The design of a reliable musculoskeletal pre-participation screening and the establishment of normative data, epidemiology of injury and risk factors for injury in adolescent and collegiate Gaelic footballers and hurlers

A thesis submitted for the Degree of Doctor of Philosophy

by

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September 2014

Authors Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Doctor of Philosophy is entirely my own work, and that I have exercised reasonable care to ensure that the work is original, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

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Table of Contents

Abstract

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Background: An inherent risk of injury exists when partaking in sport. There is currently a lack of epidemiological and risk factor for injury studies in Gaelic games, particularly in the adolescent and collegiate populations, which is essential in developing strategies for managing injuries. In addition, there is very little normative data for screenings in these populations.

Aim: For adolescent and collegiate Gaelic footballers and hurlers: (i) design a reliable screening, (ii) establish normative data, (iii) investigate the epidemiology of injury and (iv) assess possible risk factors for injury.

Methods: A screening was designed and the reliability assessed. The screening was implemented and the epidemiology of injury was captured prospectively. Risk factors for injury were identified based on the screening and epidemiology information.

Findings: Hamstring flexibility, balance, scapular control and squatting technique were identified as areas requiring improvement in Study 1. Screening tests designed by the current researchers displayed good-to-excellent absolute and relative inter-tester and intra-tester reliability. Study 2 observed 4.873 and 14.512 injuries per 1,000 hours in adolescent and collegiate Gaelic footballers and hurlers, respectively. Injuries to the lower body were predominant (hamstring, knee and ankle). Injuries to the lower back were common in adolescent participants. Poor squatting technique was identified as a risk factor for lower body and hamstring injuries, with reduced internal rotation of the shoulder and a higher BMI a predisposing factor for upper body and shoulder injuries. A navicular drop of ≥10mm was found to predispose to knee injuries; however in adolescents a lower cut off point of between 6-7mm may be more appropriate.

Conclusion: Adolescent and collegiate Gaelic footballers and hurlers are susceptible to numerous risk factors for injury and injuries have been shown to be prevalent, therefore the design of injury prevention strategies in future research is critical.

List of Figures

List of Tables

List of Equations

List of Abbreviations

ACL	Anterior Cruciate Ligament
AICc	Corrected Akaike's Information Criterion
AKE	Active Knee Extension
ANOVA	Analysis of Variation
AUC	Area Under the Curve
BMI	Body Mass Index
CT	Computed Tomography
FMS	Functional Movement Screen
GAA	Gaelic Athletic Association
ICC	Intraclass Correlation Coefficient
κ	Kappa Coefficient
MRI	Magnetic Resonance Imaging
PKE	Passive Knee Extension
ROC	Receiver Operating Characteristic
RR	Relative Risk
SE	Standard Error
SEM	Standard Error of Measurement
SLS	Single Leg Squat
TRIPP	Translating Research into Injury Prevention Practice
2D	Two dimensional
3D	Three dimensional
%LL	Percentage Leg Length

Acknowledgements

To my supervisors Dr Kieran Moran and Dr. Noel McCaffrey. I greatly appreciate your invaluable support, guidance and words of advice throughout this PhD.

To the staff and postgraduates in the School of Health and Human Performance. Thank you for all your help and support throughout my time in DCU. You all made my time in DCU so enjoyable.

To the DCU and AIT students that assisted in the testing over the years. This project would have been impossible without you. Thanks to David Kelly, Jonny Cooper, Michael Donoghue, Anna Postawa and Ciaran O Cathain for their assistance with the testing. I greatly appreciate the time and effort you put into this project.

To the schools and colleges that took part in this project. A special thanks to the DCU and AIT GAA clubs, in particular Michael Kennedy, Dr. Niall Moyna and Garry Salmon for assistance and support in the recruitment phase.

To the Irish Research Council for Science, Engineering and Technology (IRCSET) and AIT for their funding to complete the project.

To all my friends, especially Aine, Niamh, Grace, Ruth, Nobby and Ailbhe. Thank you for your many distractions, you have no idea how much it helped me.

To the staff in Athlone Institute of Technology, especially Dr. Niamh Nic Cheilleachair and Diane Cooper. It would have been impossible to finish this without you both. Your constant motivation got me here in the end ☺

To Andy, thank you for all your help over the course of this PhD, between the Excel tutorials and dinners made for me your support has been invaluable. I am so grateful to have met you and you have never failed to cheer me up no matter what the stress levels ☺

Finally, thanks to all my family, in particular Mam and Deirdre for their constant moral support and daily motivation phonecalls. I will forever be appreciative of your help and advice, especially over the last few months. I'm finally all grown up ;)

Chapter 1. Introduction

1. 1. Background and Rationale for Research

Gaelic football and hurling (collectively known as Gaelic games) are Ireland's national sports and are overseen by the governing body, the Gaelic Athletic Association (GAA). While Gaelic games are primarily played in Ireland they also have a presence in Europe, North America, Australia and Asia (Blake et al., 2009). Gaelic football and hurling can last up to 70 minutes and consists of two opposing teams of 15 players (Wilson et al., 2007, Murphy et al., 2012a). Each team comprises of a goalkeeper, six defenders, two midfielders and six forwards. Both Gaelic football and hurling are played on a rectangular field of the following dimensions: 130-145m in length and in 80-90m in width. The aim of both games is to score more points than the opposition, a point is received if the ball goes over the crossbar, a goal if the ball goes under the crossbar, with a goal is equalling three points (Murphy et al., 2012b). Gaelic football and hurling are said to be multidirectional contact games that necessitates its players to perform at a high level of intensity and velocity (McIntyre, 2005). Gaelic football has been described as a mixture of soccer and rugby and is similar to Australian Rules football. Movements and skills essential to Gaelic football include sprinting, tackling, kicking, soloing (kicking the ball to yourself when running), shouldering (shoulder to shoulder charge when making a play for the football or tackling), jumping, turning and catching (Murphy et al., 2012b). Hurling on the other hand is similar to shinty, field hockey or lacrosse and participants use a stick called a hurley to hit a small hard leather ball known as a slioter (Murphy et al., 2012a). Movements and skills essential to hurling include sprinting, catching, striking (throwing the slioter into the air and hitting it using the hurley), shouldering, blocking the slioter with the hurley, soloing (running while keeping the slioter balanced or bouncing on the hurley) and hooking (using the hurley to prevent the opposition from swinging their hurley to hit the slioter) (Murphy et al., 2012a).

Approximately 2,000 GAA parish-based clubs exist throughout Ireland. Each club plays within their own county divisions, and depending on the team's success, can compete at provincial and all-Ireland levels. There are also elite inter-county teams, which consist of players from clubs throughout the county, who play each other on a league and championship basis (Blake et al., 2009). Players are divided into teams based on their chronological age. In the juvenile section, teams are divided into Under 10's, 12's, 14's, 16's and 18's (Minor). In the adult section, teams are divided into under 21's, Junior, Intermediate and Senior. Players aged above 21 are differentiated by standard and skill level with the lowest to highest standards the Junior, Intermediate and Senior teams, respectively. Players can also simultaneously play in school and collegiate competitions whilst participating with their parish based club. Thus whilst Gaelic games are considered amateur sports some of the elite teams can train and follow match schedules approaching professional standards (Blake et al., 2009, Murphy et al., 2012b). In addition, talented players may compete with numerous teams at different levels and competitions throughout the year.

Partaking in sport provides numerous benefits including: reducing the risk of developing and assisting the management of a number of hypokinetic diseases (including cardiovascular disease, diabetes, cancer and osteoporosis), preventing obesity, increasing self-esteem and providing a social platform for participants (Warburton et al., 2006, Schneider et al., 2006). However sport has an inherent risk of injury to the participant. Injury occurs when mechanical energy is placed on the body's tissues in rates or levels that exceed the human threshold for damage i.e. relative excessive force compared to the strength of the tissue (Meeuwisse et al., 2007, McGinnis, 2013). The trauma, pain and loss of function accompanying injury can be considerably detrimental to the participant, the team and the GAA and may cause time loss from sport, time loss from work, negative psychological effects, incur a cost to both the participant and the GAA due to medical and treatment costs and place additional pressure on accident and emergency rooms in hospitals due to serious injuries requiring out of hours scans (Junge and Dvorak, 2000, Murphy et al., 2012b). Injuries have been found to be prevalent in Gaelic games and have also been shown to have a long term effect on players with 20% of elite players on a single team forced into retirement from the game of Gaelic football due to a career ending injury and 17.5% forced to change their work career due to injury (El-Gohary et al., 2009). Nonetheless, the occurrence and magnitude of the effects of many injuries may be reduced with the implementation of injury prevention techniques and programmes (Schneider et al., 2006, Meeuwisse et al., 2007).

Only recently has sports medicine professionals begun to publish epidemiological data on Gaelic games and these studies reported injury rates of between 51.2-64.0 injuries per 1000 hours of matches and 4.1-5.8 injuries per 1000 hours of training in Gaelic football, and 102.5 and 5.3 injuries per 1000 hours in matches and training, respectively in hurling (Murphy et al., 2012a, Wilson et al., 2007, Murphy et al., 2012b, Newell et al., 2013). However the amount of epidemiological studies specific to Gaelic games is relatively little in comparison to other sports. In Gaelic football six studies have evaluated injury rates, however these have been retrospective in nature (Cromwell et al., 2000, Brown et al., 2013) or else prospective over a short duration (Wilson et al., 2007, Newell et al., 2013, Watson, 1996b). Only a single study assessed epidemiological data in Gaelic footballers for more than one season (Murphy et al., 2012b). In relation to hurling only two studies have assessed injury incidence and both of these have been prospective over a single season (Murphy et al., 2012a, Watson, 1996a). Thus further data is clearly needed to conclusively assess the epidemiology of injury in both Gaelic football and hurling. Epidemiological data is primarily available for elite adult players (Murphy et al., 2012b, Murphy et al., 2012a, Newell et al., 2013, Cromwell et al., 2000) with a severe lack of data available for non-elite, adolescent or collegiate players. No epidemiological data is available specific to hurling injuries in the adolescent population and only a single study on Gaelic football injuries in adolescents has been published (Watson, 1996b). Given the large number of adolescents participating in these sports it is essential we have information on the epidemiology of injuries in this population. In addition, there is a lack of information on the epidemiology of injury in non-elite and collegiate participants in Gaelic games. Thus this PhD will examine the injury incidence of both Gaelic football and hurling injuries in adolescent and collegiate players in order to provide critical data in this area. Present literature highly recommends the standardisation of injury definition, methods of data collection, and methods of reporting data to ensure comparison not only between studies in specific sports but also between sports and countries (Chalmers, 2002). However at present this is not the case, both in epidemiology studies in Gaelic games and internationally in other sports with no clear consensus in literature on any aspects of methodological design and definition of injury which leads to serious inconsistencies in reported epidemiological data (Junge and Dvorak, 2000, Fuller et al., 2007c, Fuller et al., 2006, Brooks and Fuller, 2006). Therefore another aim of this PhD is to implement a high quality standardised epidemiological study to prospectively examine the injury incidence in Gaelic games.

Current literature in Gaelic football and hurling has focused on the epidemiology of injuries and have not as of yet followed on from this by comprehensively defining the injury mechanism and identifying possible risk factors to injury which is necessary in order to develop injury prevention programmes. Whilst the injury mechanism has been somewhat examined in three epidemiological studies (Murphy et al., 2012b, Wilson et al., 2007, Cromwell et al., 2000) they have not assessed the mechanism of injury to the recommended high standard. It is recommended that the injury mechanism definition includes information on the sport specific movement, the interaction between the player and opponent and both gross and specific biomechanical movements (Bahr and Krosshaug, 2005). Thus with regard to Gaelic games researchers should ideally note the sport specific movements that the player was undertaking during the injury (tackling, soloing, blocking, shouldering), whether foul play was involved and if this was punished by the referee (athlete becoming injured while committing or receiving a foul) the specific movement the player completed during the inciting event and whether it was contact or non-contact (e.g. landing, jumping, sprinting) and finally a precise description of that movement anatomically at the joint (e.g. valgus motion of knee, inversion of ankle) (Bahr and Krosshaug, 2005). Thus this study will aim to fully assess and examine the mechanism of injury in adherence with recommended standards in both adolescent and collegiate participants. Identifying the causative factors that could possibly contribute to injury is essential, however, in present literature on Gaelic football and hurling this is not addressed comprehensively. Only five studies have looked at possible risk factors for injury in Gaelic games and these studies are limited as they focused on a small number of possible risk factors for injury in a single particular injury (ankle, hamstring and hand injuries) (Watson, 1999, O'Sullivan et al., 2008, Lowther et al., 2012, Falvey et al., 2013). Only a single study assessed a larger number of risk factors for injury (flexibility, posture, clinical defects and previous injury) to all possible injuries however this study was not limited to Gaelic games and assessed soccer players which may have affected the results (Watson, 2001). Implementing a musculoskeletal pre-participation screening is a suggested method of identifying possible risk factors for injury in sport. Screenings are based on the premise that by implementing tests at the beginning of the season that evaluate an athlete’s ability to perform a certain task that assesses a specific risk factor for injury, it may identify possible modifiable risk factors for injury by demonstrating that those who perform poorly on this test would correspondingly sustain an injury in the following season (Maffey and Emery, 2006). However to date, there has been no standard musculoskeletal pre-participation screening developed to be used across all sports or specifically for Gaelic football and hurling (Maffey and Emery, 2006). Normative data is an essential component of any pre-participation screening as it is a standardised reference of results for each specific test in a comparable population and allows clinicians to compare their results with a similar population (Corkery et al., 2007) To date there has been no published normative data on the musculoskeletal pre-participation screening in Gaelic footballers or hurlers of any age group. Additionally there is a lack of normative data on the musculoskeletal pre-participation screening internationally in adolescent teenagers, especially within the Irish context. Furthermore the reliability (or the consistency of a test or measurement when the test is repeated or completed by a different tester) of specific tests within a musculoskeletal pre-participation is quite varied and differs greatly depending on testing protocol and equipment used (Cowley and Swensen, 2008, Hopkins, 2000). Therefore an additional aim of this study was to develop, provide normative data and assess the reliability of certain tests within a musculoskeletal pre-participation screening specific to Gaelic football and hurling in order to identify possible risk factors for injury in Gaelic games.

Chapter 2. Literature Review

2. 1. Introduction to Literature Review

As outlined in the previous chapter there is a clear need for further research examining the incidence of injury and possible modifiable risk factors for injury in adolescent and collegiate Gaelic footballers and hurlers. There is a lack of high quality research studies investigating the epidemiology of injury in Gaelic games which can have far reaching consequences on the standard of epidemiological data collected. This literature review will initially examine the injury description conveyed in Gaelic games research. Identifying possible modifiable causative factors for injury is an essential component of the both the TRIPP and van Mechelen models of injury prevention (Finch, 2006, van Mechelen et al., 1992) and so this literature review aims to examine potential risk factors for injury in Gaelic games. In light of the importance of risk factors for injury, musculoskeletal pre-participation screenings will be discussed. This chapter will evaluate the common tests included in screenings and establish their appropriateness, effectiveness and reliability. Disparity between gender/sex has been observed for injury incidence and performance in screening tasks due to differences in flexibility (Wang et al., 1993), strength (Lephart et al., 2002), biomechanics (Kerrigan et al., 1998, Kernozek et al., 2005) inherent anatomical differences such as greater q-angle (Woodland and Francis, 1992). Therefore a clear delimitation of this PhD research and therefore the review of literature is to consider male adolescents and collegiate Gaelic players only.

Injury prevention research should ideally utilise a six stage sequence of studies proposed by Finch (2006) called the "Translating Research Into Injury Prevention Practice" (TRIPP) model which is based on the original and most commonly used "sequence of prevention" model by Van Mechelen et al. (1992) (Figure 2.1). Initially researchers should gain an idea of the magnitude of the injury in the specific sport and population by identifying the incidence, prevalence and severity of injuries (van Mechelen et al., 1992, van Mechelen, 1997, Finch, 2006). Next the aetiology and mechanisms of sustaining injury in the sport is examined to identify risk factors for injury (van Mechelen et al., 1992, van Mechelen, 1997, Finch, 2006). Stage 3 is the development of the injury prevention strategy based on the risk factors for injury identified previously, stage 4 evaluates the effectiveness of the prevention strategy in an ideal scenario and stage 5 then assesses how these prevention strategies can be practically implemented into the sporting environment so that it is easily adopted by players and coaches alike (Finch, 2006). Finally the epidemiology of injury should be re-evaluated to assess the effectiveness of the injury prevention strategies (van Mechelen et al., 1992, van Mechelen, 1997, Finch, 2006). Thus the current study will abide by best practise suggested by these models by undertaking the first two steps in this sequence.

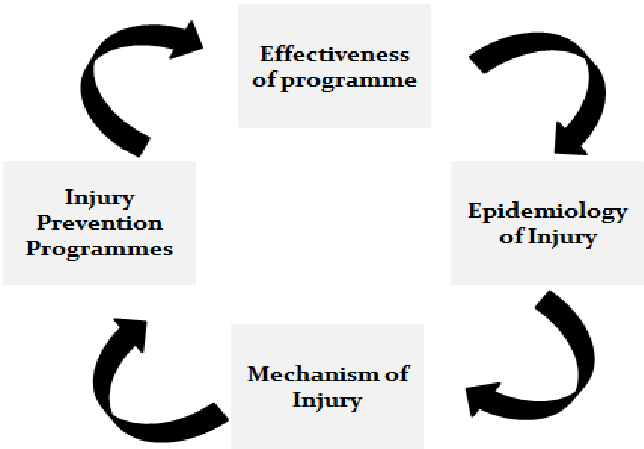

Figure 2.1: "Sequence of prevention" model for injury prevention studies adapted from van Mechelen et al. (1992)

2. 2. Epidemiology in Gaelic Games

2. 2. 1. The design of epidemiological studies in Gaelic games

Epidemiological studies in Gaelic games vary in their design, definition of injury, methods of data collection and observation periods, all of which can influence the epidemiological data collected (Junge and Dvorak, 2000). Table 2.1 highlights these differences in the seven prospective and two retrospective studies in Gaelic games and demonstrates the lack of standardisation in these studies. The method of data collection can greatly affect the standard and accuracy of the injury information collected. Medical examinations by a medical professional are considered the gold standard method of collecting injury data (Junge and Dvorak, 2000, Grossman et al., 1990), and at present, only three studies in Gaelic games epidemiology have utilised this method (Table 2.1). Ideally an injury report form accompanies the medical examinations to standardise the information gathered and ensure all aspects of the injury description is assessed (Hägglund et al., 2005).

The definition of injury should ideally be clear, well defined and standardised however no specific definition has been proposed or adopted by a large number of studies in any sport (Brooks and Fuller, 2006). In Gaelic games the definitions of injury vary greatly which can prevent direct comparisons of injury rate and injury descriptions (Table 2.1).

Two broad categories have been suggested in order to group the vast number of injury definitions: Medical Treatment definitions and Loss of Time definitions (Brooks and Fuller, 2006). Medical Treatment definitions include any injuries that necessitate treatment by a medical individual and include studies where insurance claims have been submitted, participants have been treated in hospital or by therapists associated with the team (Brooks and Fuller, 2006, Junge and Dvorak, 2000). These definitions are commonly utilised to measure the epidemiology of injury in short-term competitions (Clarsen and Bahr, 2014). The main advantage of a comprehensive Medical Treatment definition is that it incorporates all injuries that require treatment regardless of how minor the injury is and so is more likely to capture far more injury events than other injury definitions (Clarsen and Bahr, 2014). The Medical Treatment definition may misreport the true injury rate as some players may miss playing time in sport due to an injury but may not attend a medical assessment or session as they believe the injury will get better over time or may not have the finances to pay for an assessment. Loss of Time definitions are utilised more commonly in recent studies, in particular in team sports, long term prospective studies and can be further subdivided into "Loss of Time – fully inclusive" and "Loss of Time – semi inclusive" (Junge and Dvorak, 2000, Brooks and Fuller, 2006). "Loss of Time – fully inclusive" definitions include injuries that require the participant to miss training or competition and are frequently used in Gaelic games epidemiological studies. "Loss of Time – semi inclusive" definitions include injuries that require the participant to miss competition only (Brooks and Fuller, 2006). The frequency of matches, individual player pain thresholds and psychological factors may all contribute to a player's likelihood of being noted as injury using this definition (Brooks and Fuller, 2006, Junge and Dvorak, 2000, Clarsen and Bahr, 2014). In addition, players that continue training and playing matches but have a reduction in performance or modify their training in order to continue are not noted as injured (Clarsen and Bahr, 2014). Consensus statements in the area of epidemiology including soccer (Fuller et al., 2006) and rugby (Fuller et al., 2007c) propose the utilisation of an "all complaints" approach to defining injury; however this has not been utilised frequently in studies (Clarsen and Bahr, 2014). This definition requires the recording of all complaints including injuries that do not require medical treatment (Clarsen and Bahr, 2014). Thus as a larger proportion of injuries is captured using this definition, it is the ideal definition for use in an epidemiological study in adolescent and collegiate Gaelic footballers and hurlers.

Table 2.1: Epidemiological Studies in Gaelic games

Sport	Authors	Research Design	Participant Details	Injury Definition
Gaelic football	Murphy et al. (2012b)	Prospective Medical Assessment 4 seasons	Elite Adults Male 851	Injury that prevents a player from taking a full part in all training and match play activities typically planned for that day, where the injury has been there for a period greater than 24 hours from midnight at the end of the day that the injury was sustained
	Wilson et al. (2007)	Prospective Telephone Interview 6 months	Adult Male 83	Injury that caused a player to miss one training or match or that required at least one treatment
	Newell et al. (2013)	Prospective Medical Assessment 1 season	Elite Adults Male 511	Injury that caused player to be unable to participate fully in training or games for a period of at least forty-eight hours after the injury was sustained
	Watson (1996b)	Prospective Questionnaire 7 months	Adolescents Male 150	Any injury that occurred during Gaelic Football that restricted activity to any significant specified extent.
	Cromwell et al. (2000)	Retrospective Questionnaire 6 months	Elite Adults Male 107	Injury sustained during training or competition resulting in restricted performance or time lost from play
	Brown et al. (2013)	Retrospective Questionnaire Over playing career	Adult Female 74	Any injury that occurred during match or training in Gaelic football
Hurling	Murphy et al. (2012a)	Prospective Medical Assessment 1 season	Elite Adults Male 127	Any injury that prevents a player from taking full part in training and match play activities typically planned for that day, where the injury has been there for a period greater than 24 h from midnight at the end of the day that the injury was sustained
	Watson (1996a)	Prospective Medical	Elite and non-elite Adults	An injury occurring as a result of training for or participation in the game of hurling that resulted in incapacity to train or compete normally

		Assessment 8 months	Male 74	
Hurling & Camogie	Crowley et al. (1989)	Prospective Emergency Department 1 year	Adolescents and Adults Male & Female 817	Injury noted when athlete presented to the accident and emergency centre in the Cork Regional Hospital
All sports (including Gaelic football and hurling)	Watson (1984)	Prospective Questionnaire filled in by PE teacher 1 academic year	10-18 year olds Male & Female 6,799	An incident resulting in at least 1 day of incapacity or necessitating medical treatment

2. 2. 1. 1. Age of Population

Epidemiological data is primarily available for adult players in Gaelic games (Murphy et al., 2012b, Murphy et al., 2012a, Newell et al., 2013, Cromwell et al., 2000, Wilson et al., 2007, Brown et al., 2013) or older retired players (El-Gohary et al., 2009) with a severe lack of data available for adolescent or collegiate players (Table 2.1). No epidemiological data is available specific to hurling injuries in the adolescent population and only a single study on Gaelic football injuries in adolescents (mean=16.94 years) over one season has been published (Watson, 1996b). As the process of maturation is incomplete in adolescents, this may leave them susceptible to different types or an increased amount of injuries compared to adults (Yde and Nielsen, 1990). In addition, there are certain injuries occur specifically in adolescent populations including: Osgood-Schlatter disease at the knee, Sever's disease at the heel and Little league elbow (Adirim and Cheng, 2003), and the incidence of these injuries has not been identified in Gaelic games. During puberty an adolescent's height, weight and body composition changes substantially and this process begins typically aged 13 in adolescent males (Rogol et al., 2002). Male adolescents gain approximately 28cm during the pubertal growth spurt with peak height velocity commonly reached by 14 years (Rogol et al., 2002). Adolescents undergoing a growth spurt may have a rapid increase in bone length and male adolescents have been shown to accumulate substantial bone mineral after their growth spurt (between 15-18 years) and may only reach full bone mass in adulthood; this inherent weakness of adolescent bones has been suggested as a possible reason why adolescents are prone to developing fractures and avulsion fractures during sporting activity (Michaud et al., 2001, Rogol et al., 2002). In fact, fractures were found to be the second most common cause of injury in a study assessing school aged participants taking part in all sport in Ireland (Watson, 1984). The increase in bone length causes subsequent longer levers and possibly increases torque at the joints which can increase risk of joint injury in particular to ligaments (Quatman et al., 2006). This growth spurt has also been attributed to a loss of coordination which has been linked to an increased likelihood of developing injury (Michaud et al., 2001). Weight also increases substantially during puberty with male adolescents gaining 50% of their adult body weight during this time and peak weight velocity is similarly achieved by 14 years (Rogol et al., 2002). A change in body composition is also noted, with a maximal decrease in adipose tissue and increase in muscle mass occurring alongside peak height and weight velocity. This increase in skeletal size and muscle mass causes a consequential increase in strength in adolescent males (Rogol et al., 2002). In fact, a “neuromuscular spurt” is found in adolescent males, whereby their power, strength and coordination increase during maturation (Quatman et al., 2006). This increased power, strength, and coordination can affect the neuromuscular control of their lower extremities which may improve their sporting performance and performance in certain pre-participation screening tasks such as squatting techniques and balance tests. Knee valgus during functional tasks is considered a risk factor for injury, and it has been demonstrated that as male adolescents matured, they exhibited reduced knee valgus during the drop jump due to increased neuromuscular control (Schmitz et al., 2009). This indicates that adolescents who have undergone their neuromuscular spurt may be at reduced risk of knee injury. The influence of maturation on sporting performance has been assessed, with Malina (2005) reporting that male adolescents aged between 13-15 in advanced maturation perform better in four of the six soccer specific sporting tasks assessed, however the difference found was small. This increased sporting performance may be due to the increase in strength, power and coordination that was previously mentioned, but may also be associated with: increased aerobic capacity which occurs alongside peak height and weight velocity (Meylan et al., 2010, Pearson et al., 2006, Philippaerts et al., 2006), sprint speed (Pearson et al., 2006), speed of limb movement (Philippaerts et al., 2006), upper body muscular endurance (Philippaerts et al., 2006), agility (Philippaerts et al., 2006) and jump performance (Meylan et al., 2010, Pearson et al., 2006). These differences due to maturation stages may also correspondingly affect the players’ performance in a pre-season screening. Older male adolescents have been identified as at a greater risk of injury than younger males as their body size and muscular strength tends to be higher which consequentially causes them to be faster, heavier and stronger and so generate more force on impact which may increase the likelihood of injury (Caine et al., 2008). Parents, coaches and clinicians may worry that injury may damage the growing skeleton and tissues, and may possibly lead to permanent lasting damage, thus identifying the injury incidence and risk factors for injury is critical in adolescent Gaelic footballers and hurlers (Yde and Nielsen, 1990).

Conversely older players have also been theorised to be more prone to injury due to age related deficits, including the depletion of skeletal muscle mass as age progresses (Gabbe et al., 2006). Reduced range of motion due to repeated stress placed on the tissue over time may also contribute to a higher injury rate. The increased likelihood of previous injury in an older player may cause consequential deficits in strength, range of motion and proprioception and may increase the risk of sustaining another injury in the injured or different area (Maffey and Emery, 2006, Garrick, 2004). In fact, Arnason et al. (2004) found that older soccer players had a significantly increased risk of sustaining an injury in general and also injury specifically to the hamstring, which is a predominant injury in Gaelic football and hurling.

2. 2. 1. 2. Severity of Injury

The severity of injury is important to quantify as it can indicate the effect the injury has on the participant due to time loss from sport, work and cost of medical treatment (Junge and Dvorak, 2000). In Gaelic games, time lost from sport definitions have primarily been used, however the classification of severity varies between studies (Table 2.2). The majority of studies differentiate injuries into minor, moderate and severe, however the cut off points between moderate and severe varies. Minor injuries are classified as occurring between 1-7 days (Murphy et al., 2012b, Wilson et al., 2007, Newell et al., 2013, Cromwell et al., 2000, Murphy et al., 2012a) , with moderate injuries defined as injuries that last between 8-21 days (Wilson et al., 2007, Newell et al., 2013) or 8-28 days (Murphy et al., 2012b, Cromwell et al., 2000, Murphy et al., 2012a) and severe injuries have been identified as greater than 21 or 28 days. Watson (1996b, 1996a) reported severity of injury as a mean amount of days lost from sport by all participants, which is not ideal, as it does not provide a comprehensive view of the severity of injury. Moderate injuries are by far the most common severity of injury reported accounting for between 42-56% of injuries in Gaelic games (Table 2.2) (Murphy et al., 2012b, Newell et al., 2013, Cromwell et al., 2000, Murphy et al., 2012a, Wilson et al., 2007).

Table 2.2: Severity of injury in Gaelic games

Study	Severity classification	Severity definition	Severity reported
Gaelic football			
Murphy et al. (2012b)	Mild	1-7	13.2%
	Moderate	8-27 days	45.2%
	Severe	>28 days	41.6%
Wilson et al. (2007)	Mild	1-7 days	4.3 per 1000/h
	Moderate	8-21 days	6.4 per 1000/h
	Severe	>21 days	2.5 per 1000/h
Newell et al. (2013)	Mild	1-7 days	10.0%
	Moderate	8-21 days	56.0%
	Severe	>21 days	34.0%
Watson (1996b)	Mean time off sport	Mean±SD days	34.3±37.1
Cromwell et al. (2000)	Minor	1-7 days	38.0%
	Moderate	8-27 days	42.0%
	Major	>28 days	20.0%
Brown et al. (2013)	NM	NM	NM
Hurling			
Murphy et al. (2012a)	Mild	1-7 days	45.0%
	Moderate	8-27 days	45.5%
	Severe	>28 days	9.5%
Watson (1996a)	Mean time off sport	Mean±SD days	20.3±19.3

NM; Not measured. Per 1000 h; per 1000 hours

2. 2. 1. 3. Injury rate

There are three broad methods of reporting injury rates in epidemiology studies: absolute number, prevalence and incidence of injuries (Knowles et al., 2006). The prevalence of injury details the proportion of participants in a sport that are injured at a particular time and incidence indicates the number of injuries that occur during a specified time in a study (Knowles et al., 2006). The incidence is beneficial to note as it takes into account the exposure of different players (Brooks and Fuller, 2006). Injury incidence is analysed to help athletes, researchers and clinicians understand the amount of injuries that occur in sport. Incidence proportion measures the risk of injury or the probability that an injury will occur and this measurement is easily understood and explained to an athlete (Knowles et al., 2006). However, if a participant receives more than one injury throughout the testing period, it is only noted as one injured participant in this method and so repeat incidence proportion should ideally also be calculated (Knowles et al., 2006). Thus repeat incidence proportion could help an athlete already injured what is their risk of having another injury that season (Knowles et al., 2006). Incidence rate captures the rate of injury with respect to exposure to the sport and is usually expressed with respect to hours or athletic exposures (Knowles et al., 2006). This measurement can be of benefit to researchers and clinicians (Knowles et al., 2006).

Clinical incidence measures neither injury risk or injury rate but is beneficial as it assesses the frequency of injuries that occur within a given amount of participants (Knowles et al., 2006). Clinical incidence can assist clinicians and therapists, as it can help them understand the amount of injuries that will occur and may need to be dealt with during a specified time from a resource aspect (Knowles et al., 2006).Overuse injuries can be challenging to capture using these methods, as they are chronic in nature and have periods of worsening or lessening pain. In fact, athletes with jumper's knee have symptoms for an average of 32 months and only 25% developed the problem during the same season; this would lead to a misrepresentation with overuse injuries underreported by injury incidence (Lian et al., 2005).

While there is a wide variance of measures for incidence of injury in sport (Brooks and Fuller, 2006), injuries per 1,000 hours has been identified as the most common, ideal and useful method of assessing injury incidence (Bailey et al., 2010, Fuller et al., 2006) and is the predominant method used in Gaelic games (Table 2.3). Hurlers (102.5 per 1000 hours) display a higher incidence of injury in matches than Gaelic footballers (51.2 -64.0 per 1000 hours) (Table 2.3) (Murphy et al., 2012a, Wilson et al., 2007, Murphy et al., 2012b, Newell et al., 2013). This could be due to the increased physicality in hurling or that hurlers are not as physically fit as Gaelic footballers, and so the increased demands of the game may cause a higher risk of injury in hurling (Murphy et al., 2012a, McIntyre, 2005). In fact, hurlers have been found to have a higher percentage body fat, lower aerobic fitness, speed endurance and upper body strength than Gaelic footballers (McIntyre, 2005). There was an increased risk of injury in matches (17.5-64.0 injuries per 1000 hours) compared to training (3.1-5.8 injuries per 1000 hours) (Table 2.3) in Gaelic football (Watson, 1996b, Wilson et al., 2007, Murphy et al., 2012b), even though players spent 11 times more playing time in training than in matches (Murphy et al., 2012b). Similarly, injuries in hurling occurred more commonly in matches (102.5 and 34.2 injuries per 1000 hours) than training (5.5 and 4.3 injuries per 1000 hours) (Murphy et al., 2012a, Watson, 1996a). In fact, hurling matches were found to have 19 times a greater risk of injury compared to training (Murphy et al., 2012a). This is expected as there is an increased intensity during matches with larger physical and physiological stresses placed on the athlete which could increase the risk of injury (Yung et al., 2007). Foul play could also contribute as it would be expected to occur at a higher level during matches (Murphy et al., 2012a). Players could also put themselves in positions where an injury might occur, because of their desire to win the match (Wilson et al., 2007). Training is a controlled aspect of Gaelic games and while the low training injury rate is expected, injuries still occur during training. If players are training at a high level and playing a large amount of matches they may be at risk of overtraining and developing overtraining syndrome (Borresen and Lambert, 2009). Poor training techniques and unsupervised individual skill and gym sessions outside of normal trainings may also increase their risk of injury.

Gaelic football has a higher reported match injury rate than community level Australian rules football (20 injuries per 1000 hours) (Braham et al., 2004), professional soccer players (27.7 injuries per 1,000 hours) (Hawkins and Fuller, 1999) and high school soccer players (7.15 injuries per 1,000 hours) (Yard et al., 2008b). As mentioned previously hurling is alike to shinty, lacrosse and field hockey. Unfortunately limited information on shinty and men's field hockey is available to date, with only a single emergency department based epidemiological study completed in 1989 in shinty and no epidemiological analysis in men's field hockey. Hurling has a higher match injury rate than male collegiate lacrosse players (12.58 injuries per 1,000 hours) (Dick et al., 2007).

Table 2.3: Injury rate in Gaelic games

Study	Injury rate		
	Total	Match	Training
Gaelic football			
Murphy et al. (2012b)	NR	61.86 per 1000 h	4.05 per 1000 h
Wilson et al. (2007)	13.5 per 1000 h	51.2 per 1000 h	5.8 per 1000 h
Newell et al. (2013)	11.8 per 1000 h	64 per 1000 h	5.5 per 1000 h
Watson (1996b)	106.8 per 10,000h	175.98 per 10,000 h	31.06 per 10,000 h
Cromwell et al. (2000)	1.78 per player per year	NR	NR
Brown et al. (2013)	1.88 per injured player	NR	NR
Hurling			
Murphy et al. (2012a)	NR	102.5 per 1000 h	5.3 per 1000 h
Watson (1996a)	NR	342.47 per 10,000 h	43.83 per 10,000 h

NR; Not reported. Per 1000 h; per 1000 hours. Per 10,000 h; per 10,000 hours

2. 2. 2. The injury Description

2. 2. 2. 1. Onset of injury

Acute injuries are more prominent in Gaelic games with only 17.4% and 19% of injuries, overuse in nature in adult Gaelic footballers and hurlers, respectively (Murphy et al., 2012b, Murphy et al., 2012a). Only 0.5% of injuries were found to be chronic in nature in Gaelic footballers (Murphy et al., 2012b). Wilson et al. (2007) found that overuse injuries were the sixth most common type of injury and accounted for approximately 6% of injuries in adult Gaelic footballers. However, Cromwell et al.

(2000) did not report the injury rates for overuse injuries and Newell et al. (2013) actually removed the term overuse as an option in their study as they found the term vague and difficult to define, which is a serious limitation to both papers. New injuries were predominant in Gaelic games, accounting for 74.7% and 65% injuries in Gaelic football (Murphy et al., 2012b, Cromwell et al., 2000) and 85.4% of injuries in hurling (Murphy et al., 2012a). In Gaelic footballers, late recurrent injuries (2-12 months after initial return to full participation) were prevalent and accounted for 10.6% of all injuries, followed by early recurrent (<2 months) (6.9%) and delayed recurrent (>12 months) (6.3%). Structural damage like scar tissue or reduced proprioception of the injured area may last a lot longer than two months after the player returns to the sport. In fact, some injured tissues may never return to the pre-injured structural integrity and have an increased risk of injury for life, as is the case with players that undergo ACL reparative surgery (Hägglund et al., 2005). Further research on the incidence of overuse and recurrent injuries in adolescent Gaelic footballers and hurlers is essential as no information is currently available in this population.

2. 2. 2. 2. Injury Mechanism

Information surrounding the inciting event of an injury is essential to capture as it provides critical clues that indicate possible risk factors for injury that may assist with the development of injury prevention strategies. Non-contact injuries are predominant in Gaelic football accounting for 60% and 67.8% of injuries (Newell et al., 2013, Murphy et al., 2012b). Running, twisting, accelerating and decelerating were the most common non-contact mechanisms of injury, with collision with another player, being tackled and being struck by the opposition player the most common contact mechanisms of injury noted by Newell et al. (2013), however no indication of the percentage of injuries related to each mechanism was provided. No information on the mechanism of injury in hurling has been analysed to date, however in collegiate lacrosse players, a sport most similar to hurling with available epidemiological studies, noted that contact with another player accounted for 45.9% of all match injuries (Dick et al., 2007). Other contact with the ball, ground or stick and non-contact match injuries accounted for a similar percentage of injuries (26.7%, 26.4%) (Dick et al., 2007). In contrast, non-contact injuries (50%) were far more predominant during training. Table 2.4 demonstrates the top four mechanisms of injury reported in Gaelic games. Tackling (27.8%, 12.5%) has been proposed as a common mechanism of injury in Gaelic games (Wilson et al., 2007, Cromwell et al., 2000). One of the biggest attractions to Gaelic games is the physicality of the sports where players are allowed to aggressively tackle the opposition in order to win possession of the ball. In fact, players are allowed to shoulder (shoulder to shoulder hit) another player if the player is in possession of the ball or if both players are competing to win possession of the ball (Murphy et al., 2012b). Sprinting (26.8%, 14.4%, 13.0%), turning (12.0%, 13.3%, 18%) and landing (7.1%) have also been identified as common mechanisms of injury in Gaelic football (Murphy et al., 2012b, Wilson et al., 2007, Cromwell et al., 2000). During sprinting the sudden acceleration/deceleration or the excessive loading placed on the body's tissues during this high intensity movement may lead to an increased likelihood of injury (Newell et al., 2013, Murphy et al., 2012b). In addition, players with poor strength or flexibility may have a lower threshold for injury and so the high intensity sprinting motion may further lead to an increased likelihood of injury (Gabbe et al., 2006, Woods et al., 2007). Players with poor landing or cutting technique may have an increased valgus motion occurring at their knee which may lead to an increased likelihood of injury occurring during landing or turning (Weeks et al., 2012). In addition, poor balance and landing techniques could increase the likelihood of ankle injuries during landing (Plisky et al., 2006, Clark et al., 2010). Collisions have also been identified as a common mechanism of injury. While no specific epidemiological data on common mechanisms of injury in hurling is available, in male high school lacrosse players cutting or dodging accounted for 15% of injuries, legal body-to-body contact (i.e. tackling) was the mechanism for injury in 12% of injuries, followed by falling (11%) (Hinton et al., 2005). Thus further research on the mechanism of injury in hurling is needed.

Table 2.4: Top four most frequent mechanism of injury reported in studies on Gaelic games

Authors	Mechanism of Injury							
	1	%	2	%	3	%	4	%
Gaelic football								
Murphy et al. (2012b)	Sprinting	26.8%	Turning	12.0%	Landing	7.1%	Kicking	4.5%
Wilson et al. (2007)	Being tackled	17.8%	Sprinting	14.4%	Turning	13.3%	Tackling opposition	10.0%
Newell et al. (2013)	NR	NR	NR	NR	NR	NR	NR	NR
Watson (1996b)	NR	NR	NR	NR	NR	NR	NR	NR
Cromwell et al. (2000)	Collision	23.0%	Twist/Turn	18.0%	Running	13.0%	Tackle	12.5%
Brown et al. (2013)	NR	NR	NR	NR	NR	NR	NR	NR
Hurling								
Murphy et al. (2012a)	NR	NR	NR	NR	NR	NR	NR	NR
Watson (1996a)	NR	NR	NR	NR	NR	NR	NR	NR
Crowley et al. (1989)	NR	NR	NR	NR	NR	NR	NR	NR

NR; Not reported

2. 2. 2. 3. Body Part Injured

Lower limb injuries were found to be much more common in Gaelic games, with 70-77% of injuries occurring in the lower limb in Gaelic football and 70.1% in hurling (Cromwell et al., 2000, Murphy et al., 2012b, Wilson et al., 2007, Newell et al., 2013, Murphy et al., 2012a). Table 2.5 displays the top five most frequent sites of injury reported in epidemiology studies in Gaelic games. The hamstring, ankle, knee and groin were the most common sites of injury reported in Gaelic football and hurling (Murphy et al., 2012b, Wilson et al., 2007, Newell et al., 2013, Watson, 1996b, Cromwell et al., 2000, Brown et al., 2013, Murphy et al., 2012a, Watson, 1996a). The hamstring was the most commonly reported site of injury making up between 6.5-24% of injuries in Gaelic games (Murphy et al., 2012b, Wilson et al., 2007, Newell et al., 2013, Watson, 1996b, Cromwell et al., 2000, Brown et al., 2013, Murphy et al., 2012a, Watson, 1996a). The possible mechanisms of hamstring, ankle and knee injuries are outlined in Section 2.2.2.2. Groin injuries have been shown to be common in sports that require quick acceleration and sudden changes in direction which are inherent skills necessary in both Gaelic football and hurling (Maffey and Emery, 2007).

Only 5-34.7% of injuries occurred in the upper limb in Gaelic football and 15.2% in hurling (Brown et al., 2013, Cromwell et al., 2000, Murphy et al., 2012b, Newell et al., 2013, Murphy et al., 2012a). In contrast, the majority of injuries occurring in adolescent Gaelic footballers that presented to the emergency department occurred in the upper body (68%), in particular the hand (O'Rourke et al., 2007). Similarly, in an analysis of emergency department presentations in hurling and camogie players, the hand (36%) and face (22%) were the most common injuries (Crowley and Condon, 1989). The higher percentage of upper body injuries is because emergency department based studies inherently capture more serious injuries, and not the most common injuries in a sport, as predominantly suspected fractures or serious injuries present to the hospital. The most common site of injury in the upper limb was the shoulder (12%, 7% and 6.2% of injuries) (Cromwell et al., 2000, Newell et al., 2013, Murphy et al., 2012b). Injuries to the shoulder could be related to the high physicality of the game and may occur during the sport specific action of shouldering or else could be due to overuse during high catching and carrying of the ball during games (Cromwell et al., 2000).

Table 2.5: Top four most frequent sites of injury reported in studies in Gaelic games

Authors	Site of Injury							
	1	%	2	%	3	%	4	%
Gaelic football								
Murphy et al. (2012b)	Hamstring	24.0%	Knee	11.3%	Ankle	10.0%	Pelvis & groin	9.4%
Wilson et al. (2007)	Ankle	13.3%	Posterior thigh	12.2%	Anterior thigh	12.2%	Knee, Groin, Lower leg	8.0%
Newell et al. (2013)	Hamstring	22%	Knee	13%	Ankle	11%	Groin	9%
Watson (1996b)	Ankle	15.1%	Back	10%	Fingers	9.5%	Hamstring	6.5%
Cromwell et al. (2000)	Ankle	21%	Hamstring	13%	Knee	13%	Shoulder	12%
Brown et al. (2013)	Fingers	22.5%	Ankle & foot	19.4%	Knee	10.2%	Hamstring	8.2%
Hurling								
Murphy et al. (2012a)	Hamstring	16.5%	Ankle	9%	Groin	9%	Quadriceps	9%
Watson (1996a)	Finger	13%	Hamstring	12%	Back	9%	Knee/ankle, Back	9%
Crowley et al. (1989)	Hand	36%	Face	22%*	Leg	10%*	Ankle	9%*

NR; Not reported. *Computed from data in the study

2. 2. 2. 4. Nature of Injury

The most common tissues damaged during injury in Gaelic games and the different classifications of the nature of injury between studies are displayed in Table 2.6. Muscle injuries accounted for 33-49.1% of injuries, with muscle strains (23-42.2%) and bruises and contusions (6-27.8%) commonplace (Murphy et al., 2012a, Murphy et al., 2012b, Brown et al., 2013, Cromwell et al., 2000, Newell et al., 2013, Wilson et al., 2007, Watson, 1996a). The high incidence of muscle injuries could be related to the high incidence of hamstring and groin injuries reported in Gaelic games. Both muscle strains ($p<0.001$) and bruises and contusions ($p=0.01$) occurred more often in matches than training, with muscle strains three times more likely to occur in a match; this could be due to the increased physicality and higher intensity in matches (Newell et al., 2013). Ligaments were also susceptible to injury and ligament sprains could be related to ankle or knee injuries that are also common in Gaelic games. Fractures were not as common as other less severe injuries (Murphy et al., 2012b, Wilson et al., 2007, Cromwell et al., 2000, Murphy et al., 2012a) and were also statistically significantly more likely to occur in a match than a training session ($p<0.001$) (Newell et al., 2013).

Table 2.6: Nature of injury reported in epidemiological studies in Gaelic games

Nature of Injury	Murphy et al. (2012b)	Wilson et al. (2007)	Newell et al. (2013)	Cromwell et al. (2000)	Brown et al. (2013)	Murphy et al. (2012a)	Watson (1996a)
Classification	**GF**	**GF**	**GF**	**GF**	**GF**	**H**	**H**
Muscle	42.6	NR	NR	33.0%	35.5%	49.1%	NR
Ligament	13.2	NR	NR	32.0%	16.1%	15.2%	NR
Tendon	9.2	NR	NR	16.0%	6.1%	6.9%	NR
Bone	NR	NR	NR	NR	NR	17.2%	NR
Cartilage/meniscus	NR	NR	NR	3.0%	3.5%	0.4%	NR
Muscle strain	NR	23.3%	42%	NR	NR	42.2%	24.4%
Ligament sprain	NR	17.8%	26%	NR	NR	NR	15.6%
Bruises/contusion	NR	27.8%	17%	6.0%	13.0%	6.9%	16.3%
Fractures	4.4%	10.0%	NR	5.0%	12.9%	7.4%	NR

NR; Not reported. GF; Gaelic football. H; Hurling

2. 2. 2. 5. Further tests and surgery

The presentation of athletes to emergency departments places a huge burden on staff and resources. It has been shown that recreational sports injuries account for approximately 12.3% of all emergency department injuries and 68% of these required operative management. In fact, 10% of all operations in the hospital studied were due to sports injuries (Delaney et al., 2009). There has been no definitive studies completed on the amount and type of further tests required in injured Gaelic footballers and hurlers. It is commonplace for medical professionals to refer injured players for further tests to confirm the diagnostic evaluation or degree of severity of the injury. In a study on adolescent sports injuries presenting to the emergency department in a number of sports including Gaelic football, plain X-rays were ordered in 91% of cases. CT scans (0.6%) and blood tests (0.5%) were also required however no MRI or ultrasound examinations were ordered (O'Rourke et al., 2007). However since this evaluated injuries presenting in an emergency department the lack of MRI referral is expected. Thus a comprehensive assessment on the amount and type of further tests completed due to Gaelic football and hurling injuries, and the amount and type of operative and surgical interventions completed, may provide essential information on the burden of GAA related sporting injuries in Irish hospitals.

2. 3. Risk Factors for injury in Gaelic games

A risk factor for injury is any entity that contributes to the occurrence of a sporting injury (Maffey and Emery, 2006). Various research designs are utilised to assess injury risk, but two main categories exit; descriptive (case reports, cross sectional studies and correlational studies) or analytical studies (case control (case series), intervention and cohort studies) (Brooks and Fuller, 2006, Chalmers, 2002, Bahr and Holme, 2003). However, a cohort study is considered the gold standard method of assessing injury risk, as it is a prospective method of confirming a cause/effect relationship (Goldberg et al., 2007, Brooks and Fuller, 2006, Bahr and Holme, 2003). Meeuwisse et al. (2007) proposed a dynamic recursive model of sports injury that demonstrates the effects intrinsic (i.e. age, gender, previous injury) and extrinsic (protective equipment, playing environment, weather) risk factors for injury have on increasing injury risk (Figure 2.2). This model highlights the many risk factors that integrate to cause an athlete to become injured (Meeuwisse et al., 2007). It is essential to identify modifiable risk factors for injury in sport for the development of injury prevention strategies. Possible modifiable risk factors for injury are balance (Plisky et al., 2006), flexibility (Bradley and Portas, 2007), core stability (Cowley and Swensen, 2008), low fitness levels (McIntyre, 2005), poor technique (Meeuwisse et al., 2007), biomechanical factors (Meeuwisse et al., 2007) etc. To date a comprehensive examination of causative factors in Gaelic games has not been completed. Only five studies have looked at possible risk factors for injury in Gaelic games and these studies are limited as they focused on a small number of possible risk factors for injury in a single particular injury (ankle, hamstring and hand injuries) (Watson, 1999, O'Sullivan et al., 2008, Lowther et al., 2012, Falvey et al., 2013). Only a single study assessed a larger number of risk factors for injury (flexibility, posture, clinical defects and previous injury) to all possible injuries however this study was not limited to Gaelic games and also analysed soccer players which may have affected the results (Watson, 2001). In addition, three of these studies were completed in adult males (Watson, 2001, Falvey et al., 2013, Watson, 1999) and two with collegiate participants (O'Sullivan et al., 2008, Lowther et al., 2012), with no studies in the adolescent population. Thus it is essential that a comprehensive analysis of a large number of possible risk factors for injury in Gaelic games is needed, particularly in the adolescent population.

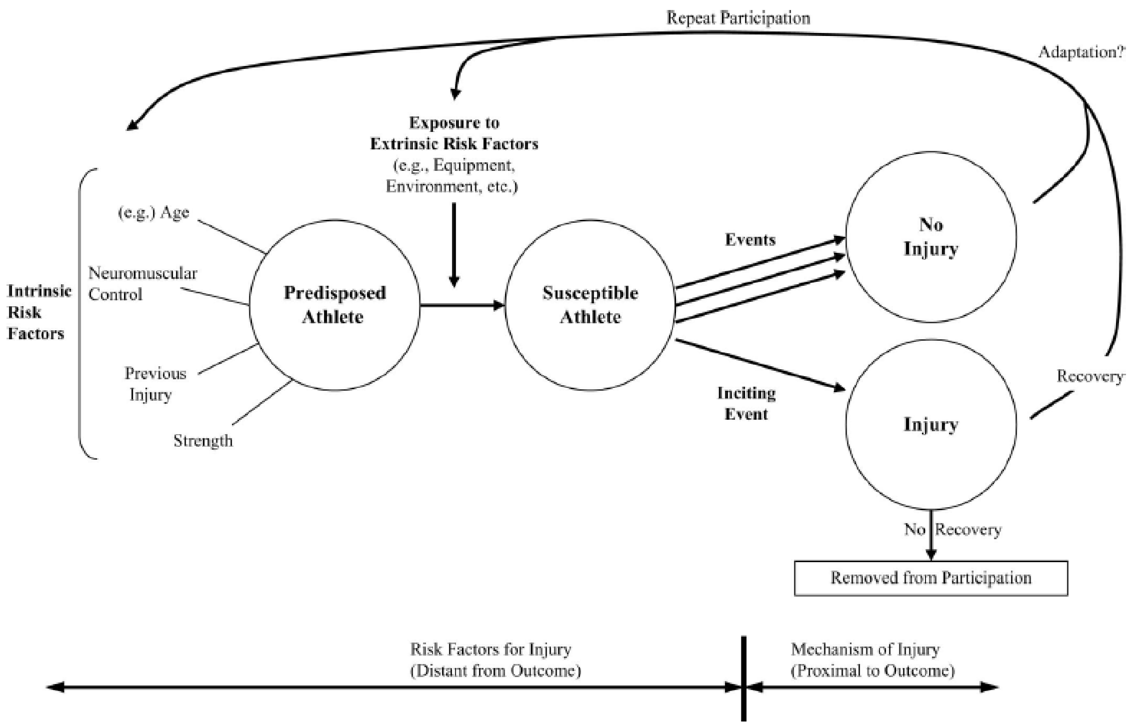

Figure 2.2: The Meeuwisse et al. (2007) Dynamic, Recursive model of Sport Injury

2. 3. 1. Possible risk factors from the injury event in Gaelic games

2. 3. 1. 1. Position on pitch

Certain playing positions may predispose to an increased risk of injury in Gaelic games. No statistically significant difference was found between injury rate due to playing position in Gaelic footballers or hurlers ($p>0.05$) (Watson, 1996b, Newell et al., 2013, Brown et al., 2013). No significant difference was found between outfield players in adult Gaelic footballers, however goalkeepers (7.14 per 1000 hours) were found to have a higher injury rate than half forwards (6.06 per 1000 hours) and half backs (5.05 per 1000 hours) in Gaelic footballers (Wilson et al., 2007). In contrast, midfielders had the highest and goalkeepers had the lowest proportion of injuries in relation to other playing positions in a prospective study on Gaelic football (Murphy et al., 2012b). A study on the physiological profile of elite Gaelic footballers found that midfielders were taller, had significantly higher body mass, higher maximal oxygen consumption and higher vertical jumping ability than backs and forwards. This suggests that their aerobic capacity, strength and power is enhanced compared to other positions (McIntyre, 2005). These physiological enhancements could be related to the nature of the game as midfielders in Gaelic football would be relied on to jump and catch high balls numerous times during a match, cover larger portions of the field and be a lot more physical by "shouldering" other players (McIntyre, 2005). Thus this high level of intensity and physicality may lead to an increased risk of injury in this playing position.

2. 3. 1. 2. Relative age

The age group in which a player competes and trains is important to categorise, especially in younger participants. Players are divided into teams and competitions based on their chronological age in Gaelic games which theoretically allows fair competition and a fair chance of success (Helsen et al., 2005). Unfortunately, there are no restrictions placed on young players to prevent them from playing at higher age levels, for example, a talented young under-16 Gaelic footballer may be required to play minor, under 21 and even senior standard depending on the club and player. This can greatly affect the development of a player which could predispose to injury or overtraining (Helsen et al., 2005). Even the restriction of separating players from under 12 to under 14 may be too general and there may be a significant difference in body type between a child just turned 12 and one who is just under the age restriction for under 14. The risk of playing outside a player's relative age has yet to be assessed in Gaelic games.

2. 3. 1. 3. Level of Playing

There is inconclusive consensus on the effect level of playing has on the risk of sustaining an injury in field sports. In rugby union it has been found that professional level rugby has the highest injury rate of all levels of competitions and that the injury rate increases as the competition grade increases (Bathgate et al., 2002, Bird et al., 1998). Similarly, elite high school rugby players were at a higher risk of injury in comparison to less elite players (odds ratio=2.12) (Richmond et al., 2012). In Australian rules football, which is similar to Gaelic football, elite players were found to have an increased risk of hamstring injuries compared to non-elite (Verrall et al., 2001). This increased risk of injury could be attributed to the longer and more frequent training sessions and higher match intensities (Verrall et al., 2001, Takemura et al., 2007) and the higher level of skill, fitness and experience required in elite players (Takemura et al., 2007). In contrast, lower level soccer players had a higher rate of injury despite their lower exposure rates as undertook on average half the amount of training hours (Peterson et al., 2000). A similar match exposure time was reported between both levels of play which may explain the discrepancy as injuries predominantly occur during matches (Peterson et al., 2000). Lower level players would have lower skill levels, less experienced in the sport, may not have the fitness levels required and may have higher body mass levels which may predispose to injury (Takemura et al., 2007, Richmond et al., 2012).

No direct comparisons in the same study have been made between level of playing and injury risk in Gaelic games. Elite Gaelic footballers were found to have higher match injury rates of 64.0 (Newell et al., 2013) and 61.8 injuries per 1000 hours (Murphy et al., 2012b) in comparison to non-elite players 51.2 injuries per 1000 hours (Table 2.3) (Wilson et al., 2007). Similarly, elite hurlers were found to have a higher incidence of injury (102.5 injuries per 1000 hours) (Murphy et al., 2012a) than non-elite players (34.2 injuries per 1000 hours) (Table 2.3) (Watson, 1996a). Further research to directly compare elite versus non-elite Gaelic footballers and hurlers is necessary to confirm these trends.

2. 3. 1. 4. Time of Season

Injury rates have been shown to change over the course of a season in field sports (Takemura et al., 2007). Seasonal bias in field sports suggests an increased amount of injuries in the preseason/early season (Takemura et al., 2007). This could be due to more enthusiastic play because of greater motivation early on in the season, insufficient match fitness levels and also decreased motivation in reporting injuries later on in the season (Takemura et al., 2007). In fact, players would tend to be under conditioned and playing an increased number of games with higher intensity. Thus if the body isn’t fit and able to handle the increased demands placed on it, it is more likely to become injured in response to these demands. However in Gaelic games the highest incidence of injuries occurred during April and June (Cromwell et al., 2000, Wilson et al., 2007, Murphy et al., 2012a, Crowley and Condon, 1989). Elite Gaelic footballers were found to have increased incidence of injury in June (Cromwell et al., 2000) and April and June (Wilson et al., 2007). Elite hurlers and hurling and camogie injuries that presented in the emergency department found the highest percentage of injuries occurring in April (Murphy et al., 2012a, Crowley and Condon, 1989). This is significant as April corresponds to the beginning of the competitive season and June corresponds to the beginning of the championship (Wilson et al., 2007). Consequently during these months enhanced demands are placed on the body which can lead to soft tissue failure and injury (Cromwell et al., 2000). During May the amount of injuries reported reduced and researchers theorised that this was due to a decrease in under-age matches during this month (Crowley and Condon, 1989). However, data on this is not conclusive and it is necessary to further prospectively analyse time of season and its likelihood for an increased risk of injury in both adults and adolescent players to clarify this issue.

