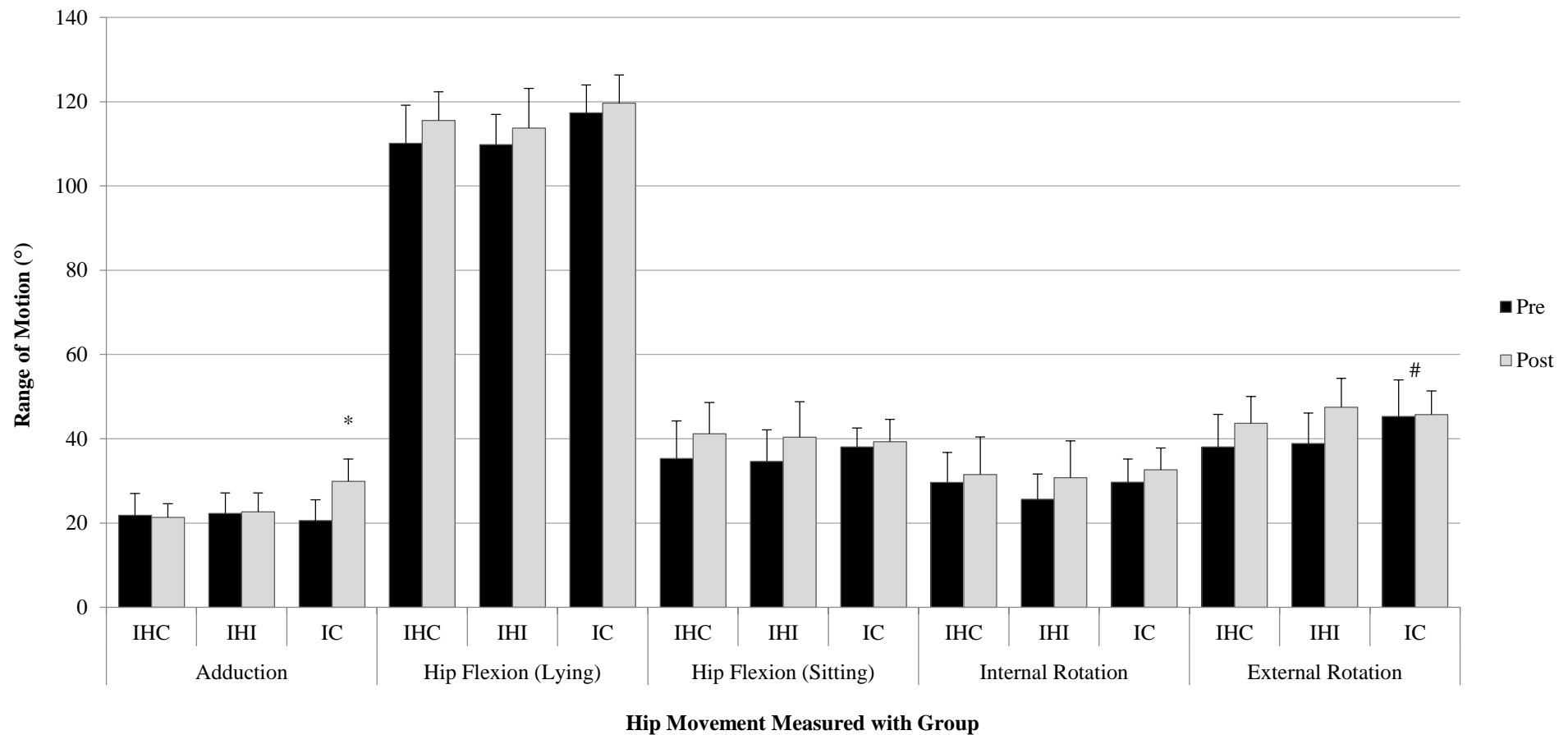


Figure 8.1 Mean and standard deviation ROM differences between pre and post-intervention for all groups with Dom and Ndom limbs combined

* The IC group displayed a greater increase from pre-intervention compared to both the ice hockey control ($p = 0.002$) and ice hockey intervention ($p = 0.018$) group. * The IC group displayed significantly greater post-intervention hip adduction compared to both IHC ($p < 0.001$) and IHI group ($p < 0.001$). # The IC group displayed significantly higher external rotation compared to the IHC group ($p = 0.045$) when both pre and post-intervention scores were combined.

Table 8.3 Percentage change over time for ROM measures

Measure		Change over time (%)		
		IHC	IHI	IC
Adduction	Dom	-0.7	-4.0	40.3
	Ndom	-3.6	7.5	50.3
Hip Flexion (Lying)	Dom	2.5	2.5	2.0
	Ndom	7.4	4.6	2.0
Hip Flexion (Sitting)	Dom	21.2	25.6	6.4
	Ndom	11.6	7.6	0.3
Internal Rotation	Dom	5.1	17.7	5.7
	Ndom	7.6	22.0	14.2
External Rotation	Dom	22.9	25.0	6.5
	Ndom	7.7	19.7	-4.4

8.3.2 Strength

Mean hip strength pre and post-intervention results are displayed in Table 8.4 (page 164).

There were no significant differences between groups or limbs in pre or post-intervention testing.

8.3.2.1 Effect of the intervention

The post-intervention testing presented significant increases over the pre-intervention testing for hip abduction ($F(1, 29) = 12.225$, $p = 0.002$, $Peta^2 = 0.297$), hip flexion in lying ($F(1, 29) = 13.392$, $p = 0.001$, $Peta^2 = 0.316$), hip flexion in sitting ($F(1, 29) = 13.208$, $p = 0.001$, $Peta^2 = 0.313$) (Table 8.4, page 164) and adduction:abduction strength ratio ($F(1, 29) = 11.354$, $p = 0.002$, $Peta^2 = 0.281$) when all groups and limbs were combined (Figure 8.3, page 166). However, there were no significant interactions between the changes from pre to post-intervention results between groups.

In order to comparatively analyse the changes seen by all groups over the intervention period the percentage change was calculated for all strength variables (Table 8.5, page 166), demonstrating that all variables, excluding hip abduction and hip flexion in sitting on the Dom limb, increased more in the IHI and IC groups over time than the IHC group.

Of particular note is the positive increase in strength seen in Ndom abduction between the IHC and IHI group whose scores were 7.4% compared to 17.2% respectively. Another notable change was in Dom adduction again between the IHC and IHI group whose scores were 2.2% compared to 10.8% respectively. The Ndom limb showed larger percentage increases in both the IHC and IHI groups across all variables (Table 8.5, page 166).

There were also main effect differences observed between groups for the adduction:abduction strength ratio when both Dom and Ndom limbs were combined ($F(2, 31) = 4.366, p = 0.022, \text{Peta}^2 = 0.231$), the IC group were significantly closer to one (equal muscle strength) than the IHC ($p = 0.012$) and IHI ($p = 0.017$) groups following the intervention programme (Figure 8.3, page 166). Although non-significant, Figure 8.3 (page 166) shows that both the IHI and IHC groups post-intervention adduction:abduction ratios decreased to become closer to one, and were therefore more evenly matched between adduction and abduction strength.

8.3.2.2 Group and limb differences

There were no significant interactions observed between groups when both Dom and Ndom limbs were combined for any of the strength measures (Figure 8.2, page 165). However, the Dom limb displayed a higher adduction:abduction strength ratio ($F(1, 29) = 15.798, p < 0.001, \text{Peta}^2 = 0.353$) compared to the Ndom limb when all groups were combined across all time points (Figure 8.3, page 166).

Table 8.4 Mean and standard deviation strength scores pre and post-intervention programme on both limbs

Hip movement measured (Nm/kg)	IHC (Mean \pm SD) n = 12				IHI (Mean \pm SD) n = 11				IC (Mean \pm SD) n = 9			
	Dom		Ndom		Dom		Ndom		Dom		Ndom	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Abduction	1.91 \pm 0.32	2.32 \pm 0.63	2.03 \pm 0.38	2.18 \pm 0.24	1.91 \pm 0.36	2.32 \pm 0.29	1.98 \pm 0.28	2.32 \pm 0.24	2.23 \pm 0.42	2.28 \pm 0.20	2.22 \pm 0.41	2.22 \pm 0.22
Adduction	2.44 \pm 0.34	2.49 \pm 0.25	2.25 \pm 0.33	2.27 \pm 0.33	2.42 \pm 0.34	2.68 \pm 0.37	2.25 \pm 0.40	2.28 \pm 0.40	2.39 \pm 0.40	2.31 \pm 0.19	2.20 \pm 0.39	2.23 \pm 0.23
Hip flexion in sitting	1.66 \pm 0.16	1.79 \pm 0.22	1.62 \pm 0.21	1.74 \pm 0.23	1.76 \pm 0.38	1.87 \pm 0.26	1.70 \pm 0.35	1.88 \pm 0.33	1.50 \pm 0.30	1.60 \pm 0.26	1.56 \pm 0.25	1.59 \pm 0.35
Hip flexion in lying	1.44 \pm 0.16	1.48 \pm 0.22	1.45 \pm 0.18	1.52 \pm 0.20	1.44 \pm 0.27	1.58 \pm 0.23	1.45 \pm 0.26	1.56 \pm 0.24	1.42 \pm 0.23	1.52 \pm 0.17	1.46 \pm 0.20	1.55 \pm 0.17

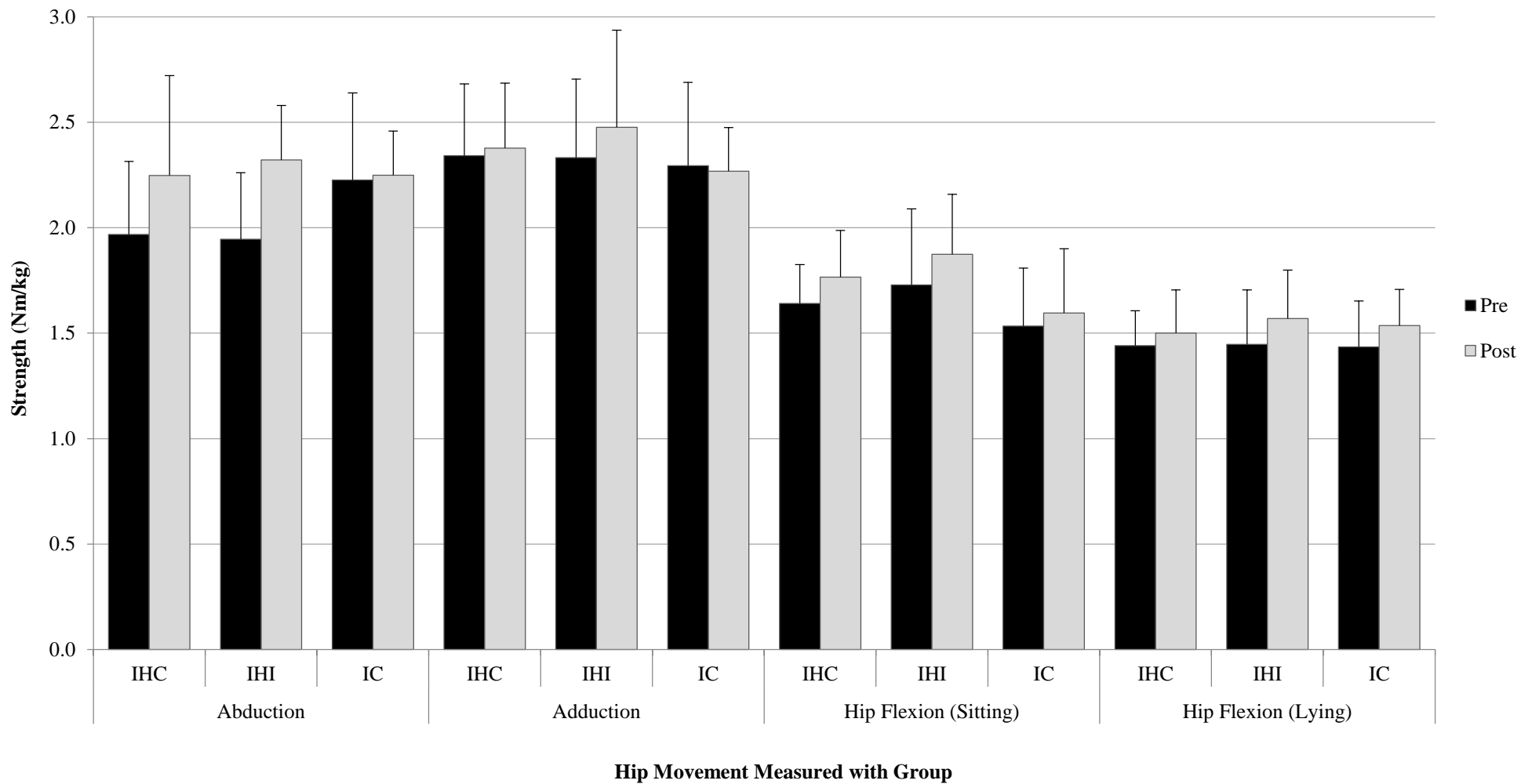


Figure 8.2 Mean and standard deviation strength differences between pre and post-intervention for all groups with Dom and Ndom limbs combined