2. 3. 1. 5. Time of Injury

The risk of injury has been shown to increase as the session progresses in Gaelic games. The majority of injuries occurred in the second half (56.9-60.8%) (Wilson et al., 2007, Murphy et al., 2012b, Murphy et al., 2012a) with significantly more injuries occurred in the final quarter ($p<0.05$) (Newell et al., 2013). In fact, 29.3%-38% of injuries were found to occur in the final quarter (Wilson et al., 2007, Murphy et al., 2012a, Newell et al., 2013) however, in contrast, Murphy et al. (2012b) found that the majority of injuries occurred in the third quarter (35.9%), followed by the second (29.1%) and the final quarter (23.1%). Fatigue is considered the primary contribution to the increased injury risk as it has been shown to reduce motor coordination, neuromuscular control and affect muscle mechanics of a participant (Wilson et al., 2007, Hawkins et al., 2001, Bahr and Holme, 2003). This injury risk may be further enhanced, when a fatigued player increases their efforts in order to compete in the last few minutes of a close game (Wilson et al., 2007). Anecdotally it has been suggested that a large amount of coaches include speed work and sprints at the end of a training session; thus an already fatigued player is required to complete a number of high intensity activities which can predispose to injury (Newell et al., 2013). A rule change to divide the game into four quarters rather than the two halves at present may be beneficial, as it would introduce more breaks and possibly reduce fatigue (Wilson et al., 2007). Introducing rolling substitutes (as seen in basketball) may also help reduce fatigue, as currently only a set number of substitutions may be made throughout a match in Gaelic games (Wilson et al., 2007). Coach education on appropriate methods of training and advice to introduce high intensity sprint sessions earlier in a training session may also reduce injury rates (Newell et al., 2013).

2. 3. 1. 6. Playing Surface

Gaelic games are played on two major different types of surfaces: natural grass and artificial turf. Grass is the traditional and most used surface, however as some astroturf pitches can be used in all weathers they are increasingly being utilised. Artificial turf has been shown to be harder than natural grass (Orchard, 2002) and a major review article found a 30-50% increased risk of lower limb injury on artificial turf (Skovron et al., 1990). In addition, it was also concluded that there is an increase in less serious injuries, a possible enhanced risk of severe knee and ankle injuries and found no difference in severe injuries on artificial turf when compared to grass (Nigg and Segesser, 1988). A higher incidence rate of 15.2 injuries per 10 games on field turf was found in high school athletes compared to 13.9 injuries per 10 games on natural grass, however this didn’t correspond to a longer time loss from sport and was associated with a higher incidence of surface or epidermal injuries (Meyers and Barnhill, 2004). Wounds, burns and friction injuries were also found to be more common on artificial turf in elite soccer (Ekstrand et al., 2006). However no major differences were noted between the incidence, severity, nature or cause of training or match injuries received on artificial turf or grass by male or female university soccer teams. (Fuller et al., 2007a, Fuller et al., 2007b).

Ground condition and ground hardness has been suggested as possible predisposing factors to injury. Ground hardness is a combination of soil structure, soil compaction and grass type and each of these factors can be moderated by weather conditions and usage of the pitch (Takemura et al., 2007). Some studies have shown an increased risk of injury with ground hardness including a study on non-contact ACL injuries (Orchard, 2001). Hard ground produces faster running speeds, quicker movements and greater external force placed on the body if a player falls which has been suggested as the reasons why it causes an enhanced injury risk (Orchard, 2002, Takemura et al., 2007). In Gaelic football the condition of the pitch was reported as being a factor in sustaining an injury in 29% of all cases (Cromwell et al., 2000). Dry/hard pitch contributed to the injury in 43% of cases, wet/soft in 39% and uneven in 18% of cases (Cromwell et al., 2000). In addition, poor state of the pitch was the most common cause of minor injury in school Gaelic football and accounted for 17.42% of injuries (Watson, 1996b). Thus the surface Gaelic games is played on could be a predisposing factor to injury and must be further assessed in Gaelic games.

2. 3. 1. 7. Weather conditions

Weather conditions have been suggested as a possible risk factor for injury however this has not been conclusively supported in literature (Orchard, 2002, Orchard and Powell, 2003, Gabbett et al., 2007). While weather itself may be statistically linked to reduced incidence of injury, it is not thought to directly affect the injury rate (Gabbett et al., 2007), as it is theorised that it is the weathers effect on ground conditions that directly influences injury rate (Gabbett et al., 2007, Orchard, 2002). Higher rainfall over the year was found to be significantly associated with lower injury rates, due to the softer ground conditions it produced (Gabbett et al., 2007). Orchard & Pollard (2003) found that cold weather was associated with a lower incidence of ACL injuries in both grass and artificial turf in American football. This was due to the fact that during warmer weather there was less rainfall and greater evaporation of water from the pitch surface which lead to harder ground surfaces and greater shoe-surface friction (Orchard and Powell, 2003). In addition, in hurling the majority of injuries occurred during dry conditions (66.7%) (Murphy et al., 2012a).

2. 3. 1. 8. Protective equipment

Protective equipment can be used to help prevent injury or re-injury in sport (Crowley et al., 1995). Recently the GAA implemented rule changes whereby there is a mandatory use of helmets in all levels of hurling and gum shields in Gaelic football. While these are positive steps taken by the GAA, they provide a relatively small amount of protection for the high physicality of these sports. In order for an injury prevention strategy to be effectively implemented and adopted by all in the Gaelic games community, the strategy must not alter the nature of the game or cause negative perceptions for players (Finch, 2006). Anecdotally it is suggested that players consider protective equipment to be quite restricting and some players believe it will reduce their performance due to this restriction in motion. With regard to helmets, 78% of players reported that comfort was paramount with 60.5% reporting the look of the helmet was vital (Hennessy et al., 2007). Significantly, only 40.6% reported the safety of the helmet as an important factor (Hennessy et al., 2007). The current usage of protective equipment among players in Gaelic games is essential, in order to understand current uptake of protective equipment. In a study completed before the rule change in Gaelic football, Cromwell et al (2000) found that 49% of footballers did not wear any form of protective equipment with gum shields (29%) and ankle supports (22%) the most popular type of protective equipment.

2. 3. 1. 9. Foul Play

Foul play is extensive across all cultures, levels and types of sport (Fields et al., 2007, Fields et al., 2010) and has been found to predispose to injury to various degrees in adolescent and adult soccer (Peterson et al., 2000, Chomiak et al., 2000) and high school soccer, American football, basketball, softball, volleyball and baseball (Collins et al., 2008). Foul play has been related to 35% of injuries in school Gaelic footballers, 10% in adult club level Gaelic footballers and 41% in adult hurlers (Watson, 1996b, Wilson et al., 2007, Watson, 1996a). In fact, foul play and recklessness were found to be the highest contributors to injury in Irish adolescents in sport (Watson, 1984). The behaviour players exhibit when fouling is commonly dismissed as part of the game and some coaches even encourage such play, despite the fact that if behaviour similar to this was to occur outside of a sporting event it would be deemed as violence (Fields et al., 2010). Therefore the attitudes of players and coaches to foul play can be a strong contributing factor in its related link to injury. Further research on the relationship between foul play and injury in Gaelic football and hurling is essential in order to develop injury preventative strategies to reduce the risk of injury due to foul play in the Irish context.

2. 4. The musculoskeletal pre-participation screening

Predisposing factors to injury may be identified not only from the injury event itself, but also from a musculoskeletal pre-participation screening (also known as a pre-participation examination, pre-season examination or a screening examination) completed by a therapist prior to the season commencing. The musculoskeletal pre-participation screening is purported to assist with the identification of possible modifiable risk factors for injury, and so, aid the development of a suitable injury prevention strategy and injury prevention programme to reduce the likelihood of an athlete receiving an injury in the impending season (Maffey and Emery, 2006). This musculoskeletal pre-participation screening differs from a medical screening or a physician based pre-participation screening as it does not include a cardiac assessment, a review of medications being taken by an athlete or an assessment of underlying medical conditions that may predispose an athlete to injury or require medical treatment before participation in sport (e.g. asthma, diabetes, eyesight, hearing, mental status etc) (Maffey and Emery, 2006, Carek and Mainous, 2003). Whilst the musculoskeletal pre participation screening is commonly completed internationally, as teams are under legal and insurance obligations to do so in the USA and Canada, in Ireland this is not an essential requirement (Carek and Mainous, 2003). In fact, in the United Kingdom the musculoskeletal pre-participation screening mainly occurs in elite teams and even then, fewer than 50% of soccer clubs (premiership and championship) and rugby union clubs (premiership) completed the screening (Fuller et al., 2007d).

There are significant costs associated with diagnosing and treating injuries and this places a huge financial burden on individual athletes, sporting bodies and emergency and surgery departments. In addition, sporting injuries may provide additional pressures on employers and individual athletes due to time loss from work. However the introduction of a screening and the resulting injury prevention programme may reduce the injury rates in sports and so decrease the negative aspects associated with injury. The screening may positively affect performance by optimising athletes' musculoskeletal health and ensuring athletes are at their physiological and biomechanical peak (Maffey and Emery, 2006). By interacting with the athletes prior to the season commencing, it is also possible for the therapist to develop a professional relationship and rapport with the athletes and coaches. Additionally it gives an excellent opportunity for the therapist to educate the team on injury prevention and injury treatment strategies (Maffey and Emery, 2006). It is imperative that the Irish healthcare system, sporting bodies and team therapists in this country begin to introduce means to prevent injuries in the sporting population and the screening is one method to accomplish this.

At present, no standardised musculoskeletal pre-participation screening has been developed specifically for Gaelic games or indeed generically for use across all sports (Maffey and Emery, 2006). At present, therapists are advised to examine the injury rates, mechanisms of injury, common locations of injury, biomechanical and physiological requirements of the sport to identify possible risk factors for injury (Maffey and Emery, 2006). Using this information, therapists are then instructed to research evidence based practice to identify adequate and reliable tests to examine these possible predisposing factors to injury (Maffey and Emery, 2006). Normative data is an essential component of any screening as it is a standardised reference of results for each specific test in a comparable population (Corkery et al., 2007). To date, there has only been a single published study on normative data in Gaelic footballers and hurlers (Fox et al., 2013), however, this was completed on adult players only and utilised the FMS protocol which has inherent serious limitations (Section 2.4.1.2). Thus, there is a clear need for research on normative data in adolescent and collegiate Gaelic footballers and hurlers. Additionally, there is a lack of normative data in screenings internationally in adolescent teenagers.

2. 4. 1. Components of the musculoskeletal pre-participation screening

The musculoskeletal pre-participation screening is composed of many different components depending on the sport, playing level of the team, time constraints, financial constraints, equipment available and qualifications and experience of the therapist completing the screening (Maffey and Emery, 2006). Garrick (2004) proposed that the screening should be accurate (high in sensitivity and specificity), practical in nature, suitable to apply to a large number of players, and the tests utilised must be safe to administer and acceptable to players. In addition, Miller & Callister (2009) suggested screening tests that are easily executed; measured, cost effective and utilise transportable equipment. Maffrey & Emery (2006) recommended that the screening should be completed within 45 minutes, a similar timeframe to an injury assessment by a therapist in a clinic. As time constraints are clearly evident with a screening, therapists may have to prioritize the most essential and sport specific components of the screening in order to provide a cost effective service and ensure compliance by players (Maffey and Emery, 2006). Various differing components of the screening has been suggested including: a neurological examination, range of motion, muscle strength, articular testing (joint glides), muscle recruitment and inhibition tests, ligamentous stability/laxity, posture, balance, core stability and functional assessments (assessing contralateral imbalances, muscle inhibition and compensatory strategies in squat, landing tests, lunge etc.) (Maffey and Emery, 2006, Chorba et al., 2010). There is a lack of consensus on aspects of the screening including: the included tests, the threshold for abnormality, the predictive value an abnormality has on the development of an injury and whether corrective exercises as an intervention actually prevents injuries occurring (Carek and Mainous, 2003) Furthermore, the reliability of a large number of commonly used clinical screening tests has not been established as of yet (Gabbe et al., 2004). Gabbe et al (2004) proposed that the tests chosen should be simple to execute, able to be implemented in various settings and utilise minimal and inexpensive equipment.

2. 4. 1. 1. Reliability and validity in a musculoskeletal pre-participation screening

Ideally any test utilised in a screening should have minimal measurement error (Atkinson and Nevill, 1998, Hopkins, 2000). Measurement error is the difference between the true and observed result (Hopkins, 2000). Poor reliability and validity contributes to increased measurement error (Hopkins, 2000) Reliability is the consistency of a test or measurement; is the observed value reproducible if the test is repeated or completed by a different tester (Cowley and Swensen, 2008, Hopkins, 2000). Validity is the ability of the test to actually measure what it is intended to measure; the agreement between the true and observed result (Kivlan and Martin, 2012, Hopkins, 2000). It is essential the reliability and validity of a test is established to accurately interpret the outcome of the test; if this is not completed, the test results may not only be dependent on the performance of the participant during the test, but also possibly due to bias and error (Cowley and Swensen, 2008, Cowley et al., 2009). High reliability and validity of all tests included in the screening is essential to accurately assess the susceptibility of injury of an athlete and to compare results between athletes in the same team and between teams, seasons and sports (Maffey and Emery, 2006). Unfortunately, Hopkins (2000) has noted that reliability and validity studies in the sports medicine context are rarely completed with a high methodological and statistical standard. In addition, Garrick (2004) highlighted the fact that studies have shown sensitivity of tests in the screening area that has only approached 50% and have commonly reported false positives and false negatives. It is recommended that all reliability and validity studies should utilise a sample group from a similar population to those who will complete the tests in any following studies in order to accurately generalise the results to the population to be tested (Kivlan and Martin, 2012).

A certain amount of error exists in any measurement and a measure should be deemed reliable if it has an acceptable level of measurement error (Hopkins, 2000). Error in measurement is usually attributed to two complications, systematic bias and random error (Hopkins, 2000). Systematic bias pertains to changes in a measure over time; three common sources of systematic bias are learning effect, training effect and motivation. Learning effect occurs when participants acquire the skills and movement required in the test in their initial testing session; thus in the following testing sessions their score may increase due to these acquired movement patterns and would not accurately reflect an increase in the measure being tested (Atkinson and Nevill, 1998). Training effect refers to tests that may be physically challenging; if inappropriate recovery time is provided between tests, fatigue may affect the results and so affect reliability (Atkinson and Nevill, 1998, Hopkins, 2000). Motivation may also contribute to systematic bias with participant's motivation to complete the test to the best of their ability affected by mood, athletic success or failure and interest or understanding of the relevance of the test or in fact the musculoskeletal pre-participation screening itself (Tse et al., 2005, Atkinson and Nevill, 1998). Random error on the other hand is due to biological or mechanical variation e.g. calibration error with equipment, changes in how the equipment functions, error in the implementation of the testing protocol by the tester and natural biological variability in tissues dependant on time (Cowley and Swensen, 2008, Shultz et al., 2013, Atkinson and Nevill, 1998, Hopkins, 2000). It is crucial that all researchers minimise and control for systematic bias and random error prior to and during all testing sessions (Atkinson and Nevill, 1998, Hopkins, 2000, Eliasziw et al., 1994).

Reliability studies in current literature utilise a number of different statistical measures including: pearson's product correlation, paired t-test, analysis of variation (ANOVA), intraclass correlation coefficient (ICC), regression analysis, standard error of measurement (SEM), limits of agreement, coefficient of variation, kappa, weighted kappa, Krippendorff's alpha (Atkinson and Nevill, 1998, Hopkins, 2000, Eliasziw et al., 1994, Fleiss, 1971, Hayes and Krippendorff, 2007). Reliability can be further subdivided in three different ways. Firstly, Baumgarter (1989) divided reliability into absolute and relative reliability (Atkinson and Nevill, 1998). Absolute reliability refers to the degree of variation between repeated results in a group of participants and is expressed either in the units of measurement of the variable itself or else a dimensionless ratio of that variable e.g. SEM, coefficient of variation, limits of agreement (Atkinson and Nevill, 1998). Relative reliability on the other hand is the degree that a participant maintains the same position in the group during repeated testing e.g. ICC, pearson's correlation coefficient, ANOVA, regression etc (Atkinson and Nevill, 1998). Within sports medicine research the most commonly used and recommended measures to assess absolute and relative reliability are the ICC and SEM statistics (Hayen et al., 2007). The ICC assesses the variation between cases in relation to the total variation in all observations in a sample; i.e. the greater the variation between or within testers the smaller the ICC value (Frohm et al., 2012). If no reliability exists, the ICC value will equate to 0, if there is no variation within or between testers an ICC value of 1 will occur (Frohm et al., 2012). SEM on the other hand looks at the repeated measurements and their relationship with the mean of the results. The SEM is beneficial as it is expresses in the units of the tested variable which allows researchers to understand the magnitude of measurement error within the test (Atkinson and Nevill, 1998). Secondly reliability may be subdivided into internal consistency and stability reliability which are differentiated by the timing of repeated testing (Atkinson and Nevill, 1998). When testing internal consistency, testing consists of a number of measures occurring during a single day (Atkinson and Nevill, 1998) Stability reliability on the other hand looks at the day to day variation in results and is the most commonly tested form of reliability (Atkinson and Nevill, 1998). Finally and most importantly in a clinical scenario, reliability may be assessed on its objectivity or ability of the tester/s to accurately capture the result of the test. When assessing reliability in this manner researchers evaluate the inter-tester (between tester) and intra-tester (within tester) reliability (Eliasziw et al., 1994). Inter-tester reliability measures the degree of similarity between the measurements taken by different testers (Hayen et al., 2007, Eliasziw et al., 1994). In contrast intra-tester reliability evaluates how consistent a tester is when repeatedly capturing a test's result (Eliasziw et al., 1994, Hayen et al., 2007).

2. 4. 1. 2. The Functional Movement Screen

Originally screenings were sport specific and aimed to identify specific factors that may predispose an athlete to injury. However, a popular screening system is The Functional Movement Screen (FMS^{TM}) (Cook, 2010, Cook et al., 2006a, Schneiders et al., 2011). In fact, the only normative data on a screening published in Gaelic games utilises the FMS screen on male adult Gaelic footballers and hurlers. The FMS is based on the assumption that identifiable alterations in the biomechanics of fundamental movement patterns can predispose to injury and that a participants ability to complete these movement patterns is dependent on integration of their muscle strength, flexibility, range of motion, coordination, proprioception and balance (Schneiders et al., 2011). The FMS consists of seven tests (deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push up and rotatory stability) that identify restrictions or changes in movement (Appendix Q). The aim of this screening is to challenge the mobility and stability of the body as a whole and the joint by joint interactions during fundamental functional movement patterns (Chorba et al., 2010, Schneiders et al., 2011, Cook et al., 2010). The FMS aims to capture the movement pattern quality with a grading system that can be used to demonstrate limitations of stability and mobility within the body (Cook et al., 2006a). The FMS tests necessitate a controlled neuromuscular movement and those who perform poorly in these tests have adapted inefficient movement strategies which may reinforce their poor movement patterns which may cause repetitive microtrauma and lead to an increased likelihood of developing an injury (Chorba et al., 2010). Each of the tests is marked out of a maximum score of 3 and the highest score for the three trials was recorded in each test, with a composite score is then produced by adding the results of each of the seven tests with the maximum value of 21. The lowest score was used in any of the tests that assess bilaterally e.g. hurdle step, in-line lunge, active straight leg raise (Cook et al., 2010). While the FMS is commonly used both in a clinical and research setting there is a lack of comprehensive inter and intra- tester reliability studies (Shultz et al., 2013). In fact, six studies assessed the reliability of these tests and the majority of these have been published quite recently; five studies examined inter-tester reliability and four studies also looked at intra-tester reliability (Appendix R). Within these limited studies consensus in reliability was not reached with excellent inter-tester reliability of 0.97 found in trained testers (Schneiders et al., 2011), 0.91 in untrained testers (Jade and Street, 2013) and 0.87-0.89 in a mixture of trained and untrained testers (Smith et al., 2013), good reliability of 0.74 found in novice testers (Teyhen et al., 2012) however Shultz et al. (2013) reported poor inter-tester reliability of (Kα=0.38) for the composite score for testers assessing the FMS. The intra-tester reliability ranged from excellent, with ICC’s of 0.81-0.91 (Smith et al., 2013) and 0.75 (Gribble et al., 2013) to good with ICC’s of 0.74 (Teyhen et al., 2012) and 0.60 (Shultz et al., 2013). Therefore consensus on the reliability of the FMS yet to be reached (Shultz et al., 2013).

A poor result in the FMS screening has been purported to lead to an increased risk of developing a lower extremity injury in the following season (Kiesel et al., 2007, Kiesel et al., 2011, Chorba et al., 2010, O’Connor et al., 2011). However there are few prospective large scale research studies completed on this topic in the sporting population. Kiesel et al. (2007) examined the relationship between FMS preseason composite scores and occurrence of injury in the following season found that those who scored 14 or below were at an eleven-fold higher risk of sustaining an injury. Kiesel et al. (2007) also noted that the probability of sustaining an injury increased from 15% to 51% if a participant received a score of 14 or less. Since this study additional research studies and clinicians worldwide have adopted this cut off point value of 14 proposed by Kiesel et al. (2007). Three prospective studies have supported the research proposed by Kiesel et al. (2007) in female collegiate athletes (Chorba et al., 2010), marine officer candidates (O’Connor et al., 2011) and firefighters (Butler et al., 2013a). Chobra et al. (2010) found a strong correlation (r=0.952) between the composite FMS score and lower limb extremity injury when the shoulder mobility test was removed. Subjects with a composite score of less than or equal to 14 were found to be significantly four times more likely to sustain an injury, with 69% of subjects sustaining an injury in the following season (Chorba et al., 2010). Both O’ Connor et al. (2011) in marine officer candidates and Butler et al. (2013) in firefighters found that a score of 14 or lower in the FMS had the ability to predict injury with O’Connor et al. (2011) identifying the tests had the sensitivity of 0.45 and the specificity of 0.71 in marine officer candidates (O’Connor et al., 2011) In addition to the three prospective studies an off season intervention programme was shown to increase the percentage of American football players who score greater than 14 in the FMS from 11% to 63% which perhaps indicates that an injury prevention programme can substantially reduce the risk of injury in players as the issues identified in the FMS are modifiable.

Researchers have identified a number of serious limitations with the FMS. The cut off value determined by Kiesel et al. (2007) has been, as mentioned previously, adopted by researchers and clinicians worldwide based on this single study, however, Kiesel et al. (2007) completed this research with a small sample size of 45 and with athletes of a single sport (American football). Thus the capability of generalising this cut off point to other sports is seriously questionable and researchers note that this cut off point should be used with caution (Schneiders et al., 2011). Three studies found that their mean composite normative results were under or very close to the 14 cut off point (Gribble et al., 2013, Smith et al., 2013, Schneiders et al., 2011). There is also a lack of research on sporting populations as studies were completed on convenience sample populations e.g. military, university students and fire fighters with a single study completed on Gaelic games in an adult population only. An additional serious limitation with the FMS is that no research has assessed the FMS scoring ability to predict injury with longitudinal follow up (Teyhen et al., 2012). Researchers have also identified concerns with the rotatory stability tests. Researchers and clinicians have noted that very few participants are able to complete this test with Teyhen et al. (2012) noting only 5 out of 68 participants were able to gain a score of 3 in this test. This indicates that this test is too difficult for participants to complete and so may reduce a large amount of participants’ overall composite scores. In addition, it was found that firefighters could significantly improve their scores on the FMS from 14.1 to 16.7 when they were informed of the specific grading criteria used in the FMS protocol ($p<0.0001$) (Frost et al., 2013). Thus, improvements on the FMS in the follow up sessions may be due to knowledge of the grading criteria rather than improvements in the tasks (Frost et al., 2013). Finally the scoring system itself is proposed as a further limitation to the FMS (Frost et al., 2012). The ordinal scoring system of 0-3 is quite general; researchers have shown that some tests have increased reliability than others and have suggested this could possibly be due to the definitions of each of the scales in the scoring system. For example, the hurdle step classification is more complicated than the more easily defined shoulder mobility test, and so the shoulder mobility test has demonstrated higher reliability than the hurdle step (Jade and Street, 2013). One of the biggest drawbacks to the FMS is that the 0-3 scoring system is quite crude in nature and does not differentiate between the different compensation strategies that the participant may have displayed during the test. Thus as a clinician from the scoring system alone, aside from knowledge of an asymmetry, it is challenging to identify the specific compensation strategy a participant has been utilising during functional movement. Take for example a participant who scored a 1 in the deep squat test, this score could be due to one or all of the following compensation strategies; the upper torso is not parallel with the tibia or toward vertical, the femur is not below horizontal, the knees are not aligned over the feet, the dowel is not aligned over the feet, and so this lack of distinguishing between the faults in the performance of the test limits the specificity of a subsequently developed injury prevention programme (Frost et al., 2012). To combat these major issues researchers have developed two new scales; the 100 point scale that weights specific compensations (research standard) and a modified 100 point scale where grades are allocated based on the number of compensations noted (Frost et al., 2012). Both scales rate both sides of the body separately and specific criteria in the tests are weighted in the scoring system (Frost et al., 2012). Appendix S displays the weightings and scoring system of the standard 21 point scale, 100 point research scale and 100 point modified scale. While these new scales are beginning to address the issues raised with the FMS further research is essential to standardise these scales and assess the reliability and relationship to injury in the sporting population. Finally the use of the FMS solely as the only tests included in a screening is questionable. Each different sport requires specific skills, movement patterns and has its own epidemiological injury rates and common injuries. Thus it would seem that the ideal scenario would involve a therapist looking at the injuries that commonly occur in the sporting population they are dealing with and then tailoring their screening to these injuries. This critique of the FMS questions the idea and appropriateness of a universal screening whatsoever and perhaps raises the idea that these battery of tests may perhaps be a basic movement screening which can be supplemented with other sport specific and tests related to the common injuries that occur in epidemiological studies (Frohm et al., 2012).

2. 4. 1. 3. Anthropometric Data

Anthropometric data refers to the evaluation of body composition, usually completed by measuring height, weight and Body Mass Index (BMI) measurements. BMI has been used to classify adults and adolescents into four separate categories as per international guidelines (Janssen et al., 2002, Cole et al., 2000). Adult classifications and a sample categorisation of adolescents aged 15.5 years old are displayed in Table 2. (Janssen et al., 2002, Cole et al., 2000).

Table 2.7: BMI Category cut off points in adult and adolescent 15.5 year old populations

BMI Category	Adults Cut off Point	Adolescent Cut off Point	
		Male	Female
Underweight	<18.50	<17.26	<17.69
Normal	18.50-24.90	17.27-23.59	17.70-24.16
Overweight	25.00-29.90	23.60-28.59	24.17- 29.28
Obese	>30	>28.60	>29.29

Adapted from Janssen et al. (2002) and Cole et al. (2000)

BMI has been found to be a significant predictor of numerous injuries including running related injuries (Buist et al., 2010), knee injuries (Yard and Comstock, 2011), medial tibial stress syndrome (Plisky et al., 2007) and noncontact ankle sprains (McHugh et al., 2006, Fousekis et al., 2011). In the adolescent population those who were classified as obese had a 34% increased risk of injury than those in the normal BMI range in a large prospective cohort of physically active high school participants (Richmond et al., 2012). In contrast, Lowry et al. (2007) and Kemler et al. (2014) found that high BMI was not significantly related to an increased incidence of injury and suggested that this was due to this population’s lack of exposure to physical activity. The overweight population did not take part in high levels of physical activity and so their injury risk was lower. However, these studies did not consider the effect of young adolescents or adults increasing their physical activity levels and its effect on injury and so further research is needed (Kemler et al., 2014).

BMI has been theorised to be a predictor of injury in a number of ways. Predominantly it is thought that high BMI places extra physical stress on body structures and these additional forces help contribute to injury as soft tissue and joints are required to absorb larger forces, especially in high impact, contact sports (Richmond et al., 2012) such as Gaelic games. If an individual has a high BMI over an extended period of time these excessive forces are constant and so could lead to overuse injuries and/or the development of degenerative injuries like osteoarthritis (Buist et al., 2010, Foss et al., 2012). Poor coordination has been identified as a predictor for injury and BMI has been shown to have an inverse relationship with coordination (Foss et al., 2012). Children with higher BMI were found to have lower motor coordination and a significant difference in motor coordination was shown between children in the normal BMI range and obese range children in motor coordination ($p<0.001$) (Lopes et al., 2012). In addition, Ku et al. (2012) found that healthy young adults with higher BMI have reduced postural control which can predispose to injury. Higher BMI has been suggested to reduce balance due to uneven weight distribution which may affect the stable base, also the increased pressure and contact area on the feet due to the excess weight may reduce the somatosensory ability and so consequently reduce balance (Ku et al., 2012). Conversely it has been theorised that those with low BMI and in the underweight category also have an increased likelihood of injury due to possible lower bone density; this has been supported by Yard & Comstock (2011) where high school adolescents with low BMI sustained significantly more bone fractures than those in the normal BMI range (injury proportion ratio=1.45).

While BMI is a widely used tool to assess body composition, in the athletic population it is questionable (Richmond et al., 2012). BMI is a crude predictor of body fat with a prediction error of greater than 5.0% body fat (Heyward, 2006). This is especially the case if athletes have a greater than average lean body mass as it can cause misclassification of the athlete into the overweight or even obese category when in reality they have very little body fat (Richmond et al., 2012). Alternative methods of assessing body composition have been suggested, including skinfold measurements and Dual Energy X-Ray Absorptiometry (DEXA) scans however these methods are time consuming and require expensive equipment not readily available in the clinical setting (Richmond et al., 2012).

In general it is suggested that Gaelic footballers are alike in body composition to Australian Rules football players, smaller than rugby players and larger than soccer players (Reilly and Doran, 2001). Table 2.8 demonstrates the mean and standard deviation for height, weight and body mass index (BMI) in Gaelic footballers and hurlers of various ages and levels of playing. The majority of literature focuses on anthropometric data in elite adult Gaelic footballers, with merely a single study evaluating hurling and another on elite adolescent Gaelic footballers. Thus it is essential normative data on non-elite hurlers and adolescent Gaelic footballers and hurlers is measured. High reliability was reported in elite adolescent Gaelic footballers when measuring height using a portable stadiometer (ICC=0.99), weight using a calibrated scale (ICC=0.99) and the calculation of BMI (0.89) (Cullen et al., 2012).

Table 2.8: Anthropometric data of Gaelic footballers and Hurlers

Study	Age group	Level of play	Sport	Height (cm) Mean±SD	Weight (kg) Mean±SD	BMI (kg/m^2) Mean±SD
McIntyre (2005)	Adult	Elite inter county	Gaelic football	179±6.0	81±9.0	25.28*
			Hurling	177±6.0	83±9.0	26.49*
Reilly (1990)	Adult	Elite inter county	Gaelic football	183±5.0	82.2±7.4	24.54*
			Gaelic football	182±5.0	81.7±6.1	24.66*
Keane et al. (1997)	Adults	Elite inter county	Gaelic football	181±4.0	82.6±4.8	25.21*
		Club	Gaelic football	175±6.0	76.5±6.7	24.68*
Reilly & Doran (1999)	Adult	Elite inter county	Gaelic football	179±7.0	79.9±8.2	24.93*
Watson (1995)	Adult	Elite inter county	Gaelic football	181.4±8.2	81.9±6.9	24.7
Florida-James & Reilly (1995)	Under 21	Club	Gaelic football	176±5.8	70.7±7.7	22.82*
Kirgan & Reilly (1993)	Adults	Club	Gaelic football	174±5.0	73.3±9.3	24.21*
Cullen et al. (2012)	Adolescents	Elite inter county	Gaelic football	178.11±6.27	72.09±8.68	22.69±2.15

*computed by the primary researcher in this study

2. 4. 1. 4. Dominance

Dominance is defined as a limb that displays increased dynamic control due to an imbalance in muscular strength and neural recruitment patterns (Jacobs et al., 2005). A dominant leg is most commonly defined as the preferred kicking leg (Witvrouw et al., 2003) but also the limb that can kick a football the furthest (Brown et al., 2009), the leg used to regain balance when pushed from behind and also the leg you land on from in a one legged jump (Hoffman et al., 1998). Hand dominance on the other hand can be determined by observing which hand the participant uses to write with on the screening sheet (Schneiders et al., 2011). Dominance has been theorised as a possible predictor to injury and studies have shown that 43% and 59% of all injuries occurred on the dominant limb in elite Gaelic footballers and 56% of injuries occurred on the dominant hand in a study specifically dealing with hand injuries in hurlers (Cromwell et al., 2000, Newell et al., 2006, Kiely et al., 2003). Newell et al. (2006) found a significant difference between injury rates in the dominant and non-dominant limb in elite Gaelic footballers (p=0.001). In fact, it has been noted that a side-to-side strength difference of greater than 10% between limbs has been shown to enhance injury risk (Jacobs et al., 2005). Joints and tissues are placed under more intensive and frequent usage in the dominant limb; this higher activity level places increased stress on joints and tissues and even daily functional movements may lead to tissue adaptation which may increase the risk of injury (Jacobs et al., 2005). However this increased dependence on one limb compared to another has been suggested to be detrimental to both limbs (Jacobs et al., 2005). Dominant behaviour may cause weakness in tissues and structures in the non-dominant limb, this lessens the ability of that limb to absorb large forces that occur in the sporting environment and may predispose the athlete to injury (Jacobs et al., 2005). Dominance has also been suggested to affect range of motion, especially in the upper limb (Conte et al., 2009). Increased external rotation and reduced internal rotation of the dominant shoulder has been demonstrated in men and women of all ages and this alteration in range of motion has been suggested as a possible cause of shoulder injury (Conte et al., 2009, Wang and Cochrane, 2001).

Thus establishing normative dominance data and examining dominance as a possible risk factor for injury is needed in Gaelic games.

2. 4. 1. 5. Hamstring Flexibility

Hamstrings are the most common site of injury in both Gaelic football and hurling (Murphy et al., 2012a, Murphy et al., 2012b). Almost a quarter of all injuries sustained in a four year study in Gaelic football were to the hamstring and 16.5% of all injuries in elite hurlers (Murphy et al., 2012b, Murphy et al., 2012a). Flexibility is defined as the ability to move joints fluidly through complete ranges of motion without injury and is measured by the range of motion (ROM) available at a joint (Heyward, 2006, Bradley and Portas, 2007). Poor muscle flexibility has been the most commonly hypothesised link to an increased likelihood of sustaining a lower extremity injury however there is a lack of prospective research on this area (Bradley and Portas, 2007, Lowther et al., 2012, Witvrouw et al., 2003). No related studies have been completed in hurling and only a single retrospective study has been completed to assess this issue in Gaelic footballers; Lowther et al., (2012) found that Gaelic footballers who had previously sustained a hamstring muscle strain had a significantly lower hamstring flexibility in comparison to an uninjured group however this study did not control rehabilitation and flexibility of the injured group which may have confounded the results ($p<0.05$). Consensus in the literature with regard to the effects of poor muscle flexibility on injury rate in other related sports is not yet reached. In two prospective studies on soccer players comparing preseason hamstring flexibility (Witvrouw et al., 2003) and preseason knee flexor range of motion (Bradley and Portas, 2007) with the likelihood of sustaining a hamstring muscle strain during the consecutive season found that those who became injured (Witrouw et al: 88.1° & Bradley and Portas: 9.9±3.0°), had a significantly lower hamstring flexibility (or knee flexor range of motion) than the uninjured players (Witrouw et al: 96.1°,$p=0.002$ & Bradley and Portas: 12.9±4.2°, $p=0.03$). Conversely in two prospective studies on Australian rules footballers, both Orchard et al. (1997) and Gabbe et al. (2004) found that poor hamstring flexibility did not correlate to an increased likelihood of sustaining a hamstring muscle injury. Researchers have hypothesised that a lack of appropriate and standardized methodology can be attributed to the ambiguity in the research on the effect of flexibility on sustaining an injury (Lowther et al., 2012, Weldon and Hill, 2003). In particular the tests utilised and the functional relevance of the tests may have affected the outcome of these prospective studies.

There are numerous different proposed flexibility tests with varying inter and intra reliability, including: active knee extension (AKE), passive knee extension (PKE), sit and reach test and straight leg raise. Table 2.9 displays the variations and reliability of the tests. The majority of literature assessed concurrent validity which is considered inferior to comparing each test to a criterion gold standard test (Davis et al., 2008). While the active knee extension (AKE) and passive knee extension (PKE) tests have been found to be both accurate and reliable, the sit and reach test and straight leg raise have disputed accuracy and reliability due to the possibility that pelvic rotation and foot position may affect the results (Lowther et al., 2012, Gabbe et al., 2004, Orchard et al., 1997). Tight hip flexor muscles may reduce posterior rotation of the pelvis and so lower the hamstring flexibility a participant may achieve (Gajdosik et al., 1993). Tight hip flexors on the limb not being tested may also interfere with the hamstring flexibility results and it has been suggested that the contralateral limb should be placed in slight flexion (Gajdosik et al., 1993). A foot placed in dorsiflexion during the straight leg raise elongates the sciatic nerve and so may cause reduced hamstring flexibility if a participant has neurological issues (Gajdosik and Lusin, 1983). Furthermore the straight leg raise test is a neurological test itself and so could be more of use in this capacity rather than as test to measure hamstring flexibility (Norris and Matthews, 2005). Differences between participants in leg, trunk and arm length may also compound results in the sit and reach test (Shimon et al., 2010). In fact, Orchard et al. (1997) attributed the lack of a significant correlation between poor flexibility and increased likelihood of sustaining a hamstring injury in his prospective study on Australian rules footballers to the nonspecific nature of the sit and reach test they utilised.

Gajdosik & Lusin (1983) proposed the AKE test to circumvent the complications that arise from completing the straight leg raise and sit and reach tests. The AKE test was proposed by Davis et al. (2008) as the criterion gold standard hamstring flexibility test based on the literature available presently. The AKE test was found to be accurate and reliable in various collegiate and sporting populations (Gabbe et al., 2004, Norris and Matthews, 2005, Sullivan et al., 1992, Gajdosik and Lusin, 1983, Gajdosik et al., 1993) and also in school aged children (Rakos et al., 2001). The AKE test is a quick assessment which has been found to take approximately 20 seconds to complete per test per leg (Shimon et al., 2010). The AKE test is a measure of hamstring muscle length in a position of hip flexion which is similar to running, kicking and striding activities (Gabbe et al., 2004). This is critical as it has been demonstrated that hamstring injuries commonly occur while the player is accelerating (Verrall et al., 2005). Therefore this test is highly functional and applicable to Gaelic football as the skill specific movements in Gaelic football are very similar to Australian Rules football. The AKE requires the participants to actively move into their full range of motion and so is suggested to be more sports specific than tests that require passive motion (the PKE or straight leg raise) as it tests the functional range of motion available to the athlete when completing sport specific activities. It is also deemed a safer test as the participants themselves control the full range of motion and the end point of the test (Norris and Matthews, 2005). In addition, if a tester passively assesses muscle length and moves the joint into its full range of motion, the force applied between tests (intra-tester) and between testers (inter-tester) may vary greatly. Therefore variations in the results may not be due to a difference in hamstring flexibility but variances in the force applied during the passive test (Gajdosik and Lusin, 1983). In fact a significant difference in mean hamstring flexibility was found between the AKE and PKE tests on the same subjects ($p<0.001$) and may be due to these factors (Gajdosik et al., 1993). The AKE also consists of movement at the knee only as the hip is stationary throughout the testing procedure. This is beneficial as in the straight leg raise and sit and reach test movement occurs at the hip and knee (straight leg raise) and at the hip and lower back (sit and reach) which is more difficult to control (Norris and Matthews, 2005).

Table 2.9: Hamstring Flexibility Tests

Starting Position and Test	Directions	Measurement	Variations	Equipment	Placement	Reliability	
						Inter-tester	Intra-tester
AKE							
-Supine -Hip and knee at 90° flexion -Participant actively extends knee	-Straighten knee until point of severe stretch -Or first point of discomfort	-Angle between the vertical and tibia	Hamid et al. (2013)	Goniometer	Aligned from lateral joint line to apex of lateral malleolus and greater trochanter	ICC=0.81, 0.87 SEM=3.8°, 3.5°	ICC=0.78-0.92 SEM=2.3°-3.9°
			Gabbe et al. (2004)	Inclinometer	Anterior tibial border below the tibial tuberosity	ICC=0.93 SEM=4°	ICC=0.94-0.96 SEM=3°
			Sullivan et al. (1992)			ICC=0.93 SEM=4.81°	ICC=0.99 SEM=1.75°
			Gajdosik & Lusin (1983)	Goniometer	Along longitudinal axis of leg (line from head of fibula to lateral malleolus)	NT	r=0.99
			Gajdosik et al. (1993)	Goniometer	Along longitudinal axis of leg (line from head of fibula to lateral malleolus)	NT	ICC=0.86
			Norris & Mathews (2005)	Goniometer	Axis at lateral joint line Line drawn from axis point to centre of greater	ICC=0.76	NT

					trochanter of femur and second line from axis to lateral malleolus		
			Rakos et al. (2001)	Goniometer		ICC=0.79	NT
			Webright et al. (1997)	Video	Adhesive tape placed 5cm proximal to greater trochanter, 5cm proximal to lateral femoral epicondyle, 5cm distal to fibular head and 5cm proximal to inferior lip of lateral malleolus	ICC=0.98 SEM=1.67°	ICC=0.98 SEM=1.68°-1.70°
			Worrell & Perrin (1992)	Fluid filled Goniometer	Velcro strap placed 1 inch inferior to head of fibula with goniometer attached to Velcro strap	ICC=0.93 SEM=4.81°	ICC=0.96 SEM=1.82°
			Shimon et al. (2010)	Lift and raise instrument with set angles displayed on a board	Lift and raise instrument fixed on wall	NT	ICC=0.944

PKE							
-Supine -Hip and knee at 90° flexion -Tester passively extends knee	-Straighten knee until resistance to further motion felt by examiner -Or participant stated they were unable to allow their knee to extend further	-Angle between the vertical and tibia	Gajdosik et al. (1993)	Goniometer	Along longitudinal axis of leg (line from head of fibula to lateral malleolus)	NT	ICC=0.90
			Davies et al. (2008)	Inclinometer	Distal anterior tibia	NT	ICC=0.94
			Bandy & Irion (1994)	Goniometer	Axis on lateral aspect of knee Greater trochanter of femur, lateral epicondyle of femur and lateral malleolus marked to align the goniometer	NT	ICC=0.98
Straight leg raise							
-Supine -Leg straight and relaxed on plinth -Tester passively lifts the subjects leg off the plinth with the knee extended	-Lift leg until subject reports severe stretch -Or first point of discomfort	-Angle between leg and horizontal using inclinometer placed on anterior tibial border below the tibial tuberosity	Gabbe et al. (2004)	Inclinometer	Anterior tibial border 15cm below mid-point of tibial tuberosity	ICC=0.93 SEM=4°	ICC=0.91 SEM=4°
			Gajdosik et al (1993)	Goniometer	Along longitudinal axis of leg (line from head of fibula to lateral malleolus)	NT	ICC=0.83
			Davis et al. (2008)	Inclinometer	Placed on distal thigh	NT	ICC=0.92

Sit and Reach tests							
-Subject sits on floor with both knees extended and feet flat against measuring box -Participant reach forward over measuring device	-Reach forward over the measuring box until severe stretch -Or first point of discomfort and hold for 2 seconds	-Distance from plantar surface of feet (0) to tip of middle finger to nearest 0.5cm	Davis et al. (2008)	Sit and reach measuring box	Distance from plantar surface of feet to tip of middle finger	NT	ICC=0.94
			Gabbe et al. (2004)	Sit and reach measuring box	Distance from plantar surface of feet to tip of middle finger	ICC=0.97 SEM=2°	ICC=0.98-0.99 SEM=1°

The starting position, test, directions and measurement are the usual directions reported in the literature. Variations are discussed within the main body of the text. In reliability ICC's of >0.75 is excellent, 0.40-) 0.75 is fair to good and 0-0.40 is poor (Landis & Koch, 1997)

Vast differences exist in the methodology utilised in the AKE test, principally in the attempt to keep the hip placed at 90° throughout the test as the thigh naturally moves into slight extension as the participant extends the knee (Gajdosik and Lusin, 1983). The most common method utilised to stabilise the thigh in this position is to place a metal or plastic cross bar on the anterior surface of the thigh (Lowther et al., 2012, Gajdosik and Lusin, 1983, Gajdosik et al., 1993, Worrell and Perrin, 1992) and straps and belts can be placed at the level of the hip and mid-thigh to minimise any compensatory lumbar or hip movements during the test (O'Connor et al., 2011, Gajdosik and Lusin, 1983). However, the methodology used in these studies are often not practical, as the apparatus used are complex, takes time to set up, is not available in most clinical settings, is difficult to transport, may require therapists to build the equipment themselves and may require two testers to conduct the test in some methodologies (Hamid et al., 2013). Normative data is severely lacking in present literature with a single study assessing AKE in collegiate participants aged 18-22 (Corkery et al., 2007). Corkery et al., (2007) reported a higher average in males (right=35.0±11.3°, left=37.1±9.1°) than females (right=25.5±12.4°,left=25.9±13.7°). Shimon et al. (2010) reported that knee extension measured within 20° of full extension (90°) is considered to be within normal limits of hamstring flexibility. Asymmetric differences between legs may also indicate an increased likelihood of injury (Corkery et al., 2007).

While the active knee extension test has been proposed as the gold standard test to assess hamstring flexibility, many variations of this test are employed, and many utilise complex apparatuses that are time consuming to set up, difficult to transport and not available in most clinical settings. Thus the development of a methodology that utilises minimal, inexpensive and readily available equipment is justified to facilitate the use of this test in the screening setting. The reliability and normative data for this methodology subsequently needs to be determined.

2. 4. 1. 6. Shoulder Mobility

While the majority of injuries occur in the lower limb in Gaelic games, upper limb injuries are still present with 17-23% occurring in Gaelic football and 15.9% in hurling (Wilson et al., 2007, Cromwell et al., 2000, Newell et al., 2013, Murphy et al., 2012a). The shoulder predominated (12% of 17%) the upper limb injuries which may be due to the nature of Gaelic football and hurling. The shoulder is involved in high catching, hand passing, striking, blocking and a shoulder led charge called "shouldering" which is allowable in Gaelic games, all of which can leave the shoulder susceptible to injury (Cromwell et al., 2000). Several risk factors for injury have been highlighted, including shoulder mobility impairment and joint hyper-laxity (Wang and Cochrane, 2001) Internal rotation impairment and external rotation hyper-movement of the shoulder have been commonly measured to identify possible risk factors for injury. Internal rotation of ≥20° less than the non-dominant shoulder or a total range of motion (internal and external rotation added together) difference between both sides greater than 5° has been proposed as a possible method of identifying athletes susceptible to a shoulder injury (Wilk et al., 2011). Research has demonstrated a reduction in internal rotation of the dominant or playing arm in various sports including baseball, swimming, volleyball and tennis (Wang and Cochrane, 2001, Torres and Gomes, 2009). In addition, it has shown a negative correlation between years of playing a sport that utilises the upper limb and internal rotation on the dominant limb (Wang and Cochrane, 2001). Torres & Gomes (2009) assessed asymmetry of range of motion and found a statistical significant difference between sides in tennis players (23.9°), swimmers (12°) and a physically active population who did not play an upper body sport (4.9°). While the control group reached statistical significance between sides this was noted as not clinically significant and was possibly due to dominance alone (Torres and Gomes, 2009). A prospective study over 3 seasons found that baseball players with an internal rotation deficit of greater than 20° compared to the non-dominant arm were twice as likely to become injured, however this did not reach statistical significance (Wilk et al., 2011). In addition, pitchers with a total rotational deficit of greater than 5° had a higher injury rate (Wilk et al., 2011). Therefore asymmetry in motion between sides may have an impact on acquiring an injury in the shoulder. A reduction in internal range of motion may be due to chronic eccentric stress placed on the posterior capsule of the shoulder, this can consequently cause thickening of this capsule which in turn may alter the range of motion of the shoulder. In addition the eccentric loading may also cause tightness of the posterior rotator cuff muscles which may further restrict internal range of motion. Increased external range of motion may be due to stretching of the anterior capsule due to throwing activities (Thomas et al., 2010). Literature has focused on sports that primarily use the upper body (e.g. tennis, baseball, swimming, volleyball).

In a study comparing high school and collegiate baseball players it was found that high school players had significantly less internal rotation deficit, greater external rotation gain and less total motion deficit than collegiate players (Thomas et al., 2010). Therefore, teenagers possibly have more internal rotation available, as their training age is less than collegiate players and so may not have developed the consequential posterior capsule and muscle thickening and tightness that can reduce range of motion. A possible explanation for collegiate players having less external rotation may be due to a greater tightness of the pectoralis major muscle which would restrict external rotation (Thomas et al., 2010).

A variety of methods are available to assess range of motion including visual estimation, still photography and video analysis however a goniometer and inclinometer are the most extensively used (van de Pol et al., 2010, Hayes et al., 2001). Both inclinometers and goniometers have been proposed as non-invasive, inexpensive and simple methods to objectively assess range of motion (Torres and Gomes, 2009). The reliability of the tests used and equipment utilised is displayed in Table 2.10. Fair to good inter-reliability and intra-reliability was found for external rotation using visual estimation, still photography and goniometry (Hayes et al., 2001). Low inter-tester reliability has been reported for measuring internal rotation using a goniometer (Riddle et al., 1987) however a strong correlation (r=0.854) was reported between goniometers and an electromagnetic tracking device when assessing rotation of the shoulder (Torres and Gomes, 2009). Inclinometers have been suggested to be superior to goniometers as they allows a single examiner to complete the shoulder rotation range of motion test which would make it easily adapted in a clinical or testing setting (Awan et al., 2002). Error can be introduced to the testing procedure in a variety of ways including: inconsistent readings of markings and placement of the instruments, variable forces being placed on the participant during the passive rotational movements by the testers, participants relaxing their shoulder to different degrees in different trials, and error between different types of instruments (MacDermid et al., 1999).

Normative data for various sports can vary widely, which is more than likely due to differences between sports, gender, populations' studied and also from a lack of standardised methodology between studies (MacDermid et al., 1999). Table 2.11 displays normative data for shoulder range of motion in various different sports. Thus the establishment of normative data for both adolescent and collegiate Gaelic footballers and hurlers is essential. In addition, examining limited or excessive shoulder range of motion as a possible predisposing factor to injury in Gaelic games is needed.

Table 2.10: Shoulder mobility tests (passive internal and external range of motion)

Starting position	Directions	Measurement	Study	Equipment	Placement	ROM	Reliability	
							Inter-tester	Intra-tester
-Supine with scapula stabilised against plinth -Shoulder in 90° of abduction, in the scapular plane, elbow flexed to 90°	-Passively move into external/ internal range until an end point is felt -Or participant complains of severe stretch/ discomfort –Or compensatory movement (including scapular motion) is visualised	-Range of motion (°)	Wilks et al. (2011)	Bubble goniometer and standard goniometer	Olecranon	Internal	NT	ICC=0.81
						External	NT	ICC=0.87
			Thomas et al. (2010)	Digital inclinometer	Dorsal surface of forearm	Internal	NT	ICC=0.989 SEM=1.03°
						External	NT	ICC=0.943 SEM=2.55°
			Ellenbecker et al. (1996)	Goniometer		Internal	NT	ICC=0.34 r=0.89
						External	NT	ICC=0.39 r=0.94
			Conte et al. (2009)	Goniometer	Not stated	Internal	NT	ICC=0.92-0.96
						External	NT	ICC=0.92-0.97
			Riddle et al. (1987)	Goniometer (small and large size)	Not stated	Internal	ICC=0.43-0.55	ICC=0.93-0.94
						External	ICC=0.88-0.90	ICC=0.98-0.99
			Awan et al. (2002)	Digital inclinometer	Not stated	Internal	ICC=0.62,0.66	ICC=0.64,0.71
						External	ICC=0.41,0.51	ICC=0.58,0.67
			Dwelly et al. (2009)	Inclinometer	Forearm	Internal	ICC=0.72-0.79 SEM=2.57-2.75°	NT
						External	ICC=0.94-0.96 SEM=1.66-2.94	NT
			de Winter et al. (2004)	Digital inclinometer	Not stated	External	ICC=0.90	NT

			Macdermid et al. (1999)	Goniometer	Olecranon process. Shoulder placed in 20-30° of flexion	External	ICC=0.85-0.86 SEM=7.5-8.0°	ICC=0.89-0.94 SEM=4.9-7.0°
			Hayes et al. (2001)	Goniometer	Olecranon process of ulna	External	ICC=0.64 SEM=14°	ICC=0.65 SEM=14°
				Visual Estimation		External	ICC=0.57 SEM=14°	ICC=0.67 SEM=11°
				Still Photography	Perspective aligned with the axis of joint motion	External	ICC=0.62 SEM=15°	ICC=0.60 SEM=13°
			Terwee et al. (2005)	Visual Estimation	Sitting rather than supine	External	ICC=0.73	NT
			Nomden et al. (2009)	Visual Estimation	Sitting rather than supine	External	ICC=0.70	NT

In reliability ICC's of >0.75 is excellent, 0.40-0.75 is fair to good and 0-0.40 is poor (Landis & Koch, 1997). NT: Not tested

Table 2.11: Normative data for external, internal and total rotation movement of the shoulder in different sports

Sport	Age	Study	External		Internal		Total rotational movement	
			Dom	Non-dom	Dom	Non- dom	Dom	Non-dom
Baseball	A	Wilks et al. (2011)	136.1±11.2	128.6±11.0	47.5±10.6	59.1±11.0	183.7±14.5	187.7±14.5
Baseball (pitchers only)	A	Ellenbecker et al. (2002)	103.2±9.1	94.5±8.1	42.4±15.8	52.4±16.4	145.7±18.0	146.9±17.5
Tennis	A	Torres & Gomes (2009)	104.7±9.0	100.7±6.9	42.9±7.7	66.8±10.1	147.6±6.6	167.5±8.3
	J	Ellenbecker et al. (2002)	103.7±10.9	101.8±10.8	45.4±13.6	56.3±11.5	149.1±18.4	158.2±15.9
Swimming	A	Torres & Gomes (2009)	103.4±6.6	100.8±7.0	52.6±10.1	64.6±8.2	156.0±11.2	165.4±9.8
Baseball & softball sports	C	Dwelly et al. (2009)	96.2±12.7	92.0±10.0	45.5±11.1	52.7±11.8	141.7±15.0	144.7±14.4
Physically active (not upper body sport)	A	Torres & Gomes (2009)	99.0±5.6	96.5±5.1	70.5±7.8	75.4±6.5	169.5±2.8	171.9±1.9

A=adult, J=junior, C=collegiate, Dom; Dominant. Non-dom; Non-dominant

2. 4. 1. 7. Foot function

Poor foot function which predominantly presents as excessive pronation has been identified as a predisposing risk factor to a number of injuries including metatarsalgia, plantar fasciitis, stress fractures, medial knee pain, ACL tears, patellofemoral pain syndrome and running related injuries (Bonci, 1999, Picciano et al., 1993, Buist et al., 2010, Barton et al., 2010). Appropriate foot function and pronation allows forces to be absorbed and so reduces the forces that transfer upward through the ankle, shin, knee and hip that are produced during walking, running and sporting activities (Bonci, 1999). While pronation is an essential component to adequate gait, excessive or prolonged pronation during heel rise and lift-off of the foot causes the medial longitudinal arch to fall which alters foot structure and also allows abnormal forces be transmitted upwards through the kinetic chain which can predispose to injury (Bonci, 1999, Picciano et al., 1993). Excessive or prolonged pronation can also cause excessive internal tibial and femoral rotation which places the knee into a knee valgus position which places tension on the ACL and causes increased pressure on the lateral aspect of the patellofemoral joint due to the increased quadriceps angle (Bonci, 1999, Picciano et al., 1993, Barton et al., 2010).

There are numerous methods to assess pronation including: original navicular drop test, modified navicular drop test, dorsal arch height, foot posture index, cinematography during dynamic motion (2D motion analysis system), 3D electromagnetic motion analysis system and dynamic analysis using force plates (Brody, 1982, Buist et al., 2010, McPoil et al., 2008, Barton et al., 2010). While dynamic walking and running analysis utilising force plates and cinematography is proposed as the gold standard method, as it places high extrinsic loading onto the foot during movements that occur in the sporting setting; this equipment is expensive, not readily available and the tests can be somewhat time consuming (Bennett et al., 2001, Dicharry et al., 2009). Dorsal arch height is suggested as an alternative to the navicular drop test as it does not require palpation of the navicular tuberoisity which has been highlighted as a possible source of error in the test; however it also requires the use of expensive equipment or novel equipment that is not readily available in the clinical market (Barton et al., 2010, McPoil et al., 2008). The foot posture index is six item foot posture assessment tool that requires inexpensive equipment however it is time consuming (Barton et al., 2010). Therefore the navicular drop test is commonly utilised as it is a quick, minimally invasive, reliable tool that requires simple readily available equipment (Barton et al., 2010, Bennett et al., 2001, Plisky et al., 2007, McPoil et al., 2009).

The navicular drop measures the amount of pronation that occurs at the subtalar joint and has been proposed as a clinical method to identify athletes who are predisposed to injury (Bennett et al., 2001, Plisky et al., 2007). Five main studies have analysed the predictive effect of the navicular drop on identifying athletes predisposed to injury. Firstly, a poor result in the navicular drop test was found to be the only significant predictor for sustaining a running related injury in female novice runners during a 8-13 week running study (hazards ratio=0.87; 95% CI=0.77-0.98) (Buist et al., 2010). With regard to patellofemoral pain syndrome, a significant difference in navicular drop results existed between the injured and non-injured groups (p=0.003, effect size=1.02) (Barton et al., 2010). Bennett et al. (2001) and Moen et al. (2012) found that a poor navicular drop result significantly predicted athletes that may sustain medial tibial stress syndrome in high school runners (p=0.003) and army recruits (p=0.03), however this was not supported by Plisky et al. (2007). In addition, the navicular drop test accurately predicted those who developed medial tibial stress syndrome in 68% of cases in high school runners (Bennett et al., 2001).

The original navicular drop test compares the reduction in navicular height between a participant in subtalar joint neutral foot position while standing when partially placing their weight on the foot, to a relaxed stance with equal weighting on both feet (Brody, 1982, Picciano et al., 1993, Bennett et al., 2001). The modified navicular drop test on the other hand compares the difference in navicular height an un-weighted sitting position to a weightbearing standing relaxed position (Bonci, 1999, Moen et al., 2012, Buist et al., 2010). Subtalar joint neutral is defined as the position of the foot where there is maximum congruency between the talus and calcanuous bones of the foot and so is identified as the optimal foot position (Bonci, 1999). The reliability of the original and modified navicular drop test has been reported in numerous studies and range from poor to excellent (Table 2.12). The two primary sources of error in this test is purported to be difficulty in placing the foot in a subtalar neutral position and marking the most prominent aspect of the navicular tuberosity (Picciano et al., 1993, McPoil et al., 2008, McPoil et al., 2009). Failure to normalise the results with regard to foot size of participants is also significant, as this test is suggested to be only meaningful in context with the size of the foot (Bennett et al., 2001, Barton et al., 2010).

Various cut off points to classify excessive pronation has been reported. Brody (1982) who proposed the original navicular drop test suggested a drop of greater than 15mm however cut off points of 5mm (Moen et al., 2012), 10mm (Plisky et al., 2007, Buist et al., 2010, McPoil et al., 2008, Bennett et al., 2001) and 13mm (Beckett et al., 1992) have also been proposed. Criticism of the original cut off point of 15mm is warranted as the author provided no data to support the claim that a difference of greater than 15mm could predispose to injury (Picciano et al., 1993). The most commonly used cut off point is 10mm (Plisky et al., 2007, Buist et al., 2010, McPoil et al., 2008). Side to side differences between feet has also been identified as a possible method of identifying those who are predisposed to injury, with differences of 3mm the most commonly used cut off point reported (Plisky et al., 2007).

There is lack of comprehensive normative data for the navicular drop test which has been suggested as a possible negative to the usage of this test in the clinical and screening setting (McPoil et al., 2008, Nielsen et al., 2009). However healthy males are reported to have a mean navicular drop of 5.3 ± 1.8mm (Nielsen et al., 2009) and 5.06 ± 3.21mm (McPoil et al., 2013), with a higher mean reported in collegiate cross-country runners by Bennett et al. (2012) (8.5 ± 4.1 and 8.7 ± 4.3). There is no available normative data for Gaelic footballers or hurlers in any age group which prevents comparison between players, teams and sports. Thus normative data using the navicular drop test should be developed and the number of possible at risk adolescent and collegiate Gaelic players should be measured to examine whether excessive foot pronation is a predisposing factor to injury in adolescent and collegiate Gaelic players.

Table 2.12: Navicular drop tests

Starting Position and Test	Directions	Measurement	Equipment	Study	Reliability	
					Inter-tester	Intra-tester
Original Navicular drop test						
-Mark the most prominent part of the navicular tuberosity using a marker -While participant is standing with most of weight on opposite leg but foot in contact with the ground place the foot in subtalar joint neutral by palpating medial and lateral talar depressions with thumb and forefinger, invert and evert the foot until both talar heads are equal -Using a ruler/card note the level of the previously marked navicular tuberosity -Participant then stands in a relaxed bilateral stance with weight equally distributed between both sides -Note the height of navicular tuberosity in relaxed stance -Repeat on other foot	-Stand -Allow tester to move your foot and hold your foot in the position the testers places it in -Shift your weight so that your weight is equally distributed onto both feet and stand with your feet in a relaxed position	-Difference between the unweighted and weighted navicular tuberosity position in standing is noted in mm -Difference between the navicular drop in left and right foot is noted in mm	-Marker -Ruler/card	Picciano et al. (1993)	ICC=0.57 SEM=2.72mm	ICC=0.61-0.79 SEM=1.92-2.57mm
				Sell et al. (1994)	ICC=0.73 SEM=2.1mm	ICC=0.83 SEM=1.7mm
				Bennett et al. (2001)	NT	ICC=0.67 SEM=1.56mm
				Barton et al. (2010)	ICC=0.76-0.93	ICC=0.83-0.95
				Piva et al. (2006)	ICC=0.93 SEM=0.7mm	NT
Modified Navicular drop test						

-Mark the most prominent part of the navicular tuberosity using a felt tipped marker -While participant is sitting with no pressure on their feet, place the foot in subtalar joint neutral by palpating medial and lateral talar depressions with thumb and forefinger, invert and evert the foot until both talar heads are equal -Using a ruler/card note the level of the previously marked navicular tuberosity -Participant stands without moving their feet into a relaxed stance with equal weight on both legs -Mark the level of the navicular tuberosity in the standing stance -Repeat on other foot	-Sit with no weight on legs in a position where you can stand without moving your feet -Allow tester to move your foot and hold your foot in the position the testers places it in -Stand without moving your feet into a relaxed position as you normally would with your weight equally distributed between both feet	-Difference between the sitting and standing navicular tuberosity position is noted in mm -Difference between the navicular drop in left and right foot is noted in mm	-Marker -Ruler/card -Chair	Plisky et al. (2007)	NT	ICC=0.88-0.91

2. 4. 1. 8. Balance

Balance (postural control) is one of the foundation components in performance of functional movements and is defined as the ability to perform a dynamic functional movement while maintaining a stable position (Robinson and Gribble, 2008, Bressel et al., 2007, Plisky et al., 2006, Munro and Herrington, 2010).

Poor balance occurs from deficiencies in the somatosensory, visual and vestibular systems, which can lead to inaccurate sensory information transferring to the brain which may affect the ability of the brain to distinguish the current precise position of the body and limbs (Bressel et al., 2007, Martínez-Ramírez et al., 2010). Mechanical deficiencies may also contribute to poor balance due to damage to ligaments, proprioceptor receptors and cutaneous receptors (Martínez-Ramírez et al., 2010, Hoch et al., 2011). These deficiencies then affects the motor system and can cause a consequential reduction in the individual's ability to maintain a stable base, motor coordination, range of motion and strength of muscles (Bressel et al., 2007). Thus poor balance has been identified as a predictor for injury (Plisky et al., 2006, Clark et al., 2010) leading to twice as many injuries in elite Australian footballers (Hrysomallis et al., 2007) and seven times as many ankle injuries in high school basketball players (McGuine et al., 2000). Participants that displayed poor balance in the normalised composite reach distance of ≤94% of leg length in the modified star excursion balance test were 6.5 times more likely to sustain a lower extremity injury ($p<0.05$) (Plisky et al., 2006). Participants with an asymmetrical difference between legs of greater than 4cm were 2.5 times more likely to sustain a lower limb injury ($p<0.05$) (Plisky et al., 2006). Side to side differences are essential to assess as this difference may cause increased stress being placed on the more proficient limb with the opposite limb unable to effectively provide a stable base for sporting movements (Plisky et al., 2006).

Numerous balance tests are available including: star excursion balance test, modified star excursion balance test (Y balance test), single leg balance, rhomberg test, balance error scoring system, modified balance error scoring system, dynamic postural control index, time to stabilisation test and stabilometry (Clark et al., 2010, Plisky et al., 2006, Bressel et al., 2007, Martínez-Ramírez et al., 2010). Whilst stabilometry, dynamic postural control index and time to stabilisation test are considered gold standard tests for assessing balance, they are time consuming and require expensive equipment and a large amount of space (Clark et al., 2010, Bressel et al., 2007, Martínez-Ramírez et al., 2010). While the single leg balance, rhomberg and balance error scoring system are less time consuming and require little if any equipment, they are quite static in nature and so do not provide an accurate evaluation of balance in a sporting environment (Martínez-Ramírez et al., 2010). Thus the original and modified star excursion balance test (Y balance test) are considered gold standard clinical and field balance measures as they are simple quick tests that utilise portable and inexpensive equipment (Clark et al., 2010, Plisky et al., 2006, Thorpe and Ebersole, 2008).

The star excursion balance test is a multidirectional test of balance where participants are required to maintain a single leg stance on one leg while maximally reaching with the contralateral leg in 8 different directions and the distance reached is measured (Cook, 2010, Robinson and Gribble, 2008), (Hoch et al., 2011, Thorpe and Ebersole, 2008). Adequate muscular strength, proprioception, neuromuscular control and range of motion of the joints of the lower limb is necessary to effectively execute this test (Munro and Herrington, 2010). However there are four main issues with the star excursion balance test. Firstly the starting placements of the stance foot has not been standardised and so studies have recorded starting positions at the most distal aspect of toes, the centre of the foot and at the bisection of the lateral malleolus which affects reliability and prevents direct comparisons between studies (Plisky et al., 2009). Secondly a standardised testing order has not been developed which may affect the reliability and performance of the test due to fatigue of limbs during testing (Plisky et al., 2009). Thirdly maximum reach is deciphered by touching down on the athletic tape on the floor; however support may be gained from this touching down (Plisky et al., 2009). Finally, to score the test the tester must mark the point of maximum reach with chalk on the floor and then using tape measure from the centre of the grid to the marked point on the floor which is time consuming (Plisky et al., 2009). The modified star excursion balance test was developed to reduce the time taken to complete the test by decreasing the amount of directions tested, thus the anterior, posteriomedial and posteriolateral directions were suggested as three directions that capture differing information on an individual's balance as the muscle activation during each direction is diverse (Plisky et al., 2006, Hoch et al., 2011). The vastus medialis and vastus lateralis were most active during the anterior reach, the anterior tibialis in the posteriomedial reach and the biceps femoris and anterior tibialis in the posteriolateral reach which ensures a comprehensive dynamic analysis of balance (Plisky et al., 2006). The Y balance test and Y balance testing kit was developed to increase the reliability and standardise the testing protocol of the modified star excursion balance test (Plisky et al., 2009). The testing kit consists of a rectangle plastic platform for placement of the stance foot and three plastic pipes attached to the stance platform in the anterior, posteriomedial and posteriolateral directions with three mobile reach indicators on each plastic pipe. The posteriomedial and posteriolateral pipes are positioned 45° between each other and 135° from the anterior pipe (Plisky et al., 2009). The Y balance test and testing kit provide a standardised starting position for the foot where the most distal part of the foot must be behind the red line on the stance platform. The standardised testing order aims to prevent fatigue of each limb by alternating the stance foot between reach directions. The reach indicator slides along the pipe during the participant's maximum reach; this prevents the participant gaining support from the floor as they touch down during the reach movement in the Y balance test. In addition the Y balance test protocol is time efficient as the testing kit reduces set up time and allows for a more instantaneous measurement of maximal reach as the pipes are marked in 5mm increments (Plisky et al., 2009, Cook, 2010). It is strongly recommended in present literature to normalise the Y balance test scores for leg length as Gribble & Hertel (2003) has shown a significant correlation between leg length and reach distance ($p<0.05$) This is expected as this test assesses the distance a participant can reach and so the longer the leg, the further the reach and the higher the score.

The Y balance test has been proposed as a reliable method of evaluating balance in the athletic population during screenings (Table 2.13) (Plisky et al., 2006). The Y balance test has been shown to be influenced by the time of day, with the best scores occurring in the test in the morning; therefore it is essential that when re-testing athletes or undertaking reliability analysis to ensure the testing sessions occur consistently at the same time of day (Gribble et al., 2007). There is a lack of normative data in present literature using the Y balance test protocol and testing kit and Gorman et al. (2012) recommends future research should focus on normative data in differing sports and age groups. Therefore establishing normative data utilising the Y balance test in adolescent and collegiate Gaelic players is essential and further examination of balance as a possible risk factor for injury in this population would be beneficial. Table 2.14 displays the normative data adapted from Gorman et al. (2012) study on high school athletes in those who play a single and multiple sports.

Table 2.13: Balance tests

Starting position	Directions	Measurement	Equipment	Study	Reliability	
					Inter-tester	Intra-tester
Original star excursion balance test						
-Grid is laid out on floor with 8 lines extending at 45° angles from the centre of the grid -Participant stands barefoot in single leg stance on dominant foot with heel at centre of grid and maximally reaches with the opposite limb -Participant touches down with most distal part of foot on the tape -Maximum reach distance marked with chalk immediately next to the tape that corresponded to site of touchdown	-Remove shoes -Stand with your heel on the centre of the grid -Reach as far forward as you can in each direction -Touch down with your toes onto the tape -Repeat this two more times in this direction	-Distance from centre of grid to point of touchdown with tape measure -Average of the 3 trials used -All 8 directions were noted on both feet	-Tape measure -Scoring sheet -Pen	Munro & Herrington (2010)	NT	ICC=0.84-0.92 SEM=2.21-94cm
				Hardy et al. (2008)	NT	ICC=0.94-98
				Lanning et al. (2006)	NT	ICC=0.84-0.97 SEM=1.64-3.70cm
				Kinzey & Armstrong (1998)	NT	ICC=0.67-0.87 SEM=3.43-4.78cm
				Hertel et al. (2000)	ICC=0.35-0.93 SEM=2.33-4.96cm	ICC=0.78-0.96 SEM=1.78-3.38
Modified star excursion balance test/Y balance test						
-Participant stands in the centre of the platform with their right foot behind the starting line -Participants push the reach indicator anteriorly with their free foot as far as possible. -Complete 6 practice trials in the anterior, posteriormedial	-Remove shoes -Stand with your right leg in the centre of the platform with your foot just behind the starting line -Reach forward with your free leg and push the target as far forward as you can -Do this 3 times.	- Maximum reach distance measured by observing the point where the target stopped -Average of 3 trials used -All 3 directions	- Y balance test kit -Scoring sheet -Pen	Clark et al. (2010)	ICC=0.91	ICC=0.98
				Plisky et al. (2006)	NT	ICC=0.84-0.87
				Plisky et al. (2009)	ICC=0.97-1.00 SEM=0.68-3.31cm	ICC=0.85-0.89 SEM=2.01-5.81cm
				Filipa et al. (2010)	NT	ICC=0.81-0.96

and posteriolateral directions -For the test start on the right leg and complete 3 trials in each direction on both feet	-Repeat in the forward direction with your left foot - Do the same motion 3 times to the side and backward on both feet while maintaining single leg stance -You will fail if you touch your foot on the ground, kick, place foot on top of or lean on the reach indicator to stabilise yourself	were noted on both feet				

NT; Not tested

Table 2.14: Normative data for the Y balance test

Variable	Single sport		Multiple sport	
	Mean	SD	Mean	SD
Anterior reach score (%LL)	75.5	7.1	76.4	7.9
Posteriomedial reach score (%LL)	108.2	10.3	109.1	10.2
Posteriolateral reach score (%LL)	107.4	11.04	105.8	11.1
Composite rearch score (%LL)	97.1	8.2	97.1	8.4
Anterior difference (cm)	2.8	2.2	3.6	3.8
Posteriomedial difference (cm)	4.6	4.4	4.3	3.8
Posteriolateral difference (cm)	4.3	4.3	5.0	4.2

%LL; Percentage leg length. Table adapted from Plisky et al. (2006).

2. 4. 1. 9. Squatting Techniques

Functional tests require the movement, control and integration of multiple joints in the body to complete a movement pattern (Alentorn-Geli et al., 2009). By assessing global movement patterns you are examining the participant's range of motion, strength, control, endurance, coordination, balance and neuromuscular control of all the individual joints working in synchrony to complete a functional movement (Kivlan and Martin, 2012, Butler et al., 2010). Neuromuscular control is an unconscious muscle activation and control of motion without which, joints may become more susceptible to injury due to reduced stability of the joint (Alentorn-Geli et al., 2009, Whatman et al., 2012). The squat motion is a movement pattern proposed as an essential component of daily activities, it is the most commonly used movement in sports and is termed the "athletic ready position" (Lamontagne et al., 2009, Cook, 2010, Cook et al., 2006b). It challenges the body's mobility and stability in order to control and move the ankle, knee and hip joints in a bilateral, symmetrical and functional manner (Cook et al., 2006a, Butler et al., 2010). Poor performance or kinematic patterns have been linked to an increased likelihood of sustaining ankle, knee and hip injuries (Weeks et al., 2012). Ankle dorsiflexion is necessary to effectively complete a squatting motion and at least 10° of dorsiflexion is needed for adequate gait in walking and running (Cook et al., 2006a, Malliaras et al., 2006, Brukner and Khan, 2006). Reduced dorsiflexion can occur due to tight calf muscles and/or ankle joint stiffness after sustaining an ankle injury (Brukner and Khan, 2006, Hoch et al., 2011). Participants with reduced dorsiflexion may implement compensation strategies to achieve adequate dorsiflexion to complete a squat which replicates gait where athletes tilt their feet outwards to pronate further and achieve more dorsiflexion. Reduced dorsiflexion is proposed to predispose to overuse injuries as the resulting excessive pronation places excessive loading on the shin, knee and hip joint (Brukner and Khan, 2006). In fact, Malliaras et al. (2006) found that dorsiflexion of less than 45° increased the risk of developing patellar tendinopathy by

1.8-2.8 times. In addition, if tight calves are contributing to the reduced dorsiflexion, the squat can highlight this compensation strategy and reduce the risk of a calf strain injury and/or Achilles tendinopathy (Brukner and Khan, 2006). In relation to the knee, increased knee valgus has been identified as a risk factor for knee injury (Weeks et al., 2012), including non-contact anterior cruciate ligament (ACL) tears (Alentorn-Geli et al., 2009) and patellofemoral pain syndrome (Weeks et al., 2012). Kinematic studies have demonstrated that reduced neuromuscular control and also both femoral adduction and internal rotation contribute to increased knee valgus, therefore if knee valgus is viewed during a squat, weakness of the hip abductors may be present and contributing to this issue (Claiborne et al., 2006, Weeks et al., 2012). This was supported by the fact that a high concentric hip abduction value was found to be a significant predictor of less knee valgus position when completing a single leg squat (r^2=0.13) (Claiborne et al., 2006, Weeks et al., 2012). With regard to the hip joint, reduced hip flexion range of motion in the squat could highlight mobility issues of the hip joint (Cook, 2010, Frohm et al., 2012). In fact, reduced depth of the squat occurred in those with femoroacetabular impingement (41.5%) in comparison to the uninjured control group (32.3%) (Lamontagne et al., 2009). Additionally a posterior to anterior tilt of the pelvis commonly occurs during the squatting motion which is commonly identified as the compensation strategy of excessive trunk flexion (i.e a forwardly tilted lower back). This is commonly due to tight hip flexor muscles which place the pelvis in the anterior tilted position (Brukner and Khan, 2006) and this poor flexibility may predispose the hip flexors to muscle tears. Consequently the anterior tilted position of the pelvis causes lengthening of the corresponding hamstring muscle as it attaches to the hip joint, this may predispose the hamstring to a muscle tear injury due to loading of the hamstring in a lengthened position over an extended period of time (Brukner and Khan, 2006). A unilateral problem of the ankle, knee and hip may be identified in a bilateral squatting movement which may indicate asymmetry between sides and is a commonly acknowledged risk factor for injury (Cook et al., 2006a, Cook, 2010).

The squat has been suggested to be superior than landing tasks as it is easier to assess as it is performed more slowly (Whatman et al., 2012). Numerous variations of the squat exist including: deep squat, maximal squat, small knee bend, partial squat, mini squat, squat jump etc (Whatman et al., 2012). However the most commonly used squat that assesses the functional movement pattern in totality is the deep squat as described by Cook et al. (2006a). The deeper the squat completed, the greater the joint moments and so incremental stress is placed on the ankle, hip and knee throughout the motion; this demands greater stability and mobility of these joints and so highlight dysfunctions that may not be observed when completing a squat of less depth (Butler et al., 2010). The specific instructions and grading system of the deep squat utilised varies between studies (Frohm et al., 2012). The single leg squat is a similar lower extremity screening test that assesses an identical movement pattern of the squat but utilises a unilateral movement on one leg. The single leg squat assesses the same variables as the squat, however as it is a unilateral movement, certain subtle dysfunctions that may be passed over in the squat may be highlighted and side by side comparisons can be made (Whatman et al., 2012). Balance may also play a superior part in this unilateral movement than the squat.

Three dimensional kinematic analyses is considered gold standard for assessing movement patterns (Maclean et al., 2005). However while extremely accurate and reliable, it is expensive and so is not suitable for a screening (Poulsen and James, 2011). Two dimensional analysis utilising high definition cameras therefore has been suggested and has been validated against three-dimensional analysis for several functional movement tests (Miller & Callister, 2009). An alternative to two dimensional analysis is live visual assessments, while similar, live allow testers to view the squat motion from all angles in real time which is a limitation of two dimensional analysis (Poulsen and James, 2011).

The deep squat has been suggested as a valid method of assessing functional movement (Butler et al., 2010). Butler et al. (2010) aimed to validate the deep squat by comparing groups that scored the lowest (one), middle (two) and highest (three) score as graded by the FMS system in comparison to ankle, knee and hip motion while assessing the squat using three dimensional analysis. Butler et al. (2010) suggested that those who score higher in the deep squat would demonstrate greater joint excursion, peak joint motion and peak joint moments in comparison to those who score lower. Butler et al. (2010) found that those who scored the optimal result (three) displayed significantly greater peak dorsiflexion movement (31.4±1.8°) and dorsiflexion excursion (28.9±1.5°) than those who scored a one (24.5±2.3°, $p=0.03$; 20.5±2.5°, $p=0.04$ respectively). No statistically significant difference was found between those who scored a two and a three in the grading system ($p>0.05$). This indicates that those with reduced dorsiflexion score poorer in the deep squat (Butler et al., 2010). With regard to the knee joint, significantly greater peak knee flexion (130.7±3.8°) and joint excursion (131.9±4.2°)

was observed in those that scored three in comparison with those who scored two (111.0±4.9°, 113.5±5.4°, $p<0.01$) or one (84.7±4.3°,80.5±4.4°, $p<0.01$). Furthermore those who scored two had significantly greater knee extension joint moments (0.555±0.052 Nm/kg/m) than those who scored one (0.448±0.039 Nm/kg/m). In relation to the hip joint significantly greater peak hip flexion, hip flexion excursion and peak hip extension moments was displayed by those who scored three (121.1±2.0°, 122.6±2.1°, -0.545±0.044 Nm/kg/m) and two (117.1±4.0°, 119.2±4.2°, -0.556±0.047 Nm/kg/m) in comparison to those that scored one (88.8±5.1°, 91.0±3.9°, -0.361±0.071 Nm/kg/m). Therefore this suggests the deep squat is a valid method of assessing functional movement of the ankle, knee and hip. The reliability of the deep squat according to FMS research and single leg squat studies that utilised ordinal scales is displayed in Table2.15. Normative data for the individual results for the deep squat is limited however Schneiders et al. (2011) found that the vast majority of young active males received an "average", followed by "excellent" and "poor". Thus normative data for squatting techniques is required for Gaelic games and further analysis of poor performance during the overhead squat and single leg squat and its effect on injury risk would be valuable.

Table 2.15: Squat and Single leg squat

Starting position	Directions	Measurement	Study	Equipment	Reliability	
					Inter-tester	Intra-tester
Deep Squat						
-Stand tall with feet approximately shoulder width apart and toes pointing forward -Grasp dowel in both hands and place it horizontally on top of your head so shoulders and elbows are at 90°	- Press the dowel so that it is directly above your head -While maintaining upright torso, and keeping heels and dowel in position, descend as deep as possible -Hold position for a count of one and return to starting point -Repeat 3 times	-0-3 ordinal scale according to FMS criteria	Schneiders et al. (2011)	- FMS kit	κ=1.00 100% agreement	NT
			Minick et al. (2010)	- FMS kit	Expert testers κ=0.64 76.9% agreement	NT
					Novice testers κ=0.80 87.2% agreement	NT
			Schultz et al. (2013)	- FMS kit	Kα=0.41	NT
			Teyhen et al. (2012)	- FMS kit	κ=0.68	κ=0.76
			Smith et al. (2013)	- FMS kit	NT	ICC=0.82-0.90
			Frohm et al. (2012)	-FMS kit	NT	ICC=0.73
Single Leg Squat						
-Stand on one leg with the contralateral leg bent and hip slightly flexed	-Squat as far down as you can while maintaining your balance on the single leg -Repeat 3-5 times -Repeat on the other leg	-0-5 ordinal point scale assessing alignment of each segment: trunk, pelvis, hips & thigh	Poulsen et al. (2011)	-None	κ=0.68	κ=0.38-0.94
		-1-3 ordinal point scale assessing the following criteria -Hip, knee and foot aligned -Pelvis in horizontal line -Upper body is vertical	Frohm et al. (2012)	-None	NT	ICC=0.53

2. 4. 1. 10. Scapular Control

Adequate scapular control and symmetry is required for effective motion of the shoulder, to provide a stable base for activation of the rotator cuff muscles and is a vital link in the kinetic chain of the shoulder (Ellenbecker et al., 2012, Kibler and Sciascia, 2010). No consensus on normal scapular motion exists, however it is agreed that during shoulder elevation, the scapula upwardly rotates, externally rotates and tilts posteriorly with the bulk of the tilting and external rotation occurring after 90° of humeral elevation (Struyf et al., 2011). Previously it was thought that for every 2° of humeral elevation the scapula upwardly rotates 1° however it is now accepted that the movement is more complex than this simplified theory (Johnson et al., 2001). The presence of a setting phase during the first few degrees of shoulder elevation where there is a downward rotation of the scapula is disputed, however it is thought that the weight of the arm and the muscular forces that move the arm and scapula may attempt to pull the scapula inferiorly in order to create adequate length-tension relationships of the muscles (Struyf et al., 2011). Scapular dyskinesis is a qualitative collective term for dysfunctional scapulae with an observable alteration in the position or motion of the scapulae relative to the thoracic cage which may alter scapula-humeral rhythm and shoulder arthrokinematics (Thomas et al., 2010, Kibler and Sciascia, 2010, Uhl et al., 2009, Kibler et al., 2002). It has been identified as a risk factor for injury in upper limb sports (Wang and Cochrane, 2001, Thomas et al., 2010, Ellenbecker et al., 2012). A commonly observed dysfunction of the scapulae is scapular winging, where the medial border of the scapula protrudes and does not lie flat on the ribs (Kibler and Sciascia, 2010). Scapulae may also become depressed, become lateralised, have increased protraction, may tilt anteriorly, have decreased upward rotation and may be unstable, all of which may be due to weakness and imbalance of stabilisers in the thoracic spine and shoulder, alterations in muscle activation patterns, damage to nerves that innervate the scapular stabilisers (long thoracic, dorsal scapular and spinal accessory nerve), reduced pectoralis minor muscle length and adaptations in bony stabilisers (Thomas et al., 2010, Wang and Cochrane, 2001, Kibler and Sciascia, 2010, McClure et al., 2009). This malalignment and change in motion may affect the normal functioning of the shoulder complex and could cause narrowing of the subacromial space and prevent the acromion from rotating out of the way of the humeral head which may cause impingement and impaired motion of the upper limb (Wang and Cochrane, 2001, Thomas et al., 2010). Athletes with reduced internal rotation of the shoulder usually presented with protracted and internally rotated scapulae (Thomas et al., 2010). When an athlete with poor internal rotation throws, the scapula must travel up and around the thoracic cage in order to achieve enough internal rotation to follow through effectively, which may lead to adaptation by the shoulder complex and abnormal positioning of the scapulae (Thomas et al., 2010). Poor posture like slouching, rounded shoulders and increased thoracic kyphosis may force the scapulae into increased upward rotation. Also, scapulae may lag or move slower compared to the corresponding scapula, this may be due to inhibition of the serratus anterior and lower trapezius which rotate the scapulae and so can alter motion of the shoulder complex and increase the likelihood of injury (Thomas et al., 2010). Scapulae position at rest and during dynamic motion are considered two separate entities, and ideally both should be assessed in a comprehensive scapular dyskinesis test (Kibler and Sciascia, 2010).

A single clinically feasible and reliable method of assessing scapular dyskinesis has not yet been established (Uhl et al., 2009, McClure et al., 2009). During dynamic motion, a complex three dimensional pattern occurs where testers must consider three rotational and two translations of movement simultaneously (Uhl et al., 2009, McClure et al., 2009). Proposed scapular assessment tests include: the lateral scapular slide test, posterior displacement test, scapular upward rotation test, visual assessment and three dimensional kinematics assessments using electromagnetic tracking devices (Uhl et al., 2009, McClure et al., 2009, Kibler et al., 2002) and their reliability is presented in Table 2.16. Scapular dyskinesis was originally assessed in the static position (Uhl et al., 2009). Kibler (1991) proposed the lateral scapular slide test which measures scapular position by comparing side to side scapular distances from the inferior angle of the scapulae to the parallel thoracic spinous process in the horizontal plane and a cut-off point of 1.5cm difference between sides indicates asymmetry (Odom et al., 2001). This measurement was completed in three separate positions to measure the ability of the scapular stabilizers to control the scapula during various positions of loading: position 1 in 0° of humeral elevation (i.e. with hands by the side), position 2 in 40° elevation, and position 3 places in 90° elevation (Odom et al., 2001). The posterior displacement test assess winging and tilting of the inferior angle of the scapula with respect to the posterior thorax using a large measurement tool termed the “Perry Tool” (Plafcan et al., 1997). This measurement was taken at the resting position with arms by their sides and in a weighted position while holding 10% of their body weight (Plafcan et al., 1997). While this test was found to be reliable (Table 2.16) the Perry Tool is not widely commercially available (Plafcan et al., 1997). The scapular upward rotation test measures scapular rotation at rest, at 60°, 90° and 120° during abduction (Johnson et al., 2001). A guide pole positions the arm and a pin is inserted to ensure the arm is kept in position (Johnson et al., 2001, Thomas et al., 2010). This test was found to be reliable (Table 2.16), valid and demonstrated good to excellent (r=0.59-0.92) correlations between a digital inclinometer against a 3d electromagnetic tracking system in all arm positions (Johnson et al., 2001). Watson et al. (2005) modified the scapular upward rotation test by examining the intra-tester reliability in the full range of scapular abduction rather than stopping at 120° in order to increase the functionality and clinical relevance of the test.

Assessing scapular asymmetry in a static position does not capture the three dimensional movement patterns that occur during motion of the shoulder in sport (McClure et al., 2009). Furthermore scapular abnormalities were more apparent during dynamic rather than static assessments in an injured population (McClure et al., 2009). Therefore, both a static and dynamic motion using a visual examination or three dimensional kinematics assessment (using electromagnetic tracking devices) would be superior to other static scapular assessments (Uhl et al., 2009, Kibler et al., 2002, Oyama et al., 2008). However 3d kinematic analysis is time consuming, requires expensive equipment and is inapplicable in a field setting (Kibler et al., 2002). Visual observation during resting and dynamic motion is the ideal field based method of assessing scapular asymmetry despite its subjectivity. The downward motion is essential to assess as mal-alignment is more pronounced during the lowering phase as muscles are working eccentrically under an increased load (Kibler et al., 2002). Asymmetry, winging, stability and speed of the movement of the scapulae should be noted (Kibler and Sciascia, 2010, Kibler et al., 2002).

Kibler et al. (2002) developed a qualitative clinical evaluation system to quantify abnormal scapular motion which divided dyskinesis into four patterns. Participants were videotaped while they abducted and elevated both arms in scaption at a rate of 45°/s, however low to moderate reliability is reported (Table 2.16) (Kibler et al., 2002, Ellenbecker et al., 2012). In addition, participants can display more than one pattern of scapular dyskinesis and the clinician must pick the dominant pattern which is an inherent source of error (Kibler et al., 2002, Ellenbecker et al., 2012), additionally these may not be exclusive categories and could often occur concurrently (McClure et al., 2009). Kibler et al. (2002) only used a ten minute familiarisation presentation to testers which may be inadequate to fully explain the four patterns of motion described.

Videotaping rather than live evaluation prevents testers viewing the scapulae from different angles which may cause further error (Kibler et al., 2002). Uhl et al. (2009) assessed the validity of the Kibler classification against 3 dimensional electromagnetic tracking device and found an inter-rater agreement of 69%, low sensitivity (10-54%), moderate to good specificity (62-94%) and variable positive predictive values which indicates the probability that the tests accurately predicts the 4 patterns of scapular dyskinesis (20-71%) (Uhl et al., 2009). The occurrence or severity of specific criteria in scapular dyskinesis can also be measured. Uhl et al. (2009) proposed and validated a yes/no method in a visual examination against a 3 dimensional electromagnetic tracking device which produced an inter-rater agreement of 79%, sensitivity of 76%, specificity of 30% and a positive predictive value of 74% (Uhl et al., 2009) While the test was deemed valid, poor specificity indicates that there may be an increased likelihood of false positive findings (Uhl et al., 2009). McClure et al. (2009) proposed a graded system that classifies participants based on the severity of scapular dyskinesis during shoulder flexion and abduction in the frontal plane while holding different weighted dumbbells depending on the participant's body weight (McClure et al., 2009). McClure et al. (2009) found that inter-tester reliability was increased by using standardised videotaped examples of normal and abnormal scapular movement shown to testers during the familiarisation stage instead of written descriptions (McClure et al., 2009). Tate et al. (2009) validated this test using an electromagnetic based motion capture system and participants rated in the obvious scapular dyskinesis group demonstrated less scapular upward rotation, less clavicular elevation and greater scapular clavicular protraction ($p<0.05$) (Tate et al., 2009). Participants in the scapular dyskinesis group displayed approximately 9° more downward rotation from 0-60° humeral elevation in the scapular plane, however while large differences were visible throughout the entire movement, they eventually caught up and achieved the same maximal amount of upward rotation as the normal group. This is clinically relevant as impingement symptoms commonly occur between 60-120° of elevation and the rotator cuff, subacromial bursa and long head of the biceps tendon that are commonly involved in impingement are more likely to become increasingly compressed with a reduction in upward rotation (Tate et al., 2009). Less clavicular elevation was also noted in the obvious scapular dyskinesis group at 30° and 60° of arm elevation which presents visually as a lower scapula than the other side. In addition, increased protraction of the scapula at rest and a more protracted position throughout the entire lifting and lowering movement was noted in those with obvious scapular dyskinesis which may further compress the structures within the subacromial space (Tate et al., 2009).

No gold standard clinically feasible and reliable test is available to assess scapular dyskinesis. In fact, as previously mentioned, proposed tests tend to assess scapular asymmetry in the static position and do not capture the three dimensional movement patterns utilised in sport, require expensive equipment which may not be readily available in the clinical setting and have widely varying and complicated scoring systems with unclear definitions (McClure et al., 2009, Uhl et al., 2009, Kibler et al., 2002). Thus, a simple screening test that addresses these issues for scapular dyskinesis is necessary to be developed for use in the sporting population. This test should ideally be dynamic in nature and assess all components of scapular dyskinesis during the abduction movement. The inter-tester and intra-tester reliability and normative data for this developed screening test should then be established.

Table 2.16: Scapular Asymmetry and Control (motion) tests

Starting position	Directions	Measurement	Study	Equipment	Reliability	
					Inter-tester	Intra-tester
Scapula lateral slide test						
-Stand in a normal relaxed posture -0°, 40° and 90° of glenohumeral abduction with maximal internal rotation measured -Modified version the hands are at the sides, hands on hips and 90° abduction	-Stand relaxed with hands at side -Move your arms up to 40° -Then move arms to 90° elevation	-Distance in cm between tip of inferior angle of scapula and corresponding thoracic spinous process	Odom et al. (2001)	String	ICC=0.43-0.74 SEM=0.79-1.20	ICC=0.75-0.80 SEM=0.58-0.80
			Wang and Cochrane (2001)	Not stated	NT	ICC=0.88-0.95
			Thomas et al. (2010)	Vernier caliper	NT	ICC=0.935-0.975 SEM=0.186-0.328cm
			Gibson et al. (1995)	String	ICC=0.18-0.69	ICC=0.81-0.95
Posterior displacement test						
-Stand in normal relaxed position with arms by side -Then participant holds 10% of body weight with arms at side	-Stand relaxed with hands by your side -Stand relaxed while holding 10% of your body weight	-Degree of posterior displacement of the inferior angle of the scapula	Plafcan et al. (1997)	Perry Tool	ICC=0.92-0.97 SEM=1.1-1.7°	ICC=0.97-0.99 SEM=0.6-1.1°
Scapular upward rotation						
-Stand in normal relaxed posture -A guide pole positions arm in 60°, then 90°,	-Abduct arm until it is positioned against the pin -Hold until	-Lateral arm of inclinometer placed over posterior-lateral acromion and medial	Thomas et al. (2010)	Digital inclinometer	NT	ICC=0.965-0.974 SEM=0.70-0.89°
			Johnson et al. (2001)	Digital inclinometer	NT	ICC=0.89-0.96 SEM=2.0-2.8°

then 120° abduction -Once in position a pin is inserted into guide pole and measurement is taken	measurement completed	arm placed over root of scapular spine	Watson et al. (2005)	Bubble Inclinometer	NT	ICC=0.81-0.94 SEM=1.7-5.2°
Visual Examination: static and dynamic motion assessment						
-Stand with normal posture with arms at sides, elbows in full extension and thumbs facing forward -Participants asked to elevate arms for 3-5 repetitions	-Slowly lift your arms as far as you can while keeping your elbows straight 3-5 times	-Scapular position -Winging -Asymmetry between sides -Scapular motion assessed	Tripp et al. (2006)	3d electromagnetic tracking device	NT	ICC=0.77-0.90 SEM=0.76-1.51°
Visual Examination: Classification according to Kibler et al. (2002)						
-Abduct and elevate arms in scaption (45° anterior to the frontal plane) 3 times in a randomized manner at a rate of 45°/s	-Slowly lift your arms as far up as you can while keeping your elbows straight (randomise the abduction and elevation in scaption 3-5 times)	-Visual assessment -Rated participants into 4 different patterns of movement	Kibler et al. (2002)	Video	κ=0.31,0.42	Ꮶ=0.49,0.59
			Ellenbecker et al. (2012)	Video	κ=0.186,0.245	NT
			Uhl et al. (2009)	Visual examination	κ=0.44 61% agreement	NT
Visual Examination: Scapular Dyskinesis Test (SDT)						
Actively flex and abduct (in frontal	-Elevate arms overhead as far as	-Visual assessment -Rated participants	McClure et al. (2009)	Visual examination and	Visual: κ=0.57	NT

plane) the shoulder while holding 2 dumbbell 5 times	possible to a 3 second count while your thumbs face upwards. -Lower to a 3 second count	as normal, subtle or obvious dyskinesis		Video	Video: κ=0.54	
Visual Examination: Yes/no method						
-Abduct and elevate arms in scaption (45° anterior to the frontal plane) 3 times in a randomized manner at a rate of 45°/s	-Slowly lift your arms as far up as you can while keeping your elbows straight (randomise the abduction and elevation in scaption 3-5 times)	-Visual assessment -Rated “yes” when scapular dyskinesis is present -Rated “no” when scapular dyskinesis is not present	Uhl et al. (2009)	Visual examination	κ=0.41 79% agreement	NT

NT: Not tested. In reliability ICC’s of >0.75 is excellent, 0.40-0.75 is fair to good and 0-0.40 is poor (Landis & Koch, 1997)
κ=Kappa coefficient used to measure agreement in categorical data

2. 4. 1. 11. Core stability

Core musculature contract to support the lumbo-pelvic-hip complex and stabilise the spine, pelvis and kinetic chain during movement (Faries and Greenwood, 2007). The most widely accepted classification of muscles surrounding the lumbo-pelvic-hip complex and what constitutes the core musculature can be differentiated into local and global muscles (Liemohn et al., 2010, Faries and Greenwood, 2007, Bliven and Anderson, 2013). Local muscles (primarily the transversus abdominis and the multifidi) are shorter muscles and attach directly to the vertebrae of the spine which allows them to directly stabilise each segment of the spine and consequently are the principal stabilisers (Faries and Greenwood, 2007, Liemohn et al., 2010). The primary stabilisers activate prior to movement of the body in order to stabilise the spine to prevent injury and optimise performance. In fact during tests on the reaction of the core, the transversus abdominis has been shown to contract 100 milliseconds prior to any movement of the limbs in any direction, followed then by a contraction of the multifidus (Faries and Greenwood, 2007, Bliven and Anderson, 2013). The secondary local stabilisers (medial fibres of external oblique, iliocostalis and longissimus, diaphragm, pelvic floor muscles and quadratus lumborum) have a dual role in both stabilising and producing movement of the spine (Faries and Greenwood, 2007). Global muscles on the other hand are long muscles that focus on speed and power to create high torque rather than stabilisation (Faries and Greenwood, 2007, Liemohn et al., 2010). While this classification is the basis of the majority of definitions of core stability, researchers proposed that global muscles should be subdivided into two categories, the stabilisers (internal and external obliques) and the mobilizers (rectus abdominus and iliocostalis) (Bliven and Anderson, 2013). The stabilisers eccentrically work to control movement throughout the range of motion while mobilizers concentrically work and also act as shock absorbers.

Core stability and core strength are two differing entities, however these terms are often used interchangeably with terminology varying between papers (Hibbs et al., 2008, Liemohn et al., 2005). Core strength is the capability of muscles to create force through contractile forces and intra-abdominal pressure (Faries and Greenwood, 2007). Adequate core stability is defined as the ability to stabilise the spine through integration of the passive spinal column, active spinal muscles and the neural control unit during daily activities and sporting movements (Hibbs et al., 2008, Liemohn et al., 2005, Faries and Greenwood, 2007). Poor core stability causes an unstable proximal base, so when high loading occurs, the control of and positioning of the spine and lower extremity is lessened and altered which may lead to an increased injury risk (Bliven and Anderson, 2013, Cowley and Swensen, 2008, Cowley et al., 2009, Nesser et al., 2008). Few prospective studies identifying core stability as a risk factor for injury (Bliven and Anderson, 2013). Injured collegiate athletes had lower stability results than the uninjured however this did not reach statistical significance (Leetun et al., 2004). Abt et al. (2007) found that after cyclists completed a core stability fatigue protocol their cycling mechanics became altered, with increased knee valgus and altered position of the lower extremities which may put the knee under greater loading and stress, alter technique and so predispose to knee injuries. However research has demonstrated that it is the timing of muscle recruitement and not the strength of the core is essential in preventing injuries (Bliven and Anderson, 2013). In addition, there is no conclusive definition of core stability and core musculature, thus core stability tests may not be accurately measuring true core stability and so any links between core stability and injury rates would be expected to be tenuous at best (Hibbs et al., 2008). Good core stability has been theorized to improve performance as a strong core allows the transfer of forces generated from the ground through the lower limbs, trunk and upper limbs, however few studies have demonstrated a direct relationship between core stability and improved athletic performance (Sato and Mokha, 2009). Core stability was only low to moderately significantly correlated with performance in strength and performance tests in American footballers (Nesser et al., 2008). Sato and Mokha (2009) found that a six week core strength training programme improved 5000m running time in runners. Conversely, Tse et al. (2005) found no improved functional performance measures after an eight week core endurance training programme on collegiate rowers ($p>0.05$), however an improvement in core endurance was shown ($p<0.05$). Thus programmes that emphasis core strength may directly improve performance, however core stability may reduce injury risk.

No gold standard core stability test is available and various core stability tests are proposed including: the front abdominal power test (FAPT), side abdominal power test (SAPT), McGill protocol isometric flexor endurance, McGill protocol isometric extensor endurance, McGill protocol isometric side bridge, plank to fatigue, double leg lowering test and trunk stability test (Cowley and Swensen, 2008, McGill et al., 1999, Cowley et al., 2009, Krause et al., 2005, Cook et al., 2006b). The reliability and explanations of these tests is presented in Table 2.17. However, these tests are not considered ideal for use in a screening or clinical environment as some tests actually measure core strength not core stability (FAPT and SAPT), some test core stability in a single position which does not reflect the demands placed on the core during most sporting movements (isometric flexor endurance, isometric extensor endurance, isometric side plank, plank to fatigue), some take a significant amount of time to complete (isometric flexor endurance, isometric extensor endurance, isometric side bridge, plank to fatigue), some have vague or unclear scoring systems (isometric flexor endurance, isometric extensor endurance, isometric side bridge, plank to fatigue, double leg lowering test) or require expensive equipment or necessitate therapists to develop or build equipment (double leg lowering test, isometric flexor endurance, isometric extensor endurance) (Cowley and Swensen, 2008, Nesser et al., 2008, Cowley et al., 2009, Krause et al., 2005). The development of a gold standard test for core stability is challenging because not only is there no widely accepted definition of core stability, there are numerous different muscles that assist in core stability and the interaction between the muscles of the lumbo-pelvic-hip is complex, hence it is difficult for researchers to develop a single test that incorporates all muscles and structures (Cowley and Swensen, 2008, Cowley et al., 2009, Hibbs et al., 2008).

Current core stability measures tend to look at isolated aspects of core stability in stationary and uniplanar positions, however the trunk stability test in the FMS™ is purported to observe reflex core stabilisation by initiating movement with the upper extremities while completing a push up while not permitting any movement to occur in the spine or hips (Cook, 2010). This movement pattern aims to test the ability of the core to stabilise the spine in the sagittal and anterior/posterior plane during a closed kinetic chain, upper body symmetrical pushing movement (Cook, 2010). The trunk stability test has been tenuously linked to having more sensitivity to core stability issues rather than upper extremity strength problems. Chobra et al. (2010) found that when the trunk stability test was removed from the FMS screening, correlations between lower extremity injury and core stability reduced. Therefore the trunk stability test is proposed to test a person's movement pattern and core stability under functional loading during a dynamic movement which may be a more conclusive and relative test in the athletic population (Bliven and Anderson, 2013, Chorba et al., 2010). The trunk stability push up test has shown excellent reliability (Table 2.17),is quick to administer, has a clear and well defined scoring system, requires no equipment and demonstrates more functionality than other tests proposed in literature (Chorba et al., 2010, Schneiders et al., 2011). In a study identifying normative data in the FMS, the majority of participants scored the highest score (3) in the trunk stability push up test. When looking at males only, 76.2% scored a three in a young physically active population (Schneiders et al., 2011).

Thus this review of core stability literature indicates that the trunk stability test is the most applicable and reliable core stability measure, however its ability to differentiate between those with higher core stability results may be questionable due to the high percentage of participants that receive the highest score using published normative data. Therefore adapting this test to further challenge core stability may be beneficial in order to sub-classify participants' core stability capabilities. Following this evaluating adolescent and collegiate normative data for this adapted test would be needed, and an analysis of core stability as a risk factor for injury is required.

Table 2.17: Core stability Tests

Starting position	Directions	Measurement	Study	Equipment	Reliability	
					Inter-tester	Intra-tester
McGill Protocol: Isometric flexor endurance						
-Sit on bench and place upper body against support angle of 60° -Flex knees and hips to 90° -Fold arms across chest with hands on opposite shoulders -Place toes under toe straps	-Hold this position while supporting wedge is pulled back 10cm	-Time in seconds until upper body fell below 60° angle or hits the wedge	McGill et al. (1999)	-Stopwatch -Bench/plinth -Back support at a 60° angle -Strap for toes	NT	ICC=0.93
McGill Protocol: Isometric extensor endurance						
-Prone on bench with lower body fixed to bed at ankle, knees, hips and upper body extended off the plinth -Bench was 25cm above floor -Rest upper body on floor -Fold hands across chest with hands on shoulders	-Lift upper body off the floor to lie horizontal to the floor -Hold position for as long as possible	-Time in seconds from point participant reached horizontal until body came in contact with floor	McGill et al. (1999)	-Stopwatch -Plinth -Straps for	NT	ICC=0.99
McGill Protocol Isometric side bridge						
-Lie on a matt on sides with legs extended -Place top foot in front of other foot for support and place uninvolved arm across chest to the shoulders	- Support yourselves by lifting your hips off the mat and maintain a straight line over full body. - Support yourself with elbows and ankles -Hold position for as long as possible	-Time in seconds until hips touched the mat	McGill et al. (1999)	-Stopwatch	NT	Right ICC=0.96 Left ICC=0.99
Front Abdominal Power Test (FAPT)						
-Lie on back on mat with arms along sides and feet shoulder width apart	-Keep shoulders, elbows, wrists locked in starting position and throw while	-Mean distance the medicine ball travelled from tip of participant's feet to where the medicine ball	Cowley & Swensen, (2008)	Measuring tape	NT	ICC=0.95 SEM=24cm

-Bend knees to 90° and place arms overhead -Align tip of feet with end of mat -Flex shoulders and keep the elbows and wrists extended with the hands supinated and thumbs from the left and right hands touching -2kg medicine ball placed into hands	using the arms as a lever to project the medicine ball -Feet and buttocks must remain in contact with the floor -Medicine ball must only be released out of the hands when over knees	landed in 3 trials	Cowley et al. (2009)	Measuring tape	NT	ICC=0.95
Side Abdominal Power Test (SAPT)						
-Sit on mat with knees bent at 90° and feet shoulder width apart with the left edge of the left foot aligned with the end of the mat -Subject held arms directly out in front with the elbows extended and hands supinated with the 5th digit of right and left hands touching	-Lower torso as if to lie down but stop at 45 hip angle (tester confirms position) - A 2kg medicine ball will be placed in hands and held slightly above knees -Slowly rotate torso to the right by 90 -Perform an explosive concentric contraction by rotating trunk to the left while using the arm as a lever to project medicine ball -Feet and buttocks must remain in contact with floor -Ball can only be released once over left knee	-Mean distance the medicine ball travelled from tip of participant's feet to where the medicine ball landed in 3 trials	Cowley & Swensen, (2008)	Measuring tape	NT	ICC=0.93 SEM=NT
Plank to fatigue						
-Lie prone on mat -Prop up with elbows directly underneath shoulders so upper arms are perpendicular to floor	- Hold this position for as long as you can maintain -Tester will give you verbal feedback on the position of	-Time in seconds to fatigue until participant unable to correct any deviation from starting position	Cowley et al. (2009)	-Stopwatch -Two 90cm vertical rods -Dowel	NT	ICC=0.85

-Lift hips so that a straight line can be drawn from shoulder to hip to ankle -Feet placed against wall to stabilise -A weight that weighs 10% of body weight placed on upper buttocks	your hips relative to starting position -Correct hip position to align with starting position -Tests ends when this cannot be done			-Rubber mat -Weight 10% of body weight of participant		
Double leg lowering test						
-Supine on a wooden table with a 1cm thick felt pad and arms folded across chest -Bring hips to 90° with legs extended and vertical in the air -Tester 1 places their hand under the lower back and as the participant lowers notes the time when the lower back lifts from their monitoring fingers -Tester 2 measures this position with an inclinometer or visual estimation	-While keeping your back flat on the table slowly lower your legs while keeping your legs extended to the table -When tester 1 tells you to stop lowering hold your legs in this position until told to relax	-Angle of the lower limb from the horizontal reference when the lower back began to move superiorly away from Tester 1 fingers	Krause et al. (2005)	-Digital inclinometer -Wooden bench -1cm thick felt	NT	ICC=0.98
Trunk stability push up test						
-Prone position with arms overhead with their thumbs at forehead level -Knees fully extended, ankles neutral and soles of feet perpendicular to the floor	-Perform one push up in this position -Lift the body as a unit; there should be no sway or lag in the spine	-Visual estimation of the spine and hip -If lag or sway occurs the participant should complete the test again with thumbs at chin level - Score 0-pain, 1-cannot complete at chin level, 2-can complete at chin level, 3-can complete at forehead level	Schneiders et al. (2011)	None	κ=1.00 100% agreement	NT
			Minick et al. (2010)	None	Expert tester: κ=0.78 87.2% agreement Novice tester: κ=0.87	NT

					92.3% agreement	
			Shultz et al. (2013)	None	Kα=0.31	NT
			Teyhen et al. (2012)	None	κ=0.82	κ=0.68
			Smith et al. (2013)	None	NT	ICC=0.88-0.95

In reliability ICC's of >0.75 is excellent, 0.40-0.75 is fair to good and 0-0.40 is poor (Landis & Koch, 1997)
κ=kappa coefficient used to measure agreement in categorical data

2. 5. Summary of literature review chapter

It is clear there is a lack of standardised methodology in epidemiological data across all sports, especially Gaelic games. Injuries have been found to be prevalent in Gaelic games with reported injury rates of 51.2-64.0 injuries per 1000 hours of matches and 4.1-5.8 injuries per 1000 hours of training in Gaelic football and in hurling 102.5 and 5.3 injuries per 1000 hours in matches and training respectively (Murphy et al., 2012b, Wilson et al., 2007, Cromwell et al., 2000, Watson, 1996b, Murphy et al., 2012a, Watson, 1996a). However, there is also a lack of high quality studies in the non-elite, adolescent and collegiate population in Gaelic games. Only five studies have assessed possible causative factors for injury in Gaelic games, and none were completed in adolescents (Watson, 1999, O'Sullivan et al., 2008, Lowther et al., 2012, Falvey et al., 2013, Watson, 2001). The injury description and a musculoskeletal pre-participation screening are two effective tools to decipher the risk of injury in Gaelic games (Maffey and Emery, 2006, Bahr and Krosshaug, 2005). However, as of yet there is no developed standardised screening for Gaelic games which needs to be addressed. In addition, some tests are not field based tests which is not ideal for use in screenings, and their reliability has not yet been established. Thus this research will aim to investigate these gaps in the literature to provide a comprehensive view of the epidemiology and risk factors for injury in adolescent and collegiate Gaelic footballers and hurlers.

2. 6. Primary aim of Research

The primary aim of this thesis is to capture the epidemiology of injury and identify risk factors for injury in adolescent and collegiate Gaelic footballers and hurlers.

2. 7. Aims and Objectives of Research

Study 1: The musculoskeletal pre participation screening in adolescent and collegiate Gaelic footballers and hurlers.

Aim of Study 1

- To develop and establish normative data of a musculoskeletal pre-participation screening for adolescent and collegiate Gaelic footballers and hurlers

Objectives of Study 1

- To develop a musculoskeletal pre-participation screening suitable for Gaelic football and hurling

- To develop and adapt suitable tests and scoring systems that are not sufficient or developed in current literature to include in a screening in Gaelic football and hurling
- To determine the absolute and relative inter-tester and intra-tester reliability of the developed or adapted screening tests
- To establish normative data for adolescent and collegiate Gaelic footballers and hurlers in each of the screening tests
- To compare and contrast the normative data in adolescent and collegiate Gaelic footballers and hurlers
- To compare and contrast the normative data between Gaelic football and hurling

Study 2: The epidemiology of injury in adolescent and collegiate Gaelic footballers and hurlers.

Aim of Study 2

To establish the incidence rates and epidemiology of injury in adolescent and collegiate Gaelic footballers and hurlers.

Objectives of Study 2

- To establish the incidence of injuries in adolescent and collegiate Gaelic footballers and hurlers
- To determine the epidemiology of injuries that occur in adolescent and collegiate Gaelic footballers and hurlers
- To compare and contrast the incidence and epidemiologic report of injuries in adolescent and collegiate Gaelic footballers and hurlers
- To compare and contrast the incidence and epidemiologic report of injuries between Gaelic football and hurling
- To compare and contrast the incidence and epidemiologic report of injury between fresher and senior players

Study 3: The risk factors for injury in adolescent and collegiate Gaelic footballers and hurlers.

Aim of Study 3

To identify the risk factors for sustaining an injury in adolescent and collegiate Gaelic footballers and hurlers

Objectives of Study 3

- To identify the risk factors for injury in the lower body, upper body and trunk in adolescent Gaelic footballers and hurlers and collegiate Gaelic footballers and hurlers
- To determine cut off points to identify participants at risk of injury in the lower body, upper body and trunk for adolescent Gaelic footballers and hurlers and collegiate Gaelic footballers and hurlers
- To establish the risk factors for injury in commonly injured body parts in school adolescents, adolescent Gaelic footballers and hurlers and collegiate Gaelic footballers and hurlers
- To determine cut off points to identify participants at risk of injury in each of the commonly injured body parts for school adolescents, adolescent Gaelic footballers and hurlers and collegiate Gaelic footballers and hurlers

Chapter 3. The musculoskeletal pre-participation screening in adolescent and collegiate Gaelic footballers and hurlers.

3. 1. Introduction

A musculoskeletal pre-participation screening is utilised to identify possible risk factors for injury in an athlete. The screening is based on the principle that it can evaluate a player's ability in selected tasks prior to the season commencing, which can allow therapists to develop and introduce prevention strategies to reduce the subsequent likelihood of injury where necessary (Maffey and Emery, 2006). While the benefits of implementing a screening is evident, they do not commonly take place in Ireland outside of elite county teams, because as unlike collegiate and sporting teams in the U.S.A. and Canada, Irish teams are not under legal and insurance obligations to do so (Carek and Mainous, 2003).

At present, no standardised screening has been developed specifically for Gaelic games or indeed generically for use across all sports (Maffey and Emery, 2006). Research recommends that the screening itself should be simple to execute, time efficient, suitable to administer to a large number of players and utilise field based tests that require minimal and inexpensive equipment in order to promote its usage and ensure compliance with therapists and teams (Garrick, 2004, Maffey and Emery, 2006, Gabbe et al., 2004). There is a lack of consensus in the current literature on which tests should be ideally included, however it is generally accepted that the tests chosen should be based on clinical experience, knowledge of the sport and must be prioritised to the most essential and sport specific components based on the epidemiology of injury in the sport (Gabbe et al., 2004, Maffey and Emery, 2006). High reliability (high consistency of the test or measurement) is essential for each test in the screening in order to confidently interpret the results of the testing (Hopkins, 2000). Ideally both absolute and relative inter-tester and intra-tester reliability should be established (Atkinson and Nevill, 1998, Hayen et al., 2007, Eliasziw et al., 1994).

Normative data is an essential component of any screening as it is a standardised reference of results for each specific test in a comparable population (Corkery et al., 2007). To date, there has only been a single published study on normative data in Gaelic footballers and hurlers (Fox et al., 2013), however, this was completed on adult players only and utilised the FMS protocol which has inherent serious limitations as discussed in Section 2.4.1.2. Thus, there is a clear need for normative data in adolescent and collegiate Gaelic footballers and hurlers. Additionally, there is a lack of normative data in screenings internationally in adolescent teenagers.