Table 8.5 Percentage change over time for strength measures

Measure		Change over time (%)		
		IHC	IHI	IC
Abduction	Dom	21.5	21.6	2.4
	Ndom	7.4	17.2	-0.3
Adduction	Dom	2.2	10.8	-3.4
	Ndom	0.8	1.2	1.3
Hip Flexion (Sitting)	Dom	7.9	6.5	6.3
	Ndom	7.4	10.3	1.9
Hip Flexion (Lying)	Dom	3.1	9.6	7.3
	Ndom	5.2	7.4	6.7

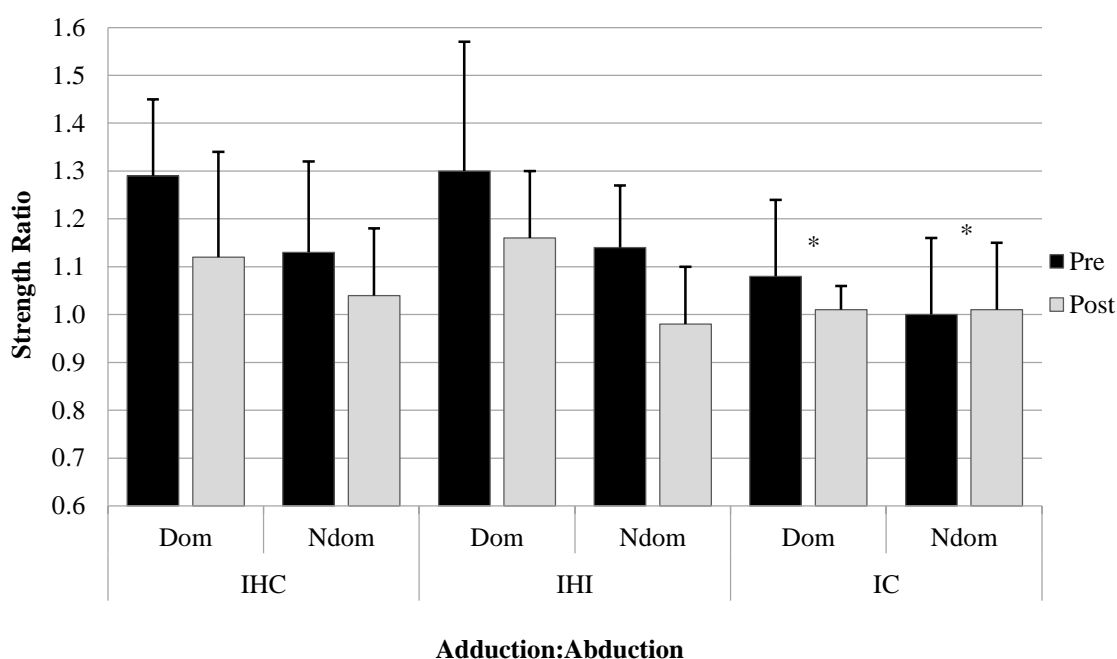


Figure 8.3 Adduction:abduction strength ratio between pre and post-intervention for all groups

* The IC group was significantly closer to one than the IHC ($p = 0.012$) and IHI ($p = 0.017$) groups.

8.3.3 Functional Testing

When both the Dom and Ndom limb were combined the IHI group (pre 15 vs. post 6) displayed a decrease in positive results for the FABER test following the intervention programme compared to the IHC (pre 15 vs. post 14) and IC group (pre 10 vs. post 9) (Figure 8.4). Figure 8.4 also displays that both the IHI (pre 7 vs. post 0) and IC group (pre

5 vs. post 2) exhibited a decrease in positive Trendelenburg tests compared to the IHC group (pre 4 vs. post 3). The IHI group (pre 2 vs. post 0) also displayed lower positive Ober's tests following the intervention programme compared to both the IHC (pre 2 vs. post 2) and IC group (pre 3 vs. post 4) (Figure 8.4).

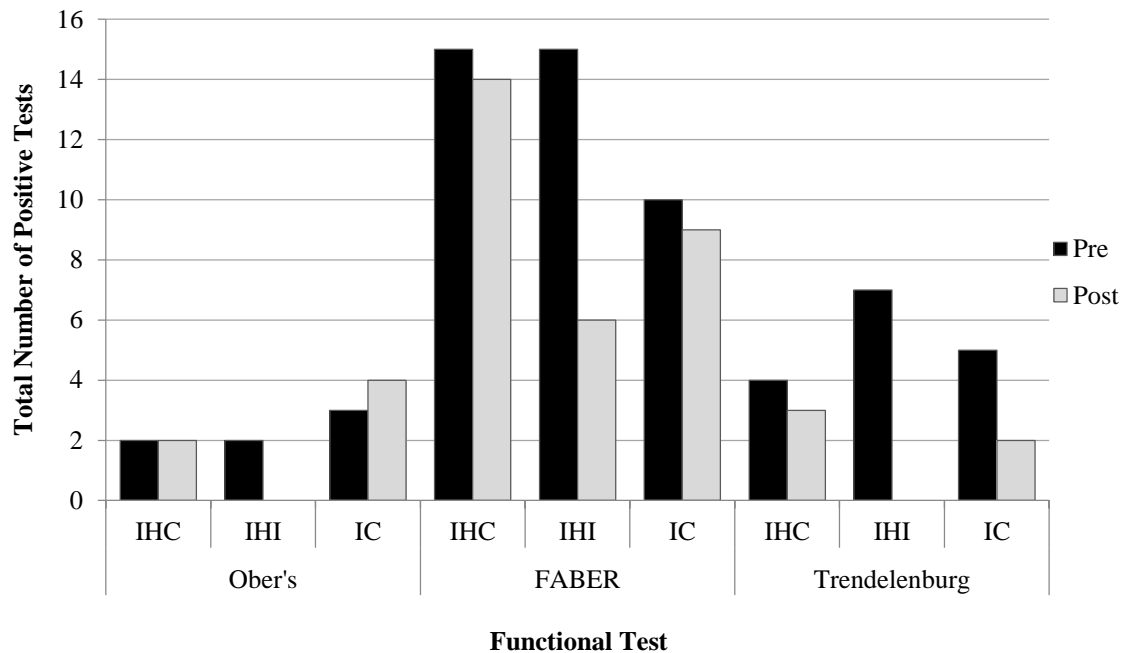


Figure 8.4 Total number of positive functional test scores for all groups' pre and post-intervention programme

8.3.4 Analysis of the screening procedures

There were no significant interactions for group, limb or time for the overall screen, ROM, strength or functional testing element of the hip screen. The post-intervention testing showed significant increases for the functional testing element of the screen ($F(1, 29) = 4.898, p = 0.035, \eta^2 = 0.144$) when compared to the pre-intervention scores when all groups and limbs were combined with larger increases in the IHI group (Figure 8.5). Table 8.1 (page 157) reports some reliability data previously reported in Chapter Seven for the overall hip screen score. Although non-significant, the change in overall screen scores from pre to post-intervention testing in the IHI group is above the MCC^{absolute}

figure of 3.78 (Table 8.1, page 157), with the IHI group increasing by 4 points (Figure 8.5). This provides clinical relevance that the increases seen within the IHI group was due to the intervention as opposed to time or training effect alone. There were no other significant interactions between group, limb or time, nor main effect differences between group, limb or time for the remaining variables.

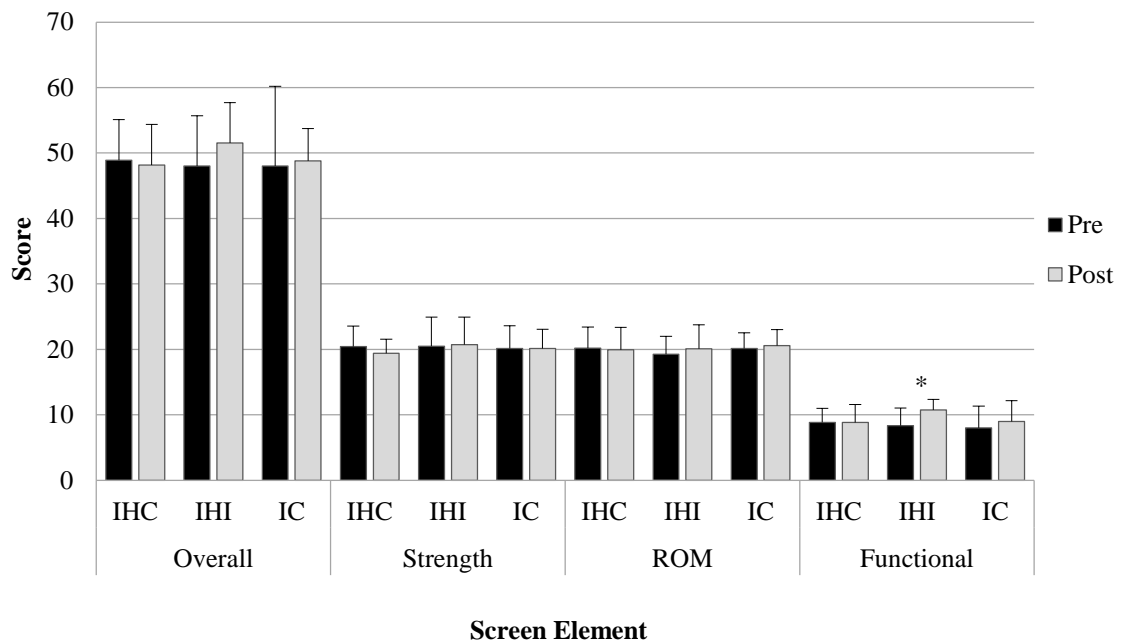


Figure 8.5 Pre and post-intervention scores for all groups in overall, strength and ROM elements of the screen

* Post intervention scores were significantly higher than pre-intervention scores for all groups when combined ($p = 0.035$).

8.4 Discussion

This study aimed to investigate the effect of an intervention programme designed to increase the strength, ROM and functional performance of the ice hockey athlete's hip, therefore increasing their overall hip screen score and potentially decreasing injury risk. The main findings were that all groups, not just intervention participants, improved their ROM (adduction, hip flexion in lying and sitting and internal and external rotation) (Table 8.2), strength (abduction, flexion in lying and sitting) (Table 8.4) and adduction:abduction

strength ratio measures (Figure 8.3) post-intervention which was not expected. A further main finding was that the IHI group improved in their overall screen score and above the $MCC^{absolute}$ value (pre 48, post 52) compared to the IHC (pre 49, post 48) and IC group (pre 48, post 49) potentially providing evidence that ice hockey athletes who completed the intervention programme showed a clinically significant change following the intervention and were therefore at a potentially lower risk of sustaining a non-contact hip injury (Figure 8.5).

8.4.1 Effect of the intervention

8.4.1.1 Range of motion

The finding that both the IHI and IHC groups increased their ROM scores over time in all variables (Table 8.2) suggests that ice hockey activity completed by all ice hockey athletes (e.g. on ice training and off-ice ice hockey specific training) during the intervention period may have had a greater impact upon the ROM scores than the intervention programme due to the non-significant differences seen between pre and post-intervention results for both groups. A further explanation may be that the intervention was not powerful or specific enough, as the IC group also increased across all variables (Table 8.1).

Although non-significant the IHI group displayed much larger percentage increases in flexion in sitting and external rotation compared to the IC group (Table 8.3; flexion in sitting: IHI, Dom 25.6%, Ndom 7.6% vs. IC Dom 6.4%, Ndom 0.3%; external rotation: IHI, Dom 25.0%, Ndom 19.7% vs. IC Dom 6.5%, Ndom -4.4%) potentially due to the additional exercises completed by ice hockey athletes, either seasonal ice hockey activity or the increased length of intervention period, that may have had an effect upon the greater increases observed in the IHI group. However, the IHC group also showed similar

increases to the IHI group in flexion in sitting and external rotation when compared to the IC group (Table 8.3; flexion in sitting: IHC, Dom 21.2%, Ndom 11.6% vs. IHI, Dom 25.6%, Ndom 7.6% vs. IC Dom 6.4%, Ndom 0.3%; external rotation: IHC, Dom 22.9%, Ndom 7.7% vs. IHI, Dom 25.0%, Ndom 19.7% vs. IC Dom 6.5%, Ndom -4.4%) suggesting that it was potentially the seasonal ice hockey activity alone that may have affected post-intervention results in both the IHC and IHI over the IC group. A further possible explanation for the percentage improvements seen in all ROM measures for both the IHC and IHI groups may be due to the athletes being from the same competitive team. This may have resulted in the IHC group also completing the intervention protocol (or at least in part) believing it would benefit them having seen the IHI completing the exercises at the training facility. This effect is known as diffusion and is common within control and intervention groups recruited from the same team (Craven, Marsh, Debus, & Jayasinghe, 2001). If diffusion were an issue within the current study it may allow the percentage increases seen in Table 8.3 in hip flexion in sitting and external rotation ROM in both groups to be due to the intervention programme as opposed to the ice hockey activity completed, however, this is speculative.