Thus, the aims of this study are:

1) Design a screening specific to Gaelic football and hurling.

2) Develop and adapt suitable tests and scoring systems for use in the screening

3) Establish the absolute and relative inter-tester and intra-tester reliability of the developed and adapted screening tests

4) Establish normative data for adolescent and collegiate Gaelic footballers and hurlers

5) Compare and contrast normative data between adolescent and collegiate Gaelic footballers and hurlers

6) Compare and contrast normative data between Gaelic footballers and hurlers

7) Compare and contrast normative data between fresher and senior players.

3. 2. Method

3. 2. 1. Subjects

771 male participants that played Gaelic football and hurling were recruited. Adolescent participants (n=426) were recruited from five, all male schools from Dublin and its surrounding areas that had a strong Gaelic football and hurling background. These schools were:

- Colaiste Eoin, Cappagh Road, Dublin
- St Aidan's Secondary School, Collins Avenue, Whitehall, Dublin
- St Declan's College, Nephin Road, Dublin
- Ardscoil Ris, Griffith Avenue, Dublin
- St Patrick's Classical school, Navan

Collegiate participants (n=345) were recruited from the male fresher and senior Gaelic football and hurling teams in Dublin City University in the first year of the study and both Dublin City University and Athlone Institute of Technology in the second year of the study. All possible participants were required to attend an information session where the testing procedure and risks of the study were fully explained. All participants were given a plain language statement form (Appendix B) and an informed consent form (Appendix C) to sign. School participants and their legal guardian were required to sign the informed consent prior to undergoing the testing. Ethical approval was granted prior to the study starting date by Dublin City University Ethics committee.

3. 2. 2. Development of the musculoskeletal pre-participation screening

This study aimed to propose a series of tests specific to Gaelic games to form a comprehensive screening. After extensive research in this area, a series of tests was proposed and the content validity of the musculoskeletal screening was initially assessed. Content validity is established by a group of experts in the area discussing and ultimately voting on the inclusion or exclusion of components of the screening (Lafave et al., 2013). Four experts with extensive experience in the screening area took part in establishing the content validity; the primary researcher in this study (Siobhán O Connor MSc. ARTC), a clinical biomechanist (Dr. Kieran Moran), a sports medicine physician (Dr Noel McCaffrey) and a lecturer in Athletic therapy (Mr Enda Whyte MSc. ARTC). A number of meetings were held to discuss the advantages and disadvantages of each test and discussions were undertaken in great detail on the purpose of each test, its relationship to injury and the practicality of the test in a screening. As previously mentioned (Section 2.4), there are a number of serious limitations of tests used in screenings in current literature. Thus, the current researcher and expert group saw the need to not only select tests for each component of the screening, they observed a need to develop (1 test) and adapt tests (4 tests) for the screening. Both scapular control and core were highlighted as components of the screening where no clear consensus was available on a clinical gold standard test. Thus, the scapular control test was developed as a dynamic comprehensive method of assessing winging, control of scapula in both the lifting and lowering motion and the symmetry of scapulae. Initially five separate tests were included in the testing protocol for an assessment of core musculature: flexor endurance test, extensor endurance test, the plank, side plank and double leg lowering test. A comprehensive scoring system was developed for the overhead squat and single leg squat as the scoring systems available in current literature were general and did not capture the full body mechanics of the action completed. In addition, the active knee extension test was adapted from the tests utilised in the present literature by removing extra equipment to ensure the test was quick to execute and used minimal equipment. Thus the following tests were suggested as possible beneficial tests for inclusion in this study and a pilot study was undertaken to assess the effectiveness of each of these tests in the screening:

- Height
- Weight
- Active knee extension test
- Internal rotation of the shoulder
- External rotation of the shoulder
- Navicular drop test
- The Y balance test
- Overhead squat
- Single leg squat
- Scapular Control test
- The Landing error scoring system (LESS)
- Flexor endurance test
- Extensor endurance test
- Plank test
- Side plank test
- The double leg lowering test

3. 2. 3. Pilot Study

The pilot study was completed prior to the normative testing being undertaken. Two under 16 male Gaelic football and hurling teams (n=63) from a local club undertook the screening. The purpose of the pilot study was to assess the appropriateness and practicality of each test in the screening. It also functioned as a trial run of the protocol designed for the study and was used as a tool to allow researchers to decide on which tests should be utilised in the final screening. The following criteria were assessed in the pilot study: time taken to implement the test, equipment needed, does the test actually assess the component to be tested, how easy the tester found the assessment of the test, the accuracy and applicability of the scoring system used, was the tests instructions easy to understand and clear and the participants view of the test. The main researcher completed screenings of this nature in collegiate Gaelic games prior to this PhD and so it was clear that the adults could complete these screening tasks. As the ability of adolescents to complete these screening tasks had not been informally assessed previously, only adolescent participants were assessed. This is a possible limitation to this pilot study.

3. 2. 3. 1. Findings from the Pilot Study

This pilot study provided insight into the screening to the current researcher and expert group. The following tests were found to work well in the screening protocol: Height, weight, active knee extension test, internal and external rotation of the shoulder, navicular drop test, the Y balance test, overhead squat, single leg squat and scapular control test. Table 3.1 displays the issues noted by the testers in this pilot study. In summary, the combined testing protocol was very time consuming as a large number of tests were included. The five core tests (flexor endurance, extensor endurance, plank, side plank and double leg lowering test) did not work well in this format as they were found to be time consuming and serious methodological errors were noted. Testers found it difficult to decide the moment of failure of the core tests and participants were able to utilise compensation strategies to prolong the test. The LESS test was found to produce redundant results in this testing format as the overhead squat and single leg squat tested the same individual criteria (e.g. knee valgus, toe out, trunk flexion) as the LESS test. Thus, testers felt that they were reporting the same faults that may predispose to injury in three separate manners. In addition, this test was found to be time consuming and some participants (especially those with previous ankle and knee injuries) were hesitant about jumping from the 30cm box for fear of re-injury.

Table 3.1: Issues surrounding tests in the musculoskeletal pre-participation screening

Test Description	Issues noticed in Pilot study
Landing Error Scoring System (LESS)	
Markers were placed on the ASIS, greater trochanter, patella, head of fibula, and big toe. Participant jumps from 30cm box onto marked surface on the floor and immediately jumps as high as possible	Similar criteria were assessed in the overhead and single leg squat. Thus the results in this test seemed redundant
	The landing occurred too quickly to mark each of the individual criteria in real time
	Filming participants under 16 and the amount of skin required to be on show for markers (especially greater trochanter) to be visible was problematic as participants became embarrassed when asked to do this
	Some participants (especially those with previous ankle and knee injuries) were hesitant to jump off the 30cm box to initiate the landing aspect of the test
Flexor endurance (Section 2.4.1.11)	
Participant sits on bench and places upper body against support wedge with knees and hips flexed to 90°. Wedge is removed and participants must hold this position until fatigue	Participants may round the back to prevent the back from hitting the wedge and prolong the test
	Participants may protract the scapulae to prevent the shoulders from hitting the wedge and prolong the test
Extensor Endurance (Section 2.4.1.11)	
Participant lies prone on a plinth with lower body fixed and the upper body extended off the end and rests on the floor. Lift upper body up off the floor so the body is horizontal and hold until fully fatigued	Difficult to decide the moment of failure of the test, test ends when the body lands on the floor however a participant may lose stability and be unable to hold the body horizontal long before this occurs
Plank (Section 2.4.1.11)	
Participants lie supine and rise into a plank position. Must hold their shoulders, hips and ankles in a straight line until they fatigue	Difficult to decide the moment of failure of the test, test ends when the body lands on the floor however a participant may lose stability and the straight line long before this occurs

Side Plank (Section 2.4.1.11)	
Participants lie on their side and lift onto their elbows and side of feet with shoulder, hip and ankle in a straight line until they fatigue	Difficult to decide the moment of failure of the side plank: test ends when the hips land on the floor however a participant may lose stability and the straight line long before this occurs
Double leg lowering test (Section 2.4.1.11)	
Participants lie supine with their hips flexed to 90° and knees fully straighten. From this position the participant slowly lowers their legs from 90°while keeping their lower back in contact with a wooden bench. The point in which the lower back moves superiorly from the wooden bench is deemed the end point (when core musculature loses control of the spine)	Difficult to decipher the exact moment the lower back lifts from the plinth

From this pilot study the expert group decided that it was not feasible to perform all measurements set out in the original protocol due to time constraints. The protocol and scoring systems developed for the scapular control test, overhead squat and single leg squat were found to be effective and easily administered, and thus all three tests were included in the final testing protocol[1]. Due to the large number of issues noted in the LESS test (Table 3.1) it was decided to remove this test from the screening protocol.

None of the core stability tests used in the original protocol were considered an appropriate test to use, therefore the expert group required a new test to address the issues demonstrated in the pilot study. The trunk stability test is one of the seven tests utilised to assesses fundamental movement in the functional movement screen (FMS™) (Cook et al., 2006b). The trunk stability test aims to measure reflex core stabilisation and requires participants to complete a closed kinetic chain, upper body symmetrical pushing movement (push up) while controlling and limiting movement of the spine and hips in the sagittal and anterior/posterior plane (Cook, 2010). Thus, it assesses core stability under functional loading during dynamic movement, which is beneficial as dynamic motion occurs during sporting movements and so is more applicable for use in a screening setting (Bliven and Anderson, 2013, Chorba et al., 2010). In addition this test requires minimal equipment and can easily be administered in a field based setting by therapists. While this test has some obvious advantages (quick to administer, requires no equipment, easy to implement, dynamic nature of the test), the current researchers felt that the trunk stability test may not be sensitive enough to differentiate between the subtle differences between good and excellent core stability, especially in the athletic population studied in this thesis. It has been demonstrated that 76.2% of young physically active males achieved the highest rating of three in this test (Schneiders et al., 2011), therefore it may difficult to sub-classify those with higher levels of core stability utilising this trunk stability test. The addition of an extra level to this test in order to incrementally challenge the core stability of an athlete may allow further subdivision of the grading system and so identify those with higher core stability. Slightly reducing the base of support to cause light to moderate instability during the test may require the core muscles to further stabilise and so impose a greater challenge to the participant (Stanton et al., 2004, Haynes, 2004). Thus, the alternative core test was adapted from the trunk stability push up test by adding an extra level

[1] Unfortunately, subsequent to our research design and testing, the 100 point research FMS scale was developed and published for the overhead squat, therefore this scale could not have utilised in our study.

whereby participants are required to lift their right leg slightly off the ground to cause a certain amount of unbalance that the participant must aim to stabilise when completing a push up. Researchers completed a small pilot study on 15 college participants to compare the trunk stability test with the adapted core stability test developed in this study. This pilot study found that 80% of participants scored a 3 (the highest score) in the trunk stability test. However when the alternative push up test was implemented, 53.3% were reported to have good core stability and received a score of three, and 26.7% scored an excellent and received a score of 4 (the highest score). This suggests that the adapted alternative push up test can subdivide the good and excellent core stability scores in this population. A full description of the test is displayed in Appendix L.

Thus the expert group proposed a revised testing protocol for the screening was as follows:

- Height
- Weight
- Active knee extension
- Internal rotation of shoulder
- External rotation of shoulder
- Navicular drop
- Y balance test
- Overhead squat
- Single leg squat
- Scapular control test
- Alternative push up test

3. 2. 4. Reliability of developed and adapted tests

Absolute and relative inter-tester and intra-tester reliability was established between three testers over two sessions. This reliability research study was completed in conjunction with this PhD but is not included as part of the final three studies in the PhD and so is detailed in full in Appendix A. These tests produced excellent inter-tester reliability and good-to-excellent intra-tester reliability, and so therapists can be satisfied when utilising these tests in a musculoskeletal pre-participation screening that the results of these tests can be interpreted with minimal error.

3. 2. 5. Experimental Protocol

Prior to testing all participants were required to return a signed informed consent form. Each school and collegiate team was assessed separately. For adolescents, testing was completed in the school hall and collegiate participant testing was completed in a large rehabilitation laboratory which was cleared of all equipment. The screening process takes approximately 30 minutes to complete per person. The equipment required to complete this screening includes a portable stadiometer, calibrated scale, plinth, inclinometer, dowel, y balance test kit, athletic tape, fine tipped non-toxic water soluble marker, pen and scoring sheet. This equipment is readily available in the clinical setting and is reusable however to buy this equipment it would cost approximately €750.

3. 2. 5. 1. Testers

Ten testers were needed to test a single team. Thus a core group of undergraduate therapists with experience in implementing screening tests were recruited. All testers underwent three training sessions. The testers were initially given a presentation on the purpose, the instructions and scoring system of each of the tests in the testing protocol. In addition, photographs were provided in this presentation of possible and common mistakes made by participants. A manual of testing instructions and scoring system for each test was given to each tester to study. Following this a demonstration of each of the tests was provided. Common mistakes made by both the testers and participants during each test were highlighted. Furthermore testers underwent three separate practice sessions where they practised each tests on a sample group of collegiate participants. Testers were encouraged to critique each other's scoring technique and the main researcher in this study assessed the ability of each tester to adequately score each test prior to the screening. This method was considered superior to other familiarisation sessions in current literature as Gabbe et al. (2004) demonstrated that two therapists with experience in assessments showed similar result after just two short training sessions. Even though testers were taught to score all tests, each tester was assigned a single test to assess throughout the screening sessions. This was done to increase reliability.

3. 2. 5. 2. Testing Protocol

Figure 3.1 displays the schematic diagram of the testing procedure utilised in this study. A circuit format was utilised as it was considered more time efficient. Testers completed a single test on all participants throughout the screening and the participants followed the circuit clearly laid out to complete each test. No warm up was completed prior to testing to ensure reliability between tests. The effects of a warm up may increase results in some tests and if the warm up effects wore off some participants nearing the end of the testing procedure this may negatively affect their results. The scoring sheet utilised is displayed in Appendix D.

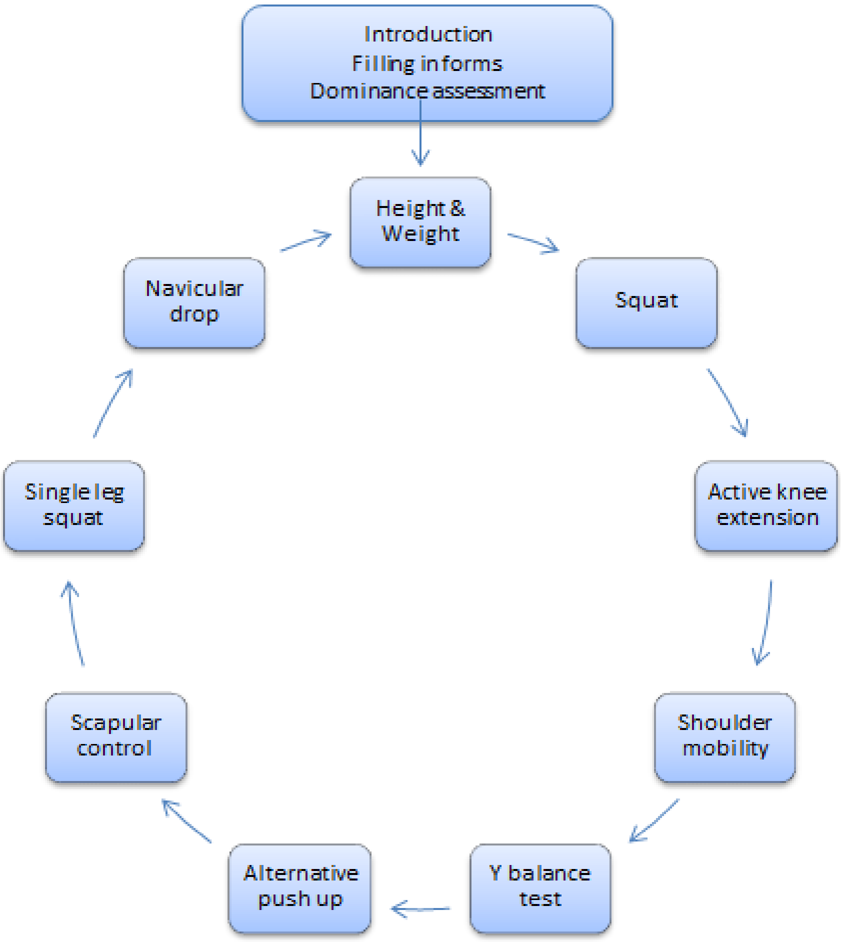

Figure 3.1: Schematic diagram of testing procedure

3. 2. 5. 3. Tests used in musculoskeletal pre-participation screening

Participants were asked to wear runners, shorts and t-shirts to testing. During no time in the testing was a participant coached or given verbal feedback on their performance of the test. Specific instructions for each test was given to each tester and testers were allowed repeat these instructions during the test if necessary. For all tests participants were asked to report pain as soon as they felt it and were instructed to stop completing the test immediately. For this study the results of the participants with pain were not taken into account in the active knee extension test, shoulder mobility tests, Y balance test, scapular control test, navicular drop test and alternative push up test. For the overhead squat and single leg squat participants that felt pain during the test were scored a "0" in the test. Appendix E-L explains in detail the equipment needed, description of test, specific instructions given to participants, number of trials completed, details of what constitutes an incomplete trial and measurement taken for all tests in the screening including: height, weight, active knee extension, internal rotation of shoulder, external rotation of shoulder, navicular drop, Y balance test, overhead squat, single leg squat, scapular control test and alternative push up test.

Anthropometric data

Height was measured to the nearest millimeter using a portable stadiometer (Leicester Height Measure; SECA, Birmingham, United Kingdom) (Appendix E). Body mass was obtained to the nearest 0.1 kg using a calibrated scale (Salter Academy Scale Kent, United Kingdom) (Appendix E). Body mass index (BMI) was calculated as body mass (in kilograms) divided by body height in square meters.

Hamstring flexibility

Hamstring flexibility was measured using the active knee extension test (Figure 3.2). The active knee extension test measures the angle between the tibia and the femur using an inclinometer to the nearest degree (Appendix F).

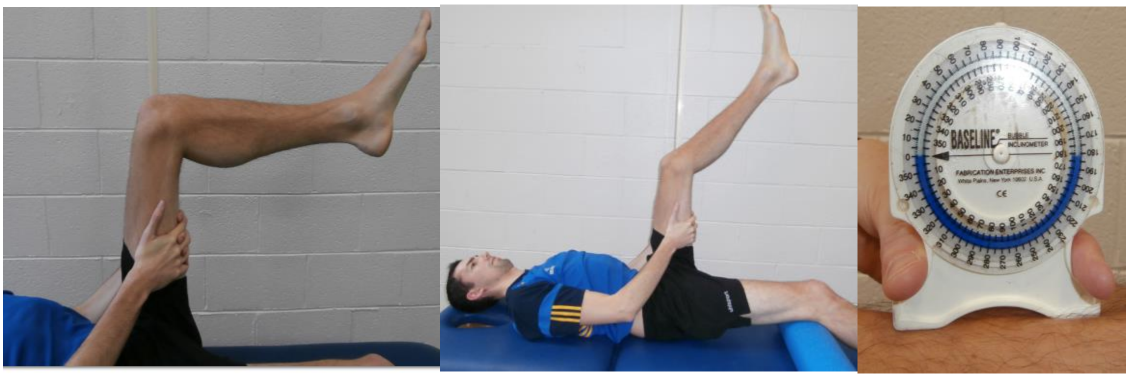

Figure 3.2: Active knee extension test

Shoulder Mobility

Shoulder mobility of the participant was measured using the internal and external range of motion tests (Figure 3.3 and Figure 3.4 respectively). The arm is placed into 90° abduction and elbow is bent to 90° flexion, the angle between the forearm and the humerus is used to measure the range of internal and external motion using an inclinometer to the nearest degree (Appendix G).

Figure 3.3: Internal range of motion test

Figure 3.4: External range of motion test

Foot Function

Foot function was assessed using the modified navicular drop test (Figure 3.5). The difference in navicular height between subtalar joint neutral position when sitting and normal standing position is measured (Appendix H). The navicular drop test is normalised with foot length for comparison purposes, thus foot length was also measured along with this test. Foot length was defined as the distance from the most posterior aspect of the calcaneus to the tip of the longest toe and was found to be a highly reliable measure (ICC=0.99) (Plisky et al., 2007, Barton et al., 2010). Foot length was measured using a cloth measuring tape. A ruler was used instead of an index card to measure the height of the navicular tuberosity due to its higher reliability (index:0.84-0.88; ruler:0.88-0.91) (Plisky et al., 2007). Increased accuracy is attributed to the ruler due to the fact a marker is not used; the thickness of the marker may over or underestimate the actual navicular height (Plisky et al., 2007). The placement of the foot into subtalar joint neutral and marking the navicular tuberosity are identified as two of the most common sources of error in the navicular drop test. Therefore to combat this issue we ensured that testers practiced these procedures repeatedly prior to testing, the main researcher in this study assessed each tester on their ability to complete these tasks prior to commencement of testing. In addition the tester chosen to complete this test was identified by the lead researcher as the most competent and confident in this task.

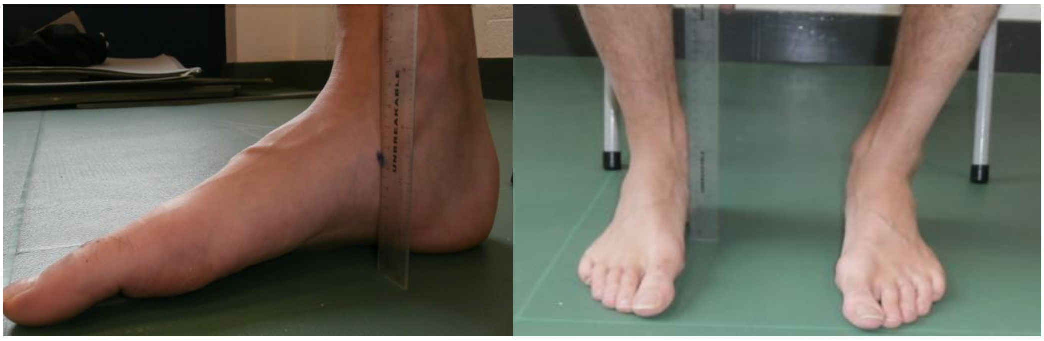

Figure 3.5: Navicular drop test

Balance

Balance was measured using the Y balance test (Figure 3.6). The Y balance test measures the reach distance in the anterior, posteriomedial and posteriolateral directions of one leg to the corresponding leg in centimetres using the Y balance test equipment (Appendix I). The Y balance test is completed shoeless and for comparison purposes the results are normalised with leg length. Leg length was defined as the distance between the anterior superior iliac spine (ASIS) to the most distal portion of the lateral malleolus (Clark et al., 2010). To measure leg length the subject is asked to get into the hook lying position, the hips are lifted off the table and returned to the starting position. The tester passively straightens the subject's legs which equalizes the pelvis. The subject's right limb is measured from the anterior superior iliac spine (ASIS) to the most distal portion of the lateral malleolus with a cloth tape measure (Clark et al., 2010). Limb length measured in this manner is shown to have high reliability (ICC=0.99) (Plisky et al., 2006). Based on the recommendation of Robinson and Gribble it was chosen that each participant completed 4 trials in each direction (Robinson and Gribble, 2008). The composite score is summated by getting the sum of the average reach distance in the anterior (A), posteriomedial (PM) and posteriolateral (PL) directions divided by three times the leg length (LL) multiplied by a hundred.

$$\text{Comosite score} = \{[(A + PM + PL) \div (LL \times 3) \times 100\}]$$

Equation 3.1: Calculation of the composite score

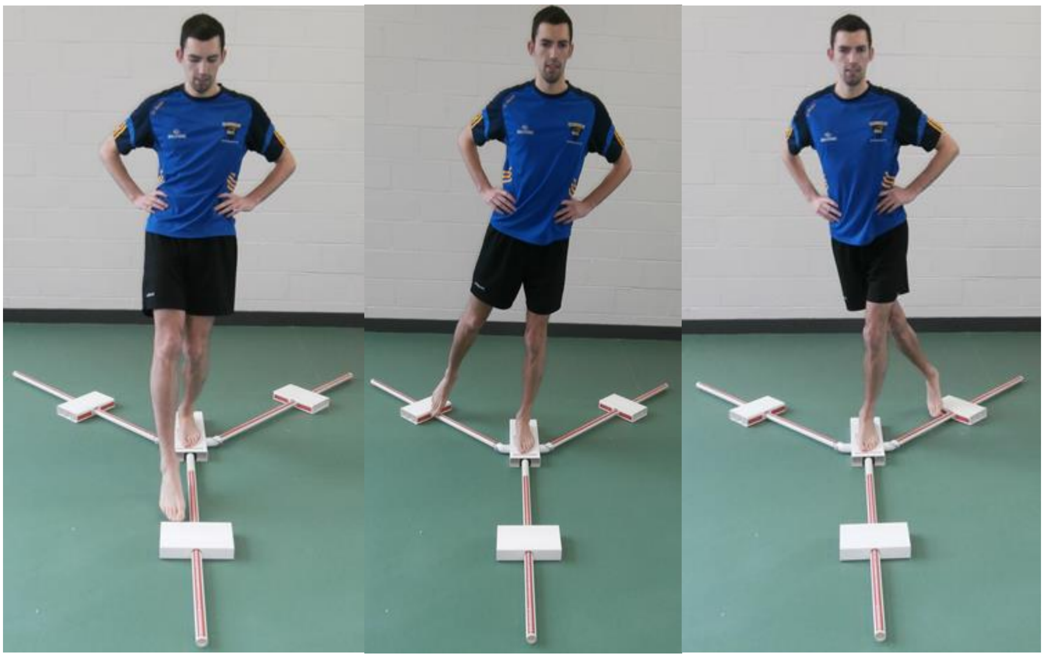

Figure 3.6: Y balance test

Squatting Techniques

Squatting techniques was assessed using the overhead squat (Figure 3.7) and single leg squat (Figure 3.8). A 0-3 rating was given for each of the following variables during the squat and single leg squat: knees over toes, knee valgus, knee varus, toe out, toe in hip flexed, trunk flexed, balance and overall impression (Appendix J). For overall impression the rating given was: 0=pain, 1=poor, 2=average, 3=excellent, and for all other variables the rating was: 0=none, 1=slight, 2=moderate, 3=severe.

Figure 3.7: Overhead squat test

Figure 3.8: Single leg squat test

Scapular control

Scapular control was assessed using the scapular control test (Figure 3.9). The scapular control test requires the subject to slowly abduct their arms 180° and slowly lower to the starting position (Appendix K). A 0-3 rating (0=none, 1=slight, 2=moderate, 3=severe) was given for each of the following variables: winging (medial border of scapulae should be flat on their ribs), control when lifting, control when lowering (must lift and lower in a controlled manner with no shaking or abnormal scapulae positioning) and symmetry of scapulae (scapulae must move together throughout the full range of motion with no lagging behind or speeding of a single scapula in relation to the corresponding scapulae). Testers stood 2-3m from the participant which is based on the recommended distance suggested by McClure et al. (2009) as it allows the tester to view the entire shoulder abduction movement on both scapulae. In addition, testers were informed that the scapula on the dominant side is characteristically positioned slightly lower than the non-dominant side and this was taken into account during this test (Oyama et al., 2008).

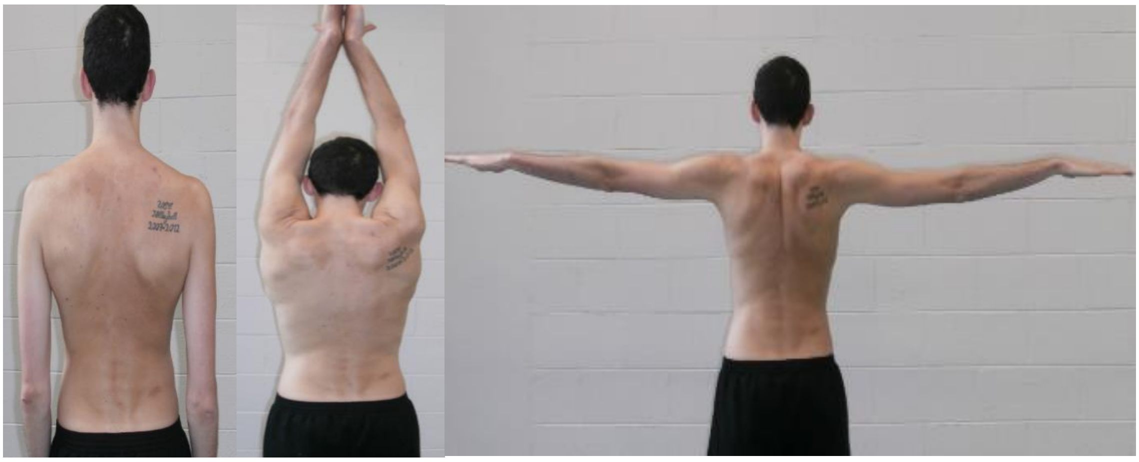

Figure 3.9: Scapular control test

Core Stability

Core stability was assessed using the alternative push up test (Figure 3.10). A 0-4 rating was given to the subject while completing a push up (Appendix L) and the rating classification is as follows:

- 4= Can complete a push up with their hands at the level of their forehead and with their right leg slightly lifted off the ground without lagging or twisting of the spine or hips
- 3=Can complete a push up with their hands at the level of their forehead and both feet together on the ground. Unable to complete the push up with the right leg lifted off the ground without lagging or twisting of the spine or hips
- 2= Can complete a push up with hands at the level of the chin and both feet together without lagging or twisting of the spine or hips
- 1=Unable to complete a push up with hands at the level of the chin with both feet together without lagging or twisting of the spine or hips
- 0= Experiences pain during the test

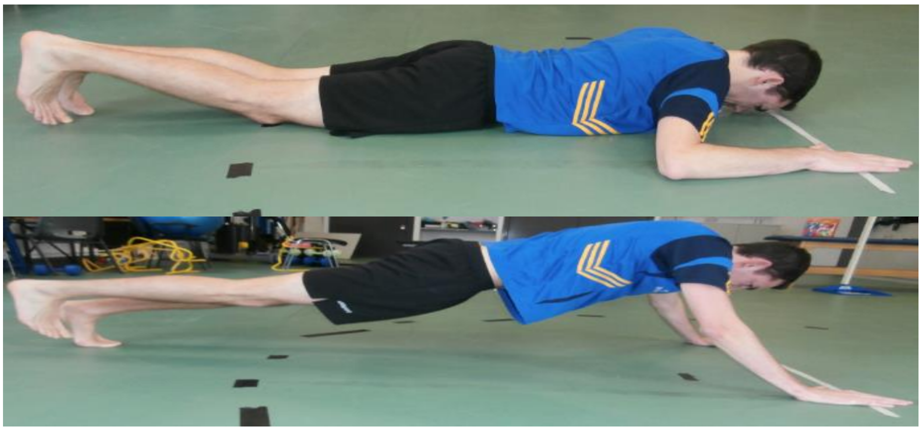

Figure 3.10: Alternative push up test

3. 2. 6. Data Processing and Statistical Analysis:

All results were inputted into Microsoft excel (2010) where the data was checked, mistakes were corrected and missing values were coded. Following this the results were inputted into the statistical package SPSS (version 20).

3. 2. 6. 1. Normative data for adolescent and collegiate participants

The normative data for each of the screening tests is presented separately for adolescent (n=426) and collegiate participants (n=345).

Anthropometrics: The mean, standard deviation and range for age, height, weight and BMI is presented. Quartile results for height, weight and BMI were also calculated. The percentage and number of right and left hand and limb dominance was assessed and reported.

Flexibility: The mean, standard deviation and 95% Confidence Intervals was presented for active knee extension, internal rotation and external rotation tests. The percentiles for each of the tests were identified. A paired samples t-test was completed to compare between the right and left sides in each of the tests. The effect size was determined using eta squared for comparison tests between groups only. Eta squared was computed using the formula below:

$$\text{Eta squared} = \frac{t^2}{t^2 + (N - 1)}$$

Where t is the t value reported in the t-test, and N is the number of participants

Equation 3.2: Calculation of Eta squared

Foot function: The mean, standard deviation and 95% Confidence Intervals were examined for the navicular drop test on the right and left side. The percentage of participants who had a greater than 10mm drop on either or both feet was assessed along with a side-to-side navicular drop difference of greater than 3mm. A paired samples t-test was completed to assess the difference between the right and left sides in participants.

Balance: The mean, standard deviation and 95% Confidence Intervals were examined for the average reach distance (cm), average reach difference (cm) and average reach normalised with leg length (%LL) in the anterior, posteriomedial and posteriolateral directions in the Y balance test. The composite score was computed as described previously and the mean, standard deviation and 95% Confidence Intervals of the composite score and average reach difference was analysed. Quartile results for each of the variables in the Y balance test was measured and reported. The percentage of participants with side-to-side differences of greater than 4cm for the anterior, posteriomedial, posteriolateral and composite scores was assessed. The percentage of participants that scored less than 94% and 89% of their average reach distance normalised by their leg length for the anterior, posteriomedial, posteriolateral and composite scores was examined (Plisky et al., 2006, Butler et al., 2013b). A one way repeated measures ANOVA was conducted to compare the average reach distance between legs for the anterior, posteriomedial, posteriolateral and composite scores. Post hoc analysis using the Bonferoni test was also completed.

Squatting techniques: The percentage and number of participant's distribution of scores for the individual criteria and overall scores for the overhead squat and single leg squat was assessed. A paired samples t-test was completed for the individual criteria scores between right and left legs in the single leg squat. The mean, standard deviation, significant difference (p value) and effect size (eta squared) was reported.

Scapular control: The percentage and number of participant's distribution of scores for the scapular control test was identified. A paired samples t-test was completed to examine the difference in scores between right and left sides. The mean, standard deviation and effect size (eta squared) was reported for this test.

Core stability: The percentage and number of participants distribution of scores for the alternative push up test was identified and reported.

3. 2. 6. 2. Analysis between the sport and level played.

A two by two ANOVA was completed to determine if sport (Gaelic football v hurling) and level played (fresher v senior) affected the screening results. The mean, standard deviation and effect size (partial eta squared) are reported using the classification proposed by Cohen (1988) [small effect size=0.01 (1% of variance), medium effect size=0.06 (6% of variance) and large effect size=0.14 (13.8% of variance)].

3. 2. 6. 3. Analysis between adolescent and collegiate participants

Independent samples t-tests were completed to compare the results of each of the screening tests between adolescent and collegiate participants. The mean, standard deviation and the effect sizes are reported. The relationship between the variables age and BMI with each of the screening tests was assessed using a Pearson's product moment correlation. The significance and strength of the relationship (r value) was examined and was classified according to Cohen (1988) (small=0.10-0.29, medium=0.30-0.49 and large=0.50-1.0).

3. 2. 6. 4. Analysis of the relationship between tests

In order to examine the relationship between tests or the extent to which some tests are redundant, the relationship between pre-selected tests was undertaken. A paired samples t-test was completed to compare hand dominance (right and left) with rotation of the shoulder (internal and external) and scapular control of the shoulder. A Pearson's product moment correlation was completed to assess the relationship between the following: rotation of the shoulder and scapular control of the shoulder, overall impression and balance scores of the overhead squat and single leg squat with the Y balance test, overall impression in the overhead squat with the single leg squat, individual criteria of the overhead squat and single leg squat, active knee extension test and the individual criteria of hip flexion and knees over toes reported in both the overhead squat and single leg squat, alternative push up test and the overall impression in both the overhead squat and single leg squat and finally the alternative push up test and the Y balance test.

3. 2. 6. 5. Effect sizes

Effect sizes were reported for t-test, analysis of variance and correlation analysis. Effect sizes establish the magnitude of the difference or relationship between two variables (Pallant, 2010). For the purpose of musculoskeletal screening research, while all the statistically significant results are reported, it was decided that significant differences with only a small effect size are considered clinically irrelevant and are treated as such in the discussion.

3. 3. Results

3. 3. 1. Adolescent Pre-Participation Screening Results

A total of 426 adolescent participants took part in the pre participation screening however full screening results was available for 378 participants only. Missing data was rare in most tests except for the Y balance test, whereby the time taken to complete the test impacted the testing process and resulted in some participants testing a single leg only.

3. 3. 1. 1. Anthropometric Data and participant information

The anthropometric data is presented in Table 3.2.

Table 3.2: Anthropometric Data for adolescent participants (n=426)

	Age (yr)	Height (m)	Weight (kg)	BMI (kg/m^2)
Mean ± Standard Deviation	15.6 ± 0.7	1.76 ± 0.74	66.9 ± 10.2	21.7 ± 2.8
Range	14-19	1.43-1.98	36-97	15.6-33.1

Quartile results for height, weight and body mass index (BMI) are presented in Appendix M. Hand and lower limb dominance is detailed in Table 3.3. Participants were predominantly right hand and lower limb dominant.

Table 3.3: Dominance

	Hand Dominance % (n)	Lower Limb Dominance % (n)
Right	87.3 (370)	85.8 (363)
Left	11.8 (50)	13.8 (59)
Ambidextrous	0.9 (4)	0.2 (1)

3. 3. 1. 2. Flexibility

Table 3.4 illustrates the mean flexibility for both right and left active knee extension, internal rotation of the shoulder and external rotation of the shoulder tests. Internal and external rotation on the left side was found to be significantly greater than the right side ($p<0.0001$) with a large and a moderate effect size, respectively; however the significant difference ($p<0.05$) between sides in the active knee extension test displayed a small effect size. An active knee extension test result of less than 70° was found in 72.8% and 77.2% of participants on the right and left leg respectively. A total range of motion (internal and external rotation added together) of greater than 5° was found in 84.6% of participants and an internal range of motion on the non-dominant side of greater than 20° than the dominant side was found in 22.1% of participants. The percentile results in the right and left side for active knee extension, internal rotation and external rotation of the shoulder is presented in Appendix N.

Table 3.4: Hamstring flexibility and Shoulder mobility tests; Mean, standard deviation, significant difference and effect size.

		Mean ± SD	*95% CI*	Sig difference	Effect size
Active knee extension (◦)	R	61.3 ± 13.4	59.9-62.7	p=0.002	small 0.02
	L	60.2 ± 13.2	58.8-61.5		
Internal rotation (◦)	R	77.8 ± 15.5	76.2-79.3	p<0.0001	large 0.23
	L	88.8 ± 19.4	86.9-90.8		
External rotation (◦)	R	85.4 ± 22.4	83.2-87.6	p<0.0001	moderate 0.07
	L	91.7 ± 14.9	90.3-93.2		

R, right; L, left

3. 3. 1. 3. Navicular Drop Test

Table 3.5 demonstrates the results of the navicular drop test in the right and left leg. A navicular drop test of greater than 10mm was found in 34.5% of participants on the right leg and 36.2% on the left leg, which can indicate an increased risk of injury (Bennett et al., 2001). However there was no statistically significant difference between the right and left feet ($p>0.05$). 30.1% of adolescent participants had a side to side difference of greater than 3mm which has also been proposed as a possible predictor of injury (Plisky et al., 2007).

Table 3.5: Navicular Drop Test

Side	Mean ± SD	Range	*95% CI*
Right (mm)	7.4 ± 5.1	0-25	6.9-7.9
Left (mm)	7.6 ± 5.4	0-25	7.1-8.2

3. 3. 1. 4. Y balance test

Table 3.6 demonstrates the average reach distance (cm), average reach difference in distance between legs (cm) and the percentage average reach in comparison to their leg lengths (%) in the anterior, posteriomedial and posteriolateral directions. The composite score and the average reach difference in distance between legs for the composite score are also included. The quartile results for the Y balance test are presented in Appendix O. Table 3.7 represents the asymmetrical differences between legs for the anterior, posteriomedial, posteriolateral and composite scores (Plisky et al, 2006). Table 3.8 displays the participants at an increased risk of injury due to a composite reach percentage of their leg length less than 94% and 89% (Plisky et al., 2006, Butler et al., 2013b). There was a significant difference between legs for the posteriomedial reach distance ($p<0.05$) which displayed a moderate effect size and anterior reach distance ($p<0.0001$) which only reported a small effect size.

Table 3.6: Y Balance test; Mean, standard deviation, 95% confidence interval, significant difference between legs and the effect size.

		Mean ± SD	*95% CI*	Sig difference	Effect size
Anterior					
Reach distance (cm)	R	67.9 ± 8.9	67-68.8	p<0.0001	moderate 0.07
	L	69.6 ± 9.1	68.7-70.5		
Reach difference (cm)		4.6 ± 3.9	4.2-4.9		
Reach (%LL)		69.8 ± 9.3	68.9-70.8		
Posteriomedial					
Reach distance (cm)	R	98.6 ± 11.1	97.5-99.8	p=0.13	small 0.01
	L	101.3 ± 22.4	99-103.5		
Reach difference (cm)		5.7 ± 4.8	5.2-6.2		
Reach (%LL)		100.9 ± 11.8	99.8-102.1		
Posteriolateral					
Reach distance (cm)	R	98.2 ± 11.9	97-99.4	ns	
	L	98.3 ± 11.9	97.1-99.8		
Reach difference (cm)		6 ± 4.8	5.6-6.5		
Reach (%LL)		99.8 ± 12.5	98.6-101.1		
Composite					
Composite score	R	92 ± 11.7	90.9-93.2	ns	
	L	93.8 ± 20.1	91.8-95.8		
Reach difference (cm)		4.3 ± 6.6	3.6-4.9		
Reach (%LL)		95.4±25.1	92.9-97.9		

%LL, percentage of leg length. R, right; L, left. ns, not significant.

Table 3.7: Y balance test; Percentage of participants at risk with asymmetries of greater than 4cm

Difference > 4cm	Anterior	Posteriomedial	Posteriolateral	Composite
Percentage	49.1%	56.7%	62.5%	47.1%
Number	189	217	238	181

Table 3.8: Y balance test; Participants at risk using cut off points with percentage leg length

Composite %LL	Percentage at risk	Number at risk
Cut off 89%	32.6%	125
Cut off 94%	51.7%	198

3. 3. 1. 5. Overhead squat and single leg squat

Table 3.9 represents the overall impression of the overhead squat and the single leg squat for each leg. 2.1%, 2.0% and 2.5% of participants had pain during the overhead squat, single leg squat on the right leg and single leg squat on the left leg, respectively. For the overhead squat a similar percentage of students received a “poor” and “average” result, however for the single leg squat on the right and the left leg an “average” result was most common. No statistically significant difference was found between the “overall impression” scores for any of the squat tests (p>0.05). Table 3.10 and 3.11 demonstrate the results of the individual criteria for the overhead squat and single leg squat on the right and left legs, respectively. For the overhead squat, participants were predominantly "normal", except for trunk flexion where the most common result was "slight". For the single leg squat on the right and left legs, knee varus, toe out, toe in and balance were predominantly "normal". However, knee over toes, knee valgus, hip flexion and trunk flexion were most commonly a "slight" problem. A statistically significant difference between the right and left leg was found for knee valgus, knee varus, hip flexion and trunk flexion ($p<0.05$) with only a small effect size demonstrated (Table 3.12).

Table 3.9: Overall impression for overhead squat and single leg squat

		Poor (1) Percentage (n)	Average (2) Percentage (n)	Excellent (3) Percentage (n)
Squat		39.7 (156)	38.4 (151)	21.9 (86)
Single leg squat	**R**	37.8 (149)	49.7 (196)	12.2 (48)
	L	34.7 (136)	52.8 (207)	12.5 (49)

R, right; L, left

Table 3.10: Individual criteria for the overhead squat

	Normal (0) Percentage (n)	Slight (1) Percentage (n)	Moderate (2) Percentage (n)	Severe (3) Percentage (n)
Knee over toes	63.9 (253)	17.9 (71)	10.9 (43)	7.3 (29)
Knee valgus	66.4 (263)	19.4 (77)	8.6 (34)	5.6 (22)
Knee varus	76.5 (303)	12.6 (50)	7.1 (28)	3.8 (15)
Toe out	59.3 (235)	21.7 (86)	13.4 (53)	5.6 (22)
Toe in	91.4 (362)	4.8 (19)	3.3 (13)	0.5 (2)
Hip flexion	41.3 (163)	30.6 (121)	22.8 (90)	5.3 (21)
Trunk flexion	24.1 (95)	38.0 (150)	26.3 (104)	11.6 (46)
Balance	60.4 (238)	28.9 (114)	10.4 (41)	0.3 (1)

Table 3.11: Individual criteria for the single leg squat

		Normal (0) Percentage (n)	Slight (1) Percentage (n)	Moderate (2) Percentage (n)	Severe (3) Percentage (n)
Knee over toes	R	23 (91)	54.4 (215)	19 (75)	3.5 (14)
	L	24.2 (95)	53.2 (209)	19.1 (75)	3.6 (14)
Knee valgus	R	24.3 (96)	48.9 (193)	19.7 (78)	7.1 (28)
	L	33.8 (133)	46.8 (184)	13.7 (54)	5.6 (22)
Knee varus	R	85.6 (338)	11.4 (45)	2.8 (11)	0.3 (1)
	L	81.9 (322)	13.2 (52)	4.6 (18)	0.3 (1)
Toe out	R	84.6 (334)	10.6 (42)	4.6 (18)	0.3 (1)
	L	87.8 (345)	9.2 (36)	2.3 (8)	0.8 (3)
Toe in	R	98.5 (388)	1.5 (6)	0	0
	L	98.5 (387)	1.5 (6)	0	0
Hip flexion	R	24.8 (98)	39.7 (157)	30.4 (120)	5.1 (20)
	L	22.6 (89)	38.9 (153)	33.6 (132)	4.8 (19)
Trunk flexion	R	15.4 (61)	55.7 (220)	20.3 (80)	8.4 (33)
	L	15.8 (62)	58.8 (231)	19.1 (75)	6.4 (25)
Balance	R	61 (241)	19.7 (78)	14.4 (57)	4.8 (19)
	L	59.8 (235)	20.9 (82)	15.5 (61)	3.8 (15)

R, right; L, left

Table 3.12: Individual criteria for single leg squat: Mean, standard deviation, significant difference and effect size (scoring ranged from 0 – 4)

	Right Mean± SD	Left Mean ± SD	Sig difference (p value)	Effect size (eta squared)
Knee over toes	1. ± 0.8	1 ± 0.8	ns	
Knee valgus	1.1 ± 0.8	0.9 ± 0.8	p<0.0001	small 0.02
Knee varus	0.2 ± 0.5	0.2 ± 0.5	p=0.04	small 0.01
Toe out	0.2 ± 0.5	0.2 ± 0.5	ns	
Toe in	0 ± 0.1	0 ± 0.1	ns	
Hip flexion	1.2 ± 0.9	1.2 ± 0.9	p=0.03	small 0.01
Trunk flexion	1.3 ± 1	1.2 ± 0.8	p=0.04	small 0.01
Balance	0.6 ± 0.9	0.6 ± 0.9	ns	

ns, not significant

3. 3. 1. 6. Scapular control

A “slight” problem result was most prevalent for winging and control of scapula when lowering on the right and left sides (Table 3.13), “no” issues was the most commonly reported result for control of scapula when lifting. When assessing the symmetry between both sides a “slight” problem result was most predominant. There was a significant difference between sides for control of scapula when both lifting and lowering ($p<0.05$) however only a small effect size was noted (Table 3.14).

Table 3.13: Scapular control

		None (0) Percentage (n)	Slight (1) Percentage (n)	Moderate (2) Percentage (n)	Severe (3) Percentage (n)
Winging	R	39.6 (163)	47.6 (196)	11.2 (46)	1.7 (7)
	L	40.8 (168)	44.7 (184)	12.6 (52)	1.9 (8)
Control of scapula lifting	R	69.2 (285)	19.9 (82)	8.5 (35)	2.4 (10)
	L	65.8 (271)	22.3 (92)	9.5 (39)	2.4 (10)
Control of scapula lowering	R	28.6 (118)	33.5 (138)	28.2 (116)	9.5 (39)
	L	23.3 (96)	33.3 (137)	33 (136)	10.4 (43)
Symmetry		37.4 (154)	43.7 (180)	14.8 (61)	4.1 (17)

R, right; L, left

Table 3.14: Scapular control test: Mean, standard deviation, significant difference and effect size (Scoring ranged from 0-3)

	Right Mean± SD	Left Mean ± SD	Significant difference (p value)	Effect size (eta squared)
Winging	0.8 ± 0.7	0.8 ± 0.7	ns	
Control of scapula lifting	0.4 ± 0.8	0.5 ± 0.8	p=0.024	small 0.01
Control of scapula lowering	1.2 ± 1.1	1.3 ± 0.9	p=0.011	small 0.01

ns, not significant

3. 3. 1. 7. Alternative push up test

The two most prevalent results for the alternative push up test were “good” followed by “excellent” (Table 3.15).

Table 3.15: Alternative push up test

Poor (1) Percentage (n)	Average (2) Percentage (n)	Good (3) Percentage (n)	Excellent (4) Percentage (n)
9.6 (38)	18.4 (73)	41.9 (166)	30.1 (119)

3. 3. 2. Collegiate Pre-Participation Screening

A total of 345 adolescent participants took part in the pre participation screening however full screening results was available for 183 participants only. Missing data was rare in most tests except for the Y balance test, whereby the time taken to complete the test impacted the testing process and resulted in some participants testing a single leg only.

3. 3. 2. 1. Anthropometric data and participant information

A total of 345 collegiate participants took part in the pre participation screening and the anthropometric data is presented in Table 3.16.

Table 3.16: Anthropometric Data

	Age (yr)	Height (m)	Weight (kg)	BMI (kg/m^2)
Mean ± Standard Deviation	19.4 ± 1.9	1.81 ± 0.72	77.7 ± 9.5	23.6 ± 2.19
Range	17-27	1.28-1.98	52-106	16.9-29.9

Quartile results for height, weight and BMI of collegiate participants are displayed in Appendix M. Participants were predominantly right hand and lower limb dominant (Table 3.17).

Table 3.17: Dominance

	Hand Dominance % (n)	Lower Limb Dominance % (n)
Right	87 (295)	86.1 (292)
Left	13 (44)	13.6 (46)
Ambidextrous	0	0.3 (1)

3. 3. 2. 2. Flexibility

Table 3.18 illustrates the mean flexibility results for both right and left active knee extension, internal rotation and external rotation of the shoulder tests. There was a statistically significant difference between sides for the active knee extension test, internal rotation of the shoulder ($p<0.0001$) and external rotation of the shoulder tests ($p<0.05$) however only external rotation displayed at least a moderate effect size. An active knee extension test result of less than 70° was found in 63.9% and 61.0% of participants on the right and left leg respectively. A total range of motion (internal and external rotation added together) of greater than 5° was found in 75.3% of participants and an internal range of motion on the non-dominant side of greater than 20° than the dominant side was found in 33.8% of participants. The percentile results in the right and left side for active knee extension, internal rotation and external rotation of the shoulder is presented in Appendix N.

Table 3.18: Hamstring flexibility and shoulder mobility: Mean, standard deviation, significant difference and effect size

		Mean ± SD	*95% CI*	Sig difference	Effect size
Active knee extension (◦)	R	64.7 ± 11.6	63.5-66	p=0.03	small 0.03
	L	65.8 ± 11	64.6-67		
Internal rotation (◦)	R	74.4 ± 18.1	72.4-76.3	p<0.0001	moderate 0.07
	L	79 ± 18.4	77-81		
External rotation (◦)	R	83.1 ± 16.8	81.3-85	p=0.025	small 0.02
	L	80.2 ± 23.3	77.7-82.7		

3. 3. 2. 3. Navicular drop

A navicular drop test result of greater than 10mm was found in 38.9% of participants on the right leg and 32.7% on the left leg (Table 3.19). No statistically significant difference between the right and left feet was found (p>0.05). 34.4% of collegiate participants had a side to side difference of greater than 3mm.

Table 3.19: Navicular drop Test

	Mean ± SD (range)	Range	95% CI
Right (mm)	8.3 ± 4.4	0-29	7.8-8.7
Left (mm)	8.2 ± 4.5	0-29	7.7-8.6

3. 3. 2. 4. Y balance test

Table 3.20 demonstrates the average reach distance (cm), average reach difference in distance between legs (cm) and the percentage average reach in comparison to their leg lengths (%) in the anterior, posteriomedial and posteriolateral directions. The composite score and the average reach difference in distance between legs for the composite score are also included. The quartile results for the Y balance test is presented in Appendix O. Table 3.21 represents the asymmetrical differences between legs for the anterior, posteriomedial, posteriolateral and composite scores which can indicate an increased risk of injury (Plisky et al, 2006). Table 3.22 displays the participants at an increased risk of injury due to a composite reach percentage of their leg length less than 94% and 89% (Plisky et al., 2006, Butler et al., 2013b). No statistically significant difference was found between legs for the anterior, posteriomedial, posteriolateral and composite average reach distance (p>0.05).

Table 3.20: Y balance test; Mean, standard deviation, 95% confidence interval, significant difference and the effect size

		Mean ± SD	*95% CI*	Significant difference
Anterior				
Reach distance (cm)	R	71.3 ± 19.1	69.1-73.5	ns
	L	70.5 ± 12.3	69.1-72	
Reach difference (cm)		6.1 ± 14.9	4.4-7.8	
Reach (%LL)		68.6 ± 42.3	62.4-74.7	
Posteriomedial				
	R	105.4 ± 13.9	103.8-107	ns
Reach distance (cm)	L	106.1 ± 13.7	104.6-107.7	
Reach difference (cm)		5.3 ± 4.8	4.8-5.9	
Reach (%LL)		103.7 ± 41.4	97.7-109.7	
Posteriolateral				
	R	107.2 ± 14.3	105.6-108.8	ns
Reach distance (cm)	L	107.6 ± 15	105.9-109.3	
Reach difference (cm)		5.7 ± 4.7	5.1-6.2	
Reach (%LL)		103.9 ± 41.5	97.9-109.9	
Composite				
Composite score	R	93.9 ± 69.9	83.8-104	ns
	L	94.6 ± 70.1	84.4-104.7	
Reach difference (cm)		3.3 ± 2.8	2.89-3.68	
Reach (%LL)		92.5±13.4	90.5-94.4	

%LL, percentage of leg length. ns, not significant

Table 3.21: Y balance test: Percentage of participants with asymmetries of greater and less than 4cm

Difference > 4cm	Anterior	Posteriomedial	Posteriolateral	Composite
Percentage	47%	56.1%	55.4%	37.1%
Number	139	166	164	69

Table 3.22: Y balance test: Participants at risk using cut off points with percentage leg length

Composite %LL	Percentage at risk	Number at risk
Cut off 89%	39.0%	71
Cut off 94%	57.7%	105

3. 3. 2. 5. Overhead squat and single leg squat

Table 3.23 represents the overall impression of the overhead squat and the single leg squat for each leg. 2.0%, 2.1% and 1.8% of participants had pain during the overhead squat, single leg squat on the right leg and single leg squat on the left leg. Table 3.24 and 3.25 demonstrate the results of the individual criteria for the overhead squat and the single leg squat on the right and left legs respectively. For the overhead squat the majority of participants were found to have an "average" result. For the right and left single leg squat the majority of participants were found to have a "poor" result. There was a statistically significant difference between the overhead squat and single leg squat on the right and left legs (Wilks Lambda=0.82, F(2,324)=36.16, p<0.0001) with a large effect size (0.18). Post-hoc comparisons using the Bonferroni test indicated that there is a statistically significant difference between the overhead squat and the single leg squat on the right and left leg (p<0.05). However there was no significant difference between the single leg squat on the right and left leg (p>0.05). In terms of the individual criteria for the overhead squat, "normal" was predominantly the most common result. With regard to the individual criteria for the single leg squat on the right and left legs, knee varus, toe out and toe in were predominantly "normal". However for knee over toes, knee valgus and balance a "slight" problem was the most commonly reported result. A "moderate" problem was predominant for hip flexion and trunk flexion. There was a statistically significant difference between the right and left leg for knee varus (p<0.05), toe out (p<0.05) and toe in (p<0.0001) however a small effect size was noted in each variable (Table 3.26).

Table 3.23: Overall impression for overhead squat and single leg squat

		Poor (1) Percentage (n)	Average (2) Percentage (n)	Excellent (3) Percentage (n)
Squat		29.3 (99)	53.3 (180)	17.2 (58)
Single leg squat	**R**	49.7 (166)	46.4 (155)	3.9 (13)
	L	48.3 (160)	47.7 (158)	3.9 (13)

Table 3.24: Individual criteria for the overhead squat

	Normal (0) Percentage (n)	Slight (1) Percentage (n)	Moderate (2) Percentage (n)	Severe (3) Percentage (n)
Knee over toes	49.6 (168)	33 (112)	15.3 (52)	2.1 (7)
Knee valgus	78.8 (267)	13.6 (46)	7.4 (25)	0.3 (1)
Knee varus	70.2 (238)	22.7 (77)	6.8 (23)	0.3 (1)
Toe out	56.3 (191)	30.7 (104)	10.6 (36)	2.4 (8)
Toe in	98.2 (333)	1.2 (4)	0.3 (1)	0.3 (1)
Hip flexed	40.7 (138)	28.9 (98)	24.2 (82)	6.2 (21)
Trunk flexed	35.4 (120)	26 (88)	27.4 (93)	11.2 (38)
Balance	71.4 (242)	21.2 (72)	6.5 (22)	0.9 (3)

Table 3.25: Individual criteria for the single leg squat

		Normal (0) Percentage (n)	Slight (1) Percentage (n)	Moderate (2) Percentage (n)	Severe (3) Percentage (n)
Knee over toes	R	19.4 (65)	44.5 (149)	31.6 (106)	4.5 (15)
	L	18.3 (61)	45 (150)	32.4 (108)	4.2 (14)
Knee valgus	R	34.6 (116)	36.4 (122)	21.5 (72)	7.5 (25)
	L	33 (110)	39.6 (132)	22.2 (74)	5.1 (17)
Knee varus	R	83.6 (280)	12.2 (41)	3.6 (12)	0.6 (2)
	L	76.9 (256)	17.4 (58)	4.8 (16)	0.9 (3)
Toe out	R	86.6 (290)	11.3 (38)	1.8 (6)	0.3 (1)
	L	91.6 (305)	6.3 (21)	2.1 (7)	0
Toe in	R	89.9 (301)	5.4 (18)	4.8 (16)	0
	L	95.8 (319)	3.9 (13)	0.3 (1)	0
Hip flexed	R	30.4 (102)	24.8 (83)	37.6 (126)	7.2 (24)
	L	28.2 (94)	26.4 (88)	37.8 (126)	7.5 (25)
Trunk flexed	R	24.8 (83)	30.7 (103)	33.7 (113)	10.7 (36)
	L	23.4 (78)	29.1 (97)	36.3 (121)	11.1 (37)
Balance	R	31.6 (106)	34.3 (115)	30.7 (103)	3.3 (11)
	L	27 (90)	38.7 (129)	30.3 (101)	3.9 (13)

Table 3.26: Individual criteria for single leg squat: Mean, standard deviation, significant difference and effect size (Scoring ranged from 0-3)

	Right Mean± SD	Left Mean ± SD	Significant difference (p value)	Effect size (eta squared)
Knee over toes	1.2 ± 0.8	1.2 ± 0.8	ns	
Knee valgus	1 ± 0.9	1 ± 0.9	ns	
Knee varus	0.2 ± 0.5	0.3 ± 0.6	p=0.02	small 0.01
Toe out	0.2 ± 0.4	0.1 ± 0.54	p=0.03	small 0.01
Toe in	0.2 ± 0.5	0.1 ± 0.2	p<0.0001	small 0.02
Hip flexion	1.2 ± 1	1.3 ± 1	ns	
Trunk flexion	1.3 ± 1	1.4 ± 1	ns	
Balance	1.1 ± 0.9	1.1 ± 0.9	ns	

ns, not significant

3. 3. 2. 6. Scapular control

A “normal” result was most prevalent for winging and control of scapula when lifting on the right and left sides (Table 2.27). A “slight” problem was the most commonly reported result for control of scapula when lowering. When assessing the symmetry between both sides a “slight” problem result was most predominant. Control of scapula when lowering was poorer on the left side compared to the right side ($p<0.05$) with only a small effect size noted, however no significant difference was found between sides for winging and control of scapula when lifting ($p>0.05$) (Table 3.28).

Table 3.27: Scapular Control

		None (0) Percentage (n)	Slight (1) Percentage (n)	Moderate (2) Percentage (n)	Severe (3) Percentage (n)
Winging	R	50.4 (174)	35.9 (124)	11.3 (39)	2.3 (8)
	L	48.1 (166)	40 (138)	9 (31)	2.9 (10)
Control of scapula lifting	R	62.6 (216)	24.3 (84)	11.9 (41)	1.2 (4)
	L	60.9 (210)	29.9 (103)	8.1 (28)	1.2 (4)
Control of scapula lowering	R	30.7 (106)	35.4 (122)	29.6 (102)	4.3 (15)
	L	23.8 (82)	39.1 (135)	32.2 (111)	4.9 (17)
Symmetry		39.4 (136)	45.2 (156)	13.6 (47)	1.7 (6)

R, right; L, left

Table 3.28: Scapular control test; Mean, standard deviation, significant difference and effect size (Scoring ranged from 0-3)

	Right Mean± SD	Left Mean ± SD	Significant difference (p value)	Effect size (eta squared)
Winging	0.7 ± 0.8	0.7 ± 0.8	ns	
Control of scapula lifting	0.5 ± 0.8	0.5 ± 0.7	ns	
Control of scapula lowering	1.1 ± 0.9	1.2 ± 0.9	p=0.001	small 0.02

ns, not significant

3. 3. 2. 7. Alternative push up test

The two most prevalent results for the alternative push up test were “excellent” followed by “good” (Table 3.29). Pain was reported by 1.5% (5) of participants.

Table 3.29: Alternative push up test

Poor (1) Percentage (n)	Average (2) Percentage (n)	Good (3) Percentage (n)	Excellent (4) Percentage (n)
2.4 (8)	7.7 (26)	25.4 (86)	64.5 (218)

3. 3. 3. Analysis between Gaelic football and hurling and between fresher and senior players in the collegiate participants

A two by two ANOVA was completed to examine if sport and level played had an effect on each of the pre-participation screening tests. The first table in each section displays the mean and standard deviation of fresher and senior Gaelic footballers and hurlers. The second table in each section demonstrates the F value, significant difference (p value) and effect size (partial eta squared) for that particular test in fresher and senior Gaelic footballers and hurlers.

3. 3. 3. 1. Anthropometric data and participant information (Table 3.30-31)

Gaelic football was the primary sport played (65.2%) with the majority of participants across both sports playing at a senior level (53.6%). Gaelic footballers were found to be statistically significantly taller than hurlers ($p<0.05$) with only a small effect size and there was no significant difference between Gaelic footballers and hurlers for age, weight and BMI ($p>0.05$). Senior players were significantly older and had a higher BMI than fresher players ($p<0.05$) with a large and moderate effect size respectively. No interaction effect was noted between sport played and level of playing.

Table 3.30: Anthropometric data; Mean and standard deviation of fresher and senior Gaelic football and hurling participants.

	Gaelic football		Hurling	
	Fresher Mean ± SD	Senior Mean ± SD	Fresher Mean ± SD	Senior Mean ± SD
Age	18.2 ± 0.7	20.5 ± 2	18.1 ± 0.6	20.5 ± 2
Height (m)	1.80 ± 0.08	1.84 ± 0.06	1.80 ± 0.07	1.81 ± 0.06
Weight (kg)	76 ± 9.8	80.7 ± 8.8	74.1 ± 10.3	77.9 ± 8
BMI	23.2 ± 2.3	24 ± 1.9	22.8 ± 2.2	24.3 ± 2.4

Table 3.31: Anthropometric data; F value, significant difference and effect size between fresher and senior Gaelic football and hurling participants.

	Sport			Level			Interaction Effect
	F	P	Effect size	F	P	Effect size	
Age		ns		182.63	<0.0001	large 0.34	ns
Height (m)	4.54	0.03	small 0.01	8.27	0.004	small 0.02	ns
Weight (kg)		ns		9.25	0.003	small 0.05	ns
BMI		ns		12.62	<0.0001	moderate 0.06	ns

ns, not significant

3. 3. 3. 2. Flexibility (Table 3.32-33)

Gaelic footballers had significantly higher mean active knee extension than hurlers on the right and left legs ($p<0.05$) however only the right leg reached a moderate effect size. Hurlers were found to have a significantly higher internal and external rotation on the left hand side (p<0.05) but only a small effect size was found. Fresher players displayed a significantly higher internal rotation on the left side (p<0.05, effect size=0.03 small) and external rotation on the right side (p<0.0001, effect size=0.07 moderate) than senior players. Internal rotation on the right was found to be significantly different between fresher and senior players (p<0.0001, effect size=0.09 moderate), however the sport and level interaction was significant (p=0.002, effect size=0.03 small). Fresher Gaelic footballers and senior hurlers displayed higher internal rotation than senior Gaelic footballers.

Table 3.32: Flexibility; Mean and standard deviation of fresher and senior Gaelic football and hurling participants

		Gaelic football		Hurling	
		Fresher Mean ± SD	Senior Mean ± SD	Fresher Mean ± SD	Senior Mean ± SD
Active Knee Extension (◦)	R	65.7 ± 10.6	69 ± 10.8	60.3 ± 11.7	59.4 ± 11.4
	L	66.1 ± 9.8	69.1 ± 10.9	61.5 ± 11.5	63.1 ± 11.1
Internal Rotation (◦)	R	82.2 ± 21.1	65.2 ± 14.3	78.2 ± 13.9	73.4 ± 14.4
	L	81.1 ± 18.8	72.9 ± 16.6	85.3 ± 17.5	80.8 ± 18.9
External Rotation (◦)	R	85.4 ± 14.1	79.2 ± 16.2	92 ± 15.8	79.3 ± 19.7
	L	79 ± 11.9	75.8 ± 34.6	88.1 ± 12.9	83.5 ± 16.6

R, right; L, left

Table 3.33: Flexibility; F value, significant difference and effect size between fresher and senior Gaelic football and hurling participants

		Sport			Level			Interaction Effect		
		F	p	Effect size	F	P	Effect size	F	P	Effect size
Active Knee Extension (◦)	R	35.1	<0.0001	moderate 0.1		ns			ns	
	L	18.1	<0.0001	small 0.05		ns			ns	
Internal Rotation (◦)	R		ns		31.22	<0.0001	moderate 0.09	9.87	0.002	small 0.03
	L	8.33	0.004	small 0.03	9.1	0.003	small 0.03		ns	
External Rotation (◦)	R		ns		25.12	<0.0001	moderate 0.07		ns	
	L	9.9	0.002	small 0.03			ns		ns	

ns, not significant. R, right; L, left

3. 3. 3. 3. Navicular Drop (Table 3.34-3.35)

No significant difference was found between sport or level in the navicular drop test (p>0.05), however the sport and level interaction was significant on the right and left feet (p<0.0001) with only a small effect size. Fresher hurlers were found to have a higher navicular drop than fresher Gaelic footballers on both feet. In contrast senior Gaelic footballers displayed a higher navicular drop than senior hurlers on both feet. Senior Gaelic footballers presented with a higher navicular drop than fresher Gaelic footballers on both feet. However for hurling, freshers were found to have a higher navicular drop than senior hurlers, but this was only noteworthy on the right foot.

Table 3.34: Navicular drop test; Mean, standard deviation, significant difference and effect size between Gaelic football and hurling participants

	Gaelic football		Hurling	
	Fresher Mean ± SD	Senior Mean ± SD	Fresher Mean ± SD	Senior Mean ± SD
Right (mm)	7.6 ± 4.3	9.1 ± 4.7	9.4 ± 4.1	7.3 ± 3.8
Left (mm	7,0 ± 4.3	9.7 ± 4.9	8.5 ± 3.9	7.2 ± 3.7

Table 3.35: Navicular drop test; F value, significant difference and effect size between fresher and senior Gaelic football and hurling participants

	Sport			Level			Interaction Effect		
	F	P	Effect size	F	p	Effect size	F	p	Effect size
Right (mm)		ns			ns		13.61	<0.0001	small 0.04
Left (mm)		ns			ns		15.54	<0.0001	small 0.04

ns, not significant.

3. 3. 3. 4. Y balance test (Table 3.36-3.37)

A significant interaction effect between sport and level was evident in all aspects of the y balance test, aside from the average reach difference in the anterior, posteriomedial, posteriolateral and composite directions. With regard to the significant differences that displayed a moderate effect size, hurlers were found to display higher anterior reach distance on the left leg compared to Gaelic footballers (p<0.0001) however no significant difference between level was noted (p>0.05). The sport and level interaction however was significant (p<0.0001, effect size-0.07 moderate). Senior hurlers displayed a higher reach distance than fresher hurlers and senior Gaelic footballers. In contrast, fresher Gaelic footballers displayed a higher reach distance than senior Gaelic footballers. A significant difference between level (p<0.05) with a small effect size (0.04) was noted in anterior average reach with respect to their leg length, however an interaction effect was significant (p<0.0001, effect size=0.07 moderate). Senior hurlers were found to have a higher reach in the anterior direction when normalised to leg length scores were taken into account than fresher hurlers and senior Gaelic footballers; fresher Gaelic footballers also displayed a higher average reach than fresher hurlers. In the posteriomedial direction the scores normalised to leg length were found to have no significant difference between sport and level (p>0.05) however an interaction effect was noted (p=0.001, effect size=0.007 moderate). Senior hurlers were found to have a higher reach distance than fresher hurlers and senior Gaelic footballers in the posteriomedial direction. Fresher Gaelic footballers also had a higher reach distance than fresher hurlers. A significant difference was found between level for the composite score on the right (p<0.0001, effect size=0.1 moderate) and left leg (p=0.001, effect size=0.06 moderate) however an interaction effect was also noted on both legs (p<0.0001) with a moderate effect size. On both legs senior hurlers displayed a higher composite score than fresher hurlers or senior Gaelic footballers. Fresher Gaelic footballers displayed a higher composite score on both legs than fresher hurlers.

Table 3.36: Y balance test; Mean and standard deviation of fresher and senior Gaelic football and hurling participants

		Gaelic football		Hurling	
		Fresher Mean ±SD	Senior Mean ±SD	Fresher Mean ±SD	Senior Mean ±SD
Anterior					
Reach distance (cm)	R	69.6 ± 11.2	68.5 ± 28.1	68.5 ± 11.9	80.7 ± 17.7
	L	69.5 ± 10.3	65.7 ± 7.9	70 ± 11.2	79.4 ± 16.6
Reach difference (cm)		4.8 ± 6.2	7.1 ± 26.7	4.9 ± 4.9	8.1 ± 7.2
Reach (%LL)		65.6 ± 5.5	64.3 ± 12.4	62.9 ± 5.6	72 ± 9.1
Posteriomedial					
Reach distance (cm)	R	103.8 ± 11.6	102.7 ± 12.4	103.1 ± 15.3	114 ± 15.5
	L	106.1 ± 11.6	102.7 ± 11.6	103.6 ± 14.8	113.2 ± 16.6
Reach difference (cm)		5.3 ± 5.4	5.5 ± 5	5.2 ± 3.6	5.2 ± 4.4
Reach (%LL)		102.8 ± 7.6	99.1 ± 18.9	96.4 ± 12.1	107.7 ± 10.3
Posteriolateral					
Reach distance (cm)	R	107.6 ± 12.7	103.5 ± 10	105.3 ± 16.6	113.2 ± 17.9
	L	107.7 ± 13.5	103.7 ± 11.4	105.7 ± 16.7	114.3 ± 18.1
Reach difference (cm)		6.1 ± 5.2	5.1 ± 4.2	6.1 ± 4.6	5.3 ± 4.5
Reach (%LL)		103.2 ± 8.7	100.3 ± 18.9	95.9 ± 10.5	106.4 ± 13.3
Composite					
Composite Score	R	90.4 ± 6	89.9 ± 8.1	84.4 ± 8.6	95.4 ± 11
	L	91.1 ± 6	90.1 ± 8.8	85.7 ± 8.5	95.9 ± 11.4
Reach difference (cm)		2.9 ± 2.4	3.2 ± 2.8	3.1 ± 2.1	4.4 ± 3.4

%LL, percentage of leg length. R, right; L, left

Table 3.37: Y balance test; F value, significant difference and effect size between fresher and senior Gaelic football and hurling participants

		Sport			Level			Interaction Effect		
		F	**P**	**Effect size**	**F**	**P**	**Effect size**	**F**	**P**	**Effect size**
Anterior										
Reach distance (cm)	R		ns			ns		8.6	0.004	small 0.03
	L	26.3	<0.0001	Moderate 0.08		ns		22.4	<0.0001	moderate 0.07
Reach difference (cm)			ns			ns			ns	
Reach (%LL)			ns		7.3	0.007	small 0.04	13.4	<0.0001	moderate 0.07
Posteriomedial										
Reach distance (cm)	R	10.8	0.001	small 0.04	9.3	0.003	small 0.03	13.9	<0.0001	small 0.05
	L		ns			ns		16.3	0.0001	small 0.05
Reach difference (cm)			ns			ns			ns	
Reach (%LL)			ns			ns		12.45	0.001	moderate 0.07
Posteriolateral										
Reach distance (cm)	R		ns			ns		12.7	<0.0001	small 0.04
	L		ns			ns		12.7	<0.0001	small 0.04
Reach difference (cm)			ns			ns			ns	
Reach (%LL)			ns			ns		9.2	0.003	small 0.05
Composite										
Composite score	R		ns		17.05	<0.0001	moderate 0.1	20.4	<0.0001	moderate 0.08
	L		ns		12	0.001	moderate 0.06	17.3	<0.0001	moderate 0.09
Reach difference (cm)			ns			ns			ns	

%LL, percentage of leg

3. 3. 3. 5. Overhead squat and single leg squat (Table 3.38-3.43)

Senior players were found to have a higher score than freshers for the squat and single leg squat on both the right and the left leg (p<0.05) with only a small effect size. Gaelic footballers were found to have a better overall impression score in comparison to hurlers for the single leg squat on the right and the left leg (p<0.05) with only a small effect size. There was no interaction effect found between sport and level played (p>0.05).

Table 3.38: Overall impression of Squat and single leg squat; Mean and standard deviation of fresher and senior Gaelic football and hurling participants (Scoring ranged from 1-3)

		Gaelic football		Hurling	
		Fresher Mean± SD	Senior Mean± SD	Fresher Mean± SD	Senior Mean± SD
Squat		1.8 ± 0.7	2 ± 0.6	1.7 ± 0.7	1.9 ± 0.7
Single leg squat	**R**	1.5 ± 0.6	1.7 ± 0.6	1.3 ± 0.6	1.5 ± 0.6
	L	1.6 ± 0.5	1.7 ± 0.6	1.4 ± 0.5	1.5 ± 0.6

R, right; L, left

Table 3.39: Overall impression of squat and single leg squat; F value, significant difference and effect size between fresher and senior Gaelic football and hurling participants (Scoring ranged from 1-3)

		Sport			Level			Interaction		
		F	P	Effect size	F	p	Effect size	F	P	Effect size
Squat			ns		8.4	0.004	small 0.02		ns	
SLS	**R**	10.1	0.002	small 0.03	6.3	0.013	small 0.02		ns	
	L	7.6	0.006	small 0.02	4.9	0.028	small 0.02		ns	

ns, not significant. R, right; L, left. SLC, single leg squat

Fresher players had a significantly lower toe out score than senior players ($p<0.05$) however an interaction effect was noted whereby it is demonstrated that this was evident for only the hurlers. An interaction effect was also noted for knees over toes, knee valgus and hip flexion ($p<0.05$). Fresher Gaelic footballers and senior hurlers displayed higher knees over toes score than fresher hurlers and senior Gaelic footballers. Senior hurlers presented with higher knee valgus scores than fresher hurlers and senior Gaelic footballers. Fresher hurlers displayed higher hip flexion scores than senior hurlers and fresher Gaelic footballers. In addition, senior Gaelic footballers displayed higher hip flexion scores than senior hurlers.

Table 3.40: Individual criteria for overhead squat; Mean and standard deviation for fresher and senior Gaelic football and hurling participants (Scoring ranged from 0-3)

	Gaelic football		Hurling	
	Fresher Mean± SD	Senior Mean± SD	Fresher Mean± SD	Senior Mean± SD
Knee over toes	0.9 ± 0.9	0.6 ± 0.7	0.5 ± 0.7	0.8 ± 0.9
Knee valgus	0.3 ± 0.6	0.2 ± 0.5	0.2 ± 0.5	0.5 ± 0.8
Knee varus	0.5 ± 0.7	0.3 ± 0.5	0.4 ± 0.7	0.3 ± 0.5
Toe out	0.6 ± 0.7	0.6 ± 0.8	0.4 ± 0.7	0.8 ± 0.8
Toe in	0 ± 0.1	0 ± 0	0.1 ± 0.5	0.1 ± 0.3
Hip flexion	0.8 ± 0.9	1 ± 0.9	1.5 ± 1.1	0.8 ± 0.9
Trunk flexion	1.1 ± 1	1 ± 1	1 ± 1.2	1.5 ± 1
Balance	0.4 ± 0.6	0.4 ± 0.7	0.4 ± 0.7	0.3 ± 0.5

Table 3.41: Individual criteria for the overhead squat; F value, significant difference and effect size between fresher and senior Gaelic football and hurling participants

	Sport			Level			Interaction		
	F	P	Effect size	F	P	Effect size	F	P	Effect size
Knee over toe		ns			ns		13.8	<0.0001	small 0.04
Knee valgus		ns			ns		8.3	0.004	small 0.02
Knee varus		ns			ns			ns	
Toe out		ns		5.8	0.02	small 0.02	4.3	0.04	small 0.01
Toe in		ns			ns			ns	
Hip flexion		ns			ns		15.5	<0.0001	small 0.04
Trunk flexion		ns			ns			ns	
Balance		ns			ns			ns	

ns, not significant

A significant difference for sport and level (p<0.0001) was found for toe in on the right leg with a moderate effect size, however an interaction effect between sport and level was also noted (p<0.05, effect size=0.07 moderate). Senior hurlers displayed a higher toe in result than senior Gaelic footballers and fresher hurlers. A significant interaction effect (p<0.0001) with a moderate effect size (0.07) was also found for trunk flexion on the right side. Senior Gaelic footballers displayed an increased amount of trunk flexion than fresher Gaelic footballers and senior hurlers. Fresher hurlers on the other hand demonstrated higher scores for trunk flexion than senior hurlers and fresher Gaelic footballers.

Table 3.42: Individual criteria for the single leg squat; Mean and standard deviation of fresher and senior Gaelic football and hurling participants (scoring ranged from 0-3)

		Gaelic football		Hurling	
		Fresher Mean± SD	Senior Mean± SD	Fresher Mean± SD	Senior Mean± SD
Knee over toes	R	1.3 ± 0.8	1.1 ± 0.8	1.4 ± 0.8	1.2 ± 0.8
	L	1.2 ± 0.8	1.3 ± 0.9	1.3 ± 0.8	1.3 ± 0.7
Knee valgus	R	1 ± 0.8	1 ± 0.9	1.2 ± 1	1 ± 1
	L	0.9 ± 0.4	0.8 ± 0.8	1.1 ± 0.9	1.3 ± 0.9
Knee Varus	R	0.3 ± 0.7	0.2 ± 0.5	0.2 ± 0.4	0.1 ± 0.3
	L	0.4 ± 0.7	0.3 ± 0.6	0.2 ± 0.5	0.3 ± 0.5
Toe out	R	0.2 ± 0.4	0.1 ± 0.3	0.4 ± 0.7	0.1 ± 0.3
	L	0.1 ± 0.3	0.1 ± 0.2	0.2 ± 0.6	0.1 ± 0.4
Toe in	R	0.1 ± 0.2	0 ± 0.2	0.1 ± 0.3	0.6 ± 0.9
	L	0.1 ± 0.3	0 ± 0.2	0.1 ± 0.2	0 ± 0.1
Hip Flexion	R	1 ± 1	1.3 ± 1	1.5 ± 0.9	1.3 ± 0.9
	L	1 ± 1	1.4 ± 0.9	1.5 ± 0.9	1.3 ± 0.8
Trunk Flexion	R	1.1 ± 1	1.7 ± 0.9	1.5 ± 1	0.9 ± 1
	L	1.2 ± 0.9	1.6 ± 0.9	1.4 ± 1	1.2 ± 1.1
Balance	R	1 ± 0.9	1.1 ± 0.9	0.8 ± 0.2	1.3 ± 0.6
	L	1 ± 0.8	1.3 ± 0.9	0.8 ± 0.9	1.3 ± 0.8

R, right; L, left

Table 3.43: Individual criteria of the single leg squat between both legs; F value, significant difference and effect size between fresher and senior Gaelic football and hurling participants (Scoring ranged from 0-3)

		Sport			Level			Interaction		
		F	P	Effect size	F	P	Effect size	F	P	Effect size
Knee over toes	R		ns			ns			ns	
	L		ns			ns			ns	
Knee valgus	R		ns			ns			ns	
	L	9.1	0.003	small 0.03		ns			ns	
Knee varus	R		ns			ns			ns	
	L		ns			ns			ns	
Toe out	R		ns		13.6	<0.0001	small 0.04		ns	
	L		ns			ns			ns	
Toe in	R	33.1	<0.0001	moderate 0.09	21.9	<0.0001	moderate 0.06	25.7	<0.0001	moderate 0.07
	L							11.4	0.001	small 0.03
Hip flexion	R	7.7	0.006	small 0.02		ns		5.92	0.016	small 0.02
	L									
Trunk flexion	R		ns			ns		27.6	<0.0001	moderate 0.07
	L							5.8	0.017	small 0.02
Balance	R		ns		7.7	0.006	small 0.02		ns	
	L		ns		15.2	<0.0001	small 0.04		ns	

ns, not significant. R, right; L, left

3. 3. 3. 6. Scapular Control (Table 3.44-3.45)

Hurlers were found to have a statistically significantly higher score for symmetry and control of scapula when lowering on the left side compared to Gaelic footballers ($p<0.05$), with a small effect size. Fresher players had a statistically significantly higher score than senior players for control when lowering on the left side ($p<0.05$) with a small effect size. A statistical significant difference ($p<0.05$) with a small effect size was noted between sport and level for scapular control when lowering on the right side however an interaction effect was also found. Senior hurlers and fresher Gaelic footballers were found to receive poorer scores in scapular control when lowering than senior Gaelic footballers. No significant difference was found between sport and level for control of the scapula when lifting on the right side and winging on the left side however a significant interaction effect was noted with a small effect size. Senior hurlers scored poorer than senior Gaelic footballers for control of scapula when lifting on the right side. Senior hurlers were found to have winging more than fresher hurlers and senior Gaelic footballers, with fresher Gaelic footballers displaying more winging than fresher hurlers and senior Gaelic footballers.

Table 3.44: Scapular control test; Mean and standard deviation for fresher and senior Gaelic football and hurling participants (Scoring ranged from 0-3)

		Gaelic football		Hurling	
		Fresher Mean± SD	**Senior Mean± SD**	**Fresher Mean± SD**	**Senior Mean± SD**
Winging	R	0.7 ± 0.7	0.5 ± 0.7	0.7 ± 0.7	0.8 ± 0.9
	L	0.8 ± 0.8	0.6 ± 0.7	0.5 ± 0.6	0.8 ± 0.9
Control of scapula lifting	R	0.6 ± 0.8	0.4 ± 0.7	0.5 ± 0.7	0.7 ± 0.8
	L	0.5 ± 0.7	0.4 ± 0.7	0.5 ± 0.6	0.6 ± 0.8
Control of scapula lowering	R	1.3 ± 0.9	0.7 ± 0.8	1.3 ± 0.8	1.2 ± 0.9
	L	1.4 ± 0.9	0.9 ± 0.8	1.5 ± 0.8	1.2 ± 0.9
Symmetry		0.7 ± 0.8	0.9 ± 0.7	1.1 ± 0.6	0.8 ± 0.8

R, right; L, left

Table 3.45: Scapular control test; Mean, standard deviation, significant difference and effect size between fresher and senior participants (Scoring ranged from 0-3)

		Sport			Level			Interaction		
		F	P	Effect size	F	P	Effect size	F	P	Effect size
Winging	R		ns			ns			ns	
	L		ns			ns		6.0	0.015	small 0.02
Control of scapula lifting	R		ns			ns		4.3	0.038	small 0.02
	L		ns			ns			ns	
Control of scapula lowering	R	10.1	0.002	small 0.03	11.2	0.001	small 0.03	5.2	0.023	small 0.02
	L	5.3	0.022	small 0.02	15.17	<0.0001	small 0.04		ns	
Symmetry		9.4	0.002	small 0.03		ns			ns	

ns, not significant. R, right; L, left

Alternative Push up test (Table 3.46-3.47)

No significant difference was found between Gaelic footballers and hurlers for the alternative push up test ($p>0.05$) however a significant difference was found between level ($p<0.05$) with a small effect size. An interaction effect was also noted with a small effect size ($p<0.0001$). Senior Gaelic footballers were found to score higher on the core test than senior hurlers and fresher Gaelic footballers.

Table 3.46: Alternative push up test; Mean and standard deviation for fresher and senior Gaelic football and hurling participants (Scoring ranged from 1-3)

Gaelic football		Hurling	
Fresher Mean± SD	Senior Mean± SD	Fresher Mean± SD	Senior Mean± SD
3.3 ± 0.8	3.8 ± 0.5	3.5 ± 0.8	3.4 ± 0.8

Table 3.47: Alternative push up test; F value, significant difference and effect sizes between fresher and senior Gaelic football and hurling participants

Sport			Level			Interaction		
F	p	Effect size	F	P	Effect size	F	P	Effect size
	ns		7.06	0.008	small 0.02	14.38	<0.0001	small 0.04

3. 3. 4. Analysis between adolescent and collegiate participants

Further analysis was completed to compare the results of the pre participation screening tests between adolescent and collegiate participants. Table 3.48, 3.49, 3.50, 3.51 demonstrates the mean, standard deviation, significant difference and effect size between the school aged and collegiate participants for anthropometric data, flexibility, navicular drop test and Y balance test respectively.

Table 3.48: Anthropometric data; Mean, standard deviation, significant difference and effect sizes between adolescent and collegiate participants.

	Adolescent Mean ± SD	Collegiate Mean ± SD	Significance difference (p value)	Effect size (eta squared)
Height (m)	1.76 ± 0.74	1.81 ± 0.72	$p<0.0001$	moderate 0.13
Weight (kg)	66.9 ± 10.2	77.7 ± 9.5	$p<0.0001$	large 0.2
BMI	21.7 ± 2.8	23.6 ± 2.19	$p<0.0001$	moderate 0.11

Table 3.49: Flexibility tests; Mean, standard deviation, significant difference and effect sizes between adolescent and collegiate participants

		Adolescent Mean ± SD	Collegiate Mean ± SD	Significant difference (p value)	Effect size (eta squared)
Active knee extension (◦)	R	61.3 ± 13.4	64.7 ± 11.6	$p<0.0001$	small 0.02
	L	60.2 ± 13.2	65.8 ± 11	$p<0.0001$	small 0.05
Internal rotation (◦)	R	77.8 ± 15.5	74.4 ± 18.1	$p=0.007$	small 0.01
	L	88.8 ± 19.4	79 ± 18.4	$p<0.0001$	moderate 0.06
External rotation (◦)	R	85.4 ± 22.4	83.1 ± 16.8	Ns	
	L	91.7 ± 14.9	80.2 ± 23.3	$p<0.0001$	moderate 0.08

ns, not significant. R, right; L, left

Table 3.50: Navicular drop test; Mean, standard deviation, significant difference and effect sizes between adolescent and collegiate participants

	Adolescent Mean ± SD	Collegiate Mean ± SD	Significant difference (p value)	Effect size (eta squared)
Right (mm)	7.4 ± 5.1	8.3 ± 4.4	$p=0.019$	small 0.01
Left (mm)	7.6 ± 5.4	8.2 ± 4.5	ns	

ns, not significant. R, right; L, left

Table 3.51: Y balance test; Mean, standard deviation, significant difference and effect sizes between adolescent and collegiate participants

		Adolescent Mean ±SD	Collegiate Mean ±SD	Significant difference (p value)	Effect size (eta squared)
Anterior					
Reach distance (cm)	R	67.9 ± 8.9	71.3 ± 19.1	p=0.005	small 0.01
	L	69.6 ± 9.1	70.5 ± 12.3	ns	
Reach difference (cm)		4.6 ± 3.9	6.1 ± 14.9	ns	
Reach (%LL)		69.8 ± 9.3	68.6 ± 42.3	ns	
Posteriomedial					
Reach distance (cm)	R	98.6 ± 11.1	105.4 ± 13.9	ns	
	L	101.3 ± 22.4	106.1 ± 13.7	ns	
Reach difference (cm)		5.7 ± 4.8	5.3 ± 4.8	ns	
Reach (%LL)		100.9 ± 11.8	103.7 ± 41.4	ns	
Posteriolateral					
Reach distance (cm)	R	98.2 ± 11.9	107.2 ± 14.3	p<0.0001	moderate 0.1
	L	98.3 ± 11.9	107.56 ± 14.95	p<0.0001	moderate 0.1
Reach difference (cm)		6 ± 4.8	5.7 ± 4.7	ns	
Reach (%LL)		99.8 ± 12.5	103.9 ± 41.5	ns	
Composite					
Composite score	R	92 ± 11.7	90.2 ± 8.8	ns	
	L	93.8 ± 20.1	90.8 ± 9.1	ns	
Reach difference (cm)		4.3 ± 6.6	3.3 ± 2.8	ns	
Composite (%LL)		95.4±25.1	92.5±13.4	ns	

ns, not significant. R, right; L, left

The overall impression of the overhead squat and single leg squat on the right and left legs between adolescent and collegiate participants is presented in Table 3.52.

Table 3.52: Overall impression overhead squat and single leg squat on the right and left legs; Mean, standard deviation, significant difference and effect size between adolescent and collegiate participants. (Scoring ranged from 1-3)

		Adolescent Mean± SD	Collegiate Mean ± SD	Significant difference (p value)	Effect size (eta squared)
Squat		1.8 ± 0.8	1.9 ± 0.7	Ns	
Single leg squat	**R**	1.7 ± 0.7	1.5 ± 0.6	p<0.0001	small 0.02
	L	1.8 ± 0.7	1.6 ± 0.6	p<0.0001	small 0.03

ns, not significant. R, right; L, left

The individual criteria for the overhead squat and single leg squat for both legs is presented in Table 3.53 and Table 3.54 respectively.

Table 3.53: Individual criteria of the overhead squat; Mean, standard deviation, significant difference and effect size between adolescent and collegiate participants.

	Adolescent Mean± SD	Collegiate Mean ± SD	Significant difference (p value)	Effect size (eta squared)
Knee over toes	0.6 ± 1	0.7 ± 0.8	ns	
Knee valgus	0.5 ± 0.9	0.3 ± 0.6	p<0.0001	small 0.03
Knee varus	0.4 ± 0.8	0.4 ± 0.6	ns	
Toe out	0.7 ± 0.9	0.6 ± 0.8	ns	
Toe in	0.1 ± 0.5	0 ± 0.2	p<0.0001	small 0.02
Hip flexion	0.9 ± 0.9	1 ± 1	ns	
Trunk flexion	1.3 ± 1	1.1 ± 1	ns	
Balance	0.5 ± 0.7	0.4 ± 0.7	p=0.006	small 0.01

ns, not significant

Table 3.54: Individual criteria for the single leg squat on the right and left legs; Mean, standard deviation, significant difference and effect size between adolescent and collegiate participants (Scoring ranged from 0-3)

		Adolescent Mean± SD	Collegiate Mean ± SD	Significant difference (p value)	Effect size (eta squared)
Knee over toes	R	1 ± 0.8	1.2 ± 0.8	p=0.002	small 0.01
	L	1 ± 0.8	1.2 ± 0.8	p<0.0001	small 0.02
Knee valgus	R	1.1 ± 0.9	1 ± 0.9	ns	
	L	0.9 ± 0.8	1 ± 0.9	ns	
Knee varus	R	0.2 ± 0.5	0.2 ± 0.5	ns	
	L	0.2 ± 0.5	0.3 ± 0.6	ns	
Toe out	R	0.2 ± 0.5	0.2 ± 0.4	ns	
	L	0.2 ± 0.5	0.1 0.4	ns	
Toe in	R	0 ± 0.1	0.2 ± 0.5	p<0.0001	small 0.03
	L	0 ± 0.1	0.1 ± 0.2	p=0.029	small 0.01
Hip Flexion	R	1.1 ± 0.9	1.2 ± 1	ns	
	L	1.2 ± 0.9	1.3 ± 1	ns	
Trunk flexion	R	1.3 ± 1	1.3 ± 1	ns	
	L	1.2 ± 0.8	1.4 ± 1	p=0.003	small 0.01
Balance	R	0.6 ± 0.9	1.1 ± 0.9	p<0.0001	moderate 0.06
	L	0.6 ± 0.9	1.1 ± 0.8	p<0.0001	moderate 0.07

ns, not significant. R, right; L, left

The scapular control test between adolescent and collegiate participants is demonstrated in Table 3.55.

Table 3.55: Scapular control test; Mean, standard deviation, significant difference and effect between adolescent and collegiate participants (Scoring ranged from 0-3)

		Adolescent Mean± SD	Collegiate Mean ± SD	Significant difference (p value)
Winging	R	0.8 ± 0.7	0.7 ± 0.8	ns
	L	0.8 ± 0.7	0.7 ± 0.8	ns
Control of scapula lifting	R	0.4 ± 0.8	0.5 ± 0.8	ns
	L	0.5 ± 0.8	0.5 ± 0.7	ns
Control of scapula lowering	R	1.2 ± 1.1	1.1 ± 0.9	ns
	L	1.3 ± 0.9	1.2 ± 0.9	ns
Symmetry		0.9 ± 0.8	0.8 ± 0.7	ns

ns, not significant. R, right; L, left

The results of the alternative push up test between adolescent and collegiate participants are displayed in Tale 3.56.

Table 3.56: Alternative push up test; Mean, standard deviation, significant difference and effect size between adolescent and collegiate participants

Adolescent Mean± SD	Collegiate Mean ± SD	Significant difference (p value)	Effect size (eta squared)
2.9 ± 0.9	3.5 ± 0.7	p<0.0001	moderate 0.11

3. 3. 5. Analysis between tests

The relationship between each of the tests and age and BMI was assessed. Further analysis was completed to identify if there were any links between certain tests in the pre-participation screening. It examined the extent to which some tests are redundant as they may possibly assess similar outcomes. It also assessed the effect of dominance on certain tests in the pre-participation screening. The effect hand dominance may have on both rotation and scapular control of the shoulder and also the effect lower limb dominance may have on both the single leg squat and the Y balance test was assessed.

3. 3. 5. 1. Relationship between age and the pre participation screening tests

The relationship between age and the pre participation screening tests that were significantly correlated is displayed in Table 3.57 ($p<0.05$). Out of all the pre participation screening tests, only twelve tests were significantly correlated with age. The strength of the significant correlations were small with the exception of the alternative push up test which had a medium strength correlation ($r=0.35$). The following variables were not significantly correlated with age: navicular drop test (right and left), control of scapula when lowering (right and left), squat (knees over toes, knee valgus, knee varus, toe out, toe in, hip flexion, trunk flexion, balance), single leg squat on the right leg (knees over toes, knee valgus, knee varus, toe out, toe in, hip flexion, trunk flexion, balance, overall impression), single leg squat on the left leg (knees over toes, knee valgus, knee varus, toe out, toe in, hip flexion, trunk flexion, balance) and Y balance test (left anterior average reach distance, anterior average reach difference, posteriormedial average reach difference, posteriolateral average reach difference, composite average reach difference, anterior average reach percentage of leg length, posteriomedial average reach percentage of leg length, posteriolateral average reach percentage of leg length, right composite score, left composite score).

Table 3.57: Significant correlations between age and other pre participation tests

		Age	
		p value	**r value**
Core			
Alternative push up test		p<0.001	medium r=0.35
Flexibility of Shoulder			
Internal rotation of shoulder (◦)	R	p<0.001	small r= -0.19
	L	p<0.001	small r= -0.24
External rotation of shoulder (◦)	R	p=0.022	small r= -0.1
	L	p<0.0001	small r= -0.26
Scapular control test			
Winging	R	p=0.014	small r= -0.1
	L	p=0.013	small r= -0.1
Control of scapula lowering	R	p=0.004	small r= -0.11
	L	p=0.003	small r= -0.11
Symmetry		p=0.044	small r= -0.1
Hamstring flexibility			
Active knee extension (◦)	R	p<0.001	small r=0.19
	L	p<0.001	small r=0.27
Squat and Single leg squat			
Squat overall impression		p=0.021	small r=0.1
Single leg squat overall impression	L	p= 0.01	small r= -0.1
Y balance test			
Anterior average reach distance (cm)	R	p=0.004	small r= 0.11
Posteriomedial average reach distance (cm)	R	p<0.001	small r= 0.28
	L	p<0.001	small r=0.22
Posteriolateral average reach distance (cm)	R	p<0.001	small r= 0.28
	L	p<0.001	small r= 0.28

R, right; L, left

3. 3. 5. 2. Relationship between BMI and the pre participation screening tests

Table 3.58 demonstrates the significant correlations between BMI and tests within the pre participation screening. Out of all the pre participation screening tests, only nine tests were significantly correlated with BMI. The strength of the significant correlations were small with the exception of right winging (r=-0.36) and left winging (r=-0.33) which had a medium correlation in the scapular control test with BMI. The following variables were not significantly correlated with BMI: internal rotation of the shoulder (right and left), navicular drop test (right and left), squat (knees over toes, knee valgus, knee varus, toe out, toe in, hip flexion, trunk flexion, balance, overall impression), single leg squat on the right leg (knees over toes, knee valgus, knee varus, toe out, toe in, hip flexion, trunk flexion, balance, overall impression), single leg squat on the left leg (knees over toes, knee valgus, knee varus, toe out, toe in, hip flexion, trunk flexion, balance, overall impression) and Y balance test (right posteriomedial average reach distance, left posteriomedial average reach distance, right posteriolateral average reach distance, left posteriolateral average reach distance, anterior average reach difference, posteriormedial average reach difference, posteriolateral average reach difference, composite average reach difference, anterior average reach percentage of leg length, posteriomedial average reach percentage of leg length, posteriolateral average reach percentage of leg length, left composite score).

Table 3.58: Significant correlations between BMI and other pre participation tests

		BMI	
		p value	**r value**
Core			
Alternative push up test		p=0.002	small r=0.13
Flexibility of shoulder			
External rotation of shoulder (◦)	R	p=0.038	small r= -0.1
	L	p=0.001	small r= -0.14
Scapular control test			
Winging	R	p<0.001	medium r= -0.36
	L	p<0.001	medium r= -0.33
Control of scapula lifting	R	p<0.001	small r= -0.2
	L	p<0.001	small r= -0.2
Control of scapula lowering	R	p<0.001	small r= -0.28
	L	p<0.001	small r= -0.28
Symmetry		p<0.001	small r= -0.21
Hamstring flexibility			
Active knee extension (◦)	R	p<0.001	small r=0.25
	L	p<0.001	small r=0.25
Y balance test			
Anterior average reach distance (cm)	R	p=0.002	small r= -0.12
	L	p<0.001	small r= -0.15
Composite score	R	p=0.42	small r= -0.1

R, right; L, left

3. 3. 5. 3. Significant difference between hand dominance and both rotation of the shoulder and scapular control of the shoulder.

There was no statistically significant difference between right and left hand dominance for internal rotation of the shoulder, external rotation of the shoulder or the scapular control test test (p>0.05).

3. 3. 5. 4. Significant difference between lower limb dominance and both the single leg squat and Y balance test

There was no statically significant difference between right and left lower limb dominance for both the single leg squat on the right and left legs and the Y balance test (p>0.05).

3. 3. 5. 5. Relationship between rotation of the shoulder and the scapular control test

There was no significant internal rotation on the left and right side and external rotation on the right side with the scapular control test ($p>0.05$). However, Table 3.59 displays the correlation between the external rotation on the left side and the scapular control test ($p<0.05$).

Table 3.59: Relationship between external rotation of the shoulder on the left side and the scapular control test

		Left external rotation of shoulder	
		p value	**r value**
Winging	L	p<0.001	small r=0.14
Control of scapula when lowering	L	p=0.042	small r=0.1
Symmetry		p=0.012	small r=0.1

R, right; L, left

3. 3. 5. 6. Relationship between the overall impression and balance scores for the overhead squat and right and left single leg squat tests with the Y balance test

The correlations between the overhead squat and single leg squat on the right and left leg's balance scores with the Y balance test is displayed in Table 3.60. Table 3.61 demonstrates the correlations between the overhead squat and single leg squat on the right and left leg's overall impression scores with the Y balance test. In summary there were a larger number of statistically significant correlations found between the overall impression scores than the balance scores when comparing the overhead squat and right and left single leg squats with the Y balance test. However, all the statistically significant correlations were found to be small.

Table 3.60: Correlation between the overhead squat, right single leg squat and left single leg squat balance scores and the Y balance test

		Squat balance		Right single leg squat balance		Left single leg squat balance	
		p value	r value	p value	r value	p value	r value
Anterior							
Reach distance (cm)	R	p<0.001	small r=0.15	ns		ns	
	L	p=0.015	small r=0.1	p=0.03	small r= -0.1	p=0.007	small r= -0.1
Reach difference (cm)		p=0.01	small r=0.1	ns		ns	
Reach (%LL)		p<0.0001	small r=0.15	p<0.0001	small r= -0.16	p<0.0001	small r= -0.17
Posteriomedial							
Reach distance (cm)	R	ns		ns		ns	
	L	ns		ns		ns	
Reach difference (cm)		p=0.014	small r=0.1	ns		ns	
Reach (%LL)		ns		p=0.035	small r= -0.1	p=0.016	small r= -0.1
Posteriolateral							
Reach distance (cm)	R	ns		ns		ns	
	L	ns		ns		ns	
Reach difference (cm)		ns		ns		ns	
Reach (%LL)		ns		ns		ns	
Composite							
Composite score	R	ns		ns		ns	
	L	ns		ns		p=0.019	small r=0.1
Reach difference (cm)		ns		ns		ns	
Composite (%LL)		ns		ns		p=0.027	small r=-0.09

ns, not significant

Table 3.61: Correlation between the overhead squat, right single leg squat and left single leg squat overall impression scores and the Y balance test

		Squat overall impression		Right single leg squat overall impression		Left single leg squat overall impression	
		p value	r value	p value	r value	p value	r value
Anterior							
Reach distance (cm)	R	p=0.006	small r=0.1	p=0.008	small r=0.1	p=0.001	small r=0.1
	L	p=0.001	small r=0.13	p<0.0001	small r=0.16	p<0.0001	small r=0.18
Reach difference (cm)		ns		ns		ns	
Reach (%LL)		p=0.002	small r=0.13	p<0.0001	small r=0.21	p<0.0001	small r=0.23
Posteriomedial							
Reach distance (cm)	R	p=0.003	small r=0.11	p=0.05	small r=0.1	p=0.008	small r=0.1
	L	p=0.008	small r=0.1	p=0.47	small r=0.1	p=0.003	small r=0.11
Reach difference (cm)		ns		p=0.039	small r=0.1	p=0.033	small r=0.1
Reach (%LL)		ns		p=0.006	small r=0.12	p=0.005	small r=0.12
Posteriolateral							
Reach distance (cm)	R	p=0.001	small r=0.13	p=0.016	small r=0.1	ns	
	L	p=0.001	small r=0.13	p=0.024	small r=0.1	p=0.007	small r=0.1
Reach difference (cm)		ns		ns		ns	
Reach (%LL)		p=0.028	small r=0.1	p=0.002	small r=0.13	p=0.016	small r=0.1
Composite							
Composite score	R	p=0.007	small r=0.11	ns		p=0.002	small r=0.13
	L	p=0.002	small r=0.13	p=0.024	small r=0.1	p<0.0001	small r=0.18
Reach difference (cm)		ns		ns		ns	
Composite (%LL)		ns		ns		p=0.003	small r=0.13

ns, not significant

3. 3. 5. 7. Relationship between the overhead squat overall impression and both the right and left single leg squat overall impression.

The relationship the overall impression score of the overhead squat with the overall impression scores of the single leg squat in the right and left leg is displayed in Table 3.62.

Table 3.62: Relationship between the overhead squat overall impression and right and left single leg squat overall impression

Right single leg squat overall impression		Left single leg squat overall impression	
p value	r value	p value	r value
p<0.0001	small r= 0.26	p<0.0001	medium r= 0.34

3. 3. 5. 8. Relationship between the individual criteria of the overhead squat and single leg squat on the right and left legs with the overall impression scores of the three tests.

The correlation between the individual criteria of the overhead squat and the single leg squat on the right and left leg with the overall impression score in each of the three tests is illustrated in Table 3.63.

Table 3.63: Relationship between the overall impression of the overhead squat, right single leg squat and left single leg squat with the individual criteria for each test

	Squat overall impression		Right single leg squat overall impression		Left single leg squat overall impression	
	p value	r value	p value	r value	p value	r value
Knees over toes	p<0.0001	medium r= -0.33	p<0.0001	medium r= -0.3	p<0.0001	small r= -0.29
Knee valgus	p<0.0001	small r= - 0.26	p<0.0001	medium r= -0.33	p<0.0001	medium r= -0.39
Knee varus	p<0.0001	small r= -0.24	p=0.003	small r= -0.13	p<0.0001	small r= -0.15
Toe out	p<0.0001	small r= -0.28	p<0.0001	small r= -0.19	p<0.0001	small r= -0.17
Toe in	p=0.002	small r= - 0.12	p<0.0001	small r= -0.17	ns	
Hip flexion	p<0.0001	large r= - 0.51	p<0.0001	medium r= -0.41	p<0.0001	medium r= -0.43
Trunk flexion	p<0.0001	medium r= -0.42	p<0.0001	medium r= -0.33	p<0.0001	medium r= -0.37
Balance	p<0.0001	small r= -0.29	p<0.0001	medium r= -0.49	p<0.0001	large r= -0.51

ns, not significant

3. 3. 5. 9. Relationship between the active knee extension test and hip flexion and knees over toes in the overhead squat and single leg squat on the right and left legs

Table 3.64 displays the correlation between the active knee extension test and two of the individual criteria (hip flexion and knees over toes) of the overhead squat and single leg squat on the right and left leg.

Table 3.64: Relationship between the active knee extension and the individual criteria of hip flexion and knees over toes in the overhead squat and right and left single leg squat

	Right active knee extension		Left active knee extension	
	p value	**r value**	**p value**	**r value**
Hip flexion				
Squat	p<0.0001	small r= -0.13	p<0.0001	small r= -0.15
Right single leg squat	p<0.0001	small r= -0.17	p<0.0001	small r= -0.17
Left single leg squat	p=0.004	small r= -0.11	p=0.002	small r= -0.17
Knees over toes				
Squat	ns		Ns	
Right single leg squat	p=0.005	small r= -0.11	p=0.008	small r= -0.1
Left single leg squat	p=0.021	small r= -0.1	p=0.18	small r= -0.1

ns, not significant

3. 3. 5. 10. Relationship between the alternative push up test and the overall impression score in the overhead squat and single leg squat on the right and left legs

The correlation between the alternative push up test and the overall impression score in the overhead squat and single leg squat on the right and left legs is demonstrated in Table 3.65.

Table 3.65: Relationship between the alternative push up test and overall impression in the overhead squat and the single leg squat on the right and left leg

Overhead squat		Right single leg squat		Left single leg squat	
p value	**r value**	**p value**	**r value**	**p value**	**r value**
p<0.0001	small r= 0.21	p<0.0001	small r= 0.14	p<0.0001	small r= 0.14

3. 3. 5. 11. Relationship between the alternative push up test and the Y balance test

The right composite score on the Y balance test had a small correlation with the alternative push up test ($r=0.21$, $p<0.0001$) however the left composite and average reach of percentage leg length in all three directions had no statistically significant correlation ($p>0.05$).

3. 4. Discussion

The current study aimed to develop a comprehensive screening with suitable test and scoring systems, specific to Gaelic footballers and hurlers, using simple field based tests. This is important because there is currently no standard one in place. Serious limitations exist in the current published tests, including: duration, low reliability, lack of ecological validity, vague or unclear scoring systems, and complex or expensive equipment that can be difficult to transport. The present study also aimed to establish normative data in both adolescent and collegiate Gaelic footballers and hurlers for each of the screening tests as this has not yet been established in current literature. Establishing normative data is vital for screening (Corkery et al., 2007).

3. 4. 1. Anthropometric data

3. 4. 1. 1. Height, Weight and BMI

The majority of studies that analysed anthropometric data assessed elite adult Gaelic footballers with only a single study evaluating hurlers (McIntyre, 2005) and a single study examining elite adolescent Gaelic footballers (Cullen et al., 2012). Thus there is a lack of information on non-elite adolescent hurlers and Gaelic footballers.

Adolescents were found to be slightly smaller, lighter and had a lower BMI than elite adolescent Gaelic footballers (Height=1.78±0.06, Weight=72.1±8.62, BMI=22.69±2.15) (Cullen et al., 2012) which is likely due to the non-elite nature of the adolescent participants in the current study. Collegiate Gaelic footballers and hurlers were taller and heavier than under 21 club Gaelic footballers (Height=1.76±0.05, Weight=70.7±7.7) (Florida-James and Reilly, 1995) and non-elite club level Gaelic footballers (Height=1.75±0.06, 1.74±0.05,Weight=76.5±6.7, 73.3±9.3 respectively) (Keane et al., 1997, Kirgan and Reilly, 1993). Collegiate Gaelic footballers had a higher BMI than under 21 club Gaelic footballers (22.82) (Florida-James and Reilly, 1995) but a lower BMI than non-elite adult club level Gaelic footballers (24.68 and 24.21, respectively) (Keane et al., 1997, Kirgan and Reilly, 1993). As expected, collegiate participants were found to be significantly taller, heavier and presented with a higher BMI than adolescents. A high BMI in Gaelic participants is worrying as this has been found to be a predictor of certain sporting injuries in both adults (Buist et al., 2010, Yard and Comstock, 2011, Plisky et al., 2007, McHugh et al., 2006, Fousekis et al., 2011) and an adolescent physically active population (Richmond et al., 2012). This increased risk has been suggested to be due to the large body mass imposing increased musculoskeletal strain on the body's tissues, and also because it may reduce balance or postural control (Jespersen et al., 2013).

Senior players had a significantly higher BMI than fresher players ($p<0.05$) as would be expected due to the age differences between groups. The alternative push up test was significantly positively correlated to age ($r=0.35$) which suggests that older players have higher core stability and so are at less risk of injury due to poor core stability (Bliven and Anderson, 2013, Abt et al., 2007). BMI was found to be negatively correlated to winging, and so participants with a higher BMI tended to have a higher incidence and severity of winging, which has not been previously observed.

3. 4. 1. 2. Dominance

No information on the effect of upper limb dominance is available from previous studies on Gaelic footballers or hurlers. Adolescent and collegiate participants were primarily right hand and right foot dominant. No significant difference was found between the dominant and non-dominant limb in the single leg squat or the Y balance test. This is in line with other studies for: single leg squat strength (McCurdy and Langford, 2005), static balance control in healthy young adults (Lin et al., 2009), and balance in amateur soccer players (Gstöttner et al., 2009) ($p>0.05$).

There was no difference between dominant and non-dominant upper limbs for either internal rotation or external rotation of the shoulder. This is in contrast to studies on the upper limb, where increased external range of motion and reduced internal range of motion on the dominant shoulder has been demonstrated in the non-athletic population and in a number of upper limb sports in both genders, in all ages (Conte et al., 2009, Wang and Cochrane, 2001). In addition, no difference was found between the dominant and non-dominant upper limbs with regard to the scapular control test. The reason dominance does not have an effect on rotation and scapular control in Gaelic games could be because an emphasis is placed in training to ensure players can kick and pass with both feet and hands in Gaelic football and swing on both sides with the hurley in hurling to enhance the player's skill level and performance. No consensus exists in current literature on the effect dominance has on injury; the dominant limb is placed under more frequent and intensive usage which may predispose to injury, conversely the tissues and structures on the non-dominant limb may be weaker due to the lessened use and so may be unable to absorb large forces placed on it which also may predispose to injury (Jacobs et al., 2005). Dominance and its effect on injury has yet to be sufficiently assessed in both Gaelic footballers and hurlers and so further research is necessary.

3. 4. 2. Hamstring flexibility

There is a general lack of normative data on hamstring flexibility using the active knee extension test, with only a single study which was completed in a convenience sample of collegiate participants (Corkery et al., 2007) and no available normative data in Gaelic footballers and hurlers.

The present study found higher flexibility in both adolescent and collegiate participants in comparison to collegiate males (right=55.0±11.3°, left=52.9±9.1°) (Corkery et al., 2007), however as the normative data reported by Corkery et al. (2007) study was from a convenience sample of college students they are not a directly comparable population as their fitness and sporting level is not identified. In contrast, adolescent and collegiate mean hamstring flexibility results were found to be lower than the mean flexibility reported in a convenience sample of collegiate men (79.75±9.48°) using the "Lift and raise" test which is similar to the active knee extension test (Shimon et al., 2010). Thus, further research on normative data in other sports utilising the active knee extension test is needed for more accurate comparisons to be made.

A hamstring flexibility result greater than 20° away from full extension (90°) (or less than 70° when measured in the manner conducted in the present study) is considered out of the normal limits of hamstring flexibility (Shimon et al., 2010, Davis et al., 2008). The majority of adolescent's results were less than 70° in the active knee extension test on both the right (72.8%) and left leg (77.2%). Collegiate participants had slightly better hamstring flexibility with 63.9% on the right and 61.0% on the left leg with results less than 70°. The high percentage of adolescent and collegiate players with substantial flexibility issues could be related to the high incidence of hamstring injuries in Gaelic games. The hamstring has been reported to account for 6.5-24% of injuries in Gaelic football (Watson, 1996b, Cromwell et al., 2000, Wilson et al., 2007, Newell et al., 2013, Murphy et al., 2012b) and 12-16.5% in hurling (Watson, 1996a, Murphy et al., 2012a), with Murphy et al. (2012b) reporting that the hamstring was the site of 52% of all muscle injuries in elite Gaelic footballers. Thus, it would seem the implementation of an appropriate injury prevention flexibility programme for the hamstrings in Gaelic games would be required (Witvrouw et al., 2003, Bradley and Portas, 2007). Gaelic footballers were found to have significantly higher hamstring flexibility than hurlers on the right leg only which contrasts to the results published by McIntyre (2005) who reported that hurlers had significantly higher hamstring flexibility than Gaelic footballers ($p<0.05$). However, McIntyre (2005) measured hamstring flexibility using the straight leg raise test which has inherent error due to possible tightness of contralateral hip flexors affecting the results and the dorsiflexed position of the foot during the movement possibly contributing a neurological component to the test (Gajdosik et al., 1993, Gajdosik and Lusin, 1983). Of concern, the mean flexibility in fresher Gaelic footballers, senior Gaelic footballers, fresher hurlers and senior hurlers were all below the 70° cut off point for ideal hamstring flexibility which suggests that both sports are at a heightened risk of hamstring injury with hurlers possibly more susceptible (Shimon et al., 2010, Davis et al., 2008). No significant difference was found between fresher and senior collegiate players in either sport ($p>0.05$).

3. 4. 3. Shoulder flexibility

Literature on shoulder flexibility has primarily focused on upper body sports with no published information available on normative data in Gaelic games. External rotation in collegiate athletes was found to be lower than physically active adults that did not play upper body sports (dominant=99.0±5.6°, non-dominant=96.5±5.1°), however, internal rotation was found to be similar (dominant=70.5±7.8°, non-dominant=75.4±6.5) (Torres and Gomes, 2009). In contrast, adolescents displayed lower external rotation (dominant=103.7±10.9°, non-dominant=101.8±10.8°) and much higher internal rotation (dominant=45.4±13.6°, non-dominant= 56.3±11.5°) than junior tennis players (Ellenbecker et al., 2002). This difference between tennis players could be due to the nature of the game which requires tennis players to constantly use their upper body. This places increased eccentric loading on the tissues of the shoulder which may cause corresponding tightness of the posterior capsule that reduces internal range of motion and stretching of the anterior capsule which may lead to increased external rotation (Thomas et al., 2010).