There was a large percentage increase seen within the IHI group in internal rotation on both the Dom and Ndom limbs (Table 8.3: 17.7% vs. 22.0% respectively) compared to the IHC group (Table 8.3: 5.1% vs. 7.6% respectively) and the IC group (Table 8.3: 5.7% vs. 14.2% respectively) suggesting that the intervention protocol within the current study did have a positive effect, especially upon 'risk' movements within ice hockey athletes. This finding, that internal rotation increased in ice hockey athletes who completed the intervention programme, is important when considering the high occurrence of ice hockey athletes who suffer from FAI injuries presenting with a lower internal rotation ROM compared to athletes who were not injured (Bizzini et al., 2007; Keogh & Batt, 2008). Therefore, the ice hockey athletes who took part in the intervention programme may not

only be at a reduced risk of sustaining a non-contact hip injury but may also benefit during the ice skating stride due to the increased internal rotation ROM exhibited (Ekstrand & Gillquist, 1983; Quinney et al., 2008; Witvrouw et al., 2003; Worrell & Perrin, 1992). This increase in internal rotation in the IHI group, above the IHC and IC group, may also be a cause of the intervention exercises particularly targeting the internal rotators more so than other muscles surrounding the hip or, more likely, as a result of the lower pre-intervention figures of the IHI observed in Table 8.2 compared to the IHC and IC groups (IHI; Dom 26.18°, Ndom 2#5.18°, IHC; Dom 29.67°, Ndom 29.58°, IC; Dom 31.22°, Ndom 28.22°).

A further finding was that the IC group improved in adduction ROM (Table 8.2; Dom pre 21.78° vs. post 30.56°, Ndom pre 19.44° vs. post 29.22°) over the course of the intervention programme compared to the IHI (Table 8.2; Dom pre 22.73° vs. post 21.82°, Ndom pre 21.82° vs. post 23.45°) and IHC groups (Table 8.2; Dom pre 22.92° vs. post 22.75°, Ndom pre 20.75° vs. post 20.00°) despite the similar pre-intervention scores. This increase in adduction observed in the IC group was significantly greater than the IHI group ($p = 0.018$) when both limbs were combined (Figure 8.1). Due to the observed increase in ROM of adduction in the IC group the percentage change increase was also larger (Table 8.3; Dom 40.3%, Ndom 50.3%) compared to both the IHC (Table 8.3; Dom -0.7%, Ndom -3.6%) and IHI (Table 8.3; Dom -4.0%, Ndom 7.5%) groups. This finding that the IC group increased in adduction ROM may be due to the IHI group being allowed to complete the intervention exercises at any time during their week, as long as this was completed twice. This may have had a negative effect upon the results shown as if the IHI group completed the intervention exercises consistently following their team practice, in a somewhat fatigued state, the intervention exercises may not have had as much of an impact as if it were completed on their off days, for instance. Further reasoning for the increased adduction ROM seen in the IC group may be due to the supervision by the

principle investigator during exercise completion, which potentially had a positive effect upon the results, especially as pre-intervention scores were similar between all groups (Table 8.2).

8.4.1.2 Strength

Measures of strength displayed similar results to that of ROM measures showing a greater increase in post compared to pre-intervention scores in all groups in hip abduction, flexion in lying and sitting (Table 8.4). These increases in the majority of strength measures are consistent with other studies that found a strength intervention increased the post intervention scores of participants (Brito et al., 2010; Kilding et al., 2008). A study by Brito et al. (2010) found that 18 athletes who completed the F-MARC three times a week for ten weeks had a significant increase in isokinetic strength of both the hamstrings and quadriceps muscles which may suggest that the intervention programme used within the current study was not challenging enough for the participants. Possibly due to its simplicity and lack of load progression. If the intervention programme within the current study were more rigorous in terms of intensity and used more challenging exercises significant results may have been found. Kilding et al. (2008) investigated performance measures of 20 m sprint time, horizontal and vertical jump height, core strength and agility finding the intervention group performed significantly better in the performance measures following the F-MARC intervention. Although Brito et al. (2010) and Kilding et al. (2008) found significant increases in strength following the F-MARC intervention they did not report any subsequent injury data making the clinical significance of the intervention debatable. Whilst the current study did not report subsequent injury of participants either, the previous findings of Brito et al. (2010) and Kilding et al. (2008) suggest that the participants in the current study may have benefited from increased performance, and therefore a decreased risk of injury due to the associated increases of

strength and ROM with deficits in these factors increasing the risk of injury. A potential performance benefit that could have been increased within the ice hockey athletes who completed the intervention programme may perhaps be the skating capabilities as the presence of greater strength may increase speed and force production (Chang et al., 2009; Stull et al., 2011; Upjohn et al., 2008).

Many other studies report significantly less injuries sustained by athletes who followed a strength and flexibility intervention programme (Myklebust et al., 2003; Olsen et al., 2005; Tyler et al., 2002; Verhagen et al., 2004), however, none give exact figures for the changes in strength or flexibility seen from either the control or intervention group making it difficult to assess if the intervention programme was successful in increasing strength along with the reported reduction in injuries. Due to the multi-factorial nature of injuries, to only report a decrease in injury occurrence does not necessarily mean the intervention was successful, as the decrease in injuries may be attributable to a number of differing factors (e.g. lower number of unpreventable contact injuries, less injuries reported to the medical staff etc.) (Collins & Raleigh, 2009; Kirkendall, 1990; Meeuwisse, 1994).

The percentage increases reported in Table 8.5 also show slight strength increases in all movements, except hip flexion in sitting, following the intervention protocol in the IHI group compared to the IHC and IC group. Large increases are displayed within hip adduction on the Dom limb of the IHI group (10.8%) compared to the IHC group (2.2%) and the IC group (-3.4%) along with Ndom hip abduction (IHC 7.4% vs. IHI 17.2% vs. IC -0.3%) (Table 8.5) suggesting that the intervention exercises particularly targeted the adduction and abduction strength of ice hockey athletes. This increase in adduction strength may be of importance as it has the potential to decrease the risk of an ice hockey athlete sustaining a non-contact hip injury, with the previous work of Tyler et al. (2001)

finding that professional ice hockey athletes with a decrease in hip adduction strength were significantly more likely to sustain a hip adductor muscle strain. The increase in both adduction and abduction strength may also be of benefit to the ice hockey athlete during the explosive ‘push off’ phase of the ice skating stride as the abductors are the main mobiliser of the joint producing the force with the adductors required to stabilise and decelerate the limb in the outer range of abduction (Chang et al., 2009; Tyler et al., 2001; Upjohn et al., 2008). The increased adduction and abduction strength may enable a more powerful ‘push off’ phase and quicker recovery stride and therefore more productive and effective technique (Chang et al., 2009; Tyler et al., 2001; Upjohn et al., 2008). Although suggestions can be made to the increase in performance and mechanics of the skating stride following the implementation of the intervention programme this was not assessed within the current study and therefore further work needs to be completed to confirm these potential associations.

Adduction:abduction strength ratios were also closer to one in all groups following the intervention programme (Figure 8.3; IHC Dom pre 1.29, post 1.12, Ndom pre 1.13, post 1.04, IHI Dom pre 1.30, post 1.16, Ndom pre 1.14, post 0.98, IC Dom pre 1.08, post 1.01, Ndom pre 1.00, post 1.01) suggesting that all participants had more equality between their adductor and abductor muscles. This ratio becoming closer to one, and therefore equal, is important when comparing the current study to the work of Tyler et al. (2001) who found that ice hockey athletes with a low adduction:abduction strength ratio, showing the adductors being weaker than the abductors, subsequently sustained a hip adductor injury. Although the current study contradicts the findings of Tyler et al. (2001) finding the adductors to be stronger than the abductors (Table 8.4) this may, however, suggest that the ice hockey population used in this study are at a greater risk of sustaining an abductor muscle strain. This potential increased risk of the ice hockey athletes in the current study sustaining an abductor muscle injury can also be seen to decrease following the

intervention programme with the IHI group improving their hip abduction strength on both the Dom and Ndom limbs by 21.6% and 17.2% respectively, making the difference in strength between the adductors and abductors much less.

A potential limitation of the current study was the exercises utilised within the intervention programme (Appendix F) targeted whole muscle groups of all participants involved within both the IHI and IC groups and not specific weaknesses of the individual participant. Targeting individual weaknesses of participants, highlighted from the screening procedures, could have had a large effect upon the results as participants may have improved, if they were weak in one specific area, where others did not during the post-intervention testing contributing to the non-significant results found within the current study.

8.4.1.3 Functional testing

Positive functional tests decreased within the IHI group compared to both the IHC and IC group in Ober's test (IHI: pre 2 vs. post 0; IHC: pre 2 vs. post 2; IC: pre 3 vs. post 4), FABER (IHI: pre 15 vs. post 6; IHC: pre 15 vs. post 14; IC: pre 10 vs. post 9) and Trendelenburg test (IHI: pre 7 vs. post 0; IHC: pre 4 vs. post 3; IC: pre 5 vs. post 2) (Figure 8.4). This finding, of better functional capabilities of the IHI group, demonstrates that although the individual ROM and strength scores may not have significantly increased, the presence of positive functional tests decreased in the IHI group compared to both the IHC and IC group suggesting the intervention may benefit the ice hockey athlete's functional performance of these tests. The decrease seen within positive FABER and Trendelenburg tests in the IHI group may be of benefit for reducing the risk of sustaining a non-contact hip injury, in particular FAI injuries, as both tests, when positive,

signify the presence, or potential, of sustaining a FAI injury (Clohisy & McClure, 2005b; Philippon et al., 2010).

8.4.1.4 Overall screen

The overall screen score of the IHI group (pre 48 vs. post 52) increased more than both the IHC (pre 49 vs. post 48) and IC (pre 48 vs. post 49) groups following the intervention period (Figure 8.5). Although the increase seen in the IHI group were non-significant in traditional statistics it can be assumed that the increases were due to the intervention programme as opposed to random error due to the difference in post-intervention scores being larger than the $MCC^{absolute}$ value of 3.78 points determined in Chapter Seven (Table 8.1). This increase in the post-intervention overall screen score displayed by the IHI group allows medical teams to interpret that the changes seen from the intervention programme have had a clinically significant increase with $MCC^{absolute}$ values accounting for measurement error within their calculation (Kempton et al., 2013). Although only the IHI group showed an increase in post-intervention overall screen scores this could suggest that ice hockey athletes who completed the intervention programme were potentially at a decreased risk of sustaining a non-contact hip injury due to the increased overall performance in the hip injury screen injury. Although it cannot be substantiated, this increased performance in the hip injury screen may also have a positive effect upon ice hockey athletes who have previously sustained a non-contact hip injury. It has previously been suggested in Chapter Six that athletes who had suffered a previous non-contact hip injury scored lower on the hip injury screen and were, therefore, at an increased risk of injury due to the accumulation of weaknesses tested within the screening procedures and by increasing the hip injury screen score, as in the current study, may decrease their risk of subsequent injury. However, this suggestion needs further work to substantiate the claim by tracking athletes longitudinally to see if those athletes who had an increase in

their overall screen score were indeed less likely to become injured after completing the intervention programme.

8.5 Conclusion

The intervention protocol had a positive effect upon participants completing it showing percentage increases in the majority of ROM and strength tests along with a decreased number of positive functional tests following the intervention programme. Although non-significant ice hockey athletes that completed the intervention programme increased their overall screen score above the level of probable clinical significance ($MCC^{absolute}$) suggesting they were at a decreased 'risk' of sustaining a non-contact hip injury following the intervention programme. This observed increase by the IHI group above the $MCC^{absolute}$ figure gives credence to the intervention programme within the current study. Further research should consider an individualised intervention programme that targets weaknesses of the individual highlighted in the hip injury screen along with tracking athletes longitudinally to confirm the success of the intervention.