Asymmetry in range of motion between sides has been identified as a possible predictor of injury in sport (Wilk et al., 2011). While left internal rotation was found to be significantly higher than the right side in adolescent and collegiate participants, external rotation was found to be higher on the left side than the right in adolescents only. The side to side difference was as previously mentioned (Section 3.4.2.2) not related to dominance. Total range of motion is defined as internal and external rotation added together and asymmetry of total range of motion of greater than 5° has been identified as a cut off point for participants at a greater risk of injury (Wilk et al., 2011). In the present study, 84.6% of adolescents and 75.3% of collegiate participants displayed asymmetry over this cut off point and so possibly are susceptible to injury (Wilk et al., 2011). While this is a significant finding, it must be noted that the increased injury rate in those past the cut–off point was found in baseball pitchers which is primarily an upper body sport, thus further research is necessary to determine if this has relevance in Gaelic games. In contrast, only 22.1% of adolescents and 33.8% of collegiate participants had an internal range of motion on the non-dominant side of greater than 20° than the dominant side, which has also been proposed as a cut off point for increased risk of injury (Wilk et al., 2011). Utilising this cut off point, baseball players were twice as likely to be injured, however it did not reach statistical significance which questions the appropriateness of this cut off point (Wilk et al., 2011).

Adolescents were found to have significantly higher internal and external rotation on the left side than collegiate participants which is similar to the results reported by Thomas et al. (2010) where high school baseball players had increased internal and external rotation than collegiate players. Fresher internal and external rotation on the right side was found to be significantly higher than senior players however the interaction effect noted in internal rotation demonstrated that this difference was particularly evident between fresher and senior Gaelic footballers. Higher internal and external rotation noted in younger participants (adolescent and fresher players) has been suggested to be due to their lower training age, which indicates that they may have not developed the consequential posterior capsule and muscle thickening that occurs due to eccentric stress being placed on the tissues, and may have less pectoralis major tightness that can reduce range of motion (Thomas et al., 2010).

No statistically significant relationship was found between internal rotation and scapular control which is perhaps surprising, as it has been noted that reduced internal rotation causes scapular dyskinesis and abnormal scapular positioning because the scapula protracts and internally rotates in order to achieve enough internal rotation to follow through with upper body movements (Thomas et al., 2010). In addition, no significant relationship was noted between increased external rotation on the right shoulder and the scapular control test, and the significant relationships found on the left shoulder only displayed a small effect size. This is also a little surprising as altering the range of motion of the shoulder could alter positioning of the scapulae, which is associated with poor control of the scapula and may affect the kinetic chain motion of the shoulder and scapula movement thereby potentially predisposing to injury (Conte et al., 2009, Wang and Cochrane, 2001, Thomas et al., 2010).

3. 4. 4. Foot function

There is a lack of comprehensive normative data for the navicular drop test for both a large cohort of physically active individuals and Gaelic games players. This lack of data has been suggested as a reason to exclude this test in a screening setting (McPoil et al., 2008, Nielsen et al., 2009). Only a single study provided normative values for the navicular drop test in healthy adults (n=280) with no current pain or deformities of the feet (Nielsen et al., 2009).

No significant difference was found between adolescent and collegiate participants on the right and left feet, with a higher mean than previously reported for healthy males by Nielsen et al. (2009) (5.3±1.8mm) and McPoil et al. (2013) (5.06±3.21mm), but a lower mean than reported in collegiate cross-country runners by Bennett et al. (2012) (8.5±4.1 and 8.7±4.3). A navicular drop of greater than 10mm has been frequently used in classifying players at risk of injury associated with excessive pronation (Bennett et al., 2001). Approximately one third of adolescent and collegiate participants presented with a navicular drop greater than the cut-off point which is similar to the 32%-40% of collegiate cross-country runners (Bennett et al., 2012). Asymmetry between feet of greater than 3mm is also suggested as a possible risk factor for injury (Plisky et al., 2007) and approximately one third of adolescent and collegiate participants also had an asymmetry higher than this cut off point. While the results are important, it is worth noting that numerous cut-off points have been suggested for the navicular drop test, with cut off points of 5-15mm suggested (Moen et al., 2012, Plisky et al., 2007, Buist et al., 2010, McPoil et al., 2008, Bennett et al., 2001, Beckett et al., 1992). The cut-off point used in the current study is the most commonly used and has been shown to have 68% accuracy in predicting medial tibial stress syndrome (Plisky et al., 2007, Buist et al., 2010, McPoil et al., 2008); however, further research is necessary to confirm its ability to predict other injuries in various populations.

3. 4. 5. Balance

There is a lack of normative data for adolescent and collegiate Gaelic footballers. The present study found that both adolescent and collegiate participants displayed 2-11%

lower Y balance results than high school athletes (Gorman et al., 2012) and 5-20% lower than high school basketball players (Plisky et al., 2006) in the anterior, posteriomedial, posteriolateral and composite reach directions. The poor balance noted in adolescent and collegiate Gaelic footballers and hurlers could be related to the high percentage of ankle injuries occurring in Gaelic games. It has been demonstrated that ankle injuries account for 10-21% of injuries in Gaelic football (Murphy et al., 2012b, Newell et al., 2013, Wilson et al., 2007, Watson, 1996b, Cromwell et al., 2000) and 9% in hurling (Murphy et al., 2012a, Crowley and Condon, 1989) and so the implementation of balance programmes may be critical in both adolescent and collegiate Gaelic football and hurling.

Cut off points have been utilised in research to establish “at risk” athletes. Using the Y balance test two main cut off points have been suggested: ≤94% (Plisky et al., 2006) and ≤89% (Butler et al., 2013b); Plisky et al. (2006) found that high school basketball players were 6.5 times more likely to sustain a lower limb injury, while Butler et al. (2013b) found that collegiate American footballers were 3.5 times more likely. The majority of adolescent (51.7%) and collegiate (57.7%) participants were noted as at risk for injury using the 94% cut off point, which is higher than the 26% reported in high school basketball players (Plisky et al., 2006). Only 32.6% of adolescent and 39.0% of collegiate participants identified as at risk utilising the 89% cut off point and to date there is no published data available on the percentage of athletes in other sports that are at risk using this newly identified cut-off point. Thus, it may be necessary to develop cut-off points for injury that is sport and population specific.

If considering the anterior direction alone, almost all participants would be classified as at risk of injury utilising the 94% cut-off point, while participants were predominantly classified as not at risk of injury in the posteriomedial and posteriolateral directions. The directional differences may reflect different muscular deficiencies. The vastus medialis and lateralis are most active in the anterior reach, anterior tibialis in the posteriomedial reach and the biceps femoris and anterior tibialis in the posteriolateral reach (Plisky et al., 2006). In addition, it has been demonstrated that the posterior directions require enhanced hip motion and so the hamstrings are under increased pressure to eccentrically control hip flexion (Butler et al., 2013b). Therefore, it may be necessary to target the deficiencies in the posterior directions because poor balance may place further loading on the already susceptible hamstrings in adolescent and collegiate participants.

Asymmetry between sides has been proposed as a possible risk factor for injury (Plisky et al., 2006) and Plisky et al. (2006) reported that participants were 2.5 times more likely to sustain a lower limb injury if they had an asymmetry of greater than 4cm in the Y balance test. While no substantial significant differences were found between sides in adolescent or collegiate participants, 47.1%-62.5% of adolescent participants (see Table 3.7) and 37.1-56.1% of collegiate participants (see Table 3.21) had an asymmetry greater than 4cm in either the anterior, posteriomedial, posteriolateral or composite directions. Side to side differences have been suggested to be clinically important as increased stress may be placed on the more capable limb attributable to the inability of the opposing limb to successfully provide a stable base of support during sporting movements; thus balance exercises may be a useful component of a preventative programme in Gaelic games (Plisky et al., 2006). The differences in susceptibility to injury between the different directions in the Y balance test are also noteworthy, as different directions require different muscles to produce the movement, as previously mentioned; thus each of these muscles must be targeted in a preventative programme for Gaelic players as all three directions have displayed susceptibility to injury (Plisky et al., 2006). With regard to normative data collected in other studies, adolescent and collegiate participants in the present study were found to display slightly higher differences between sides in the anterior, posteriomedial and posteriolateral direction (see Table 3.6 and 3.20) than high school athletes that played single (2.8±2.2cm, 4.6±4.4cm, 4.3±4.3cm respectively) or multiple sports (3.6±3.8cm, 4.3±3.8cm, 5.0±4.2cm, respectively) (Gorman et al., 2012).

No significant difference was noted between adolescent and collegiate participants for the majority of results in the Y balance test, the only significant difference that was noted with a moderate effect size was for posteriolateral average reach distance on the right and left leg. Butler et al. (2013b) similarly found that high school soccer players also scored lower than collegiate players in the posteriolateral direction ($p<0.01$) however Butler et al. (2013b) found this difference using the normalised to limb length scores, in the current study the significant difference was only noted using the raw average reach distance. Thus, differences in balance between adolescent and collegiate participants may be population specific and it is therefore advisable to develop sport specific and age specific normative data with regard to balance. Senior hurlers were found to display higher reach scores than fresher hurlers and senior Gaelic footballers, and fresher Gaelic footballers displayed higher reach scores than fresher hurlers. Thus it could be suggested that balance should be focused on in injury prevention programmes in the fresher hurling and senior Gaelic football populations.

3. 4. 6. Squat and Single leg squat

Approximately half of adolescent participants received an average overall impression result on the right and left single leg squat and a similar percentage of adolescents received a poor and an average result for the overhead squat (approximately 40% each). A third of all adolescents were found to complete a poor right and left single leg squat. Collegiate participants on the other hand primarily received an average in the overhead squat (53.3%) and in contrast they received similar poor and average results on the right and left legs. The higher percentage of adolescents that scored poorly on the overhead squat test in comparison to collegiate participants could be explained by possibly poorer neuromuscular control, or that the adolescent participants were not familiar with the squatting technique. The higher percentage of poor scores in the single leg squat in collegiate participants may be due to the previously noted poorer balance in older participants. In fact, only 3.9% of collegiate participants received an excellent score for the single leg squat on the right and left legs and poor balance itself has been attributed to the fact that as training age increases, the likelihood of previous ankle injuries that have a direct impact on balance is increased and so may affect the single leg squat result (Butler et al., 2013b).

Schneiders et al. (2011) established normative values in healthy active adults for a squat utilised in the Functional Movement Screen that was similar to the present study. While Schneider et al. (2011) found that an average score in the squat was predominant, the percentage was higher (61%) than noted in the present study in both adoelscent and collegiate participants. Similarly, the percentage of adolescent and collegiate participants that scored a poor in the squat was found to be higher than reported by Schneider et al. (2011) (15%). The functional issues noted in the overhead squat and single leg squat should be addressed in injury prevention programmes developed for adolescent and collegiate participants. In addition, adolescent and collegiate participants' squatting technique should be established prior to squats being included in strength and conditioning programmes and if poor technique or functional issues are noted, these must be addressed prior to initiating the programme.

Individual criteria scored in each of the overhead squat was also assessed, with both adolescent and collegiate participants' predominantly receiving a "normal" score, except for trunk flexion where a "slight" (38.0%) problem was most commonly received in adolescents only (Table 3.20 and 3.34). With regard to the single leg squat adolescents predominately exhibited a "slight" problem in knees over toes, knee valgus, hip flexion and trunk flexion on both the right and left legs (Table 3.21). Similarly collegiate participants predominantly displayed a "slight" problem in knees over toes and knee valgus, however for both hip flexion and trunk flexion collegiate participants displayed primarily a "moderate" problem on both legs (3.35). The common occurrence of knee valgus during the squatting movement is significant as it has been identified as a risk factor for knee injuries (Weeks et al., 2012, Alentorn-Geli et al., 2009). Knee valgus can occur due to weak hip abductors and so it may be necessary that a hip abductor strengthening programme is introduced in this population (Claiborne et al., 2006). The prevalence of a "moderate" score for excessive trunk flexion is important as it has been suggested to occur due to tight hip flexors that could be due to repetitive kicking in Gaelic football (McIntyre, 2005). The hip flexors themselves may be predisposed to tearing due to the reduced flexibility. This tightness can also place the pelvis in an anteriorly tilted position which can cause corresponding lengthening of the hamstring muscle, which may predispose to hamstring injuries due to loading of the hamstring in a lengthened position over an extended period of time (Brukner and Khan, 2006, McIntyre, 2005). A poor score for hip flexion may relate to an inability to perform a deep squat utilising the full range of motion available to the joints of the lower limb, thus reduced hip mobility may be related to the poor performance in collegiate in comparison to adolescents (Cook, 2010, Frohm et al., 2012). Collegiate participants scored primarily a "slight" problem for balance and scored significantly worse for balance in the single leg squat both on the right and left legs than adolescents. As previously mentioned, this could be due to a higher incidence of previous ankle injuries in the older participants due to their relative older training age (Butler et al., 2013b). Additional analysis was completed to assess if certain components of the squatting motion was more essential to gaining a higher score in the overhead and single leg squat by comparing the individual criteria scored and the overall impression result (Table 3.73). The individual components were found to be significantly related to the squatting technique with at least a medium effect size in all components except for knee varus, toe out and toe in, which could be due to the low occurrence of these maladaptive movement patterns. With regard to the overhead squat, lower hip flexion scores or a deeper squat was demonstrated to be significantly correlated to a higher result ($r=-0.51$). Thus injury prevention programmes that target increasing hip mobility to facilitate greater depth in the squatting motion may be beneficial (Cook, 2010, Frohm et al., 2012). Balance was found to relate the most to the overall impression result in the single leg squat on the right and left legs with issues noted in balance being significantly correlated to a lower overall impression on each leg. Since the overhead squat and the single leg squat analyses the same movement patterns, removing the single leg squat may be beneficial due to time constraints placed on therapists during the screening, especially if balance is already assessed elsewhere in the screening. However, there are inherent differences between the two tests, as an increased demand is placed on balance and therapists may find it easier to identify asymmetry between legs during the unilateral single leg squat motion (Whatman et al., 2012). The overall impression in the squat was found to be significantly correlated to the overall impression in the right leg (r=0.26) and the left leg (r=0.34). This indicates that the inclusion of the single leg squat is still necessary as demonstrated by the lower effect sizes, as other compensation strategies may be noted in the unilateral single leg squat that are absent in the bilateral overhead squat.

3. 4. 7. Scapular control

As the scapular control test utilised in this study was developed by the present researcher there is no normative data available for this test. In addition, the majority of studies use tests that assess static positioning of the scapulae, measure side to side differences of the scapulae in centimetres or measure the position of the scapulae in degrees; thus comparison between the current test and other studies is difficult as they commonly use vastly different methods of measuring scapular control. Furthermore, there is no information in current research on scapular control in Gaelic footballers or hurlers of any age using any scapular tests.

The majority of adolescents received a score of a “slight” problem on winging, control of scapula when lowering and symmetry (see Table 3.13). The majority of collegiate participants on the other hand received a score of no issues on winging and control of scapula when lifting, whereas similar to the adolescents, collegiate participants received a score of a “slight” problem on control of scapulae when lowering and for symmetry (see Table 3.27). Despite the fact the current study demonstrated a higher percentage of “slight” problems in symmetry in the scapular control test, the percentage of adolescent (37.4%) and collegiate participants (39.4%) that received no problem with symmetry was higher than a study conducted by Uhl et al. (2009) in healthy males (28.6%). Control of scapulae in lowering resulted in a poorer score in both adolescent and collegiate participants in comparison to control of scapulae in lifting, this could be due to the fact that as the scapulae lowers, the muscles that control the scapulae are forced to work eccentrically which places them under increased load, this causes any problems in controlling the scapulae to be more pronounced during this movement (Kibler et al., 2002). The prevalence of "slight" problems in participants could be mainly due to poor posture as slouching, rounded shoulders and increased kyphosis of the thoracic spine may force the scapulae into increased upward rotation, imbalance between muscles of the shoulder (inhibition of the shoulder stabilisers and muscles of the thoracic spine and increased tone of the anterior shoulder muscles and upper trapezius) and inhibition of the serratus anterior muscle which may produce winging (Thomas et al., 2010, Wang and Cochrane, 2001, Kibler and Sciascia, 2010).

3. 4. 8. Core

As the core test utilised in this study was developed by the present researcher there is no normative data available for this test. However, a study has demonstrated normative data in a young physically active population for the trunk stability push up test which is part of the functional movement screen from which the alternative push up test was developed (Schneiders et al., 2011).

Collegiate participants received significantly higher results on the alternative push up test than adolescents ($p<0.0001$) with adolescents primarily receiving a "good" on the alternative push up test (41.9%) compared to the "excellent" (64.5%) predominantly received by collegiate participants. The result in the present study is lower than reported by Schneiders et al. (2011) where 76.2% of young physically active participants scored a three which is the highest score in the trunk stability test. Nonetheless, this is not surprising, as the present researcher adapted the trunk stability test in order to make it more challenging to the sporting population as it was observed in the pilot study that a large proportion of participants were achieving the highest score easily. Thus the alternative push up test can be seen to further subdivide those with higher core stability. Only 9.6% of adolescent participants and 2.4% of collegiate participants received a "poor" result on the core test which indicates that perhaps only a small percentage of Gaelic players would be at risk of injury due to poor core stability.

3. 4. 9. Limitations to the study

There are a number of limitations to the current study. Only two colleges were assessed in this study which may have caused a certain amount of bias as the training loads in teams within each college may be similar. In addition, only 4th and 5th year adolescents were assessed and so further research on younger adolescents is needed. Another limitation is that only content validity was assessed, thus further research on the criterion validity of each of the tests that were developed or adapted should be completed. The reliability of these tests was analysed and are presented in Appendix A.

3. 4. 10. Conclusion

The current study developed a comprehensive musculoskeletal pre-participation screening, specific to Gaelic games, which utilises simple field based tests that require minimal, inexpensive equipment. This was achieved in part by both developing new and adapting previous tests and scoring systems. These developed and adapted tests demonstrated excellent inter-tester reliability and good-to-excellent intra-tester reliability. Normative data for adolescent and collegiate Gaelic footballers and hurlers were also established for all components of the screening in order to develop a standardised reference of results for both populations. This will be of great benefit to Gaelic footballers and hurlers as it will allow therapists to implement this simple time efficient screening to teams in both age groups with useful data for direct comparison. Some neuro-musculoskeletal deficiencies were identified using the screening: poor hamstring flexibility, balance, scapular control and squatting technique were noted in both adolescent and collegiate participants. Therefore injury prevention programmes should be designed to improve these deficiencies. Adolescent participants achieved a poorer score in hamstring flexibility, core stability, scapular control and the overhead squat than collegiate participants. However, in contrast, collegiate participants performed worse in the single leg squat, internal rotation and external rotation. Gaelic footballers presented with less hamstring flexibility than hurlers on the right leg, fresher hurlers and senior Gaelic footballers presented with poorer balance and younger players demonstrated worse core stability than older players. Thus these differences should be considered by clinicians when implementing injury prevention programmes in these differing populations.

Chapter 4. Epidemiology of injury in adolescent and collegiate Gaelic footballers and hurlers.

4. 1. Introduction

While participation in sport provides numerous health and social benefits, an innate risk of injury exists due to this sporting involvement (Warburton et al., 2006, Schneider et al., 2006). Injury occurs when mechanical energy is placed on the body's tissues at rates or levels that exceed the human threshold for damage i.e. relative excessive force compared to the strength of the tissue (Meeuwisse et al., 2007, McGinnis, 2013). The trauma, pain and loss of function accompanying injury can be substantially detrimental to the participant, the team and the GAA itself by preventing injured players from taking part in sport or negatively affecting their performance (Junge and Dvorak, 2000, Murphy et al., 2012b). However, the occurrence and magnitude of the effects of many injuries may be reduced with the implementation of injury prevention techniques and programmes (Schneider et al., 2006, Meeuwisse et al., 2007). The initial step in the development of injury prevention techniques and programmes is to establish the incidence and epidemiology of injury in the sport (van Mechelen, 1997).

Current research has only begun to establish the incidence of injury in Gaelic games with reported injury rates of between 51.2-64.0 injuries per 1000 hours of matches and 4.1-5.8 injuries per 1000 hours of training in Gaelic football (Wilson et al., 2007, Murphy et al., 2012b, Newell et al., 2013), and 102.5 and 5.3 injuries per 1000 hours in matches and training respectively in hurling (Murphy et al., 2012a). However, the amount of published epidemiological studies is small in comparison to international sports, with only six studies in Gaelic football and two in hurling. These studies vary in their research design and study length, with two studies retrospective in nature (Cromwell et al., 2000, Brown et al., 2013), five studies prospective over a short duration (Wilson et al., 2007, Newell et al., 2013, Watson, 1996b, Murphy et al., 2012a, Watson, 1996a) and only a single prospective study longer than one season (Murphy et al., 2012b). Current research has primarily focused on elite adult players (Murphy et al., 2012b, Murphy et al., 2012a, Newell et al., 2013, Cromwell et al., 2000) with a severe lack of research in the non-elite, adolescent or collegiate population despite the fact a large proportion of those playing Gaelic games are within these poorly examined populations. In fact, no epidemiological data is available on adolescent hurling injuries and only a single study has been published on adolescent Gaelic football injuries (Watson, 1996b). Standardising injury definition, methods of data collection and reporting procedures is highly recommended by present research however no clear consensus exists in current literature in Gaelic games or in fact internationally in other sports. This can lead to serious inconsistencies in reported data and prevent direct comparisons between studies and sports (Junge and Dvorak, 2000, Fuller et al., 2007c, Fuller et al., 2006, Brooks and Fuller, 2006, Chalmers, 2002).

Thus the aims of this study were:

1) Implement a high quality study to prospectively examine the injury incidence and epidemiology of injury in adolescent and collegiate Gaelic footballers and hurlers

2) Compare and contrast the incidence and epidemiologic report of injuries in adolescent and collegiate Gaelic footballers and hurlers

3) Compare and contrast the incidence and epidemiologic report of injuries between Gaelic football and hurling

4) Compare and contrast the incidence and epidemiologic report of injuries between fresher and senior players.

4. 2. Method

4. 2. 1. Subjects

794 male participants were recruited. Male adolescents (n=452) were recruited from the same five schools from study 1. These schools were:

- Colaiste Eoin, Cappagh Road, Dublin
- St Aidan's Secondary School, Collins Avenue, Whitehall, Dublin
- St Declan's College, Nephin Road, Dublin
- Ardscoil Ris, Griffith Avenue, Dublin
- St Patrick's Classical school, Navan

As in Study 1, collegiate participants (n=342) were recruited from the male fresher and senior Gaelic football and hurling teams in Dublin City University in the first year of the study and both Dublin City University and Athlone Institute of Technology in the second year of the study. All possible participants were required to attend an information session where the testing procedure and risks of the study were fully explained. This took place during the same session where Study 1 was explained. All participants were given a plain language statement form (Appendix B) and an informed consent form (Appendix C) to sign. Adolescents and their legal guardian were required to sign the informed consent prior to undergoing the testing. Ethical approval was granted prior to the study starting date by Dublin City University Ethics committee.

4. 2. 2. Development of the injury report form

An injury was defined as any injury sustained during training or competition resulting in restricted performance or time lost from play (Cromwell et al. (2000)). Injury severity was defined according to days missing from full participation and was divided into a minor injury (<7 days), moderate injury (7-21 days) and a severe injury (>21 days) (Newell et al., 2013). A recurrent injury was any injury of the same type and site as the original injury that occurs after a participant returns to full participation in physical activity after the original injury. This was further subclasified as an early recurrent (injury occurs <2 months after initial return to full participation), late recurrent (2-12 months after initial return to full participation) (Fuller et al., 2007c) and persistent recurring injuries. Four experts with extensive experience in assessing, treating, rehabilitating and preventing injuries developed the injury report form (Appendix P); the primary researcher in this study (Siobhán O Connor MSc. ARTC), a clinical biomechanist (Dr. Kieran Moran), a sports medicine physician (Dr Noel McCaffrey) and a lecturer in Athletic therapy (Mr Enda Whyte MSc. ARTC). The form was designed based on extensive research on epidemiological research studies in Gaelic games (Murphy et al., 2012b, Murphy et al., 2012a, Newell et al., 2013, Wilson et al., 2007, Watson, 1996b, Watson, 1996a) and consensus statements on epidemiological research studies from soccer (Fuller et al., 2006) and rugby union (Fuller et al., 2007c). The injury report form was filled out by the therapist immediately after assessing the injury and Table 4.1 displays the information captured by the injury report form.

Table 4.1: Information captured by the Injury Report Form

Main sport played	Mechanism of injury
Usual position	Activity during injury
Free taking role on the team	Contact during injury
Sport played when injured	Body part injured
Age group playing with when injured	Nature of injury
Season injury occurred during	Severity of injury
Onset of injury	Sanction during injury
Session injured (training or match)	Medical professional assessing injury
Playing surface	Further investigations needed
Weather conditions	Surgery needed due to injury
Time of injury	Days missed from light training
Type of injury	Days missed from full training
Side of injury	Days missed from full participation in sport

4. 2. 3. Pilot study

A pilot study was completed on two male non-elite under 16 Gaelic football and hurling teams (n = 63; 34 Gaelic footballers, 29 hurlers) to assess the practicality of the format for assessing injuries. These teams held an average of two training sessions per week and the lead researcher attended a training session for each team once a week for 4 weeks. However the practicality of completing this with local club teams was problematic. Attendance at training sessions was erratic, with players who were injured failing to turn up to training on a regular basis as they were unable to take an active part in training. The majority of players only returned once they were able to return to sport, thus in a large number of cases it was only possible to assess injuries a significant time after the injury occurred, which may negatively affect the accuracy of information provided in the injury report form due to recall issues. A large number of training sessions in different teams occur simultaneously, thus the practicality of the lead researcher being able to attend a each weekly training session with every team would be next to impossible. In addition it was found that some pitches used by underage teams had no adjacent dressing rooms, therefore in order to assess an injury it was necessary to complete it at the side of the pitch. This was problematic due to weather conditions and privacy issues for the patient. Compliance to the training diary was also found to be low as coaches were only seeing players once or twice a week so they were unable to remind players about filling in the diaries regularly. Thus it was decided to recruit a number of schools in order to establish the epidemiology of injury in this age group as it offered a number of solutions to the problems identified in the pilot study. School based assessments were more controlled as attendance is mandatory and so information was captured weekly. As school is five days a week, researchers attended the school during a free class at the same time and day each week in order to assess injuries. Schools provided private rooms to assess injuries which allowed assessments to be completed in private. In addition, teachers reminded all participants to fill in the training diary daily.

4. 2. 4. Experimental protocol

The experimental protocol of this study in relation to the other aspects of this PhD is provided for the adolescent and collegiate participants in Figure 4.1 and Figure 4.2 respectively. Following the screening data collection in September, weekly injury assessments (n=452, 342) were captured by therapists for the full academic year for adolescent participants (September to June) and the full collegiate sporting season in collegiate Gaelic players (September to March). This study captured injury data from elite and non-elite adolescent and collegiate Gaelic players. There were no missed observation periods for injury data collection throughout the testing period.

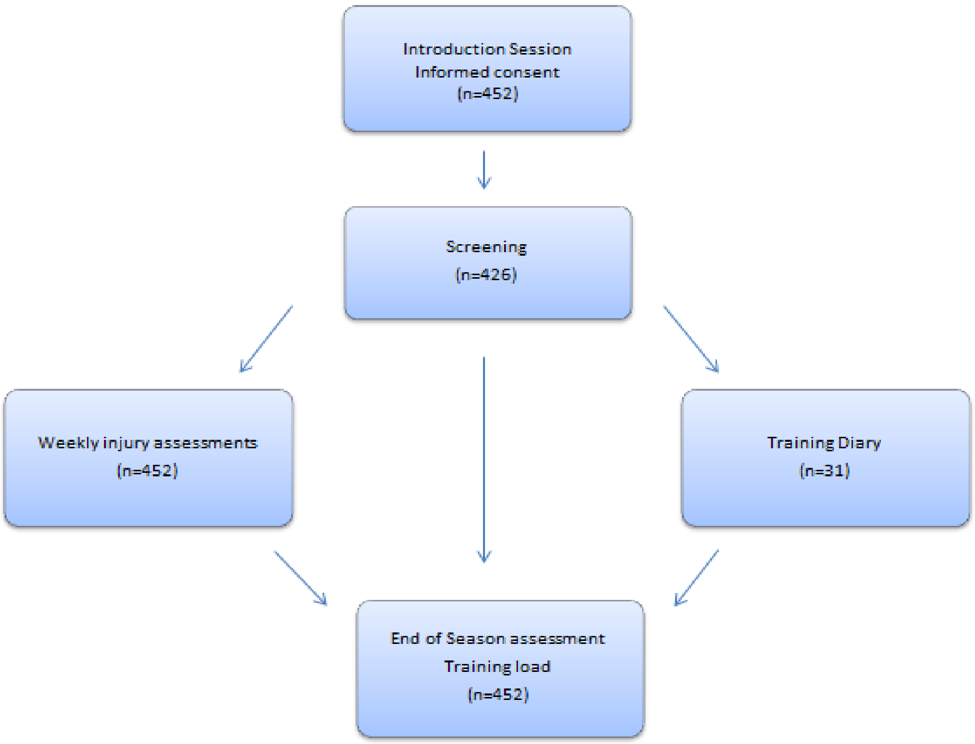

Figure 4.1: Experimental protocol for adolescents

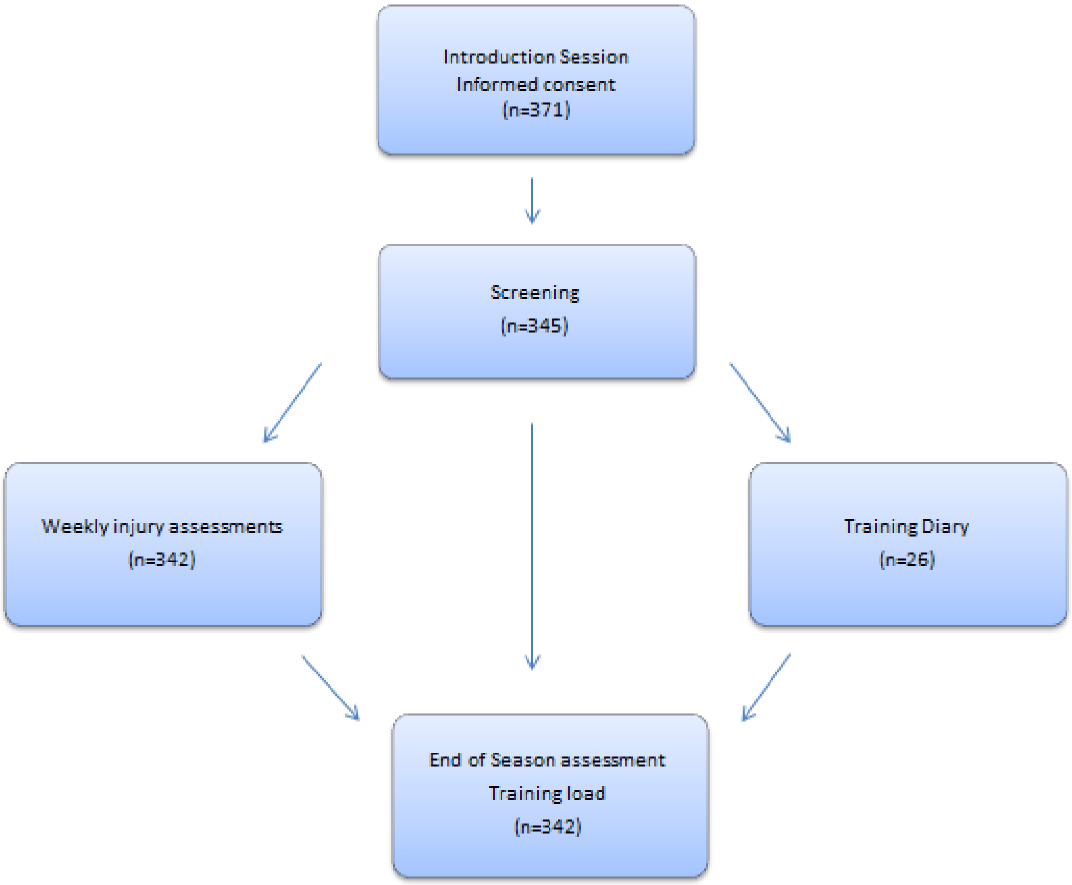

Figure 4.2: Experimental protocol for collegiate participants

All 4th year students in each of the five schools were recruited regardless of their primary sport, in two schools (Colaiste Eoin and St Patrick's Classical Schools) 5th year students took part in the study as well. The schools recruited in this study had a large number of students that primarily played Gaelic football and hurling however as these assessments were taking place during classes it was necessary to assess all students in that class in order to prevent exclusion of some students. Thus this PhD captured not only specifically Gaelic football and hurling injuries but also injuries that occur in 4th and 5th year students in a sample of Irish secondary schools. This information is extremely beneficial as the schools in this study represent a large proportion of schools throughout Ireland as Gaelic football and hurling are the most popular sports in Ireland. Thus as highlighted in Finch's (2006) TRIPP model on injury prevention, unless injury prevention strategies can be easily implemented practically to the population at risk, their effectiveness is highly reduced. Due to the issues identified in the pilot study on assessing injury epidemiology in adolescent club level teams it may be necessary for injury prevention programmes and strategies to be developed and implemented at school level to ensure high levels of compliance. Thus information on the injury epidemiology in secondary school adolescents may be imperative to assist in this development of future injury prevention programmes and strategies.

4. 2. 4. 1. Testers

Two final year students from Dublin City University were recruited to assess injuries alongside the lead researcher in the school based testing while on their final placement at university. The lead researcher was present at all adolescent injury assessments with the 4th year students assisting the data collection procedure. After each session the injury report forms were checked in detail. For the collegiate testing all 3rd year students from Dublin City University that were on placement with the fresher and hurling teams in Dublin City University were recruited. These students were required to attend all training sessions and matches with each team. Prior to the season commencing the lead researcher met with all students and the injury report form was explained in detail. Student therapists had completed all modules relating to injuries and the diagnosis of injuries in sport and had already underwent a year (two years for 4th years) of clinical and field placements prior to the season commencing. All student therapists also underwent a clinical assessment exam on injured patients to ensure they had sufficient ability to accurately diagnose injuries. The lead researcher through her role as coordinator of these placements was involved with the rehabilitation and treatment of many of the collegiate injuries, and was also available for students to contact throughout the testing year for confirmation on any issues or questions in relation to the testing or injury report form. The lead researcher was also available to re-assess any injured participants where the diagnosis was not easy to determine. The lead researcher was working

4. 2. 4. 2. Injury assessments

The injury assessments in schools were conducted on a weekly basis during the same class and at the same time and day each week. The lead researcher and two students visited each school on this day and assessed any presenting injuries. Student therapists attended every training session and match and assessed any presenting injuries with the collegiate teams during these sessions. The lead researcher met all students placed with collegiate teams each week in order to go through all injury report forms and assess any injuries that students were unsure of the diagnosis.

4. 2. 4. 3. Daily training diary

An online training diary developed by the lead researcher was utilised to assess daily training load in each participant (Appendix T). This training diary was designed to be applicable to both adolescents and adults, to be completed daily and was found to take on average 3.7 minutes to complete. The online training diary was accessed through a website which enabled participant's access to the training diary in any place and at any time. Each participant was provided with an individual username and password to ensure privacy. Reminders have been found to increase compliance with this particular training diary (O'Connor, 2012) and so daily email and text reminders were sent out to every participant throughout the entire study. Unfortunately despite daily text and email reminders, the response rate for the training diary was extremely low in both adolescent and collegiate participants. This was especially the case as the study progressed. Therefore in order to capture information on exposure rate from all participants, detailed interviews were conducted at the end of each testing year with all adolescents and coaches and therapists placed with the collegiate teams, in order to decipher training and match exposure rates per week.

4. 2. 5. Data processing and Statistical Analysis

The injury incidence was calculated using three different methods: 1) incidence proportion (IP) i.e. the average risk of injury per athlete, 2) incidence rate i.e. the incidence of injury per unit of athlete time, and 3) clinical incidence i.e. the number of injuries in a season related to the amount of participants at risk of injury (Knowles et al., 2006). Each of the calculations listed below for incidence proportion, incidence rate, clinical incidence, and the subsequent calculations used to measure Standard Error and 95% Confidence Intervals were taken from Knowles et al. 2006.

<u>Incidence proportion:</u> Incidence proportion was measured using the following calculation:

$$\text{Incidence Proportion}(\text{IP}) = \frac{\text{Number of injured participants during a specified time}^{*}}{\text{Number of participants at risk during a specified time}}$$

Equation 4.1: Calculation of Incidence Proportion

*where the number of injured athletes is defined as the number of athletes who sustain at least 1 injury, even if a participant receives numerous injuries they are only counted as one injured participant.

The 95% Confidence Intervals were calculated using:

$$95\%\,CI = IP \pm 1.96 \times SE(IP)$$

Equation 4.2: 95% Confidence Interval for Incidence Proportion

where the Standard Error (SE) was calculated using:

$$SE(IP) = \frac{\sqrt{IP \times (1 - IP)}}{N}$$

Equation 4.3: Standard Error for Incidence Proportion

where N is the number of participants at risk

However the incidence proportion does not account for participants who become injured a number of times during the study. Thus the repeat incidence proportion is analysed using the following calculation:

$$\text{Repeat Incidence Proportion} = \frac{\text{Number of repeat injured participants during a specified time}}{\text{Number of injured participants during a specified time}}$$

Equation 4.4: Calculation of Repeat Incidence Proportion

The Standard Error and 95% Confidence Intervals are measured in the same manner as the Incidence Proportion

Incidence Rate: This study calculated incidence rate as both the injuries per 1,000 hours and per 1,000 athletic exposures for comparison purposes. Thus the formula used to calculate the Incidence rate per 1,000 hours was:

$$\text{Incidence Rate (IR)} = \frac{\text{Number of injuries}}{\text{Total hours playing sport}} \times 1000$$

Equation 4.5: Calculation of Incidence Rate per 1,000 hours

The formula used to calculate the incidence rate per 1,000 hours in training was:

$$\text{Training IR} = \frac{\text{Number of injuries in training}}{\text{Total hours training}} \times 1000$$

Equation 4.6: Calculation of Training Incidence Rate per 1,000 hours

The formula used to calculate the incidence rate per 1,000 hours in matches was:

$$\text{Match IR} = \frac{\text{Number of injuries in matches}}{\text{Total hours playing matches}} \times 1000$$

Equation 4.7: Calculation of Match Incidence Rate per 1,000 hours

The 95% Confidence Intervals for the incidence rate the Standard Error was first calculated using the following formula:

$$SE(IR) = \frac{\sqrt{\text{Number of injuries}}}{\text{Total time playing sport*}}$$

Equation 4.8: Standard Error for Incidence Rate

*where the time playing sport is either hours or athletic exposures depending on the incidence rate being calculated.

Consequently the 95% Confidence Interval was calculated using this formula:

$$95\%\,\text{CI} = \text{IR} \pm 1.96 \times \text{SE}(\text{IR})$$

Equation 4.9: 95% Confidence Interval for Incidence Rate

Clinical Incidence: Clinical incidence is a common method of measuring the average risk of sports related injuries and examines the frequency of injuries that occur within a given amount of participants (Knowles et al., 2006). Incidence proportion on the other hand actually measures the probability of an athlete receiving an injury during a specified time (Knowles et al., 2006). However, clinical incidence can be a beneficial measure in order to understand the amount of injuries that will occur and may need to be dealt with during a specified time. (Knowles et al., 2006). Thus clinical incidence was measured using the following formula:

$$\text{Clinical Incidence} = \frac{\text{Number of injuries during a specifed time}}{\text{Number of participants at risk at start of specified time}}$$

Equation 4.10: Calculation of Clinical Incidence

The calculation of the Standard Error and 95% Confidence Intervals are the same as with incidence proportion, however the number of injured participants is substituted by the number of injuries during a specified time.

The frequency of the variables presented in Table 4.2 was assessed in adolescents, adolescents injured in Gaelic football and hurling only and collegiate participants.

Table 4.2: Variables where frequency of results was assessed

Sports played	Quarter of injury
Onset of injury	Sanction given
Type of injury	Type of sanction given
Side of injury	Season injury occurred
General distribution of injuries	Month injury occurred
Regional distribution of injuries	Month’s overuse and acute injuries occurred
Body part injured	Relative age group playing with when injured
General nature of injury	Position when injured
Specific nature of injury	Position when injured in different body parts
Nature of injury in different body parts	Position when injured in different natures
Stopped or kept playing	Free taking role
Severity of injury	Playing surface when injured
Severity of injury in different nature of injury	Temperature when injured
Contact or non-contact injuries	Weather conditions when injured
Mechanism of injury	Protective equipment worn
Activity during injury	Medical professional assessed injury
Time of injury	Further investigations completed

Variables assessed in the injury report form (Appendix P)

Tables, pie charts, bar charts, 100% stacked bar charts and line charts are included for visual purposes where necessary. The mean and standard deviation of the minutes in a session an injury occurred, days missed from light training, full training and full participation are reported. Two comparisons are made: firstly, between Gaelic football and hurling injuries in adolescent and collegiate participants, and secondly between fresher and senior collegiate Gaelic footballers. A very small amount of fresher hurling injuries occurred in collegiate participants thus only the epidemiology of senior hurling injuries is presented.

4. 3. Results

4. 3. 1. Epidemiological Results for school adolescents

224 injuries occurred in 452 adolescents (mean= 15.6±0.7 years, 67.1±10.2kg, 1.8±0.1m and 21.6±2.8kg/m^2). 161 of all participants became injured with 45 of these participants receiving two or more injuries. Injured participants had a total exposure time of 43,440 hours or 28,980 athletic exposures. Training exposure accounted for 37,674 hours and 23,184 athletic exposures, and match exposure was 5,760 hours or athletic exposures.

4. 3. 1. 1. Sport played by school adolescents

Figure 4.3 demonstrates the primary sports played by injured players in adolescents. The majority of participants who became injured played Gaelic football followed by hurling, soccer rugby and basketball. In total, 64.5% of injured adolescents' primary sports were Gaelic games where they played Gaelic football and/or hurling. Of those who became injured 13% played both Gaelic football and hurling in equal measures. 5.4% of those injured played sports that were not listed and included gymnastics, athletics and gym work.

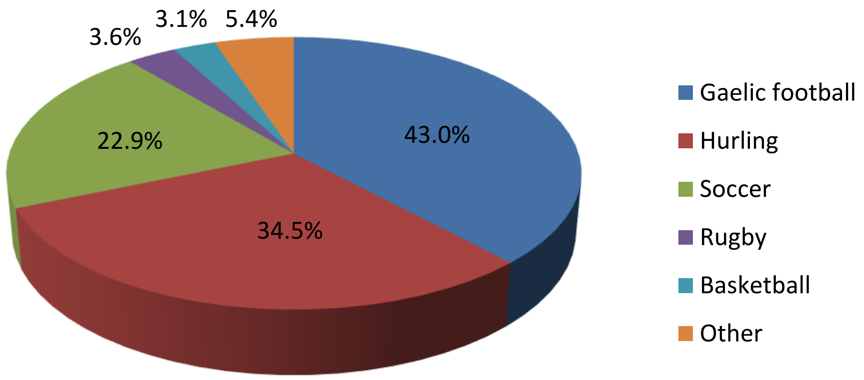

Figure 4.3: Primary sport played by injured participants

4. 3. 1. 2. Injury Incidence in school adolescents

The epidemiological incidence proportion (IP), repeat incidence proportion, clinical incidence and incidence rate are reported in Table 4.3. Incidence rate is analysed using injuries per 1,000 hours. The incidence proportion indicates that 35.6% (95% CI: 31.2%-40.0%) of school adolescents are at risk of becoming injured during a single school year. The repeat incidence proportion indicates that of those who become injured during the school year 27.9% (95% CI: 21.0%-34.8%) are at risk of developing a subsequent injury.

Table 4.3: Incidence Proportion, Clinical Incidence and Incidence Rate in school adolescents

Type of Injury Incidence Analysis	Injury Incidence	95% CI
Incidence Proportion	0.356	0.312-0.400
Repeat Incidence Proportion	0.279	0.210-0.348
Clinical Incidence	0.495	0.449-0.541
Injuries per 1,000 hours	5.156	4.481-5.831

Table 4.4 displays the training and match incidence rate per 1,000 hours. The percentage of injuries that occurred during training (44.8%) and matches (44.3%) were similar, however when exposure is taken into account, match injuries had a higher incidence rate than training injuries; this was the case even though adolescents spent 6.5 times more time training rather than playing matches.

Table 4.4 Incidence rate of Training and Match injuries

Incidence Rate	Training		Match	
	Incidence Rate	95% CI	Incidence Rate	95% CI
Injuries per 1,000 hours	2.627	2.110-3.145	16.908	13.560-20.255

4. 3. 1. 3. The Injury Description

4. 3. 1. 3. 1 . The Onset of Injury

The majority of injuries were acute in nature and accounted for 77.7% (171) of injuries in comparison to overuse injuries (22.3%, 49). New injuries predominated in adolescents and accounted for 58.9% of injuries, recurrent injuries made up 41.1% of all injuries. Table 4.5 displays the rates of new, early recurrence (<2 months), late recurrence (2-12 months) and persistent/recurring injuries.

Table 4.5: New and Recurrent injuries

	Number of injuries	Percentage of injuries
New	129	58.9%
Early Recurrence (<2 months)	26	11.9%
Late Recurrence (2-12 months)	29	13.2%
Persistent/recurring	35	16.0%

4. 3. 1. 3. 2 . Side of Injury

The right (43.9%, 97) and left (44.3%, 98) sides had a similar percentage of injuries with 11.8% (26) of injuries occurring bilaterally.

4. 3. 1. 3. 3 . Body Part Injured

Injuries predominantly occurred in the lower limb and accounted for 73.1% (163) of injuries, followed by the upper limb (13.5%, 30), trunk (11.7%, 26) and head/face (1.8%, 4) (Figure 4.3).

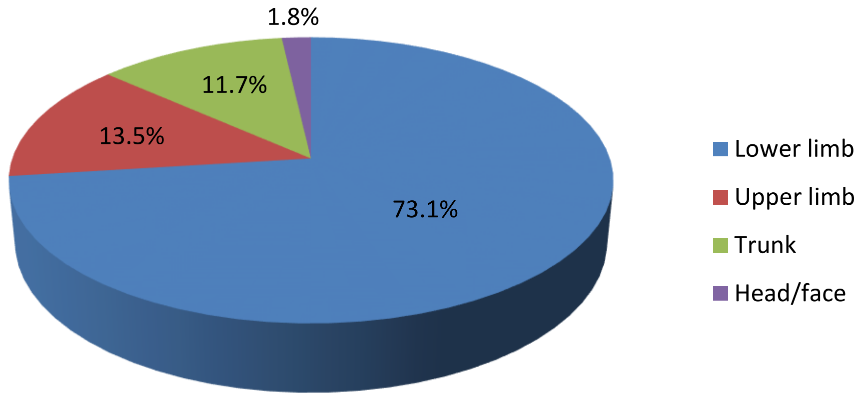

Figure 4.3: General distribution of injuries

Figure 4.4 displays the regional distribution of injuries and Figure 4.5 demonstrates the most common body parts injured. The knee (17.9%, 40), ankle (13.5%, 30), hamstring (11.7%, 26), lower back (11.2%, 25) and pelvis and groin (7.6%, 17) were the most commonly injured body parts. This indicates that lower limb injuries predominate in adolescents. The shoulder (4.9%,11), hand and fingers (4.9%,11) and wrist (2.2%,5) were the most common upper body injuries. Thigh injuries constitute 17.5% of all injuries. In fact, when the general distribution of injuries is viewed, the hip/groin/thigh accounted for 29.6% (66) of injuries, followed by the knee (17.9%,40) and shin/ankle/foot (17.5%,39).

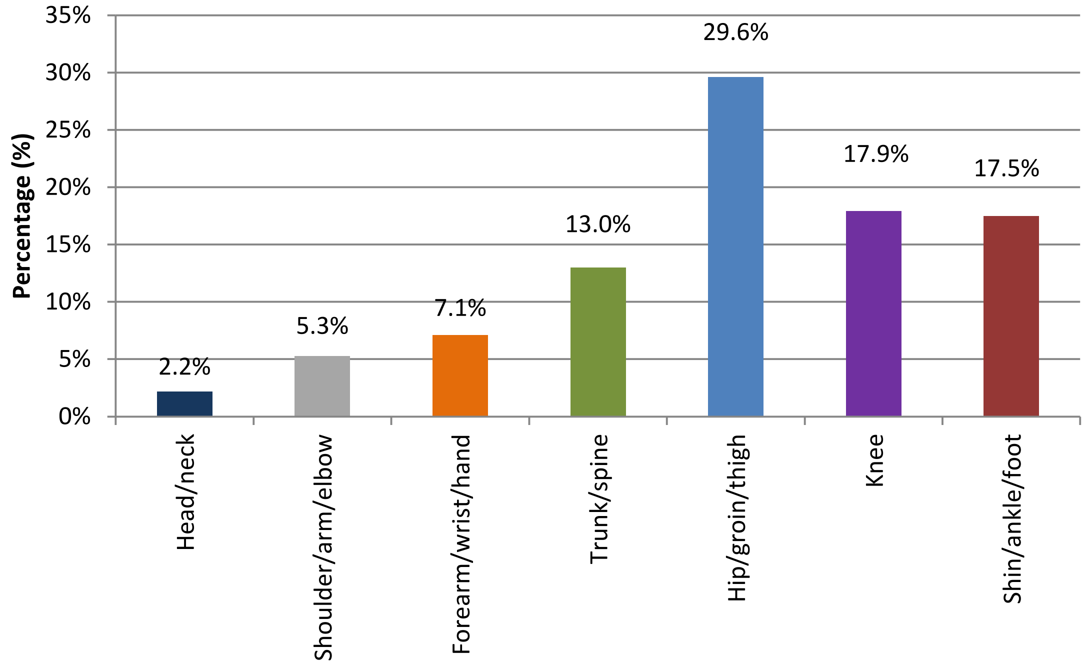

Figure 4.4: Regional distribution of injury

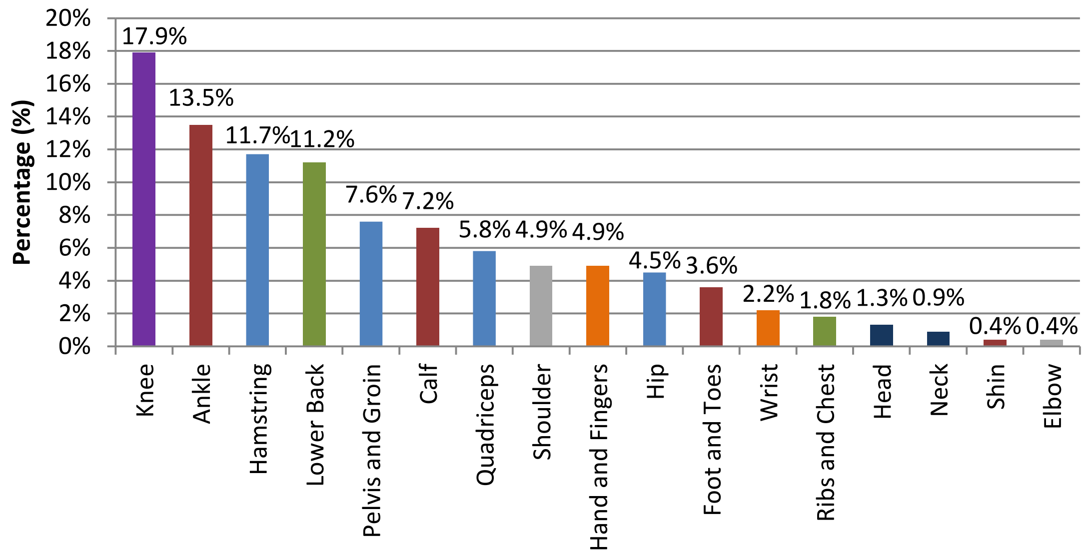

Figure 4.5: Body part injured

4. 3. 1. 3. 4 . Nature of Injury

Muscle injuries were by far the most common accounting for 57% (126) of injuries, followed by ligament (20.8%, 46), bone (9.9%, 22) and tendon (6.8%, 15) (Figure 4.6). In relation to the specific nature of injuries strains (29.4%, 65) were most common, followed by sprains (20.8%, 46), muscle tightness (14.5%, 32), contusions (13.1%, 29), tendinopathy (6.8%, 15) and fractures (5.4%, 12) (Figure 4.7). Figure 4.8 displays a visual representation of the distribution of the different nature of injuries in differing injured body parts.

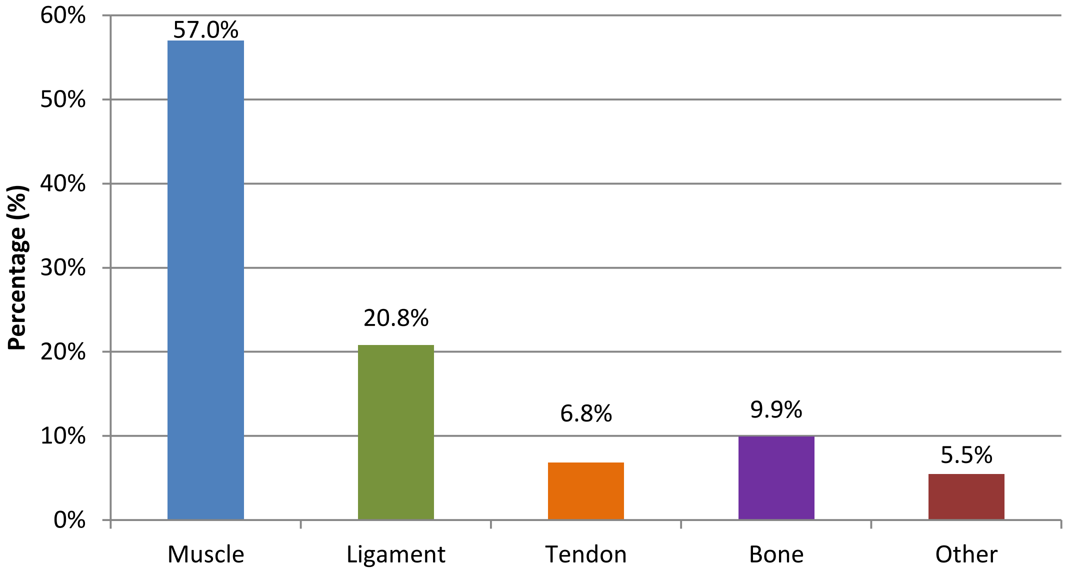

Figure 4.6: General nature of injury

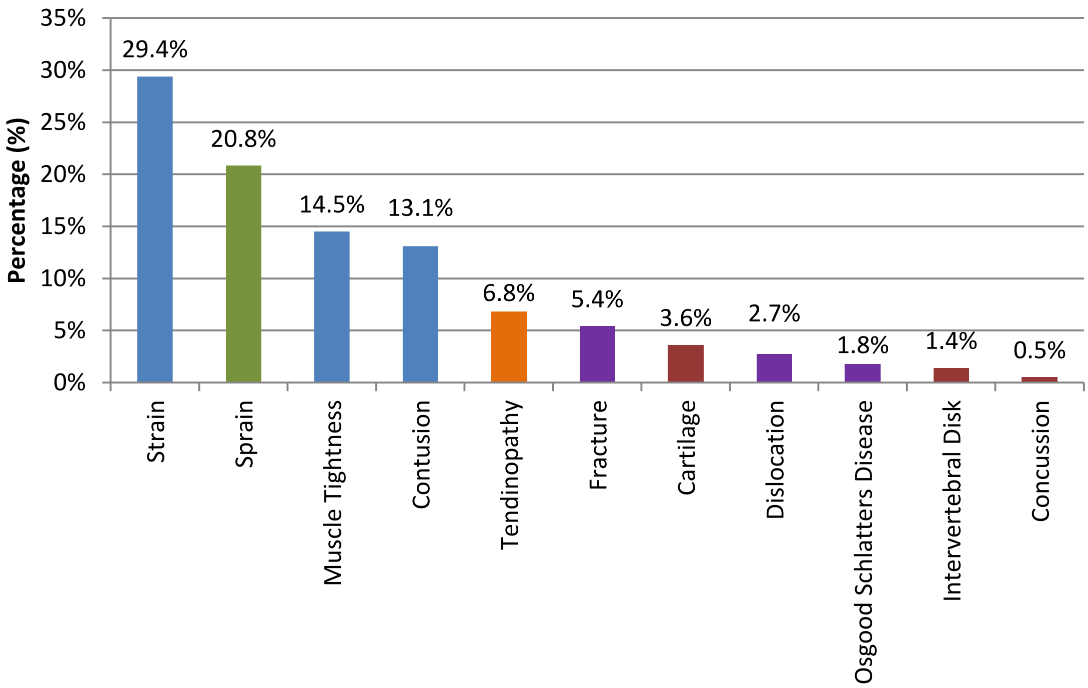

Figure 4.7: Specific nature of injury

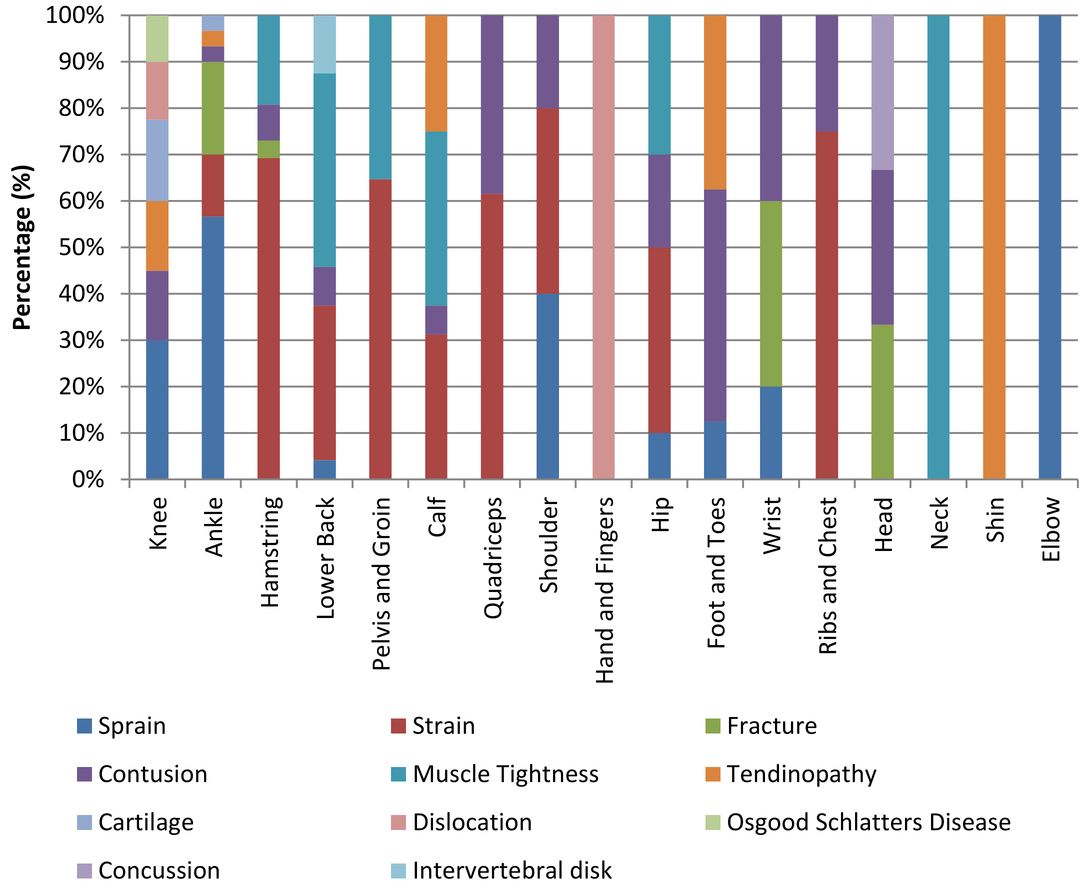

Figure 4.8: Visual representation of the nature of injuries in different body parts injured

4. 3. 1. 3. 5 . Severity of Injury

The majority of adolescents stopped playing after becoming injured (71%, 152) with only 29% (62) carrying on playing after sustaining an injury. The majority of injuries were found to be minor (0-7 days) (41.6%, 89), followed by severe (>22 days) (39.7%, 85) and moderate (8-21 days) (18.7%, 40) (Figure 4.9). The mean days lost from sport (until individual was deemed of full fitness) due to injury were 27.8±46.1. The mean days lost from sport before taking part in light training were 23.0±41.4 and from full training were 25.6±44.3. The majority (94.2%, 210) of injured adolescents did not require surgery, however 4.9% (11) required surgery during season and 0.9% (2) required surgery after the season had ended.