Chapter Nine: General Discussion and Conclusion

9.1 General discussion

The first objective of this project was to investigate the frequency, type (contact or non-contact) severity and location of injuries sustained by elite ice hockey athletes in order to gain a greater understanding and knowledge of injuries within this group. The second objective was to analyse the ice hockey athlete's hip ROM, strength and functional capabilities when compared to soccer athletes and a normal active population to observe any differences between the populations evaluating why ice hockey athletes are particularly susceptible to non-contact hip injuries. The third objective was to develop a screening protocol sensitive enough to detect previous injuries alongside the potential to evaluate the risk of future injury/re-injury due to weakness in ROM and strength measures of ice hockey athletes. The fourth objective of this project was to ensure the hip screen was both valid and reliable by determining the reproducibility of the screen both over time and between investigators to determine the applicability of the screen to be used on a wider subject population and by different clinicians with repeatable results. The fifth objective of the project was to establish whether the ROM, strength and functional test performance increased, in individual measures and the overall screen, in participants who completed the season long strength and ROM based intervention programme.

In order to discuss the findings of this project in their entirety, it is important to revisit the injury prevention cycle previously discussed in detail in section 2.1.4 (page 12). The initial step of the injury prevention model adapted from van Mechelen et al. (1992) is to identify the injury problem within the specific population, as identified in Chapter Four which investigated incidence, severity, location and type of injuries sustained in ice hockey athletes, in particular those of a non-contact nature. Results showed the hip

complex to be the most commonly injured body location of the ice hockey athlete accounting for 36 of a total 72 (50%) non-contact injuries with the next most injured body location being the knee with only 9 (13%) injuries sustained. The high number of non-contact hip injuries may be explained due to the skating pattern of the ice hockey athlete, along with the repetitive nature of this movement, placing high loads through the vulnerable hip during both the push off and recovery phase of the stride, potentially increasing the athletes risk of sustaining a non-contact hip injury (Bizzini et al., 2007; Keogh & Batt, 2008; Philippon et al., 2010; Stull et al., 2011). Another major finding was that 82 injuries (48%) were reported to the team's medical staff but required the athlete to miss no ice hockey activity. This high number of injuries causing athletes to miss zero days may cause potential problems as it has previously been discussed in section 2.2.2 (page 20) that overuse injuries are caused by many micro-traumatic repetitive forces and without the correct recovery time may potentially lead to a more severe, long lasting, injury leaving many injuries theoretically avoidable if weaknesses are highlighted early (Collins & Raleigh, 2009; Fuller et al., 2006; Hreljac, 2004; Hreljac et al., 2000). Although further work needs to be performed to substantiate this theory, it was necessary to complete the second stage of the van Mechelen et al. (1992) injury prevention model by investigating the intrinsic risk factors of ROM, strength and functional characteristics of the ice hockey athlete's hip compared to another similar sport, soccer, and control participants to examine potential causes of the high number of non-contact hip injuries in ice hockey.

In addressing the second stage of the injury prevention model (van Mechelen et al., 1992) it was demonstrated that ice hockey athletes had a decrease in strength compared to soccer athletes in hip adduction (ice hockey 2.51 Nm/kg vs. soccer 2.79 Nm/kg), flexion in sitting (ice hockey 1.84 Nm/kg vs. soccer 2.06 Nm/kg) and external rotation (ice hockey 0.84 Nm/kg vs. soccer 0.93 Nm/kg). The decreased strength of ice hockey athletes was

important to consider due to the unique locomotion within ice hockey requiring high strength from these muscles with any pre-existent weakness, or on-going micro-trauma not reported to the medical team, potentially increasing the athlete's risk of injury due to the high load placed through the hip (Stull et al., 2011; Tyler et al., 2001; Upjohn et al., 2008). This, coupled with findings that higher calibre ice skaters achieve faster speeds whilst maintaining the same stride rate, further increases the risk of injury due to the higher load placed through the hip for each stride taken by the athlete (Bizzini et al., 2007; Chang et al., 2009; Philippon et al., 2010; Stull et al., 2011; Tyler et al., 2001; Upjohn et al., 2008). In previous work by Casartelli et al. (2011) it was demonstrated that non-sporting participants with a diagnosis of FAI injuries ($n = 22$) exhibited significantly lower muscle strength in adduction and external rotation compared to non-sporting participants without FAI injuries ($n = 22$). The knowledge that individuals with FAI display less adduction and external rotation strength, was important when considering the findings of Chapter Five as the associated weakness, and mechanics of ice skating, could therefore predispose ice hockey athletes to FAI injuries.

Additionally, Chapter Five demonstrated that ice hockey athletes exhibited significantly lower ROM in external rotation compared to both soccer athletes and control participants (ice hockey 28.97° vs. soccer 37.00° vs. control 45.55°). This implied that ice hockey athletes are at an increased risk of sustaining a non-contact injury due to a lack of external rotation ROM because this limited ROM has previously been observed in many athletes who presented with FAI injuries (Philippon et al., 2007b), however the cause and effect of such injury remains undetermined at this stage. The decrease in external rotation and adduction strength and external rotation ROM in ice hockey athletes compared to soccer athletes may be explained by the more frontal (adduction) and transverse plane (external rotation) loading of the hip during the unique ice skating stride, as opposed to the more sagittal plane movements employed within soccer (Davids, Lees, & Burwitz, 2000; Katis

& Kellis, 2010; Kellis & Katis, 2007). As previously discussed a lack of external rotation ROM observed in ice hockey athletes may be explained by not only the skating pattern repetitively forcing the hip into external rotation, but also as this movement is on a transverse plane it may be utilised more in ice hockey athletes as opposed to soccer athletes (Davids et al., 2000; Katis & Kellis, 2010; Kellis & Katis, 2007; Upjohn et al., 2008). Although soccer athletes commonly complete movements in the transverse plane, these are often unloaded, for instance the leg swing when kicking a ball, as opposed to ice hockey when hip external and internal rotation are completed under load with the athlete trying to reach maximal speed, and therefore, power through the hip which may further predispose them to injuries of a non-contact nature (Bizzini et al., 2007; Davids et al., 2000; Katis & Kellis, 2010; Kellis & Katis, 2007; Stull et al., 2011). Given the findings of Chapter Five it was surmised that both strength and ROM, particularly in external rotation and adduction, were important risk factors in the next stage of the injury prevention model aimed at improving such intrinsic risk factors (van Mechelen et al., 1992). However, it was determined that to complete the next stage of the injury prevention model with confidence that the results could be effective, efficient or clinically applicable (Van Tiggelen et al., 2008) it was necessary to create an injury screening procedure to not only potentially identify athletes 'at risk' of a non-contact hip injury but also to highlight those athletes who may have suffered from incomplete, or insufficient rehabilitation of previous hip injuries. Analysis of the efficacy of a screening procedure also allows clinicians/researchers to assess if it is likely to be successful before implementation. The hip screen was therefore created using the intrinsic risk factors highlighted within Chapter Five and analysed within Chapter Six and Seven aimed to ensure the intervention protocol was effective, efficient and repeatable between the same and differing users.

Chapter Six demonstrated that athletes who had sustained a previous non-contact hip injury scored significantly lower ($p < 0.001$) on the overall screen compared to previously

uninjured athletes (overall screen score; uninjured 51 vs. previously injured 42). This indicated that the newly created screen was sensitive enough to highlight athletes who had sustained a previous non-contact hip and was therefore likely to be of clinical usefulness. Previously injured athletes also displayed a significantly lower ROM on the Dom limb for hip internal rotation (uninjured 30.84° vs. previously injured 23.38°) and external rotation (uninjured 39.26° vs. previously injured 32.75°) and significantly lower flexion in sitting (uninjured 36.16° vs. previously injured 29.00°) and internal rotation (uninjured 30.11° vs. previously injured 24.38°) on the Ndom limb. The reported decrease in ROM of internal and external rotation not only potentially increases the risk of the athlete sustaining a future injury/re-injury but it was also unclear if the lack of ROM within previously injured athletes was present before the injury, and therefore, may have led to the injury in the first instance, or if it was evident due to the injury (Bizzini et al., 2007; Keogh & Batt, 2008; Philippon et al., 2010; Stull et al., 2011). Chapter Six also reported that strength measures in previously injured athletes were significantly lower in abduction (uninjured 2.00 Nm/kg vs. previously injured 1.68 Nm/kg) on the Dom limb and flexion in lying on the Dom (uninjured 1.53 Nm/kg vs. previously injured 1.30 Nm/kg) and Ndom limb (uninjured 1.56 Nm/kg vs. previously injured 1.27 Nm/kg) compared to uninjured athletes. The general decrease in strength displayed by previously injured athletes in Chapter Six, particularly flexion in lying and abduction, is of importance when again considering the ice skating stride as the hip flexors are a major stabiliser of the lower limb with the abductors acting as a mobiliser (Tyler et al., 2001; Upjohn et al., 2008). Thus, any associated weakness in strength of either the abductors or flexors may potentially place an athlete at an increased risk of injury due to the high load, and power, being placed through the musculature (Bizzini et al., 2007; Chang et al., 2009; Philippon et al., 2010; Stull et al., 2011; Tyler et al., 2001; Upjohn et al., 2008). As previously discussed in section 2.1.3 (page 7), the presence of a previous injury may cause

the athlete to suffer from a decreased ROM, strength and functional capabilities further increasing their risk of injury/re-injury (Bahr & Holme, 2003; Bahr & Krosshaug, 2005; Hewett et al., 2005a; Holder-Powell & Rutherford, 2000; Murphy et al., 2003). It can, therefore, be surmised that uninjured athletes who also score relatively low on the hip injury screen may be classed as 'at risk' due to the weakness shown when completing the screening protocols.

With the successful creation of the screening protocol assessed in Chapter Six it was necessary to ensure that clinicians and medical teams who implement the injury screen can replicate and be confident that their findings are clinically significant and not due to testing error. It was reported in Chapter Seven that the hip screen was indeed repeatable and reliable in terms of both intra (tester 1 ICCs: 0.76 & 0.68; tester 2 ICCs: 0.91 & 0.85) and inter-tester (ICC: 0.81) reliability. A further finding was that the values of $SWC^{absolute}$ and $MCC^{absolute}$ for both intra (tester 1: $SWC^{absolute}$ 0.83 points, $MCC^{absolute}$ 3.78 points, tester 2: $SWC^{absolute}$ 0.56 points, $MCC^{absolute}$ 2.53 points) and inter-tester ($SWC^{absolute}$ 0.65 points, $MCC^{absolute}$ 2.94 points) reliability were low for the overall screen score, giving clinical values of worthwhile and probable significant changes due to the intervention, as opposed to measurement error (Kempton et al., 2013). The low figures of $SWC^{absolute}$ and $MCC^{absolute}$ reported were important as it allows clinicians and medical teams to view any increase or decrease above the $SWC^{absolute}$ or $MCC^{absolute}$ figure as clinically significant, and they can be confident that type I or II error has not occurred. This knowledge that the increase/decrease can be viewed as clinically probable or significant could have an impact when disseminating the injury screen, attempting to alter clinical practice and reduce the amount of non-contact hip injuries.

With the knowledge of the type of injuries sustained by ice hockey athletes gained from Chapter Four, the potential intrinsic risk factor differences seen in ice hockey athletes in

Chapter Five and the efficacy and reliability of the hip screening protocol in Chapters Six and Seven it was necessary and appropriate to implement the intervention programme in the next stage of the injury prevention model (Van Tiggelen et al., 2008). The intervention protocol (section 3.7, page 80) aimed at improving the ROM, strength and functional capabilities and was completed in Chapter Eight. All groups (IHC, IHI and IC) improved their post-intervention ROM and strength following the intervention period, although when assessing the percentage change between groups it was determined that the IHI group saw larger percentage increases than the IHC and IC groups in internal rotation ROM (IHI; Dom 17.7%, Ndom 22.0%, IHC; Dom 5.1%, Ndom 7.6%, IC; Dom 5.7%, Ndom 14.2%) and external rotation ROM (IHI; Dom 25.0%, Ndom 19.7%, IHC; Dom 22.9%, Ndom 7.7%, IC; Dom 6.5%, Ndom -4.4%). The larger increases seen in internal and external rotation ROM by the IHI group suggest that the intervention did have a positive effect upon 'risk' movements previously identified within ice hockey. A positive effect when considering that ice hockey athletes with FAI injuries previously presented with a lower internal rotation ROM compared to athletes who were not injured (Bizzini et al., 2007; Keogh & Batt, 2008). In addition, the IHI and IHC groups exhibited larger percentage increases than the IC group, in terms of internal and external rotation ROM, over the intervention period suggesting that the ice hockey activity completed by the IHI and IHC group (e.g. on ice training and off-ice ice hockey specific training), or the increased length of the intervention period, may have had a greater impact upon the ROM measures than the intervention programme alone. The IHI group also benefited from large strength percentage increases of hip adduction on the Dom limb (10.8%) compared to the IHC group (2.2%) and the IC group (-3.4%) along with Ndom hip abduction (IHC 7.4% vs. IHI 17.2% vs. IC -0.3%) suggesting that again the intervention exercises positively benefited the ice hockey athletes that took part. As previously discussed these increases in internal and external rotation ROM and adduction and abduction strength in the IHI

group would be of benefit when considering the skating pattern as the ‘push off’ phase requires high strength from the abductors and external rotators with stability provided by the adductors (Tyler et al., 2001; Upjohn et al., 2008). The noticeable increase in internal rotation ROM will also aid recovery of the limb during the skating pattern allowing greater force production and a more effective skating technique, along with potentially decreasing the potential risk of sustaining a FAI injury (Bizzini et al., 2007; Chang et al., 2009; Keogh & Batt, 2008; Tyler et al., 2001; Upjohn et al., 2008). It was also presented that the IHI group improved in their post intervention overall screen score (pre 48 vs. post 52) above the value of the $MCC^{absolute}$ of 3.78 points reported in Chapter Seven. This was higher than both the IHC (pre 49 vs. post 48) and the IC group (pre 48 vs. post 49) with neither group increasing above the $SWC^{absolute}$ or $MCC^{absolute}$ value. The increase seen above the $MCC^{absolute}$ value within the IHI group following the implementation of the intervention protocol provides evidence that the improvement displayed was possibly due to the intervention exercises as opposed to error within measurement or testing procedures due to the calculation of $MCC^{absolute}$ values (Kempton et al., 2013). Therefore, this increased performance seen in the IHI group in the hip injury screen following the intervention programme may have a positive effect upon both non-contact injury risk and ice hockey athletes who have previously sustained a non-contact hip injury identified in Chapter Six, however future work to track these athletes and injury prevalence would need to be undertaken to substantiate this assertion.

The results of Chapter Eight displayed that the injury prevention programme was somewhat efficient and effective and although specific measures of ROM and strength did not significantly increase using traditional statistics, they did increase when using measures of clinical significance with ice hockey athletes who completed the intervention exercises benefiting from a decreased injury screen score, potentially decreasing their risk of sustaining a non-contact hip injury. The effectiveness of the intervention programme

cannot be measured in full within the current project as it does not return to the first step of the van Mechelen et al. (1992) model of injury prevention where the successfulness of the intervention programme in preventing injuries would be accurately assessed. However, what the current project does offer to clinicians, researchers and medical teams is a method of assessing the function of the ice hockey athlete's hip and their potential risk of sustaining a non-contact hip injury. The current project also offers an intervention programme aimed at decreasing the likelihood of such an injury along with providing figures to ensure clinical meaningfulness and the ability to disseminate both the hip injury screen and intervention programme.

9.2 Limitations

It is relevant to discuss the limitations of the current project as a whole before presenting overall conclusions. The initial epidemiological study (Chapter Four) may have benefited from being in more depth and expanded to include specific types of non-contact injuries (e.g. FAI injuries) enabling a greater understanding of the injury problem faced by ice hockey athletes. Although the frequency, severity and type (contact or non-contact) of injury was considered, having specific knowledge of injuries sustained to the hip of ice hockey athletes would further inform and optimise the hip injury screening procedures with the intention of hopefully identifying those athletes classified as 'at risk'. Unfortunately this was not possible within the current project due to the retrospective nature of the injury audit and data collection methods of the different colleges used. If the current project allowed the time to complete a full and complete injury audit, with data collected prospectively using the injury audit form (Appendix A), the results of Chapter Four would have been more useful and representative of the true injury problem faced by ice hockey athletes. This completion of prospective data collection would have also allowed Chapter Four to present data relating to the exact mechanism of the injury along

with precise details of the injury giving a greater understanding of the most common types of injury, along with the already presented locations and severity of injuries sustained. When relating the available injury data presented within Chapter Four to the mechanistic details of ice skating there are some large presumptions made that may not be wholly accurate. Thus, gaining a clearer picture and therefore allowing more substantial links to the mechanistic details may have been possible allowing the current project to target problem injuries in more detail. Having the detailed knowledge of the injury problem could potentially have affected the direction taken of the current project as it may have allowed the subsequent chapters to focus on a specific injury, for example FAI, as opposed to concentrating on the hip as a whole joint to investigate potential weaknesses. This ability to focus on a specific injury may have also enabled the injury screen within Chapters Six and Seven and subsequent intervention programme within Chapter Eight to be more specific to the injury problem faced by ice hockey athletes. Thus, making both the screen and the intervention programme more accurate and potentially successful in targeting 'at risk' athletes and hopefully reducing the risk of injuries that ice hockey athletes are likely to sustain. Throughout the current project links are made between the aetiology and epidemiological results of injury to the skating mechanics of the ice hockey athlete suggesting this may be reasoning for the high number of non-contact hip injuries. However, the current project does not investigate the specifics of the skating mechanics and therefore all links are merely speculative. Completing a detailed analysis of the skating mechanics associated with ice hockey would help in the linking of injury aetiology and skating mechanics, if there exists a link, allowing future screening procedures and interventions to be more focused and potentially more successful.

It is also acknowledged that the hip injury screen (Chapter Six) demonstrated that previous non-contact hip injuries in ice hockey athletes had detrimental effects upon ROM, strength and functional capabilities but it did not allow the injury screen to

successfully identify previously uninjured athletes classified as ‘at risk’. This may have been achieved by tracking athletes who completed the hip injury screen longitudinally investigating the injury screen scores of athletes who went on to sustain an injury and those that did not. Thus, allowing the hip injury screen to be assessed for its ability to accurately predict those previously injured and uninjured athletes ‘at risk’ of sustaining a non-contact hip injury or showing the need for further development and optimisation of the screening procedures demonstrated within the current project.

A further limitation of the current project was that the intervention programme (Chapter Eight) used a relatively small sample of participants and could have benefited from using one team as an intervention group, and another team as the control group decreasing the possible effects of diffusion. Utilising a further ice hockey team as the control group, with the intention of decreasing diffusion effects, may have also allowed the efficacy of the injury prevention programme to be more accurately measured due to the potentially more accurate and reliable results. An additional limitation within the intervention programme was that the current project did not consider the athlete as an individual and instead classed all ice hockey athletes together deploying the same intervention exercises across the IHI group. The individualisation of the intervention programme would allow the exercises to target specific weaknesses of the athlete highlighted within the hip injury screen affording greater chance of success in the reduction of injuries due to the potential increases of ROM, strength and functional capabilities of the individual athlete. If individualised the intervention programme could be made much more rigorous by implementing progression and regression for individual athletes allowing them to maximise their benefit from the programme. If progression of the exercises were permitted it may have allowed a greater difference to be seen between those participants who took part in the intervention and those who did not potentially giving more clinical significance. Although the individualisation and progression of injury prevention

programmes would be of benefit to the individual athlete, it would be difficult to assess the efficacy of such a programme and time consuming for clinicians and medical teams to implement, therefore continuous adaptation and optimisation would need to be performed. It would also have been advantageous to investigate the effects of the intervention programme upon those athletes that had sustained a previous non-contact hip injury of differing severities, especially in terms of physical improvement of measures but also taking into consideration psychological factors of completing the intervention programme. Thus, allowing the efficacy of the intervention programme to not only be tested for the increase in the screen score but also assessing the usefulness in terms of reducing previously injured and uninjured athletes 'risk' of future injury/re-injury. However, caution should be applied when aiming to increase strength of the lower limb musculature as although this may decrease non-contact injuries to the hip complex, the increased strength and power associated with the increases may allow athletes to generate more speed during ice skating. Although this greater skating speed is often desired by coaches and athletes the increase would presumably lead to amplified collision speeds therefore increasing the amount of the more prevalent contact injuries within the sport. Increasing the number of contact injuries within ice hockey may pose a larger problem than decreasing the number of non-contact injuries as the majority are to the head and face area which may be more detrimental to athletes general health than a non-contact hip injury (Agel et al., 2007b; Agel & Harvey, 2010; Flik et al., 2005; Jørgensen & Schmidt-Olsen, 1986; Kujala et al., 1995; Kuzuhara et al., 2009; McKay et al., 2014; McKnight et al., 1992; Pettersson & Lorentzon, 1993; Pinto et al., 1999; Schick & Meeuwisse, 2003; Tegner & Lorentzon, 1991).

Whilst the overall project goes some way to completing both the models of prevention by Van Tiggelen et al. (2008) and van Mechelen et al. (1992) it does not however complete either model fully requiring further work to close the prevention loop entirely. The final

stage of both models of prevention requires the effectiveness of the intervention put in place to be assessed and whilst the current project assesses the success of the intervention, in terms of variable changes, it does not return to the first stage of the injury prevention models and therefore cannot confidently suggest that injuries will be reduced due to the exercises employed. Although this would be the ideal next step of the current project it was unfortunately out of the remit of the current project because of difficulties in tracking athletes longitudinally due to both time constraints and athletes leaving the medical care of the College used for experimental testing.

A further limitation is the generalisability of the current project in that the injury audit, screening procedures and intervention programme are based on values from a very specific population of not only ice hockey athletes, but ice hockey athletes playing in Division III of the NCAA. Though the current project gives an insight into injuries and potentially how to identify and reduce them in this specific population it remains unclear how this would affect a different group of ice hockey athletes. Although this intuitively limits the application of the hip injury screen and intervention programme used within the current project it does have potential impact to all ice hockey athletes due to the nature of the ice skating stride employed by all ice hockey athletes. This skating pattern, although not measured and quantified within the current project, subjects ice hockey athletes' hips to large forces whilst in vulnerable positions making the hip injury screen and intervention programme applicable to all ice hockey athletes. The current project also highlights the potential need for specific injury screening as opposed to the more general screening often utilising the FMS protocol. Employing a specific injury screen to both the chosen sport and its common injuries, as the current project has done, allows much more focus and attention to be paid to the known problem areas within the sport making it more specific and useful to clinicians/researchers working within the sport. However, a problem with only creating an injury screen for non-contact hip injuries, as the current

study has, limits the findings of general weaknesses within the athlete, and therefore using a more global injury screen such as the FMS with apparently healthy athletes has its merits. Future works should look to create not only specific joint injury screens for athletes but also a general injury screen for ice hockey athletes that will allow clinicians/researchers to successfully highlight those athletes classed as at risk to multiple injuries and not just limited to a single joint.

An additional limitation of this project as a whole is the measurements of ROM and strength utilised within the screening process in Chapters Six, Seven and Eight along with the comparison of ice hockey athletes to soccer athletes within Chapter Five. As discussed at length within section 2.6 (page 56) using a standard goniometer is potentially not as accurate as using an electronic goniometer giving significantly different results it is however reliable and valid in test-retest assessments making this a viable option of ROM measurement. Similarly the measures of strength employed within the current project using the break force method with the hand-held dynamometer may have given slightly different readings compared to either the make force method or the more reliable and accurate isokinetic dynamometer. Although an isokinetic dynamometer could have given more accurate and reliable results of strength the hand-held dynamometer has previously been described as reliable and accurate, therefore making it a valid and useful measure of strength within the current project. Whilst both the standard goniometer and hand-held dynamometer are not the gold standard measure for either ROM or strength and therefore potentially not the strongest option from a measurement aspect, they are both reliable, accurate and valid measures that are commonly utilised within clinical practice and research. Thus, making the implementation of the screening procedures more accessible to teams and clinicians working within ice hockey. Nonetheless, to increase the generalisability of the findings of this project it may be a consideration to complete ROM and strength assessments of the ice hockey athlete's hips using an electronic goniometer

and isokinetic dynamometer in future works to gain a greater insight into deficits and potential weaknesses of the ice hockey athlete.

9.3 Future research

Perhaps the most major area of future works would be in investigating the temporal parameters along with an in depth analysis of the ice skating technique in athletes who have suffered with a previous hip injury and those that have not. As previously mentioned throughout the current project links are made between the aetiology and epidemiological results of the injury audit suggesting that the high occurrence of non-contact hip injuries is potentially due to the skating mechanics of ice hockey, however, such claims are unsubstantiated. Therefore, future works investigating the skating mechanics alongside epidemiological results would allow more clear links to be made, if any exist, between injury, or the potential for injury, and the nature of skating giving future screening procedures and interventions a more focused approach potentially making them more successful.

A further area of future research would be to continue to investigate the non-contact hip injuries in ice hockey to ascertain which specific injuries were most common and how many days they caused athletes to miss, therefore giving a greater understanding of their impact upon future injury/re-injury. This could be achieved by a hand search of individual medical records of athletes searching for non-contact hip injuries as opposed to grouping both contact and non-contact hip injuries together. Along with investigating the hip further it would be of benefit to track athletes longitudinally following the completion of the hip injury screen to see any trends within the screen by the athletes who subsequently went on to sustain a non-contact hip injury. The more detailed knowledge of the ice hockey athletes hip, along with data of athletes who went on to sustain an injury, would

enable further optimisation of the screening procedures to hopefully be sensitive enough to not only highlight athletes as 'at risk' of sustaining a non-contact hip injury but also specific weaknesses of the ice hockey athlete.