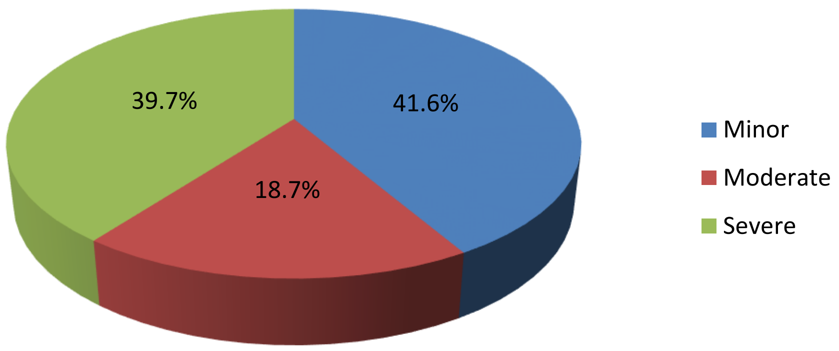

Figure 4.9: Severity of injury

Figure 4.10 demonstrates the severity of injury in relation to the nature of injury. Minor injuries were most common in injuries due to muscle tightness, contusions, tendinopathy, Osgood schlatters disease and intervertebral disk injuries. Severe injuries were most common in strains, sprains, fractures, dislocations and concussion.

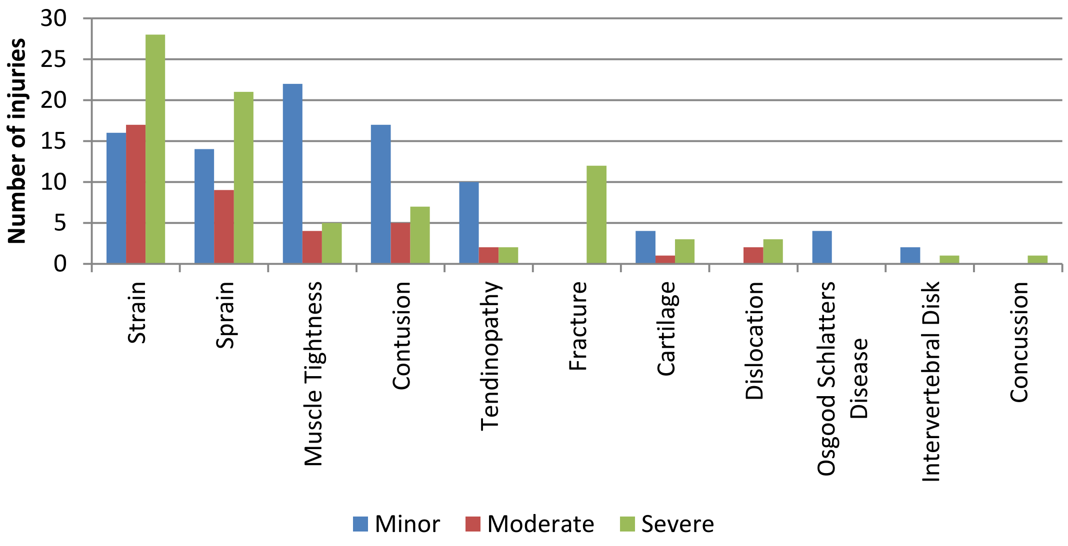

Figure 4.10: Severity of injury in relation to the nature of injury

4. 3. 1. 4. The Injury Event

4. 3. 1. 4. 1 . Mechanism of Injury

Non-contact injuries predominated accounting for 62.6% (139) of injuries, 37.4% (83) of injuries were contact in nature. Specifically 49.5% (110) of injuries were acute non-contact injuries. The remainder of the non-contact injuries were overuse injuries (13.1%, 29). Of the contact injuries the majority occurred due to contact with another player (22.1%, 49), followed by contact with the playing surface (5.0%, 11), football (4.5%, 10), hurley (1.8%, 4), and playing apparatus (1.8%,4). 1.4% (3) of injuries that occurred due to contact with another player involved assault or violence.

The majority of injuries occurred during sprinting (24.3% (53)) (Figure 4.11). Injuries that had no specific mechanism of injury (25.4%, 31) which may be related to overuse injuries occurred in 13.1% (29) of cases. Injuries occurring when a player was being tackled (14.7%, 32) was the third most common mechanism of injury followed by jumping/catching (8.3%,18), kicking (7.3%, 16) and turning (7.3%, 16). 20.2% (44) of injuries occurred during tackling (either being tackled or tackling).

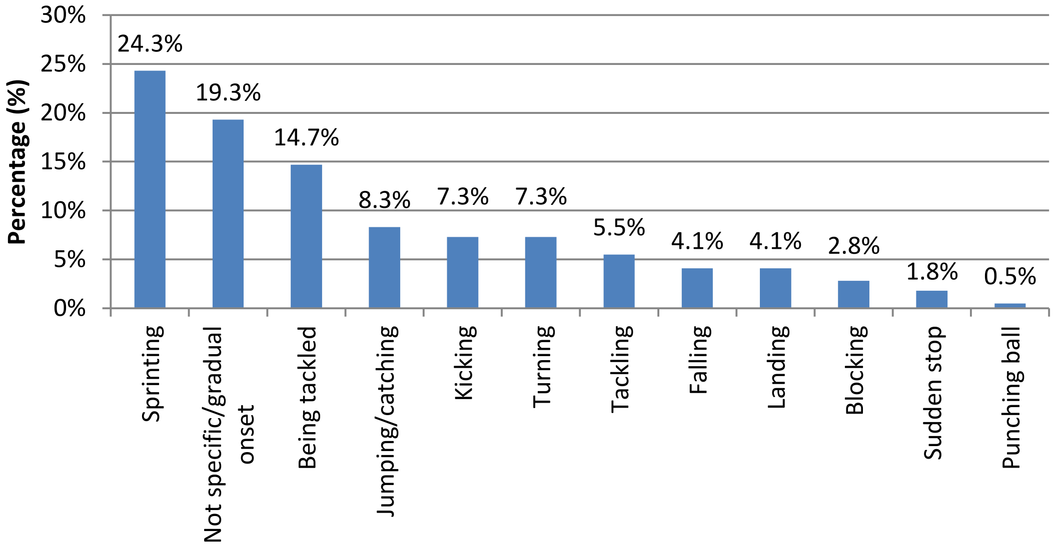

Figure 4.11: Mechanism of injury

4. 3. 1. 4. 2 . Time of Injury

82.9% (175) of injuries occurred during the training/match with only 11.8% (25) and 5.2% (11) occurring during the warm-up and cool down respectively (Figure 4.12). The mean minutes into sport adolescents sustained an injury was 35.4±21.5 (2-120). The majority of injuries occurred during the last 15 minutes of the session (39.5%).

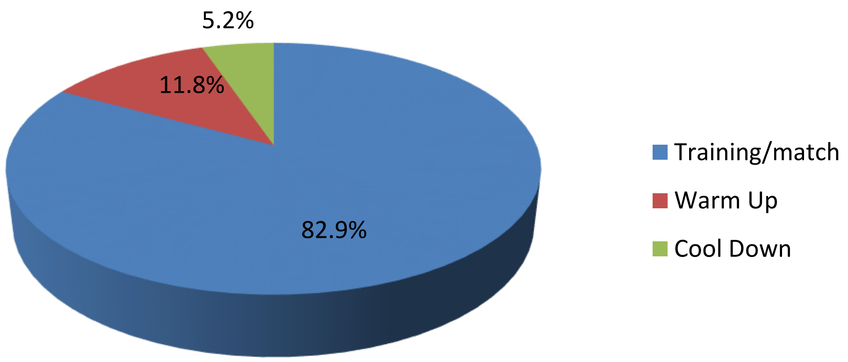

Figure 4.12: Time of injury

4. 3. 1. 4. 3 . Foul Play

Only 11.7% (26) of injuries were related to foul play, injuries due to an opponent foul accounted for 92.3% of injuries related to foul play with only 7.7% due to a foul by the injured player. With regard to the injuries that occurred during team sport, a free was given in 44.4% (16) of cases, followed by a yellow card (41.7%, 15) and a red card (13.9%, 5).

4. 3. 1. 5. Factors Surrounding the Injury

4. 3. 1. 5. 1 . Relationship between time of year and injury

The majority of injuries occurred during the season (80.5%, 178), followed by preseason (14.5%, 32) and off season (5.0%, 11). Injuries were most common at the beginning of the calendar year and dropped significantly over the summer months however increased again nearing the end of the year (Figure 4.13). The four most common months for injury were February (19.1%, 40), April (15.8%, 33), January (13.4%, 28) and March (12.0%, 25).

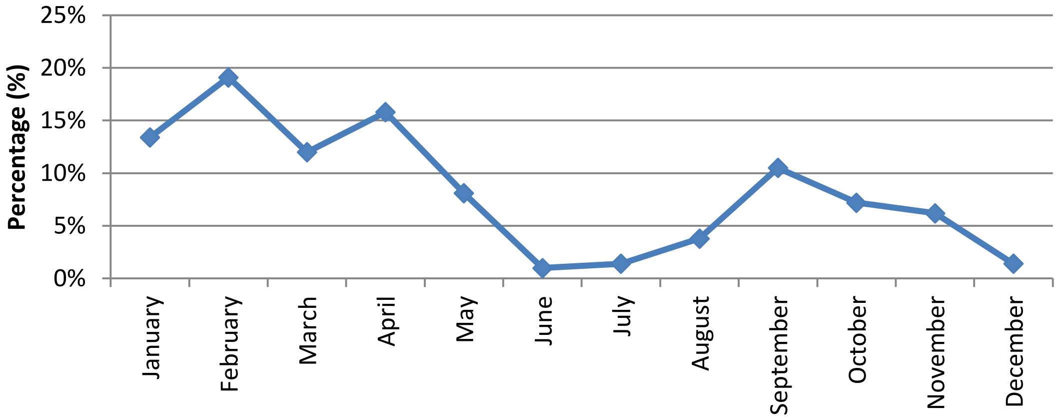

Figure 4.13: Monthly profile of injury

Figure 4.14 demonstrates the monthly profile of injuries with regard to acute or overuse injuries. Acute injuries were most common in April (31), February (27), January (22), September (20) and March (18). Overuse injuries were most common during February (9), March (7), January (6), April (5) and October (5). Both acute and overuse injuries were most common at the beginning of the year, with a reduction of injuries during the summer months and a further increase in injuries during the latter part of the year.

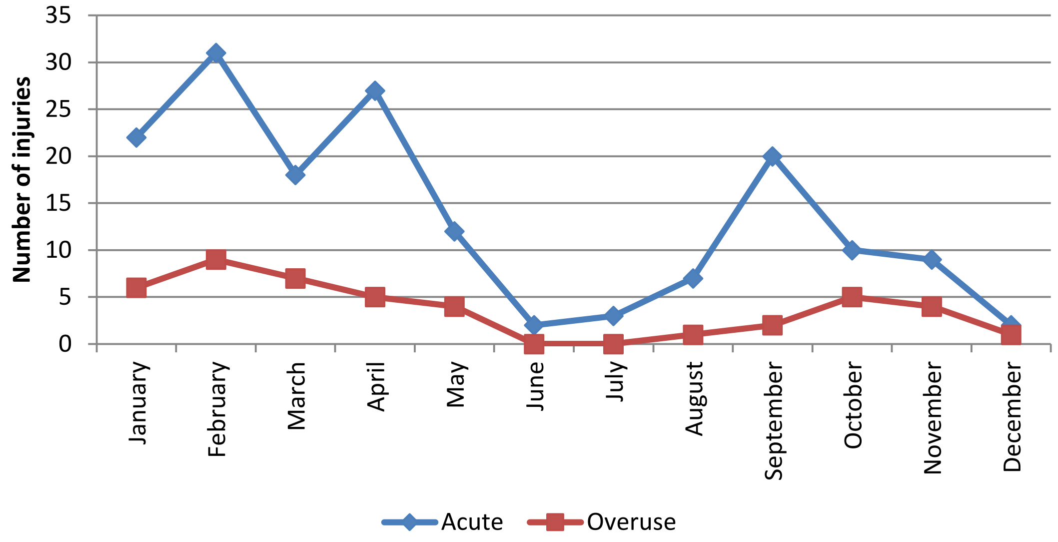

Figure 4.14: Monthly profile of injury with regard to acute and overuse injuries

4. 3. 1. 5. 2 . Relationship between relative age group and injury

The majority (91.0%, 202) of adolescents were playing with their own age group, only 9.0% (20) of players were playing with an older team.

4. 3. 1. 5. 3 . Relationship between playing position and injury

Injuries in backs (41%, 82) were the most common, followed by forwards (33%, 66), midfielders (20%, 40) and goalkeepers (6%, 12) (Figure 4.15). Knee injuries occurred more commonly in forwards (14) than backs (11), conversely ankle injuries occurred more commonly in backs (12) than forwards (9) (Figure 4.16). Strains were more common in backs (28) in comparison to forwards (13) (Figure 4.17).

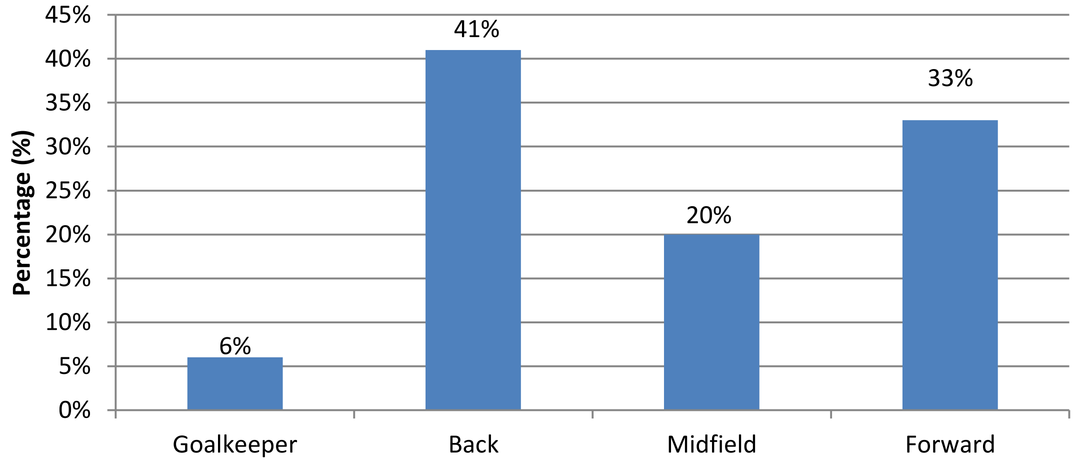

Figure 4.15: Injury prevalence of players in different positions

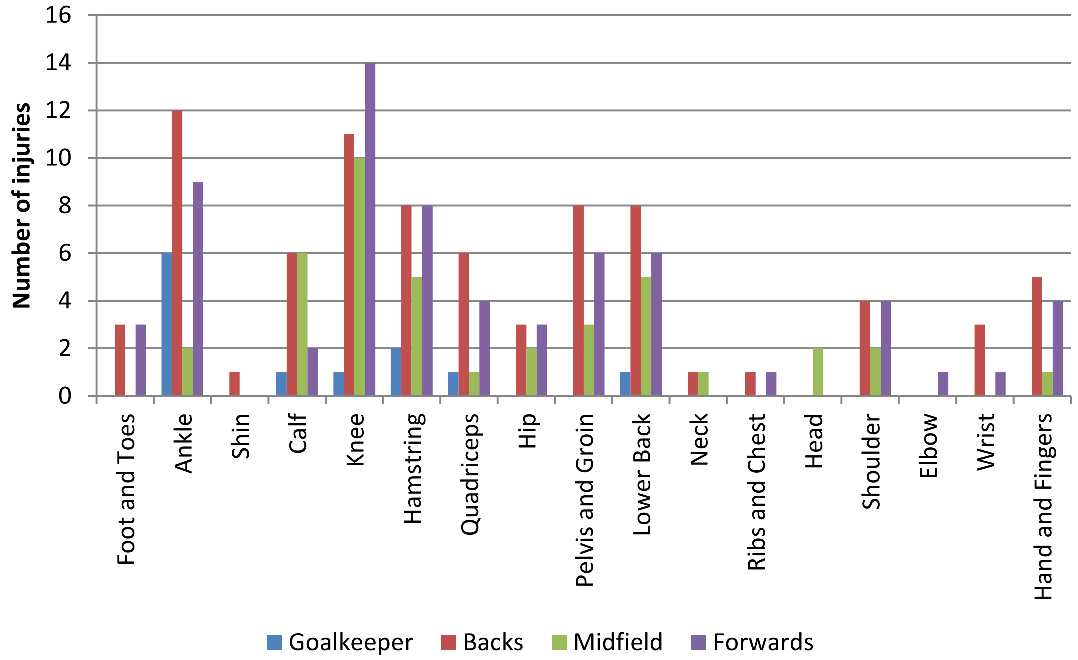

Figure 4.16: Distribution of body part injured by position

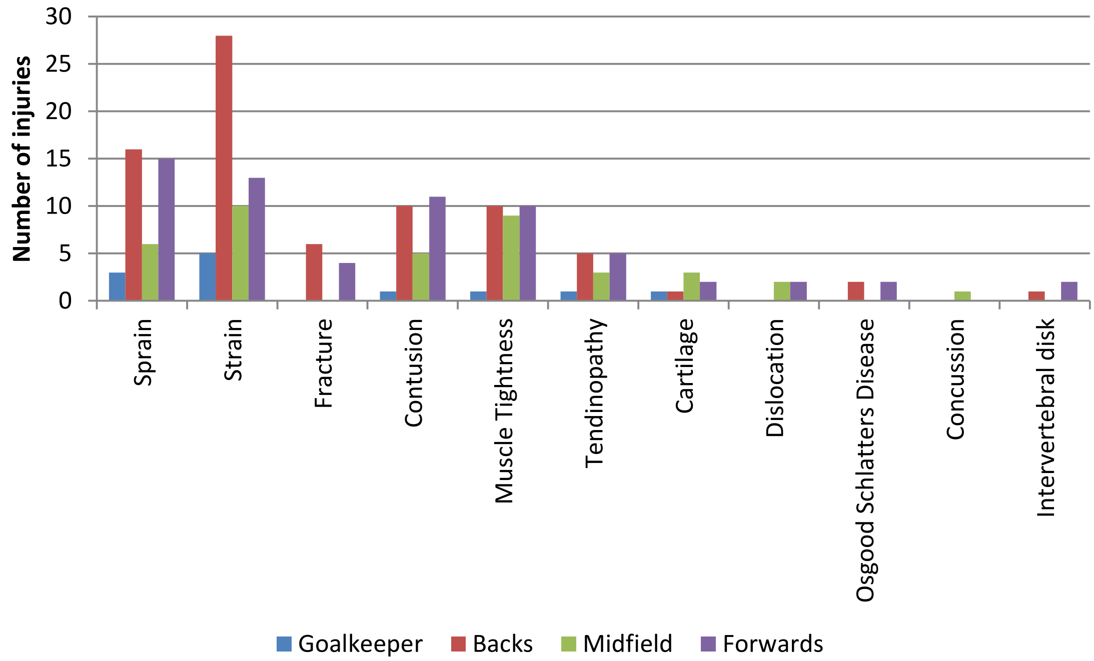

Figure 4.17: Distribution of nature of injury by position

4. 3. 1. 5. 4 . Relationship between playing surface and injury

The majority of injuries occurred on grass (62.7%, 136), followed by synthetic surfaces (21.2%, 46), indoor (10.6%, 23), road (2.3%, 5), other (2.3%, 5) and track (0.9%, 1) (Figure 4.18).

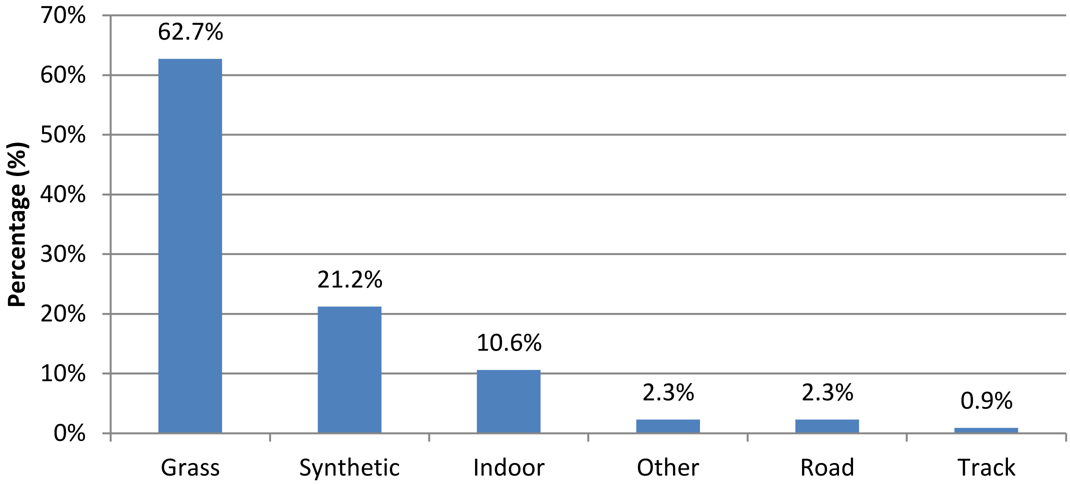

Figure 4.18: Playing Surface

4. 3. 1. 5. 5 . Relationship between weather conditions and injury

Injuries occurred outdoors (89.4%, 193) in the majority of cases with only 10.6% (23) of injuries occurring indoors. With regard to temperature, normal temperature was predominant (65.2%, 122), followed by cold (26.2%, 49) and hot (8.6%, 16). In relation to weather conditions during injury, dry weather accounted for the majority of injuries (73.7%, 126), followed by wet weather (24.6%, 42) and frozen weather (1.8%, 3).

4. 3. 1. 5. 6 . Protective Equipment worn

The majority (84.7%, 188) of adolescents wore no extra protective equipment. Mouth guards, ankle supports and wrist strapping were the only type of protective equipment worn by injured participants and these accounted for 10.4% (23), 4.5% (10) and 0.5% (1) of participants, respectively.

4. 3. 1. 6. The injury assessment

4. 3. 1. 6. 1 . Injury examination

The majority (77.9%, 173) of injuries were assessed solely by the main therapist in this study. However 22.1% (49) of injuries were referred for further assessment by an orthopaedic surgeon.

4. 3. 1. 6. 2 . Further Investigations completed

Only 21.7% of injuries required further investigations to be completed. Of these, 47.9% (21) underwent an X-ray , 33.2% (16) an MRI scan, 16.6% (1) were referred for both an MRI scan and X-ray and 2.3% (1) completed a CAT scan.

4. 3. 2. Epidemiological Results for adolescent Gaelic footballers and hurlers

4. 3. 2. 1. Epidemiological Results for adolescent Gaelic footballers and hurlers

125 injuries occurred in 292 adolescents that played Gaelic football and hurling (mean= 15.7±0.8 years, 67.7±10.1kg, 1.8±0.1m, 21.8±2.6kg/m^2). 95 of all participants became injured with 25 of these participants receiving two or more injuries. Injured participants had a total exposure time of 25,650 hours or 17,100 athletic exposures. Training exposure accounted for 22,230 hours and 13,680 athletic exposures and match exposure was 13,680 hours or athletic exposures.

4. 3. 2. 1. 1 . Primary sport played by adolescent Gaelic footballers and hurlers

Gaelic football was the primary sport played (46.4%, 58), followed by hurling (33.6%, 42) and both sports (19.2%, 24) (Figure 4.19).

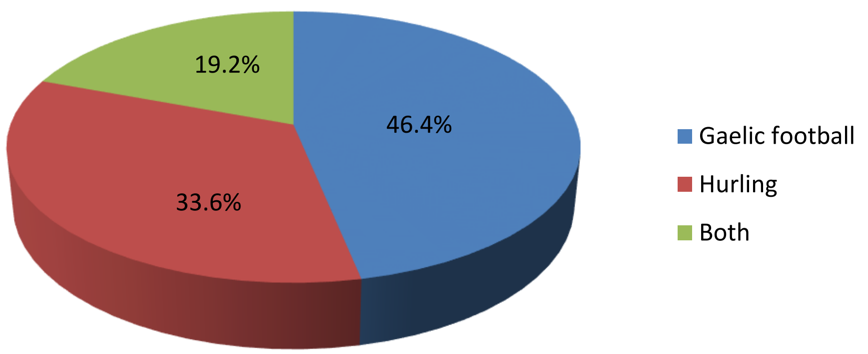

Figure 4.19: Primary sport played by injured participants

4. 3. 2. 1. 2 . Injury Incidence in adolescent Gaelic footballers and hurlers

The epidemiological incidence proportion (IP), repeat incidence proportion, clinical incidence and incidence rate are reported in Table 4.6. Incidence rate is analysed using injuries per 1,000 hours. The incidence proportion indicates that 32.5% (95% CI: 27.1%-37.9%) of adolescent Gaelic footballers and hurlers are at risk of becoming injured in a single academic year. The repeat incidence proportion indicates that of those who become injured during the school year 26.3% (95% CI: 17.4%-35.1%) are at risk of developing a subsequent injury.

Table 4.6: Incidence Proportion, Clinical Incidence and Incidence Rate in adolescent Gaelic footballers and hurlers

Type of Injury Incidence Analysis	Injury Incidence	95% CI
Incidence Proportion	0.325	0.271-0.379
Repeat Incidence Proportion	0.263	0.174-0.351
Clinical Incidence	0.428	0.371-0.481
Injuries per 1,000 hours	4.873	4.018-5.727

Table 4.7 displays the training and match incidence rate per 1,000 hours. The percentage of injuries that occurred during training (48.4%) was higher than matches (36.3%) however when exposure is taken into account, match injuries had a higher incidence rate than training injuries; this was the case even though adolescent Gaelic footballers and hurlers spent 6.5 times more time training rather than playing matches.

Table 4.7: Incidence rate of Training and Match injuries

Type of Incidence Rate	Training		Match	
	Incidence Rate	95% CI	Incidence Rate	95% CI
Injuries per 1,000 hours	2.699	2.016-3.382	13.157	9.313-17.002

4. 3. 2. 2. The Injury Description

4. 3. 2. 2. 1 . The Onset of Injury

The majority of injuries were acute in nature and accounted for 73.4% (91) of injuries in comparison to overuse injuries (26.6%, 33). New injuries predominated and accounted for 58.2% of injuries, recurrent injuries made up 41.8% of all injuries. Table 4.8 displays the new, early recurrence (<2 months), late recurrence (2-12 months) and persistent/recurring injuries.

Table 4.8: New and Recurrent injuries

	Number of injuries	Percentage of injuries
New	71	58.2%
Early Recurrence (<2 months)	15	12.3%
Late Recurrence (2-12 months)	16	13.1%
Persistent/recurring	20	16.4%

4. 3. 2. 2. 2 . Side of Injury

Right (40.7%, 50) and left (47.2%, 58) sides had a similar percentage of injuries with 12.2% (15) of injuries occurred bilaterally in adolescent Gaelic footballers and hurlers.

4. 3. 2. 2. 3 . Body Part Injured

Injuries predominantly occurred in the lower limb and accounted for 71.2% (89) of injuries, followed by the upper limb (17.6%, 22) and trunk/spine (11.2%, 14) (Figure 4.20).

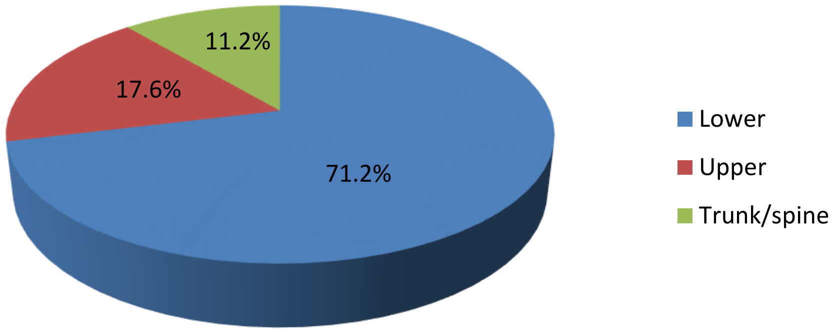

Figure 4.20: General distribution of injuries

Figure 4.21 displays the regional distribution of injuries and Figure 4.22 demonstrates the most common body parts injured. The knee (19.2%, 24), lower back (12.0%, 15), ankle (11.2%, 14), hamstring (9.6%, 12), and pelvis and groin (8.8%, 11) were the most commonly injured body parts. Thus this indicates that lower limb injuries predominate in adolescent Gaelic footballers and hurlers. The shoulder (6.4%,8), hand and fingers (6.4%,8) and wrist (3.2%,4) were the most common upper body injuries. Thigh injuries constitute 16.0% of all injuries. In fact, when the general distribution of injuries is viewed the hip/groin/thigh accounted for 25.0% (35) of injuries, followed by the knee (19.2%, 24) and shin/ankle/foot (14.4%, 18).

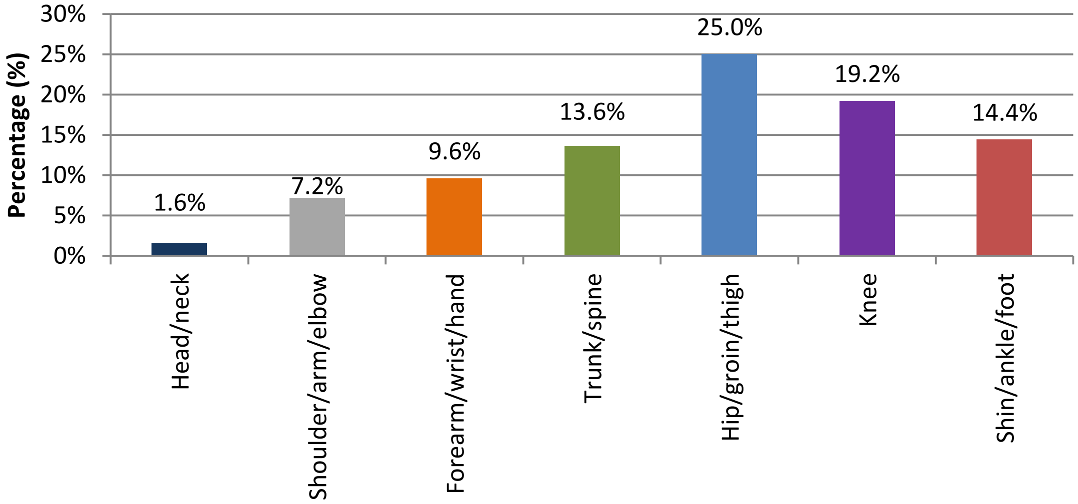

Figure 4.21: Regional distribution of injury

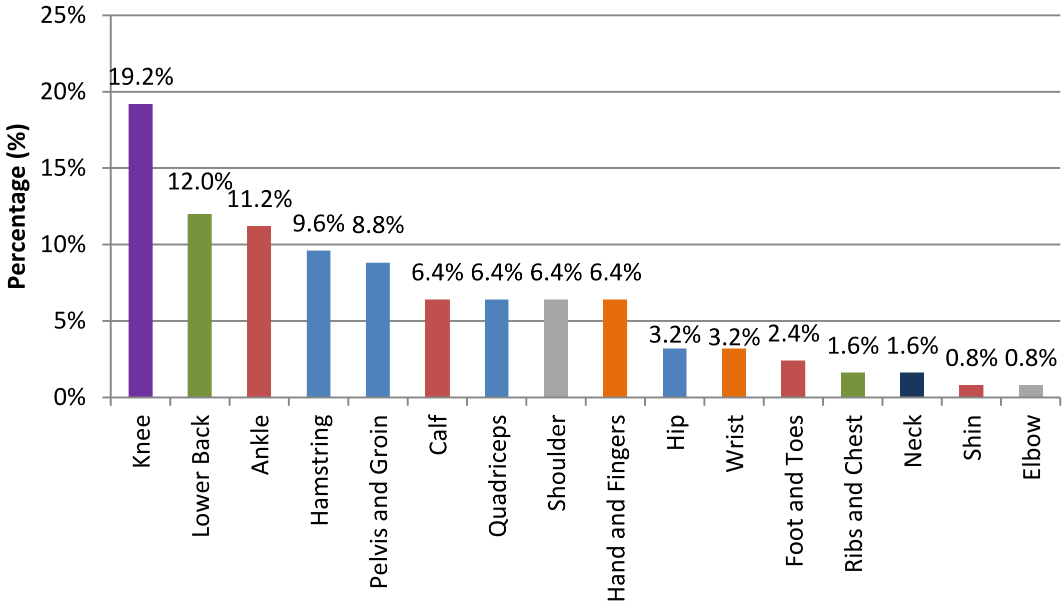

Figure 4.22: Body part injured

4. 3. 2. 2. 4 . Nature of Injury

Muscle injuries were by far the most common accounting for 56.5% (70) of injuries, followed by ligaments (19.4%, 24), tendons (10.5%, 13) and bone (8.0%, 10) (Figure 4.23). In relation to the specific nature of injuries strains (24.2%, 30) were most common, followed by sprains (19.4%, 24), muscle tightness (19.4%, 24), contusions (12.9%, 16), tendinopathy (10.5%, 13) and fractures (4.8%, 6) (Figure 4.24). Figure 4.25 displays a visual representation of the distribution of the different nature of injuries in differing injured body parts.

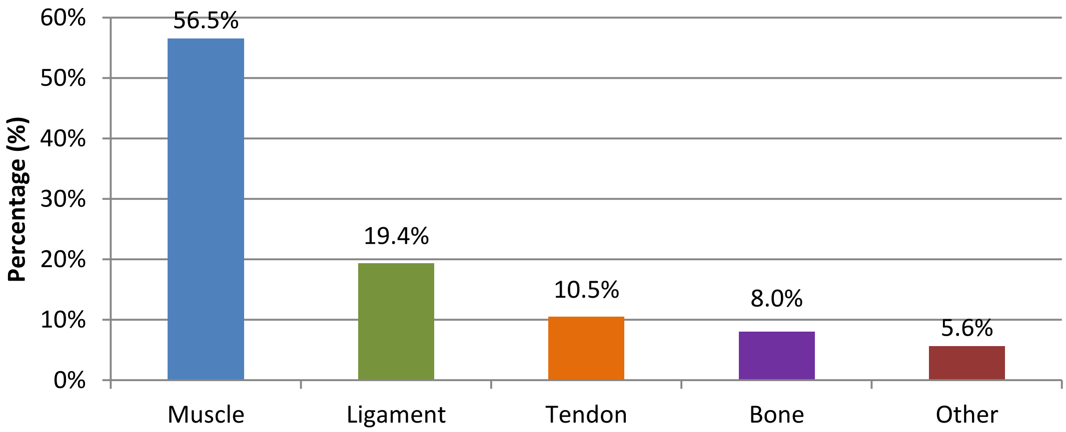

Figure 4.23: General nature of Injury

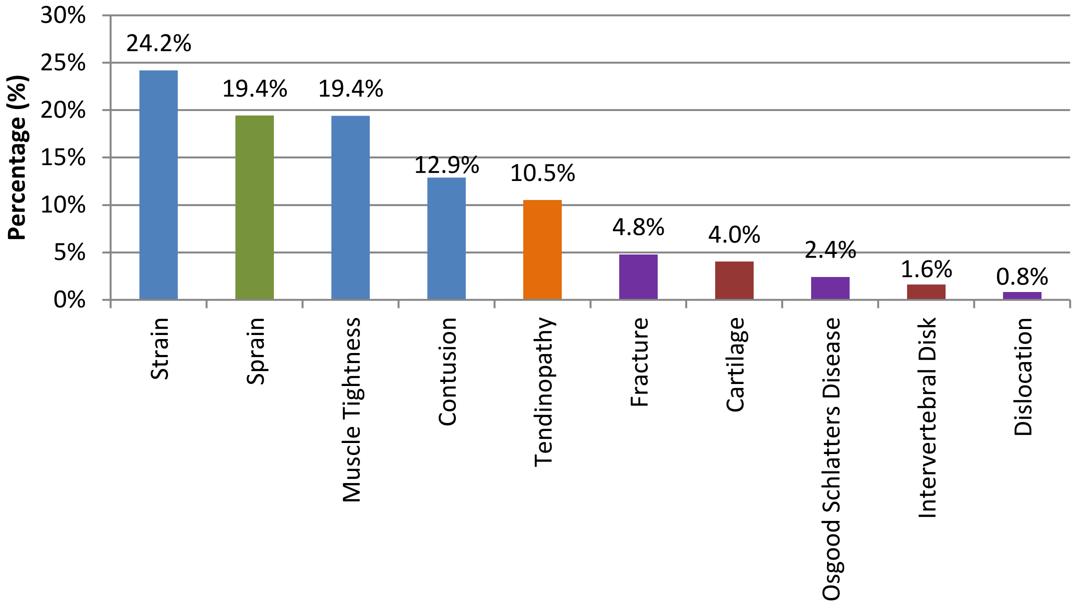

Figure 4.24: Specific nature of injury

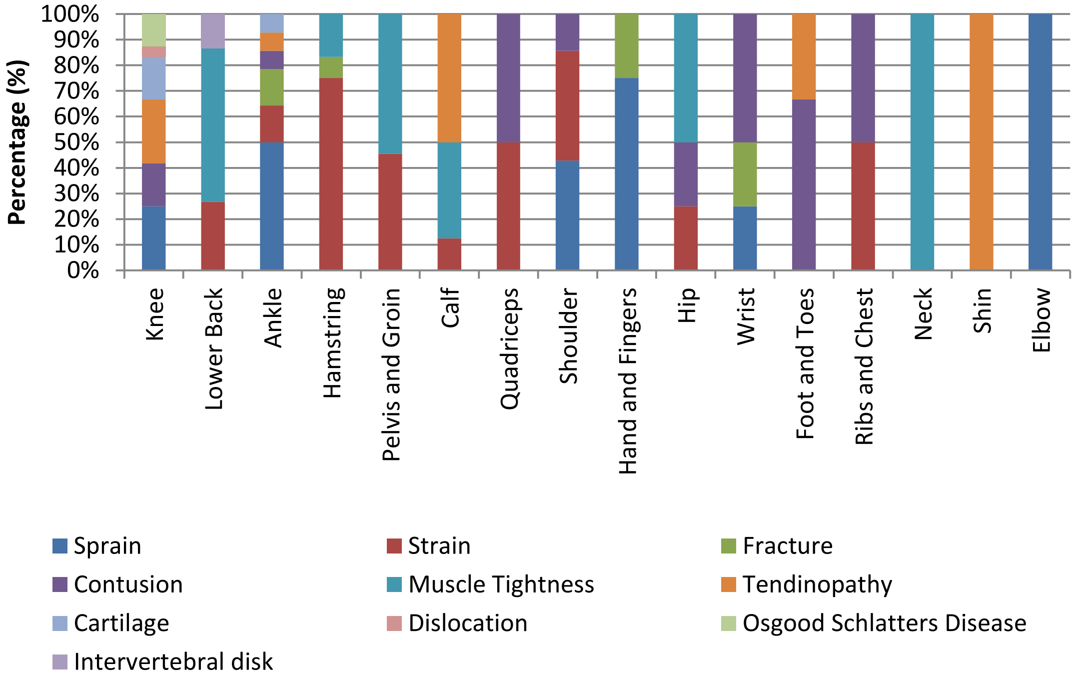

Figure 4.25: Visual representation of the nature of injuries in different body parts injured

4. 3. 2. 2. 5 . Severity of Injury

The majority of participants stopped playing after becoming injured (67.2%, 80) with only 32.8% (39) carrying on playing after sustaining an injury. The majority of injuries were found to be minor (0-7 days) (49.6%, 59), followed by severe (>22 days) (34.5%,41) and moderate (8-21 days) (16.0%, 19) (Figure 4.26). The mean days lost from sport (until individual was deemed of full fitness) due to injury were 26.5±53.6. The mean days lost from sport before taking part in light training were 22.0±49.1 and from full training were 24.7±52.1. The majority (92.8%, 116) of injured adolescent Gaelic footballers and hurlers did not require surgery, however 6.4% (8) required surgery during season and 0.8% (1) required surgery after the season had ended.

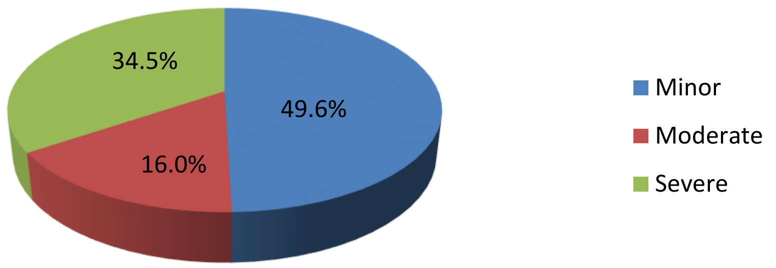

Figure 4.26: Severity of injury

Minor injuries were most common in injuries due to muscle tightness, contusions, tendinopathy, Osgood schlatters disease and intervertebral disk injuries (Figure 4.27). Strains caused an equal amount of minor and moderate injuries. Severe injuries were most common in strains, sprains, fractures, cartilage and dislocations.

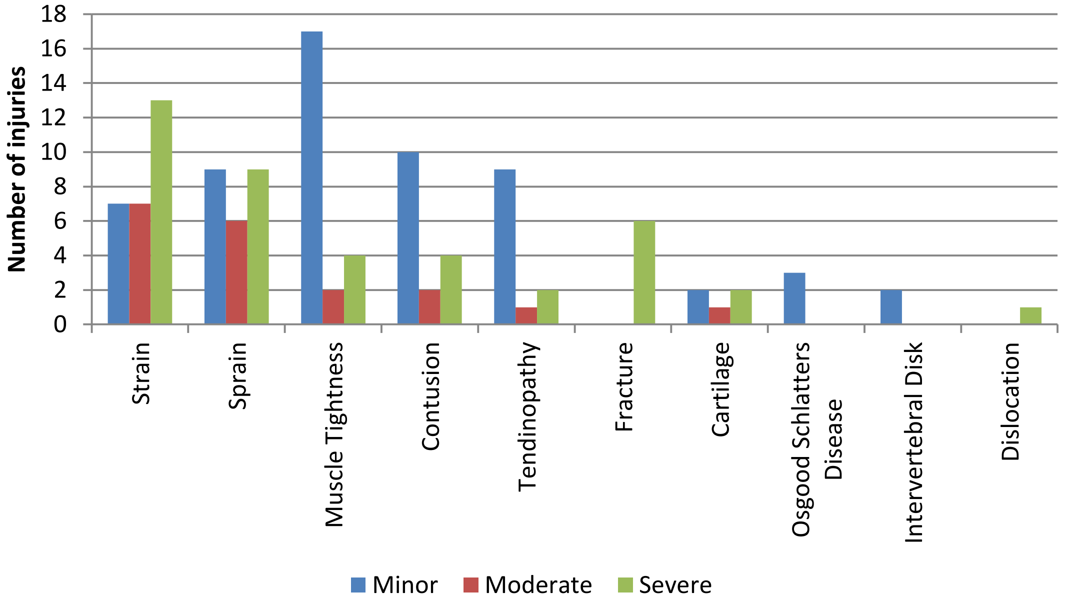

Figure 4.27: Severity of injury in relation to the nature of injury

4. 3. 2. 3. The Injury Event

4. 3. 2. 3. 1 . Mechanism of Injury

Non-contact injuries predominated, accounting for 63.7% (79) of injuries and 36.3% (45) of injuries were contact in nature. Specifically 46.8% (58) of injuries were acute non-contact injuries. The remainder of the non-contact injuries were overuse injuries

(16.9%, 21). Of the contact injuries the majority occurred due to contact with another player (20.9%, 26), followed by contact with the playing surface (5.6%, 7), football (5.6%, 7), hurley (3.2%, 4), and playing apparatus (0.8%, 1). 2.4% (3) of injuries that occurred due to contact with another player involved assault or violence. The majority of injuries had no specific mechanism of injury (25.4%, 31) which can be related to the amount of overuse injuries (Figure 4.28). Sprinting was found to be the most common specific mechanism of injuries (23.8% (29)), followed by being tackled (13.9%, 17), jumping/catching (9.0%,11), kicking (5.4%, 7) and falling (5.4%,7). Only 4.9% (6) of injuries occurred during turning and tackling. 18.8% (23) of injuries occurred during tackling (either being tackled or tackling).

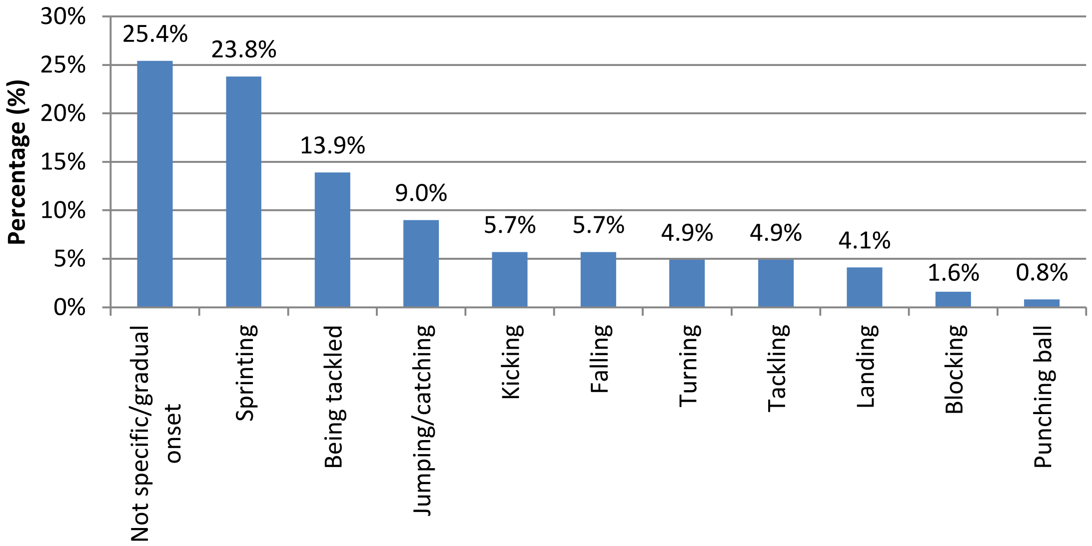

Figure 4.28: Mechanism of injury

4. 3. 2. 3. 2 . Time of Injury

80.0% (92) of injuries occurred during the training/match with only 14.8% (17) and 5.2% (6) occurring during the warm-up and cool down respectively (Figure 4.29). The mean minutes into sport adolescent Gaelic footballers and hurlers sustained an injury was 35.1±21.6 (2-120) minutes.

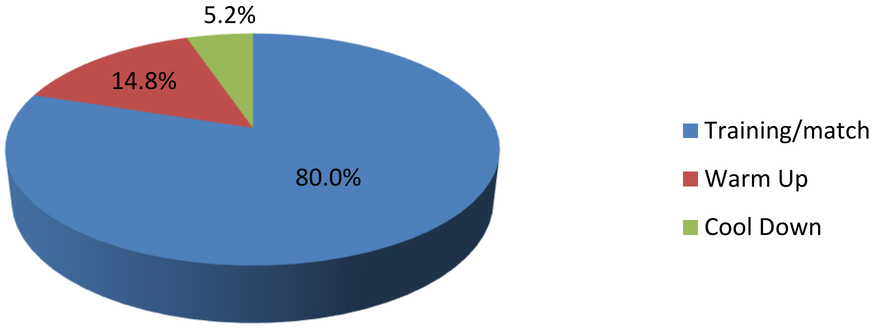

Figure 4.29: Time of injury

The majority of injuries occurred during the second half (58.3%,49) with only 41.7% (35) occurring in the first half. Injuries predominantly occurred during the 4th quarter (38.1%, 32), followed by the 2nd quarter (23.8%, 20), the 3rd quarter (20.2%, 17) and the 1st quarter (17.9%, 15) (Figure 4.30).

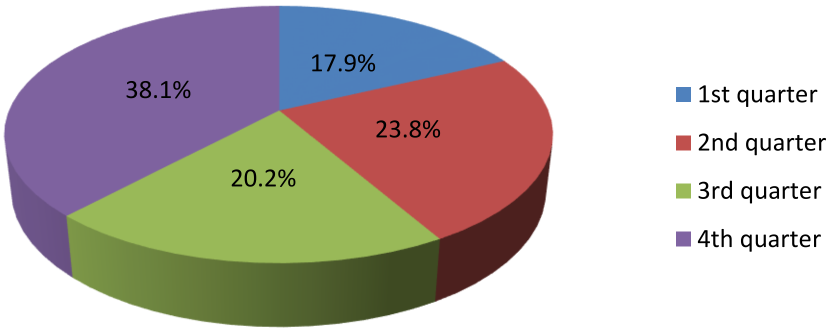

Figure 4.30: Quarter of injury

4. 3. 2. 3. 3 . Foul play

Only 11.3% (14) of injuries were related to foul play, injuries due to an opponent foul accounted for 92.9% of injuries related to foul play with only 7.1% due to a foul by the injured player. A free and yellow card was given in 45.5% (10) of cases respectively; a red card was given in only 9.0% (2) of cases.

4. 3. 2. 4. Factors Surrounding the Injury

4. 3. 2. 4. 1 . Relationship between time of year and injury

The majority of injuries occurred during the season (80.8%, 101), followed by preseason (13.6%, 17) and off season (5.6%, 7). Injuries were most common at the beginning of the calendar year and dropped significantly over the summer months however increased again nearing the end of the year (Figure 4.31). The four most common months for injury were February (19.1%, 22), April (17.4%, 20), January (14.8%, 17) and March (13.9%, 16).

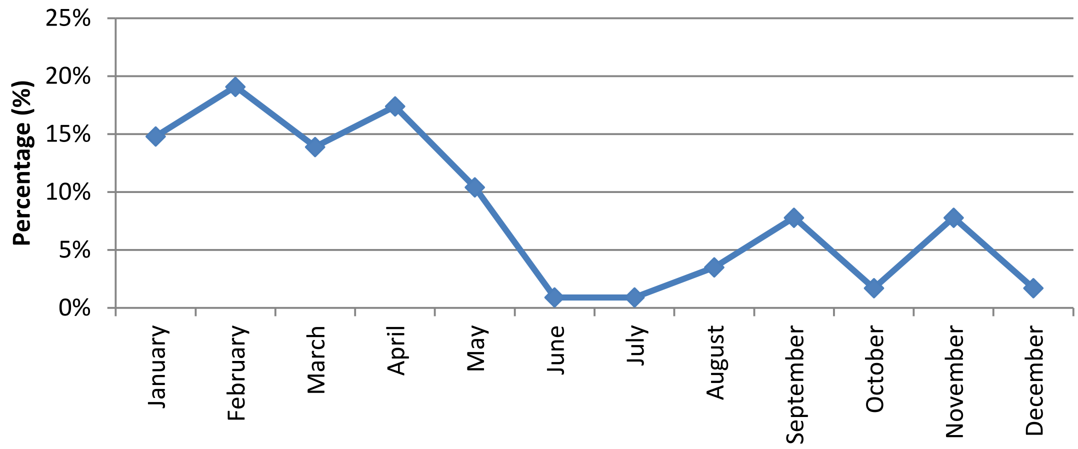

Figure 4.31: Monthly profile of injury

Acute injuries were most common in April (17), February (14), January (12) and March (12) (Figure 4.32). Overuse injuries were most common during February (8), January (5), March (4) and April (3). Both acute and overuse injuries were most common at the beginning of the year, with a reduction of injuries during the summer months and a further increase in injuries during the latter part of the year.

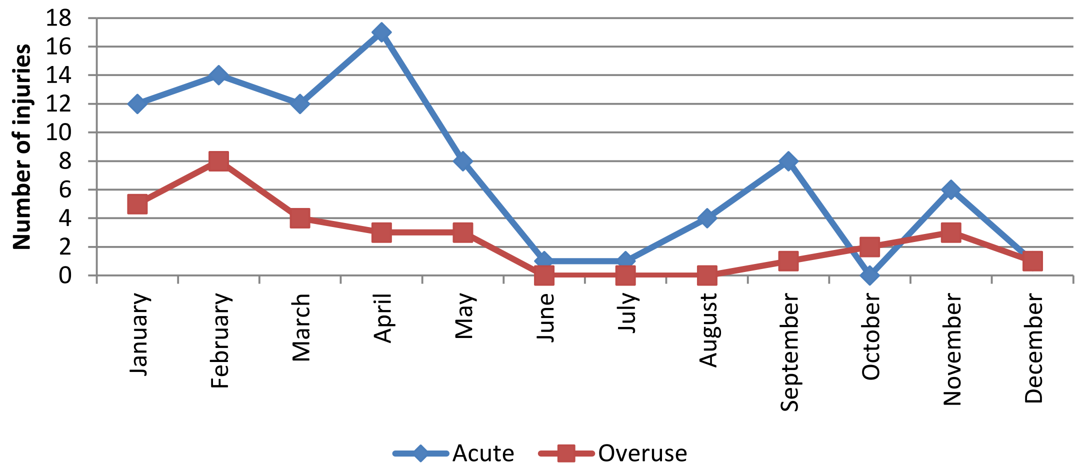

Figure 4.32: Monthly profile of injury with regard to acute and overuse injuries

4. 3. 2. 4. 2 . Relationship between relative age group and injury

The majority (92.8%, 116) of adolescent Gaelic footballers and hurlers were playing with their own age group, only 7.2% (9) of players were playing with an older team.

4. 3. 2. 4. 3 . Relationship between playing position and injury

The percentage of injuries in backs and forwards were similar and accounted for 38.7% (48) of injuries respectively (Figure 4.33). Only 19.4% (24) of injuries occurred to midfielders and 3.2% (2) of injuries occurred in goalkeepers. However, since backs and forwards have a larger number of players than goalkeepers and midfielders in Gaelic games, the injuries per position was calculated to adjust for this difference. Midfielders presented with 12 injuries per position, followed by backs (8 injuries per position), forwards (7.8 injuries per position) and goalkeepers (4 injuries per position). The majority of body parts injured and nature of injury occurred in similar amounts to backs and forwards (Figure 4.34 and Figure 4.35 respectively). Knee injuries occurred more commonly in forwards (10) than backs (7). Strains were more common in backs (15) in comparison to forwards (10) and conversely muscle contusions occurred more commonly to forwards (8) than backs (5).