A final area of further research would be to enhance the intervention programme within the current project to ensure that it is as efficient and effective as possible. Modifications would include adding greater progressions to exercises to allow a constant improvement in areas of ROM, strength and functional capabilities along with expanding the participant number to incorporate more teams allowing consideration of the differing practice and game styles employed by different teams. As previously mentioned it may be of use to individualise the intervention programme to the specific athlete, targeting weaknesses exhibited within the injury screening procedures which may further positively benefit the athlete in terms of ROM, strength and functional capabilities along with additionally reducing their risk of injury. It would also be of interest to longitudinally track athletes who complete the intervention programme, particularly those with previous non-contact hip injuries, to investigate the long-term effects of the intervention programme allowing the further optimisation and development of the programme. Following the testing of the efficacy of the intervention programme with the suggested modifications it would potentially allow the identification of certain exercises to be adopted into regular ice hockey practice, hopefully seeing a reduction in the common non-contact hip injuries. This reduction of injuries would then need to be investigated via a further injury audit to assess if the intervention programme decreased non-contact hip injuries as well as improving intrinsic risk factors.

9.4 Conclusions

The conclusions of the current project are that ice hockey athletes were more likely to sustain a hip injury via a non-contact mechanism compared to other body locations during ice hockey activity. It is suggested that the unique style of locomotion impacts upon the ROM, strength and functional capabilities of the hip whilst placing the hip in potentially vulnerable positions further increasing the risk of injury. The newly created hip screen was deemed sensitive and repeatable making it potentially useful to clinicians and medical teams in highlighting athletes classed as 'at risk' of sustaining a non-contact hip injury and with further modifications, such as encompassing more structures, should lead to a greater understanding of an individual's risk of sustaining a non-contact hip injury.

The intervention programme utilised within this project increased ROM, strength and functional capabilities of ice hockey athletes who completed the exercises, though no significant differences were observed between intervention and control groups. However, the intervention programme increased the ice hockey athletes overall screen score and therefore it can be suggested that it was a success. Thus, making the intervention programme potentially useful for ice hockey athletes who are deemed as 'at risk' following the hip screening procedures. Although an increase was displayed in ice hockey athletes' screen scores following the intervention, the optimisation of the exercises may be necessary to personalise the prescribed programme to individual athletes utilising the screen results along with tracking the athletes longitudinally to assess the success of the intervention long term. Consequently the individualisation of the intervention programme may further increase the positive effect it has upon the ice hockey athlete's susceptibility to sustaining a non-contact hip injury by increasing the ROM, strength and functional capabilities of the hip.

Chapter Ten: Reference List

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Appendices

Appendix A Pre Exercise Medical Questionnaire

Appendix B Informed Consent form for Chapter Five (USA)

Appendix C Informed Consent form for Chapter Five, Seven and Eight (UK)

Appendix D Informed Consent form for Chapter Six and Eight (USA)

Appendix E Injury Audit Form for Chapter Four

Appendix F Intervention Programme (UK & USA)

Appendix A

Pre-Exercise Medical Questionnaire

The information in this document will be treated as strictly confidential

Name:.....

Date of Birth:..... Age:.....Sex:

Blood pressure: Resting Heart Rate:

Height (cm): Weight (Kg):

Please answer the following questions by putting a circle round the appropriate response or filling in the blank.

1. How would you describe your present level of exercise activity? Sedentary / Moderately active / Active / Highly active

2. Please outline a typical weeks exercise activity

.....
.....
.....

3. How would you describe your present level of lifestyle activity? Sedentary / Moderately active / Active / Highly active

4. What is your occupation?

5. How would you describe your present level of fitness? Unfit / Moderately fit / Trained / Highly trained

6. Smoking Habits Are you currently a smoker? Yes / No
How many do you smokeper day
Are you a previous smoker? Yes / No
How long is it since you stopped? years
How many did you smoke?per day

7. Do you drink alcohol? Yes / No

If you answered Yes and you are male do you drink more than 28 units a week? Yes / No

If you answered Yes and you are female do you drink more than 21 units a week? Yes / No

8. Have you had to consult your doctor within the last six months? Yes / No
If you answered Yes, Have you been advised not to exercise? Yes / No

9. Are you presently taking any form of medication? Yes / No

If you answered **Yes**, Have you been advised **not** to exercise?

Yes / No

10. To the best of your knowledge do you, or have you ever, suffered from:

10. To the best of your knowledge do you, or have you ever, suffered from:

- | | | | |
|--|----------|--------------------------------|----------|
| a Diabetes? | Yes / No | b Asthma? | Yes / No |
| c Epilepsy? | Yes / No | d Bronchitis? | Yes / No |
| e ★Any form of heart complaint? | Yes / No | f Raynaud's Disease | Yes / No |
| g ★Marfan's Syndrome? | Yes / No | h ★Aneurysm / embolism? | Yes / No |
| l Anaemia | Yes / No | | |

11. ★Are you over 45, and with a history of heart disease in your family? Yes / No

12. Do you currently have any form of muscle or joint injury? Yes / No

If you answered **Yes**, please give details.....

.....
.....

13. Have you had to suspend your normal training in the last two weeks? Yes / No

If the answer is **Yes** please give details.....

.....
.....

14. ★ Please read the following questions:

- | | | |
|----|---|----------|
| a) | Are you suffering from any known serious infection? | Yes / No |
| b) | Have you had jaundice within the previous year? | Yes / No |
| c) | Have you ever had any form of hepatitis? | Yes / No |
| d) | Are you HIV antibody positive | Yes / No |
| e) | Have you had unprotected sexual intercourse with any person from an HIV high-risk population? | Yes / No |
| f) | Have you ever been involved in intravenous drug use? | Yes / No |
| g) | Are you haemophiliac? | Yes / No |

15. As far as you are aware, is there anything that might prevent you from successfully completing the tests that have been outlined to you? Yes / No.

IF THE ANSWER TO ANY OF THE ABOVE IS YES:

- a) **Discuss with the test administrators or another appropriate member of the department.**
- b) **Questions indicated by (★) answered yes: Please obtain written approval from your doctor before taking part in the test.**

PLEASE SIGN AND DATE AS INDICATED ON THE NEXT PAGE

Participant Signature:Date.....

Test Administrator:.....Date.....

THIS SECTION IS ONLY REQUIRED FOR RETURN VISITS!

For any future testing sessions it is necessary to verify that the responses provided above are still valid, or to detail any new information. This is to ensure that you have had no new illness or injury that could unduly increase any risks from participation in the proposed physical exercise.

ANSWER THE FOLLOWING QUESTION AT EACH REPEAT VISIT.

Is the information you provided above still correct, and can you confirm that you have NOT experienced any new injury or illness which could influence your participation in this exercise session?

Repeat 1	Yes / No *	Signature:	Date:
* Additional info required:			
Repeat 2	Yes / No *	Signature:	Date:
* Additional info required:			
Repeat 3	Yes / No *	Signature:	Date:
* Additional info required:			
Repeat 4	Yes / No *	Signature:	Date:
* Additional info required:			
Repeat 5	Yes / No *	Signature:	Date:
* Additional info required:			

Appendix B

Participant Letter of Invitation



Project title	Investigating the ice hockey player's hip: Analysis of strength, range of movement and function.
Principal investigator	Name: Dr Rebecca Vince Email address: Rebecca.vince@hull.ac.uk Contact telephone number: 01482 463176
Student investigator (if applicable)	Name: Chris Wilcox Email address: c.wilcox@2006.hull.ac.uk/chris.wilcox@cumbria.ac.uk Contact telephone number: 07887 508818

Dear Sir,

This is a letter of invitation to enquire if you would like to take part in a research project at the University of Hull.




Before you decide if you would like to take part it is important for you to understand why the project is being done and what it will involve. Please take time to carefully read the Participant Information Sheet on the following pages and discuss it with others if you wish. Ask me if there is anything that is not clear, or if you would like more information.

If you would like to take part please complete and return the Informed Consent Declaration form.

Please do not hesitate to contact me if you have any questions.

Yours faithfully,

Chris Wilcox

Project title 	Investigating the ice hockey player's hip: Analysis of strength, range of movement and function.
Principal investigator 	Name: Dr Rebecca Vince Email address: Rebecca.vince@hull.ac.uk Contact telephone number: 01482 463176
Student investigator (if applicable) 	Name: Chris Wilcox Email address: c.wilcox@2006.hull.ac.uk/chris.wilcox@cumbria.ac.uk Contact telephone number: 07887 508818

What is the purpose of this project?

The hip has previously been highlighted as the most injured area of the body through non-contact during ice hockey activity and this study aims to analyse the strength, flexibility and function of ice hockey players hips to distinguish if there is a deficit common within ice hockey player's hips that predisposes them to injury during non-contact movements. These results gained will then be compared to soccer player's hip results to assess if ice hockey players in general have a different movement pattern or lack of strength, flexibility or functionality that increases the risk of injury.

Why have I been chosen?

We are looking for male NCAA ice hockey or soccer participants aged between 18-30 years of age to complete the study and we believe you may fit the criteria. To be suitable to participate, you must not have Any history of heart conditions or a family history of sudden death, any musculoskeletal and/or orthopaedic conditions, a current injury or history of fracture within the last year, uncorrected visual impairment, a recent history of dizziness or fainting, vestibular disorders, uncontrolled hypertension or suffer a shortness of breath with minimum exertion. Your eligibility for partaking in the study will be checked using a pre-exercise medical questionnaire.

What happens if I volunteer to take part in this project?

First, it is up to you to decide whether or not to take part. If you decide to take part you will be given this Participant Information Sheet to keep and asked to complete the written Informed Consent Declaration at the back. You should give the Informed Consent Declaration to the investigator at the earliest opportunity. You will also have the opportunity to ask any questions you may have about the project. If you decide to take part you are still free to withdraw at any time and without needing to give a reason and any data will be destroyed.

What will I have to do?

You will be required to attend Bethel University laboratory once. Each visit will last approximately one hour. Please attend wearing athletic clothing and footwear suitable for carrying out athletic activity.

The following will be completed at Bethel University:

1 – Height, mass, pre-exercise medical questionnaire and written Informed consent completed

2 – Warm up

- You will be taken through a 5 minute warm up on a static bike.

3 – Strength Testing

- 1 familiarisation trial + 5 maximal per tests on both limbs
- 1 minute rest period between trials as required

4 – Flexibility Testing

- 1 familiarisation trial + 3 maximal per test on both limbs
- 1 minute rest period between trials as required

5 – Functional Testing of the Hip

- 1 test per limb Once testing is completed

There will then be a rest period to allow close monitoring.


You will be asked to arrive in a fully hydrated state having consumed a standardised breakfast at least 1 hour before testing and will be asked to abstain from alcohol and strenuous exercise in the 24 hours preceding each visit. During the visit, you will be given a full briefing regarding the testing procedure and provided with the opportunity to ask questions. You will be deemed eligible to the study should you successfully complete the pre-exercise medical questionnaire and be free from all of the exclusion criteria, fulfil the criteria for inclusion and are willing

to provide written informed consent once you are satisfied with all that is expected of you and are happy to participate.


Measures of height and mass will be taken as part of the screening process. You will then be guided through the purpose of each of the test measurements before being asked to complete them. You will be taken through a 5 minute warm up and then will be taken through the strength testing to measure your muscular strength around the hip. You will be asked to complete one familiarisation and 5 maximal strength tests for the 6 main movements of the hip with a minute rest between tests for both your dominant and non-dominant limb. This will involve either lying or sitting and pushing into a machine that will be hand-held by the investigator.

The flexibility tests will then be completed and they will be used to assess your lower limb flexibility. You again will be asked to complete one familiarisation test and 3 test reps for 6 main movements of the hip with a minute rest between each test again on both limbs. You will be asked to move your limb into certain positions whilst the investigator measures the angle achieved.


The functional testing aims to measure the functional properties of your hip and the lower extremity. This will involve either you completing specific movements outlined by the investigator or having your lower limb moved into certain positions by the investigator. All of the functional tests will only be completed once per limb without the use of familiarisation movements and the investigator will ask if the movement brings about any pain or discomfort.

Will I receive any financial reward or travel expenses for taking part? 


No

Are there any other benefits of taking part? 


From the results, comparisons can be made to previously established normative values within the general population to determine how you compare. Whilst the measures are not diagnostic measures, any potential weaknesses may be identified by the student investigator which can be discussed at your request. The student investigator will be happy to offer any suitable advice on any lifestyle adaptations to make daily tasks easier.

Will participation involve any physical discomfort or harm? 


During testing there is a possibility of a trip or fall, musculoskeletal injury, fainting or cardiorespiratory problems however the likelihood of any of them occurring is remote. There may be some pain/discomfort during the functional mobility tests but this is expected to be very short lasting and the test will be stopped at your request.

Will I have to provide any bodily samples (e.g. blood or saliva)? 


No

Will participation involve any embarrassment or other psychological stress? 


No

What will happen once I have completed all that is asked of me? 

You shall be provided with a participant debrief sheet explaining what the purpose of the study was and a summary of your results in comparison to previously established normative values for each test. The investigator will then be more than happy to discuss the findings and answer any questions you may have. You will then be free of any commitments and not required for further testing in this study.


How will my taking part in this project be kept confidential? 

You shall be allocated an anonymous participant code that will be used to identify any data that you provide. Nobody other than the principal and student investigators have knowledge of this code. All data from the trials will be kept on a password encrypted computer, and a back up kept on a password encrypted laptop/memory stick. Informed consent forms and pre-exercise medical questionnaires will be kept separate from trial data in a locked office. All information and data gathered during this research will be stored in line with the 1988 Data Protection Act and will be destroyed 5 years following the conclusion of the study. During that time the data may be used by members of the research team only for purposes appropriate to the research question, but at no point will your personal information or data be revealed.


How will my data be used? 

All data will be totally anonymous and shall be used to form analyses along with the other participants' data to see the reproducibility of each of the tests. Data will be kept on a password encrypted computer, and a back up stored on a password encrypted memory stick and personal laptop belonging to the student investigator.


This data will only be used only by members of the research team. Results from this study will be used as data for a PhD thesis and possible research publication. Should the data be published or presented in any form you will not be identifiable. If you wish to receive a copy of any potential publication/presentation this will be made available at the earliest possible opportunity.

Who has reviewed this study? 

This project has undergone full ethical scrutiny and all procedures have been risk assessed and approved by the Department of Sport, Health and Exercise Science Ethics Committee at the University of Hull.

What if I am unhappy during my participation in the project? 

You are free to withdraw from the project at any time. During the study itself, if you decide that you do not wish to take any further part then please inform the person named in Section 18 and they will facilitate your withdrawal. You do not have to give a reason for your withdrawal. Any personal information or data that you have provided (both paper and electronic) will be destroyed or deleted as soon as possible after your withdrawal. After you have completed the research you can still withdraw your personal information and data by contacting the person named in Section 18. If you are concerned that regulations are being infringed, or that your interests are otherwise being ignored, neglected or denied, you should inform Dr Lee Ingle, Chair of the Department of Sport, Health and Exercise Research Ethics Committee, who will investigate your complaint (Tel: 01482 463141; Email: l.ingle@hull.ac.uk)

How do I take part? 

Contact the investigator using the contact details given below. He or she will answer any queries and explain how you can get involved.

Name: Chris Wilcox Email: chris.wilcox@cumbria.ac.uk Phone: 07887508818

Informed Consent Declaration 



Project title	Investigating the ice hockey player’s hip: Analysis of strength, range of movement and function.
Principal investigator	Name: Dr Rebecca Vince Email address: Rebecca.vince@hull.ac.uk Contact telephone number: 01482 463176

Student investigator (if applicable)	Name: Chris Wilcox Email address: c.wilcox@2006.hull.ac.uk/chris.wilcox@cumbria.ac.uk Contact telephone number: 07887508818
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Please

Initial

- I confirm that I have read and understood all the information provided in the Informed Consent Form (EC2) relating to the above project and I have had the opportunity to ask questions.
- I understand this project is designed to further scientific knowledge and that all procedures have been risk assessed and approved by the Department of Sport, Health and Exercise Science Research Ethics Committee at the University of Hull. Any questions I have about my participation in this project have been answered to my satisfaction.
- I fully understand my participation is voluntary and that I am free to withdraw from this project at any time and at any stage, without giving any reason. I have read and fully understand this consent form.
- I agree to take part in this project.

Name of participant	Date	Signature
Person taking consent	Date	Signature

Appendix C

Participant Letter of Invitation



Project title	Investigating the ice hockey player's hip: Analysis of strength, range of movement and function.
Principal investigator	Name: Rebecca Vince Email address: Rebecca.vince@hull.ac.uk Contact telephone number: 01482 463176
Student investigator (if applicable)	Name: Chris Wilcox Email address: c.wilcox@hull.ac.uk Contact telephone number: 01482 463052

[Click here to enter a date.](#)

Dear Sir or Madam

This is a letter of invitation to enquire if you would like to take part in a research project at The University of Hull.

Before you decide if you would like to take part it is important for you to understand why the project is being done and what it will involve. Please take time to carefully read the Participant Information Sheet on the following pages and discuss it with others if you wish. Ask me if there is anything that is not clear, or if you would like more information.

If you would like to take part please complete and return the Informed Consent Declaration form.

Please do not hesitate to contact me if you have any questions.

Yours faithfully,

Chris Wilcox

Participant Information Sheet




Project title	Investigating the ice hockey player's hip: Analysis of strength, range of movement and function.
Principal investigator	Name: Rebecca Vince Email address: Rebecca.vince@hull.ac.uk Contact telephone number: 01482 463176
Student investigator (if applicable)	Name: Chris Wilcox Email address: c.wilcox@hull.ac.uk Contact telephone number: 01482 463052

What is the purpose of this project?
The hip has previously been highlighted as the most injured area of the body through non-contact during ice hockey activity. This study aims to analyse the strength, flexibility and function of ice hockey players hips to distinguish if there is a deficit common within ice hockey player's hips that predisposes them to injury during non-contact movements. You will then be given exercises to complete over a six week period.

Why have I been chosen?
You have been chosen to be part of the control group and compared to ice hockey athletes due to your sporting background

What happens if I volunteer to take part in this project?
First, it is up to you to decide whether or not to take part. If you decide to take part you will be given this Participant Information Sheet to keep and asked to complete the Informed Consent Declaration at the back. You should give the Informed Consent Declaration to the investigator at the earliest opportunity. You will also have the opportunity to ask any

questions you may have about the project. If you decide to take part you are still free to withdraw at any time and without needing to give a reason.

What will I have to do? 

The following will be completed six times (three times by investigator A and three times by investigator B) prior to the commencement of the intervention programme:

1 – Height, mass, pre-exercise medical questionnaire and written Informed consent completed

2 – Warm up

- You will be taken through a 5 minute warm up.

3 – Strength Testing

- 1 familiarisation trial + 3 maximal per tests on both limbs
- 1 minute rest period between trials as required

4 – Flexibility Testing

- 1 familiarisation trial + 3 maximal per test on both limbs
- 1 minute rest period between trials as required

5 – Functional Testing of the Hip

- 1 test per limb Once testing is completed

You will be asked to arrive in a fully hydrated state having consumed a standardized breakfast at least 1 hour before testing and will be asked to abstain from alcohol and strenuous exercise in the 24 hours preceding each visit. During the visit, you will be given a full briefing regarding the testing procedure and provided with the opportunity to ask questions. You will be deemed eligible to the study should you successfully complete the pre-exercise medical questionnaire and be are free from all of the exclusion criteria, fulfill the criteria for inclusion and are willing to provide written informed consent once you are satisfied with all that is expected of you and are happy to participate.

Measures of height and mass will be taken as part of the screening process. You will then be guided through the purpose of each of the test measurements before being asked to complete them. You will be taken through a 5 minute warm up and then will be taken through the strength testing to measure your muscular strength around the hip. You will be asked to complete one familiarisation and 3 maximal strength tests for 4 movements of the hip with a minute rest between tests for both your dominant and non dominant limb. This will involve either lying or sitting and pushing into a machine that will be hand-held by the investigator.

The flexibility tests will then be completed and they will be used to assess your lower limb flexibility. You again will be asked to complete one familiarisation test and 3 test reps for all movements of the hip with a minute rest between each test again on both limbs. You will be asked to move your limb into certain positions whilst the investigator measures the angle achieved.

The functional testing aims to measure the functional properties of your hip and the lower extremity. This will involve either you completing specific movements outlined by the investigator or having your lower limb moved into certain positions by the investigator. All of the functional tests will only be completed once per limb without the use of familiarisation movements and the investigator will ask if the movement brings about any pain or discomfort.

Once the testing has been completed three times you will be required to visit the laboratory twice a week for the following six weeks to complete the intervention programme below:

Walking lunges – take a step and touch back knee on the floor, keeping a good core position flex torso forward to front knee. Lift leg back up and return to standing but drive back leg up into hip flexion in standing. Repeat on opposite leg. Complete 15 lunges on each leg (30 total)



Laying on back:

Hold back of knee and pull knee (behind knee) towards chest keeping straight leg in contact with the floor. Hold for 25 seconds x3, repeat on opposite limb.



Lift knees up together with feet on the floor. Then walk feet out sideways (maintaining knee contact) as far as possible. Hold for 25 seconds x 3 on each limb.



Lift knees up with feet still on the floor. Raise one foot and put it on the opposite knee and allow knee to drop towards floor. Hold for 25 seconds x 3 on each limb.



Lie with bum against a wall and legs vertically up the wall. Slowly let legs fall down as far as possible, hold for 25 seconds, then return back. Once back at the start position complete 15 reps (without holding at the end position). Once completed 15 reps hold at end position for another 25 seconds.



Following the successful completion of the intervention programme you will be required to complete the initial testing again once more.

Will I receive any financial reward or travel expenses for taking part? ⓘ

No.

Are there any other benefits of taking part? ⓘ

Only the increased strength and RoM associated with the above exercises. This is hopefully likely to reduce your risk of sustaining a non-contact hip injury.

Will participation involve any physical discomfort or harm? ⓘ

No.

Will I have to provide any bodily samples (e.g. blood or saliva)? ⓘ


No.

Will participation involve any embarrassment or other psychological stress? ⓘ

No.

What will happen once I have completed all that is asked of me? ⓘ

Your data will be kept anonymous and will be used for analytical purposes.

How will my taking part in this project be kept confidential? 


All participant information will be kept on a secure computer and will be kept under codes rather than your name. Only the principle investigator will know the codes for your results.

How will my data be used? 


Your data will be compared to that of ice hockey athletes to hopefully highlight any weaknesses that ice hockey athletes have.

Who has reviewed this study? 

This project has undergone full ethical scrutiny and all procedures have been risk assessed and approved by the Department of Sport, Health and Exercise Science Ethics Committee at the University of Hull.

What if I am unhappy during my participation in the project? 

You are free to withdraw from the project at any time. During the study itself, if you decide that you do not wish to take any further part then please inform the person named in Section 18 and they will facilitate your withdrawal. You do not have to give a reason for your withdrawal. Any personal information or data that you have provided (both paper and electronic) will be destroyed or deleted as soon as possible after your withdrawal. After you have completed the research you can still withdraw your personal information and data by contacting the person named in Section 18. If you are concerned that regulations are being infringed, or that your interests are otherwise being ignored, neglected or denied, you should inform Dr Andrew Garrett, Chair of the Department of Sport, Health and Exercise Research Ethics Committee, who will investigate your complaint (Tel: 01482 463866; Email: a.garrett@hull.ac.uk)

How do I take part? 

Contact the investigator using the contact details given below. He or she will answer any queries and explain how you can get involved.

Name: Chris Wilcox Email: c.wilcox@hull.ac.uk Phone: 01482 463052

Appendix D

Informed Consent

Bethel University

Investigating the ice hockey player's hip: Analysis of strength, range of movement and function. Informed Consent Form

You are invited to participate in a research study at Bethel University. Research studies are designed to gain scientific knowledge that may help other people in the future. You may or may not receive any benefit from being part of the study. There may also be risks associated with being part of research studies. Your participation is voluntary. Please take your time to make your decision, and ask your research staff to explain any words or information that you do not understand. The results will be used for a senior research project through the Biokinetics department of Bethel University.

1. Purpose and Explanation of Study.

The hip has previously been highlighted as the most injured area of the body through non-contact during ice hockey activity and this study aims to analyse the strength, flexibility and function of ice hockey players hips to distinguish if there is a deficit common within ice hockey player's hips that predisposes them to injury during non-contact movements. These results gained will then be analysed and you may or may not be given exercises to complete throughout the season.

The following will be completed at Bethel University (for all participants):

1 – Height, mass, pre-exercise medical questionnaire and written Informed consent completed

2 – Warm up

- You will be taken through a 5 minute warm up.

3 – Strength Testing

- 1 familiarisation trial + 3 maximal per tests on both limbs
- 1 minute rest period between trials as required

4 – Flexibility Testing

- 1 familiarisation trial + 3 maximal per test on both limbs
- 1 minute rest period between trials as required

5 – Functional Testing of the Hip

- 1 test per limb Once testing is completed

There will then be a rest period to allow close monitoring.

You will be asked to arrive in a fully hydrated state having consumed a standardized breakfast at least 1 hour before testing and will be asked to abstain from alcohol and strenuous exercise in the 24 hours preceding each visit. During the visit, you will be given a full briefing regarding the testing procedure and provided with the opportunity to ask questions. You will be deemed eligible to the study should you successfully complete the pre-exercise medical questionnaire and be free from all of the exclusion criteria, fulfill the criteria for inclusion and are willing to provide written informed consent once you are satisfied with all that is expected of you and are happy to participate.

Measures of height and mass will be taken as part of the screening process. You will then be guided through the purpose of each of the test measurements before being asked to complete them. You will be taken through a 5 minute warm up and then will be taken through the strength testing to measure your muscular strength around the hip. You will be asked to complete one familiarisation and 3 maximal strength tests for 4 movements of the hip with a minute rest between tests for both your dominant and non dominant limb. This will involve either lying or sitting and pushing into a machine that will be hand-held by the investigator.

The flexibility tests will then be completed and they will be used to assess your lower limb flexibility. You again will be asked to complete one familiarisation test and 3 test reps for 4 movements of the hip with a minute rest between each test again on both limbs. You will be asked to move your limb into certain positions whilst the investigator measures the angle achieved.

The functional testing aims to measure the functional properties of your hip and the lower extremity. This will involve either you completing specific movements outlined by the investigator or having your lower limb moved into certain positions by the investigator. All of the functional tests will only be completed once per limb without the use of familiarisation movements and the investigator will ask if the movement brings about any pain or discomfort.

Once the screen has been completed you will either be given no instructions or given a specific intervention programme. This program should be completed twice a week and will be monitored. The programme should be completed post on ice workout.

It is important to understand that you may stop the measurements when you wish because of feelings of uncomfortability or any other reason. If you experience any reason which compels you to stop the testing, you must immediately inform the testing personnel involved. Participants should inform the researchers of any emotional distress associated with reflecting on questions about body image. Referral to Bethel's Counseling Services ([651-635-8540](tel:651-635-8540)) is available for those participants wishing to talk with someone further about their reactions to the study questions.

2. Attendant Risk and Discomfort

I understand that I may experience some pain or discomfort during the functional mobility tests but this is expected to be very short lasting and the test will be stopped at your request.

3. Responsibility of Participant

The responsibility of the participant is to put maximal effort into all testing and report any feelings of pain/discomfort or apprehension to the researchers. All participants will complete strength testing, flexibility and functional tests of the hip and ice hockey players will additionally complete on ice skating tests.

4. Expected Benefits

From the results, comparisons can be made to previously established normative values within the general population to determine how you compare. Whilst the measures are

not diagnostic measures, any potential weaknesses may be identified by the investigators which can be discussed at your request.

5. Confidentiality

Any information obtained in connection with this study that can be identified with you will remain confidential. Any other disclosure will be only with your permission. In any written reports or publications, no one will be identified or identifiable and only aggregate data will be presented. The data received from the research will be retained for two years after the completion of the research and will be accessible at the request of the participants. The results of the study will be kept in a locked cabinet in the Biokinetics department throughout the remainder of the study.

Your decision whether or not to participate will not affect your future relations with Bethel University or with the researching parties Chris Wilcox and Chad Osgood in any way. If you decide to participate, you are free to discontinue participation at any time without affecting such relationships.

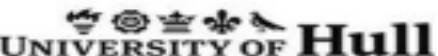
This research project has been reviewed and approved in accordance with Bethel's Levels of Review for Research with Humans. If you have any questions about the research and/or research participants' rights, please contact Chris Wilcox on +447887 508818 or chris.wilcox@cumbria.ac.uk or Chad Osgood on 651-638-6535 or chad-osgood@bethel.edu.

You will be offered a copy of this form to keep

You are making a decision whether or not to participate. Your signature indicates that you have read the information provided above and have decided to participate. You may withdraw at any time without prejudice after signing this form should you choose to discontinue participation in this study.

_____ Signature	_____ Date
_____ Signature of Witness (when appropriate)	_____ Date
_____ Signature of Investigator	_____ Date

Appendix E

 <p>UNIVERSITY OF Hull Department of Sport, Health and Exercise Science – Injury Audit Report Form</p>		
SECTION 1 – PLAYER INFORMATION		
<p>1.1 Date of Birth: DAY MONTH YEAR [] [] []</p> <p>1.2 Name: _____</p> <p>1.3 Position: Centre <input type="checkbox"/> Winger <input type="checkbox"/> Defence <input type="checkbox"/> Goalie <input type="checkbox"/></p> <p>1.4 Shoots/Catches: Left <input type="checkbox"/> Right <input type="checkbox"/></p>		
SECTION 2 – INJURY INFORMATION		
<p>2.1 Date of Injury: DAY MONTH YEAR [] [] []</p> <p>2.2 Date of Assessment [] [] []</p> <p>2.3 Activity: Training <input type="checkbox"/> Game <input type="checkbox"/></p> <p>2.4 Time of Injury:</p> <p style="margin-left: 20px;">Game – Warm up <input type="checkbox"/> 1st Period <input type="checkbox"/> 2nd Period <input type="checkbox"/> 3rd Period <input type="checkbox"/> OT <input type="checkbox"/> Penalty shots <input type="checkbox"/></p> <p style="margin-left: 20px;">Training – Warm up <input type="checkbox"/> 1st third <input type="checkbox"/> 2nd third <input type="checkbox"/> 3rd third <input type="checkbox"/></p> <p>2.5 Strapping: Yes <input type="checkbox"/> No <input type="checkbox"/> If yes, please specify _____</p>		
SECTION 3 – INJURY CLASSIFICATION		
<p>3.1 Injury Site: Left <input type="checkbox"/> Right <input type="checkbox"/> Upper Body Head <input type="checkbox"/> Neck <input type="checkbox"/> Shoulder <input type="checkbox"/> Elbow <input type="checkbox"/> Wrist <input type="checkbox"/> Hand <input type="checkbox"/> Chest <input type="checkbox"/> Abdomen <input type="checkbox"/> Upper Back <input type="checkbox"/> Lower Back <input type="checkbox"/> Face/cut <input type="checkbox"/> Ribs <input type="checkbox"/> Lower Body Hip <input type="checkbox"/> Groin <input type="checkbox"/> Thigh <input type="checkbox"/> Knee <input type="checkbox"/> Ankle <input type="checkbox"/> Foot <input type="checkbox"/></p> <p>3.2 Nature of Injury: Traumatic <input type="checkbox"/> Overuse <input type="checkbox"/> Bone _____ Fracture <input type="checkbox"/> Bruise <input type="checkbox"/> Ligament _____ Gd. I <input type="checkbox"/> Gd. II <input type="checkbox"/> Gd. III <input type="checkbox"/> Joint _____ Subluxation/Dislocation <input type="checkbox"/> Capsular Tear <input type="checkbox"/> Inflammation <input type="checkbox"/> Muscle _____ Strain <input type="checkbox"/> Total Rupture <input type="checkbox"/> Contusion <input type="checkbox"/> Other _____</p> <p>3.3 Injury Recurrence? Yes <input type="checkbox"/> No <input type="checkbox"/> If yes, previous injury date DAY MONTH YEAR [] [] []</p> <p>Return to full training date DAY MONTH YEAR [] [] []</p> <p>3.4 Invasive Procedure Required? Yes <input type="checkbox"/> No <input type="checkbox"/> Surgery <input type="checkbox"/> Injection <input type="checkbox"/> Suturing <input type="checkbox"/></p> <p>3.5 Diagnostic Investigation? Yes <input type="checkbox"/> No <input type="checkbox"/> If yes, please specify _____</p>		
SECTION 4 – MECHANISM OF INJURY		
<p>4.1 Contact: Making a hit <input type="checkbox"/> Taking a hit <input type="checkbox"/> Opponent infraction <input type="checkbox"/></p> <p>4.2 Non Contact: Shooting <input type="checkbox"/> Passing <input type="checkbox"/> Stopping <input type="checkbox"/> Turning <input type="checkbox"/> Blocking a shot <input type="checkbox"/> Trip/fall <input type="checkbox"/> Personal infraction <input type="checkbox"/> Skating <input type="checkbox"/></p>		
SECTION 5 – ADDITIONAL INFORMATION		
<p>5.1 Cessation of Training/Playing: Immediately <input type="checkbox"/> During training/game <input type="checkbox"/> Completed training/game <input type="checkbox"/></p> <p>5.2 Warm up prior to activity: Yes <input type="checkbox"/> No <input type="checkbox"/></p> <p>5.3 Cool Down following previous session: Yes <input type="checkbox"/> No <input type="checkbox"/></p>		
SECTION 5 – RETURN FROM INJURY		
<p>6.1 Return to full training/playing: DAY MONTH YEAR Expected/Actual [] [] []</p>		
FURTHER COMMENTS		
THANK YOU FOR YOUR ASSISTANCE IN COMPLETING THIS REPORT. For Enquiries/Clarification please contact Chris Wilcox on 07887508818 or C.Wilcox@hull.ac.uk		

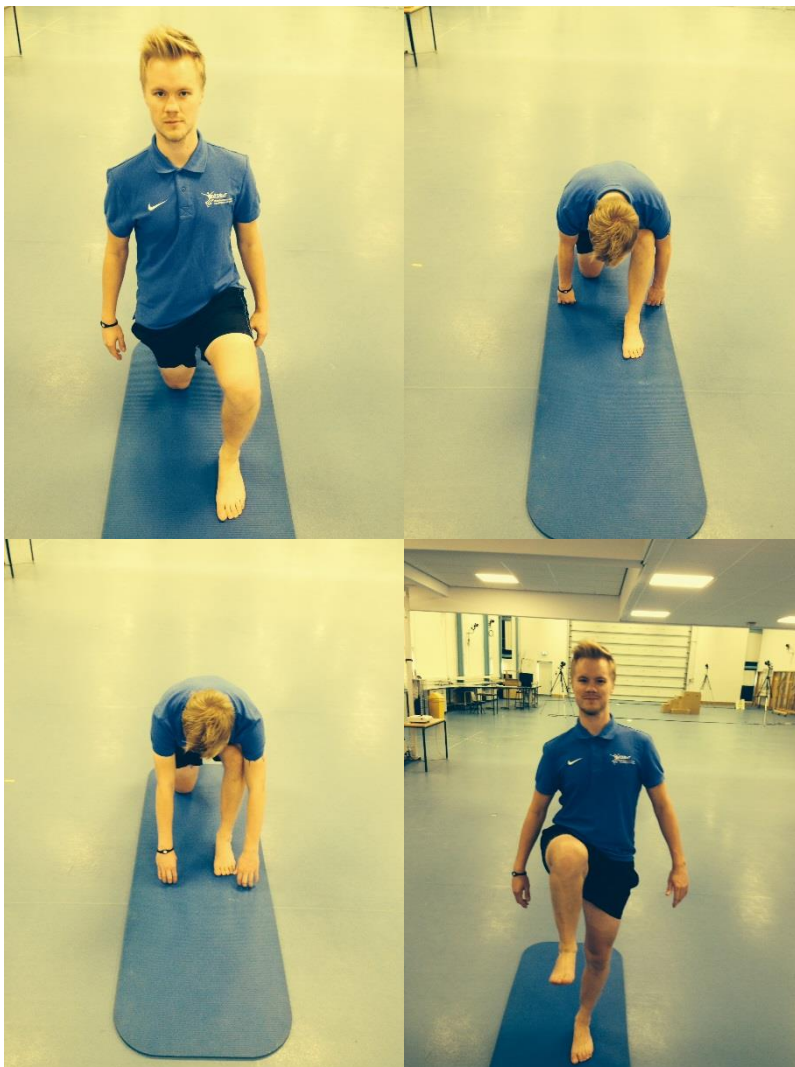
Appendix F

Hip Intervention Programme

By completing this intervention programme it is hoped that you will be reducing your risk of receiving a non-contact hip injury.

All exercises should be completed twice a week for the duration of the season. Please complete all exercises on both limbs (where applicable).

Walking lunges – take a step and touch back knee on the floor, keeping a good core position flex torso forward to front knee. Lift leg back up and return to standing but drive back leg up into hip flexion in standing. Repeat on opposite leg. Complete 15 lunges on each leg (30 total)



Laying on back:

- Hold back of knee and pull knee (behind knee) towards chest keeping straight leg in contact with the floor. Hold for 25 seconds x3, repeat on opposite limb.



- Lift knees up together with feet on the floor. Then walk feet out sideways (maintaining knee contact) as far as possible. Hold for 25 seconds x 3 on each limb.



- Lift knees up with feet still on the floor. Raise one foot and put it on the opposite knee and allow knee to drop towards floor. Hold for 25 seconds x 3 on each limb.



- Lie with bum against a wall and legs vertically up the wall. Slowly let legs fall down as far as possible, hold for 25 seconds, then return back. Once back at the start position complete 15 reps (without holding at the end position). Once completed 15 reps hold at end position for another 25 seconds.