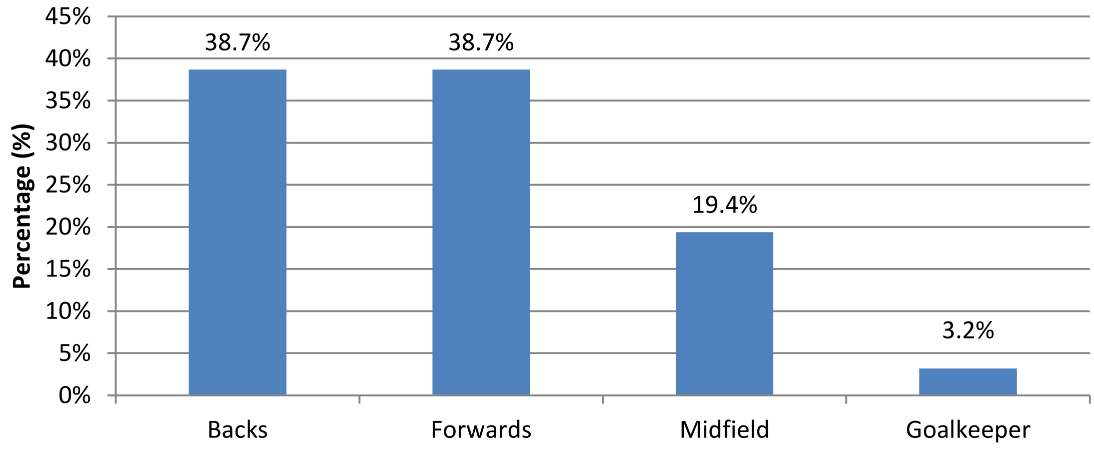

Figure 4.33: Injury prevalence of players in different positions

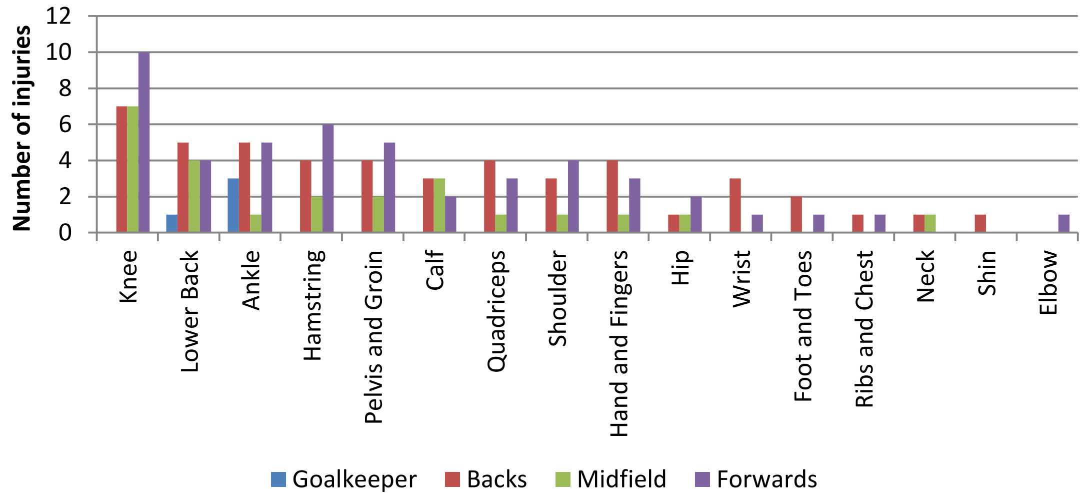

Figure 4.34: Distribution of body part injured by position

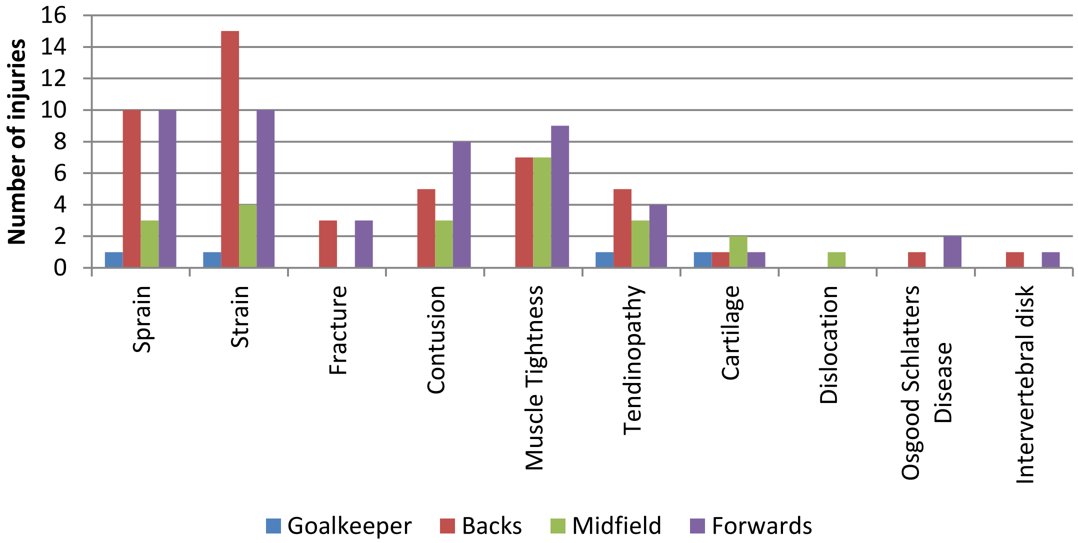

Figure 4.35: Distribution of nature of injury by position

4. 3. 2. 4. 4 . Relationship between a free taking role and injury

Participants who became injured were predominantly not a free taker (70.2%, 87) compared to a free taker (29.8%, 37).

4. 3. 2. 4. 5 . Relationship between playing surface and injury

The majority of injuries occurred on grass (68.6%, 83), followed by synthetic surfaces (19.8%, 24), indoor (8.3%, 10), road (1.7%, 2) and other (1.7%, 2) (Figure 4.36).

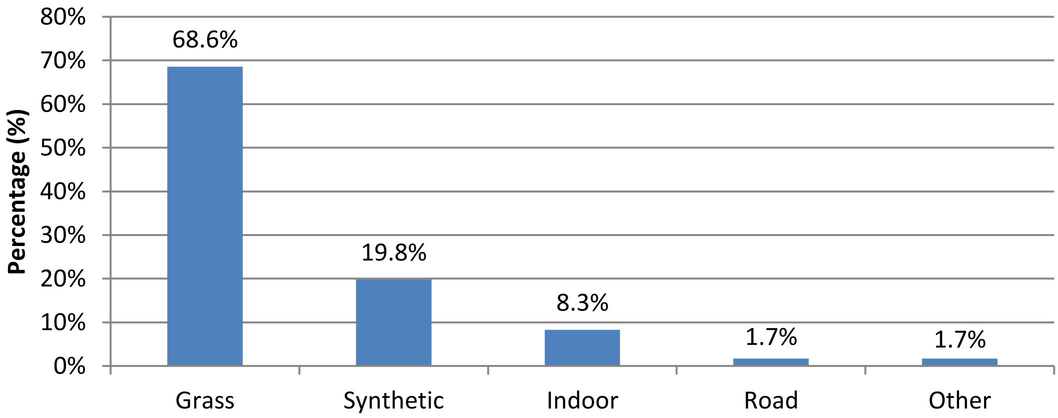

Figure 4.36: Playing Surface

4. 3. 2. 4. 6 . Relationship between weather conditions and injury

Injuries occurred outdoors (90.3%, 112) in the majority of cases with only 9.7% (12) of injuries occurring indoors. With regard to temperature during injury, normal temperature was predominant (68.9%, 71), followed by cold (25.2%, 26) and hot (5.8%, 6). In relation to the weather conditions during injury, dry weather accounted for the majority of injuries (72.7%, 72), followed by wet weather (24.2%, 24) and frozen weather (3.0%, 3).

4. 3. 2. 4. 7 . Protective Equipment worn

The majority (82.3%, 102) of adolescent Gaelic footballers and hurlers wore no extra protective equipment. Mouth guards and ankle supports were the only type of protective equipment worn by injured participants and these accounted for 14.5% (18) and 3.2% (4) of participants respectively.

4. 3. 2. 5. The injury assessment

4. 3. 2. 5. 1 . Injury examination

The majority (80.0%, 100) of injuries were assessed solely by the main therapist in this study. However 20.0% (25) of injuries were referred for further assessment by an orthopaedic surgeon.

4. 3. 2. 5. 2 . Further Investigations completed

Only 18.5% of injuries required further investigations to be completed. Of these, 39.1% (9) underwent an MRI scan, 34.8% (8) an X-ray and 26.1% (6) were referred for both an MRI scan and X-ray.

4. 3. 3. Epidemiological Results for collegiate participants

193 injuries occurred in 342 collegiate participants that played Gaelic football and hurling (mean= 19.3±1.9 years, 77.6±9.3kg, 1.8±0.1m, 23.5±2.1kg/m^2). 131 of all participants became injured with 35 of injured participants receiving two or more injuries. Injured participants had a total exposure time of 20,273 hours or 14,190 athletic exposures. Training exposure accounted for 16,797 hours and 10,741 athletic exposures and match exposure was 3,476 hours or athletic exposures.

4. 3. 3. 1. Sport played by collegiate participants

The primary sport played by participants was Gaelic football (74.6%, 144) with 25.4% (49) of participants primarily playing hurling. There was a similar percentage of fresher (48.7%, 94) and senior (51.3%, 99) players.

4. 3. 3. 2. Injury Incidence in collegiate participants

The epidemiological incidence proportion (IP), repeat incidence proportion, clinical incidence and incidence rate are reported in Table 4.9. Incidence rate is analysed using injuries per 1,000 hours. The incidence proportion indicates that 38.3% (95% CI: 33.1%-43.4%) of collegiate participants are at risk of becoming injured during a single collegiate season. The repeat incidence proportion indicates that of those who become injured during the collegiate season 26.7% (95% CI: 19.1%-34.2%) are at risk of developing a subsequent injury.

Table 4.9: Incidence Proportion, Clinical Incidence and Incidence Rate in collegiate participants

Type of Injury Incidence Analysis	Injury Incidence	95% CI
Incidence Proportion	0.383	0.331-0.434
Repeat Incidence Proportion	0.267	0.191-0.342
Clinical Incidence	0.564	0.511-0.616
Injuries per 1,000 hours	14.512	12.464-16.559

Table 4.10 displays the training and match incidence rate per 1,000 hours. The percentage of injuries that occurred during matches (56.9%, 103) was higher than training (43.1%, 78). When exposure is taken into account, match injuries also had a higher incidence rate than training injuries; this was the case even though collegiate participants spent 4.8 times more time training rather than playing matches.

Table 4.10: Incidence rate of Training and Match injuries

Type of Incidence Rate	Training		Match	
	Incidence Rate	95% CI	Incidence Rate	95% CI
Injuries per 1,000 hours	7.055	5.489-8.621	45.900	37.035-54.764

4. 3. 3. 3. The Injury Description

4. 3. 3. 3. 1 . The Onset of Injury

The majority of injuries were acute in nature and accounted for 78.2% (151) of injuries in comparison to overuse injuries (21.8%, 42). New injuries predominated in collegiate participants and accounted for 71.1% of injuries, recurrent injuries made up 23.0% of all injuries. Table 4.11 displays the new, early recurrence (<2 months), late recurrence (2-12 months) and persistent/recurring injuries.

Table 4.11: New and Recurrent injuries

	Number of injuries	Percentage of injuries
New	148	77.1%
Early Recurrence (<2 months)	13	6.8%
Late Recurrence (2-12 months)	8	4.2%
Persistent/recurring	23	12.0%

4. 3. 3. 3. 2 . Side of Injury

Injuries occurred more frequently on the right side (54.6%, 101) than the left side (38.4%, 71) and bilaterally (7.0%, 13).

4. 3. 3. 3. 3 . Body Part Injured

Injuries predominantly occurred in the lower limb and accounted for 69.4% (134) of injuries, followed by the upper limb (17.1%, 33), trunk/spine (9.3%, 18) and head/face (4.1%, 8) (Figure 4.37).

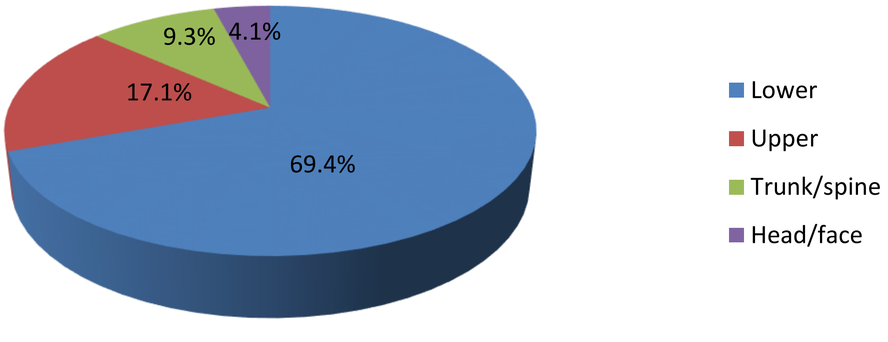

Figure 4.37: General distribution of injuries

Figure 4.38 displays the regional distribution of injuries and Figure 4.39 demonstrates the most common body parts injured. The hamstring (16.1%, 31), knee (13.0%, 25), ankle (10.9%, 21), hand and fingers (7.8%, 15), pelvis and groin (7.3%, 14) and quadriceps (7.3%, 14) were the most commonly injured body parts. This indicates that lower limb injuries predominate in collegiate participants. The hand and fingers (7.8%, 15), shoulder (5.7%, 11), and elbow (2.1%,4) were the most common upper body injuries. Thigh injuries constitute 23.4% of all injuries. In fact, when the general distribution of injuries is viewed the hip/groin/thigh accounted for 36.9% (45) of injuries, followed by the shin/ankle/foot (14.5%,28), knee (13.0%, 25) , and trunk/spine (9.6%, 15).

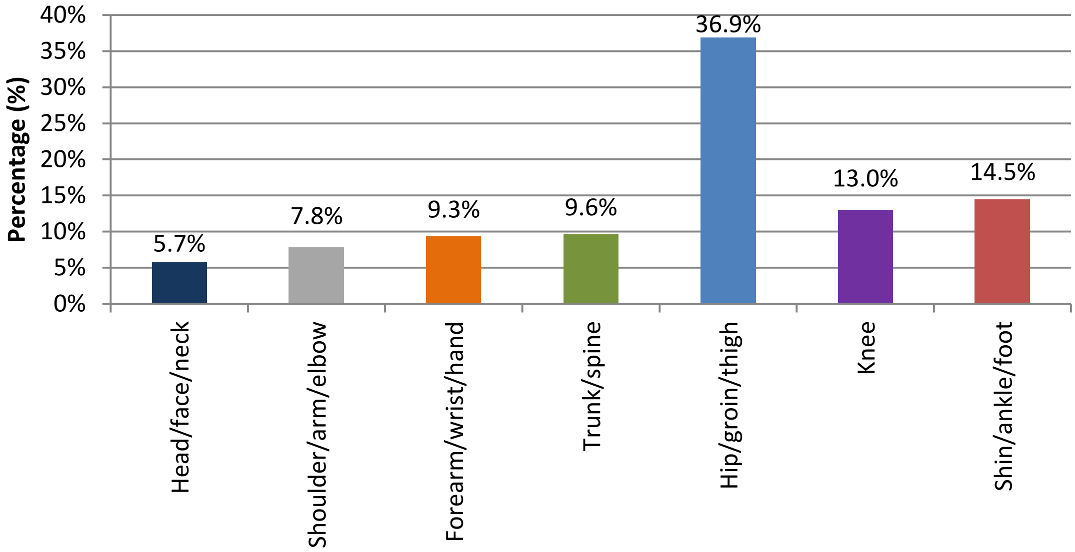

Figure 4.38: Regional distribution of injury

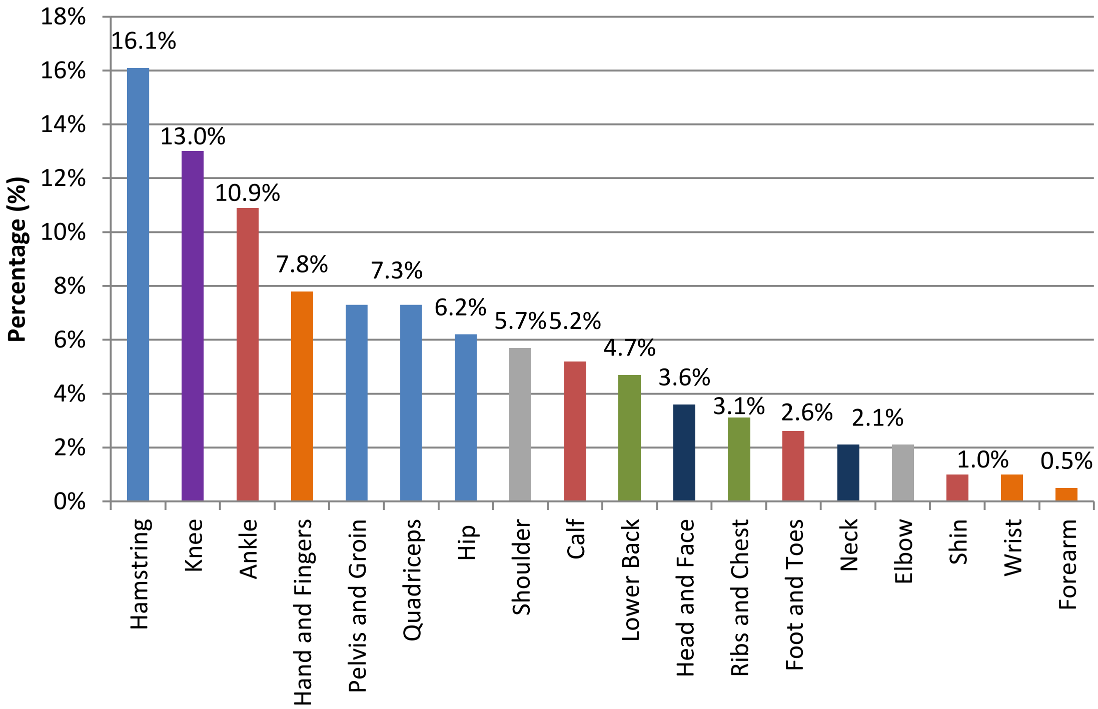

Figure 4.39: Body part injured

4.3.3.3.4 Nature of Injury

Muscle injuries were by far the most common accounting for 53.3% (103) followed by ligaments (27.5%, 53), bone (7.3%, 14) and tendon (6.7%, 13) (Figure 4.40). In relation to the specific nature of injuries strains (31.6%, 61) were most common, followed by sprains (27.5%, 53), contusions (15.5%, 30), tendinopathy (6.7%, 13), muscle tightness (6.2%, 12) and fractures (5.7%, 11) (Figure 4.41). Figure 4.42 displays a visual representation of the distribution of the different nature of injuries in differing injured body parts.

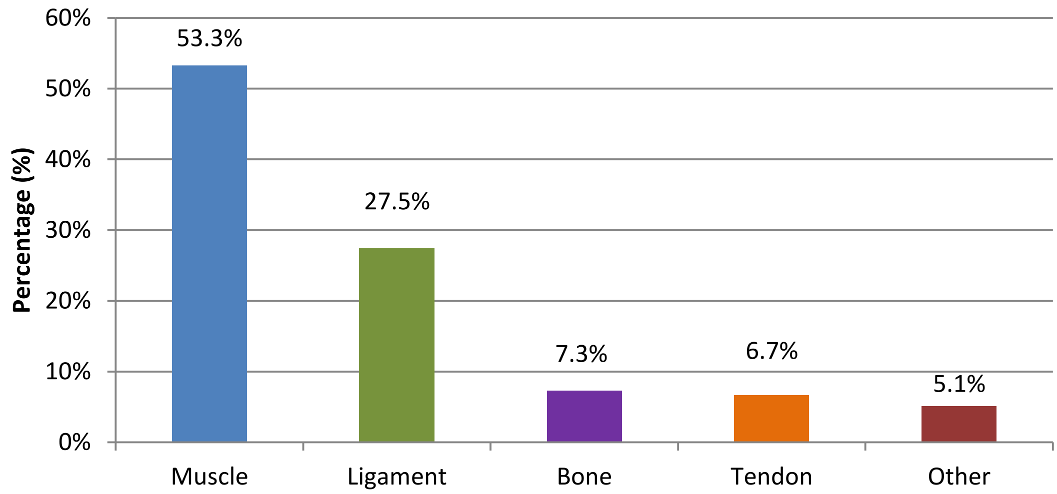

Figure 4.40: General nature of injury

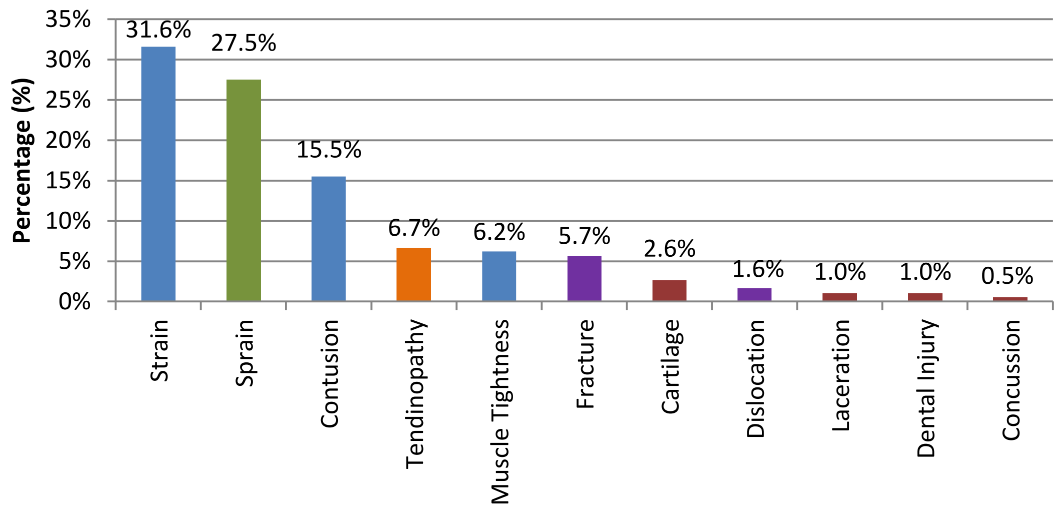

Figure 4.41: Specific nature of injury

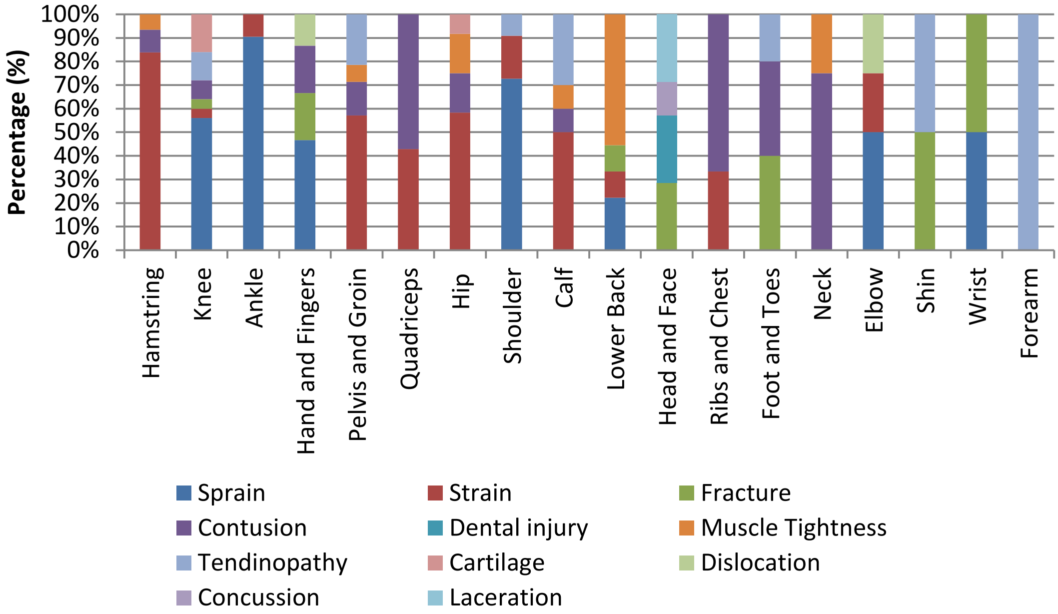

Figure 4.42: Visual representation of the nature of injury in different injured body parts

4. 3. 3. 3. 4 . Severity of Injury

The majority of collegiate participants stopped playing after becoming injured (83.9%, 161) with only 16.1% (31) carrying on playing after sustaining an injury. The majority of injuries were found to be severe (>22 days) (38.0%, 73) followed by minor (0-7 days) (35.4%, 68), and moderate (7-21 days) (26.6%, 51) (Figure 4.43). The mean days lost from sport (until individual was deemed of full fitness) due to injury were 29.2±40.5. The mean days lost from sport before taking part in light training were 25.8±42.3 and from full training were 27.2±37.7. The majority (89.6%, 173) of injured collegiate participants did not require surgery, however 6.7% (13) required surgery during season and 3.6% (7) required surgery after the season had ended.

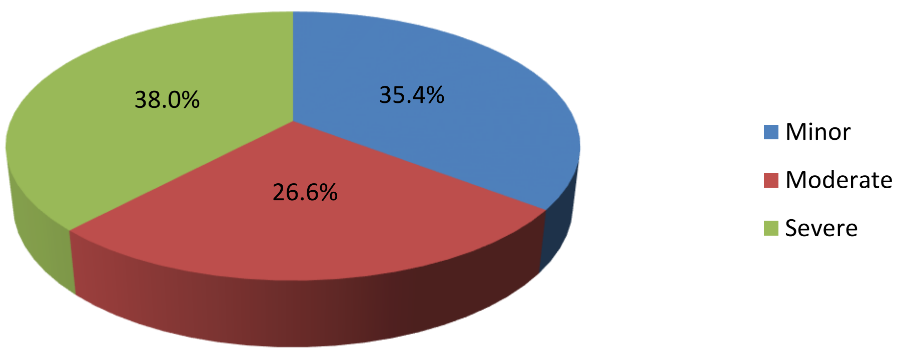

Figure 4.43: Severity of injury

Minor injuries were most common in injuries due to contusions, muscle tightness, tendinopathy, laceration and concussion (Figure 4.44). Moderate injuries primarily occurred in strains and dental injuries. Strains caused an equal amount of minor and moderate injuries. Severe injuries were most common in sprains, fractures and cartilage

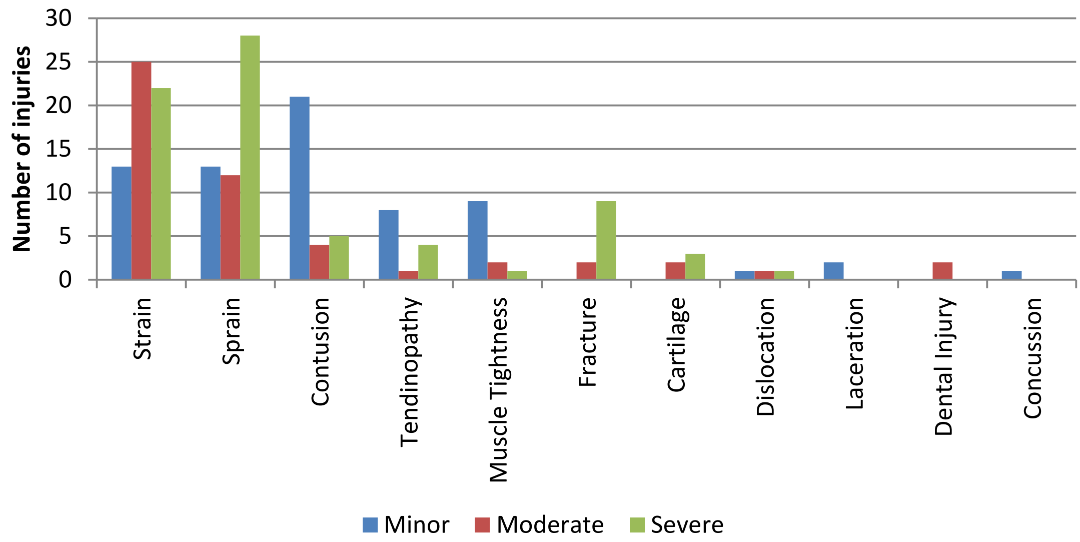

Figure 4.44: Severity of injury in relation to the nature of injury

4. 3. 3. 4. The Injury Event

4. 3. 3. 4. 1 . Mechanism of Injury

Non-contact injuries predominated, accounting for 54.4% (105) of injuries occurring, 45.6% (88) of injuries were contact in nature. Specifically 43.0% (83) of injuries were acute non-contact injuries. The remainder of the non-contact injuries were overuse injuries (11.4%, 22). Of the contact injuries the majority occurred due to contact with another player (28.0%, 54), followed by contact with the playing surface (8.3%, 16), football (4.7%, 9), hurley (3.1%, 6), and playing apparatus (1.0%, 2). Only 0.5% (1) of injuries that occurred were due to assault or violence.

Sprinting was found to be the most common specific mechanism of injuries (25.0% (48)) of injuries, followed by being tackled (15.6%, 30), turning (8.9%, 17), landing (8.3%, 16), jumping/catching (7.3%, 14) and tackling (7.3%, 13) (Figure 4.45). 22.9% (43) of injuries occurred during tackling (either being tackled or tackling). No specific mechanism of injury with a gradual onset of symptoms was noted in 11.5% (22) of injuries which can be related to overuse injuries.

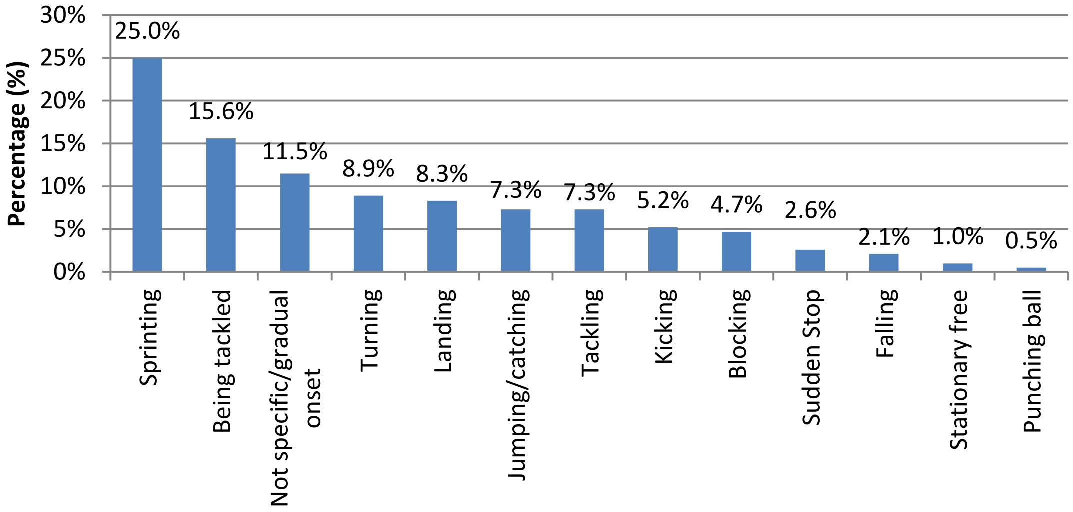

Figure 4.45: Mechanism of injury

4.3.3.4.2 Time of Injury

Figure 4.46 displays the time of injury, 92.0% (160) of injuries occurred during the training/match with only 4.6% (8) and 3.4% (6) occurring during the warm-up and cool down respectively. The mean minutes an injury was sustained was 38.4±16.7 (1-90) minutes.

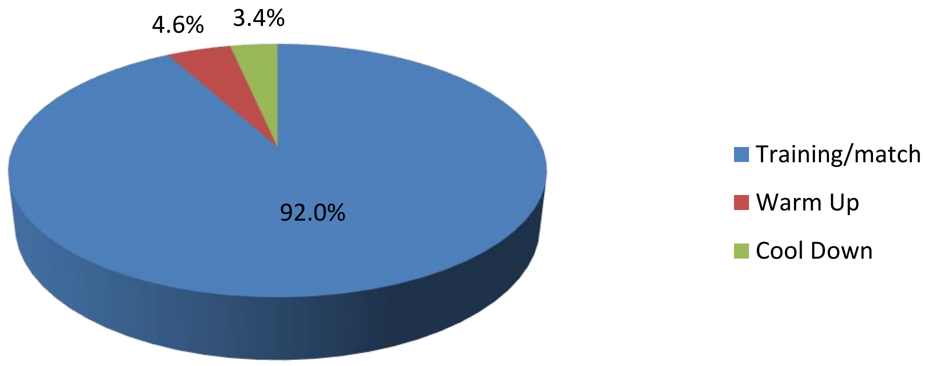

Figure 4.46: Time of injury

The majority of injuries occurred during the second half (70.3%, 97) and only 29.7% (41) occurred in the first half. Injuries predominantly occurred during the 4th quarter (48.6%, 67), followed by the 3rd quarter (21.7%, 30), the 2nd quarter (20.3%, 28) and the 1st quarter (9.4%, 13) (Figure 4.47).

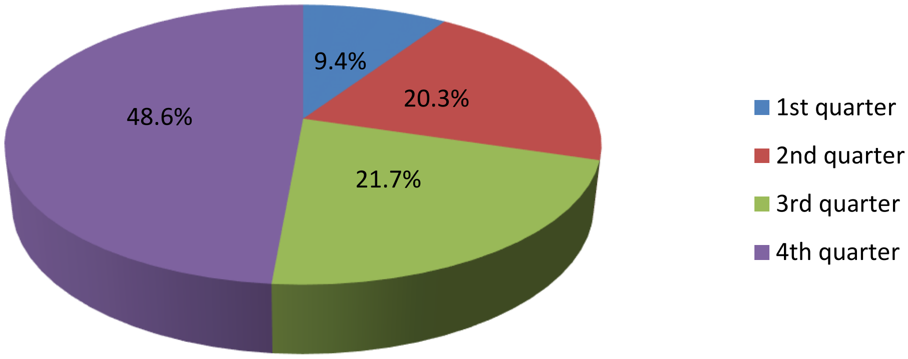

Figure 4.47: Quarter of injury

4. 3. 3. 4. 2 . Foul play

Only 5.7% (11) of injuries were related to foul play, injuries due to an opponent foul accounted for 54.5% (6) of injuries related to foul play with 45.5% (5) of injuries due to a foul by the injured player. A free (60.0%, 6) was the primary sanction given after foul play that caused an injury followed by a yellow card (30.0%, 3) and a red card (10.0%, 1).

4. 3. 3. 5. Factors Surrounding the Injury

4. 3. 3. 5. 1 . Relationship between time of year and injury

The majority of injuries occurred during the season (80.8%, 156), followed by preseason (16.6%, 32) and off season (2.6%, 5). Injuries were most common at the beginning of the calendar year and dropped significantly over the summer months however increased again nearing the end of the year (Figure 4.48). The four most common months for injury were November (22.9%, 44), October (18.2%, 35), February (15.6%, 30), January (13.5%, 26) and December (12.5%, 24). An increase in injuries occurred over two time points throughout the year, during November and February.

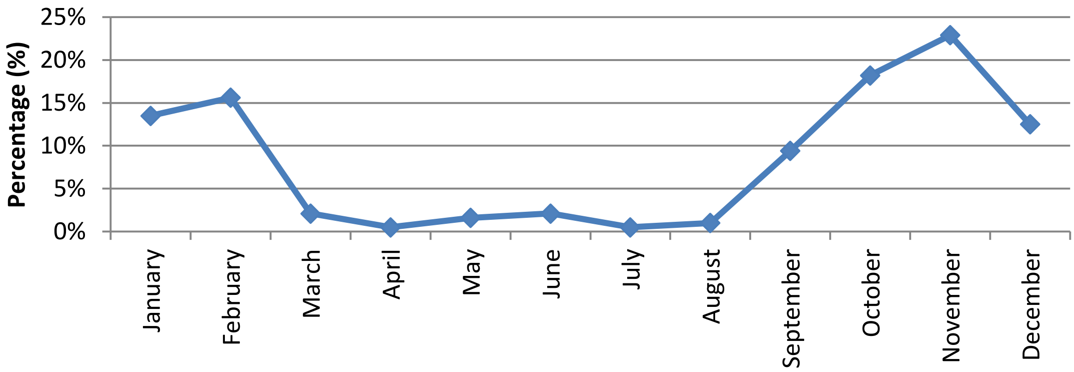

Figure 4.48: Monthly profile of injury

Figure 4.49 demonstrates the monthly profile of injuries with regard to acute or overuse injuries. Acute injuries were most common in November (35), October (29) February (21) and January (19). Overuse injuries were most common during November (9), February (9), January (7) and December (7). Both acute and overuse injuries increased in occurrence at the later part and beginning of the year with a reduction of injuries in the summer months.

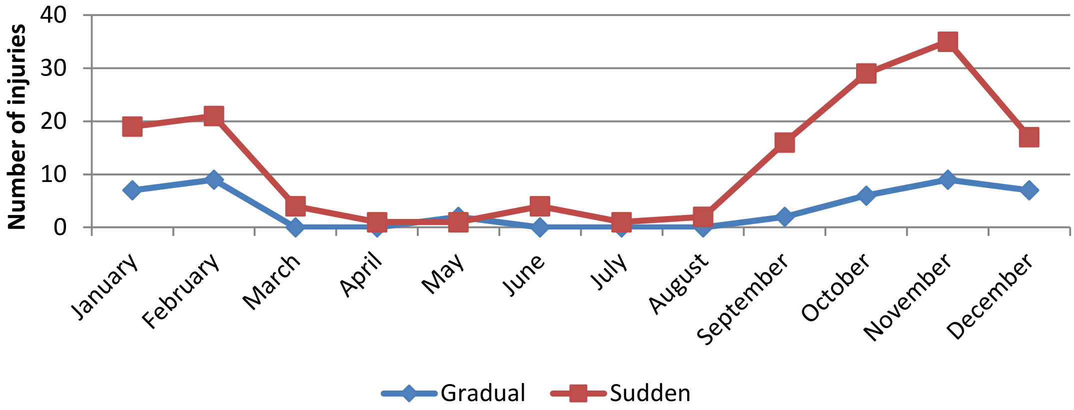

Figure 4.49: Monthly profile of injury with regard to acute and overuse injuries

4. 3. 3. 5. 2 . Relationship between relative age group and injury

The majority (92.7%, 179) of adolescents were playing with their own age group, only 7.3% (1) of players were playing with an older team.

4. 3. 3. 5. 3 . Relationship between playing position and injury

Forwards received the majority of injuries with 40.9% (79), followed by backs (38.3%, 74), midfield (12.4%, 24) and goalkeepers (8.3%, 16) (Figure 4.50). However, since backs and forwards have a larger number of players than goalkeepers and midfielders in Gaelic games, the injuries per position was calculated to adjust for this difference. Goalkeepers presented with 16 injuries per position, followed by forwards (13.2 injuries per position), backs (12.3 injuries per position) and both midfielders (12 injuries per position). The incidence of body parts injured and nature of injury was similar in backs and forwards (Figure 4.51 and 4.52 respectively). However hamstring (14), quadriceps (10) and shoulder (7) injuries occurred more commonly in backs than forwards (11, 3, 3 respectively). Knee (13), pelvis and groin (9) and ribs and chest (5) injuries occurred more commonly in forwards than backs (5, 1, 1 respectively). Strains were more common in forwards (26) in comparison to backs (23) and conversely muscle contusions occurred more commonly to backs (14) than forwards (11).

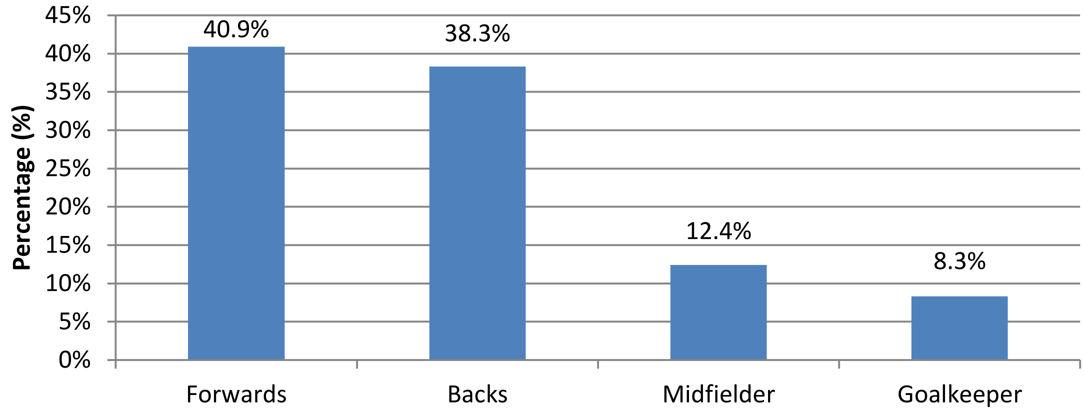

Figure 4.50: Injury prevalence of players in different positions

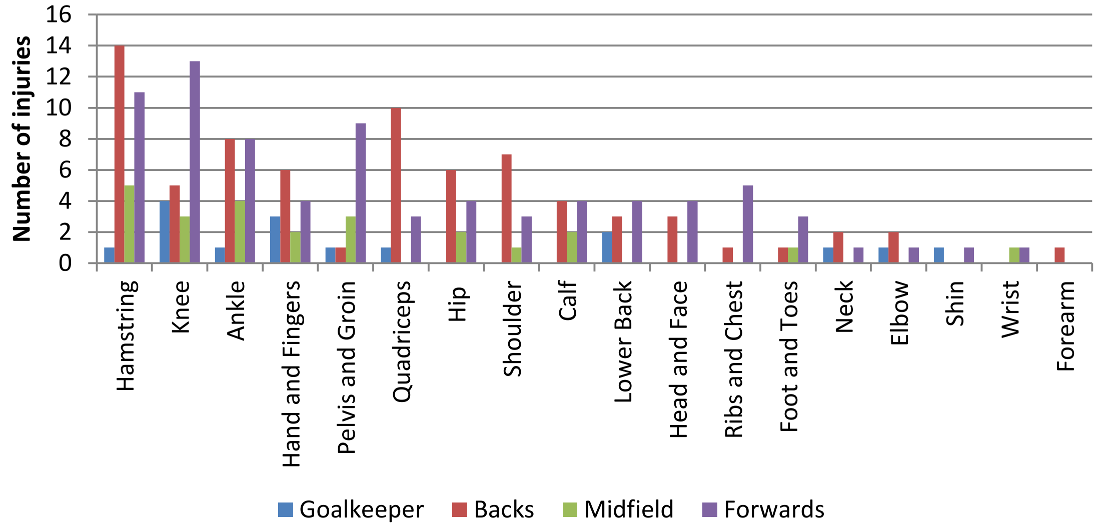

Figure 4.51: Distribution of body part injured by position

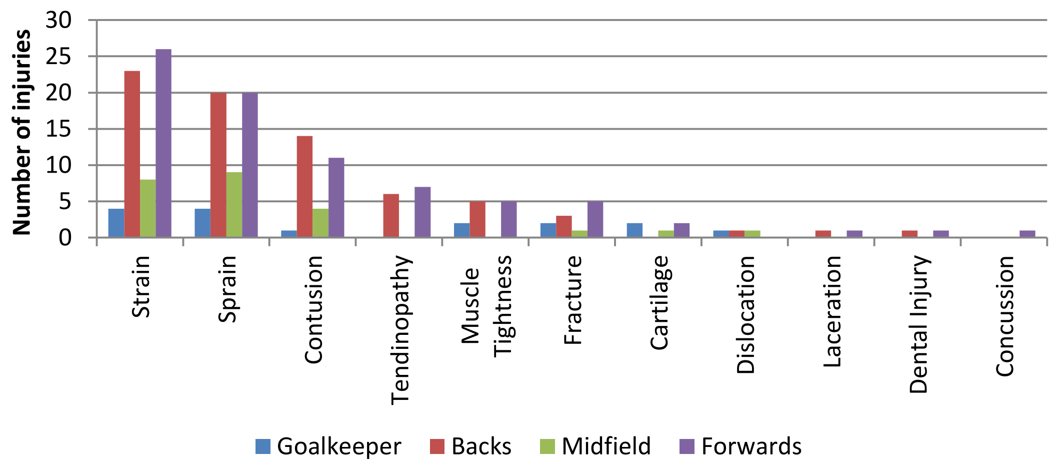

Figure 4.52: Distribution of nature of injury by position

4. 3. 3. 5. 4 . Relationship between a free taking role and injury

Participants who became injured were predominantly not a free taker (73.6%, 142) compared to a free taker (26.4%, 51).

4. 3. 3. 5. 5 . Relationship between playing surface and injury

The majority of injuries occurred on grass (84.4%, 152), followed by synthetic surfaces (13.3%, 24), indoor (0.6%, 1), beach (0.6%, 1) and other (1.1%, 2) (Figure 4.53).

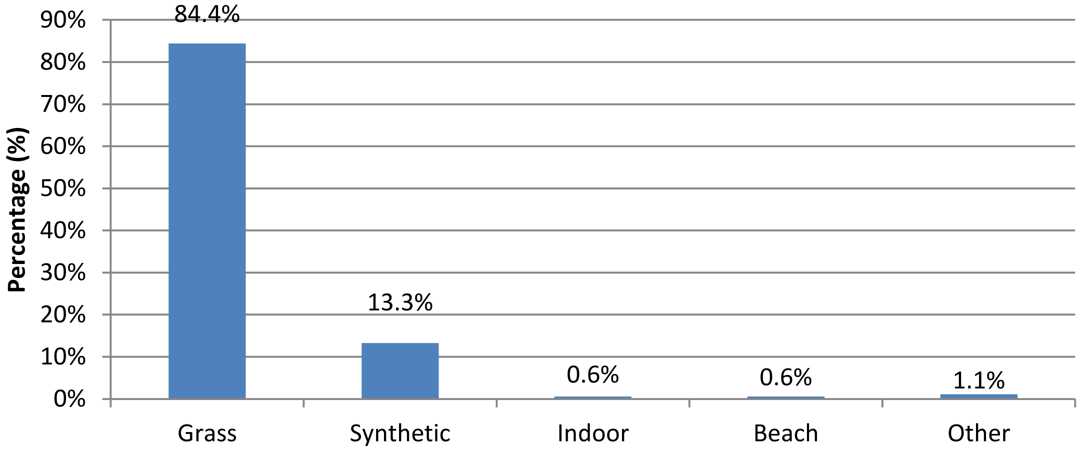

Figure 4.53: Playing Surface

4. 3. 3. 5. 6 . Relationship between weather conditions and injury

Injuries occurred outdoors (98.4%, 189) in the majority of cases with only 1.6% (3) of injuries occurring indoors. With regard to temperature, normal temperature was predominant (64.3%, 110), followed by cold (31.6%, 54) and hot (4.1%, 7). In relation to the weather conditions during injury, dry weather accounted for the majority of injuries (66.5%, 113), followed by wet weather (32.4%, 55) and frozen weather (1.2%, 2).

4. 3. 3. 5. 7 . Protective Equipment worn

The majority (81.3%, 157) of collegiate participants wore no extra protective equipment. Mouth guards and strapping were the main types of protective equipment worn by collegiate participants and accounted for 12.4% (24) and 6.2% (12) of equipment worn respectively. Ankle strapping was the most predominant type of strapping worn by collegiate participants followed by an equal distribution of thumb, patellar and wrist strapping (0.5%, 1).

4. 3. 3. 6. The injury assessment

4. 3. 3. 6. 1 . Injury examination

The majority (82.4%, 189) of injuries were assessed solely by the main therapist in this study. However 17.6% (34) of injuries were referred for further assessment by an orthopaedic surgeon.

4. 3. 3. 6. 2 . Further Investigations completed

Only 29.0% of injuries required further investigations to be completed. Of these, 33.7% (19) underwent an MRI scan, 32.0% (18) an X-ray, 1.7% underwent a blood test. A number of injured participants underwent a number of further investigations, 28.6% (16) were referred for both an MRI scan and X-ray and 3.4% (2) underwent both an X-ray and CT scan.

4. 3. 4. Comparison between Gaelic football and hurling injuries in adolescents

Further analysis of the results of the epidemiology of Gaelic football and hurling injuries in adolescents was assessed.

4. 3. 4. 1. Injury Incidence in adolescent Gaelic footballers and hurlers

Further analysis on the total, training and match injury rates of adolescent Gaelic footballers and hurlers were completed (Table 4.12). The total injury incidence was found to be slightly higher in Gaelic football than hurling. Match injuries accounted for a higher injury incidence than training in both Gaelic football and hurling however the match injury incidence in hurling was higher.

Table 4.12: Injury incidence in adolescent Gaelic footballers and hurlers

Injuries per 1,000 hours	Gaelic football		Hurling	
	Incidence Rate	95% CI	Incidence Rate	95% CI
Total	4.890	3.783-5.997	4.388	3.171-5.604
Training	3.007	2.051-3.963	2.293	1.334-3.251
Match	9.259	5.629-12.888	11.111	6.241-15.980

4. 3. 4. 2. The Injury Description

4. 3. 4. 2. 1 . Onset of injury

Acute injuries were more common and accounted for a similar percentage of injuries in Gaelic football and hurling (Table 4.13). New injuries were more common in hurling than Gaelic football; with both early recurrence (<2 months) and late recurrence (2-12 months) more common in Gaelic football than hurling and a similar percentage of persistent injuries (Table 4.13).

4. 3. 4. 2. 2 . Side of injury

Bilateral injuries were more common in hurlers than in Gaelic football (Table 4.13). In contrast injuries, to the left hand side were more predominant in Gaelic football.

4. 3. 4. 2. 3 . Body parts injured

Lower body injuries were predominant in both Gaelic footballers and hurlers. However, hurling was found to have a higher percentage of trunk/spine injuries than Gaelic football; with lower and upper body injuries occurring more frequently in Gaelic footballers (Table 4.13).

The regional distribution of injuries was similar between Gaelic footballers and hurlers with exception to the trunk/spine, hip/groin/thigh and forearm/wrist/hand. Injuries to the trunk and spine were more common in hurlers whereas hip/groin/thigh and forearm/wrist/hand injuries were more predominant in Gaelic footballers (Figure 4.54). This was further demonstrated by Figure 4.55 as it shows that hurlers had a higher incidence of lower back injuries and Gaelic footballers had a higher percentage of hamstring, quadriceps and hip injuries. In addition, Gaelic footballers had a higher incidence of hand and finger injuries.

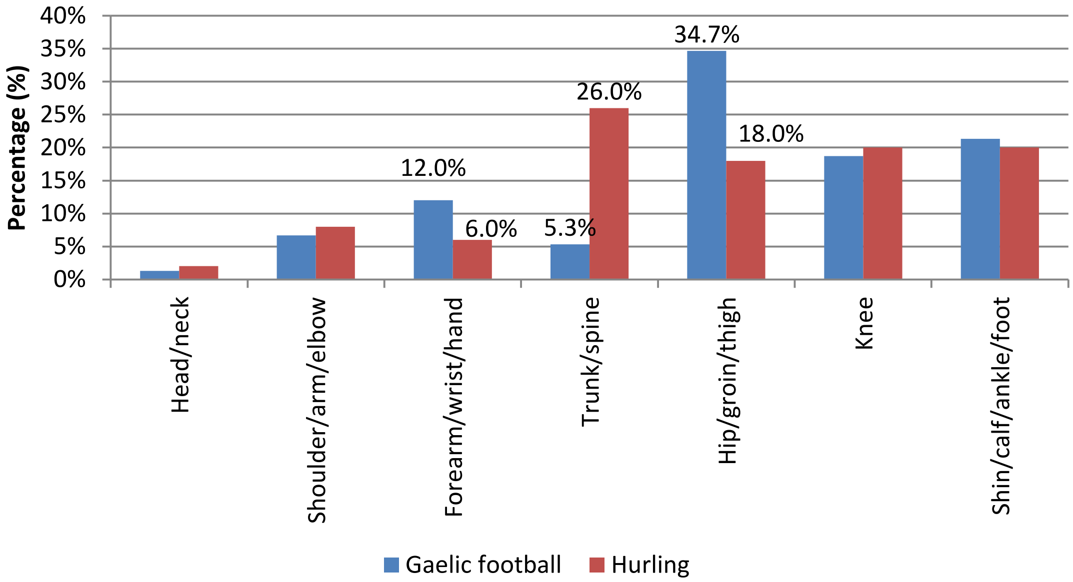

Figure 4.54: Regional distribution of injuries in adolescent Gaelic footballers and hurlers

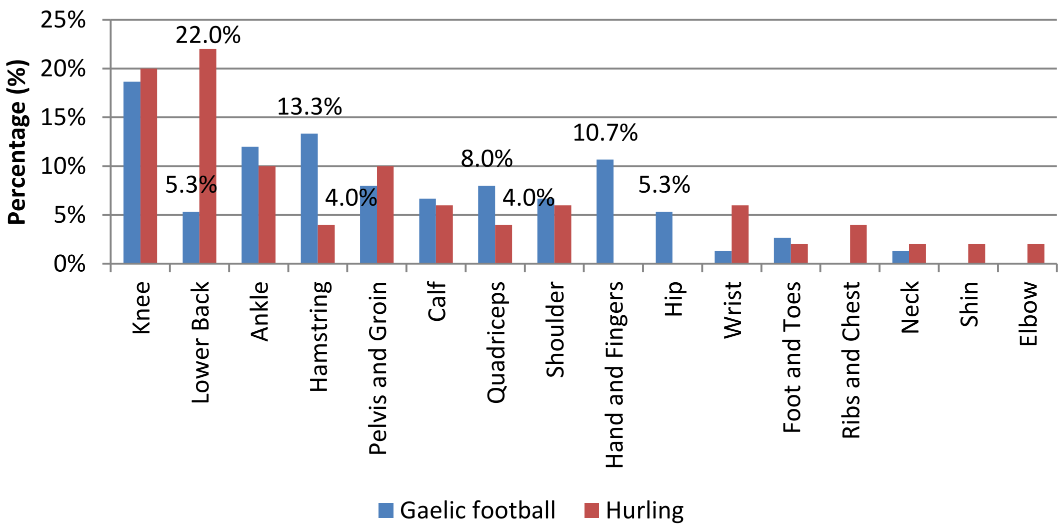

Figure 4.55: Body parts injured in adolescent Gaelic footballers and hurlers

4. 3. 4. 2. 4 . Nature of injury

Muscle injuries were predominant in both Gaelic football and hurling, however muscle injuries were more common in hurlers (Figure 4.56). Ligament and bone injuries were more common in Gaelic footballers. Figure 4.57 further demonstrates these distributions as it displays the nature of injuries in Gaelic footballers and hurlers.

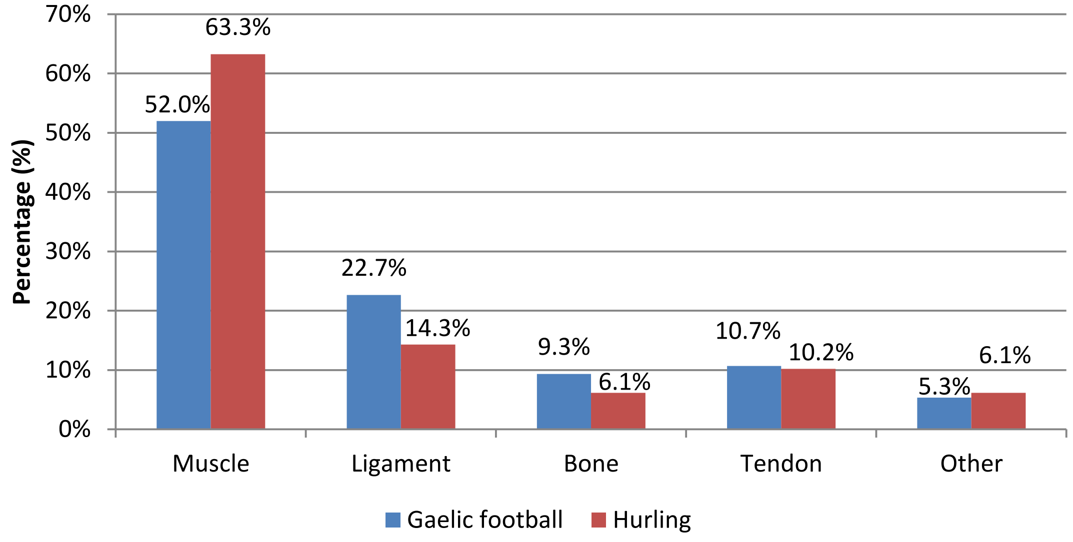

Figure 4.56: General nature of injury in adolescent Gaelic footballers and hurlers

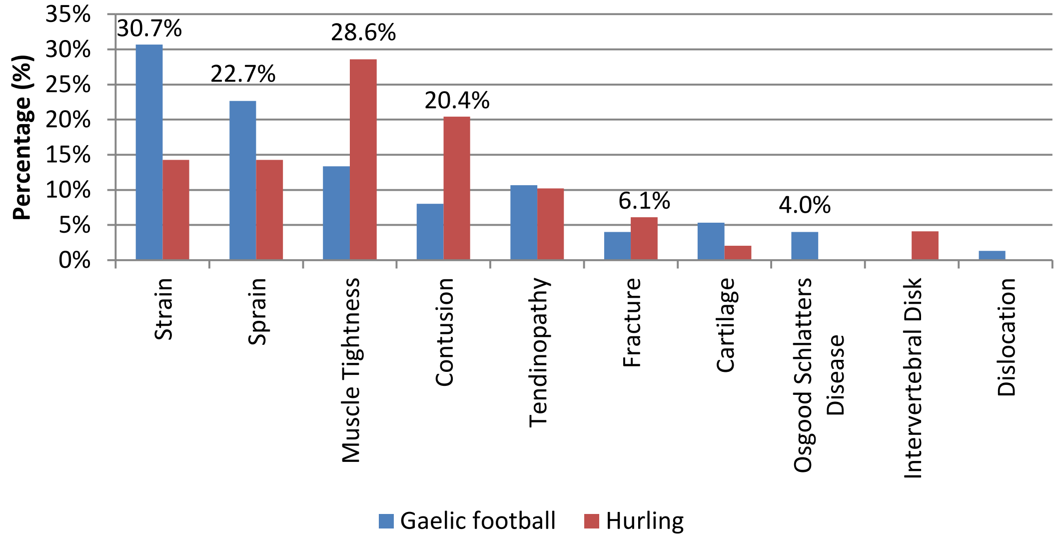

Figure 4.57: Nature of injury in adolescent Gaelic footballers and hurlers

4. 3. 4. 2. 5 . Severity of Injury

Similar percentages of Gaelic footballers and hurlers continued playing and training after the injury occurred (Table 4.13). Minor injuries were more common in hurling however moderate and severe injuries were more predominant in Gaelic football (Table 4.13). No significant difference was noted between the days missed from light training (p=0.761), full training (p=0.873) and full fitness (p=0.746) between injured Gaelic footballers and hurlers. The majority of Gaelic footballers (93.3%) and hurlers (92.0%) did not require surgery after injury. 6.7% of Gaelic footballers and 6.0% of hurlers required surgery during the season, with 2.0% of hurlers undergoing surgery after the season had ended.

4. 3. 4. 3. The Injury Event

4. 3. 4. 3. 1 . Mechanism of Injury

Gaelic footballers and hurlers had a similar percentage of contact and non-contact injuries with non-contact injuries predominating (Table 4.13). Of the non-contact injuries, 18.7% of Gaelic football and 14.3% of hurling were overuse in nature and 45.3% and 49.0% were non-contact acute injuries in Gaelic footballers and hurlers respectively. Of the contact injuries in Gaelic football, the majority were due to contact with another player (18.7%), a football (9.3%), the playing surface (4.0%), assault or violence (2.3%) and the apparatus (1.3%). The majority of contact injuries in hurling were due to contact with another player (18.4%), followed by hurley (8.2%), the playing surface (8.2%) and assault and violence (2.0%). Sprinting, jumping/catching and kicking were more common in Gaelic football however falling was more common in hurling (Figure 4.58). Tackling (being tackled and tackling) was more common in hurling and was the mechanism of injury in 25.0% of hurlers.

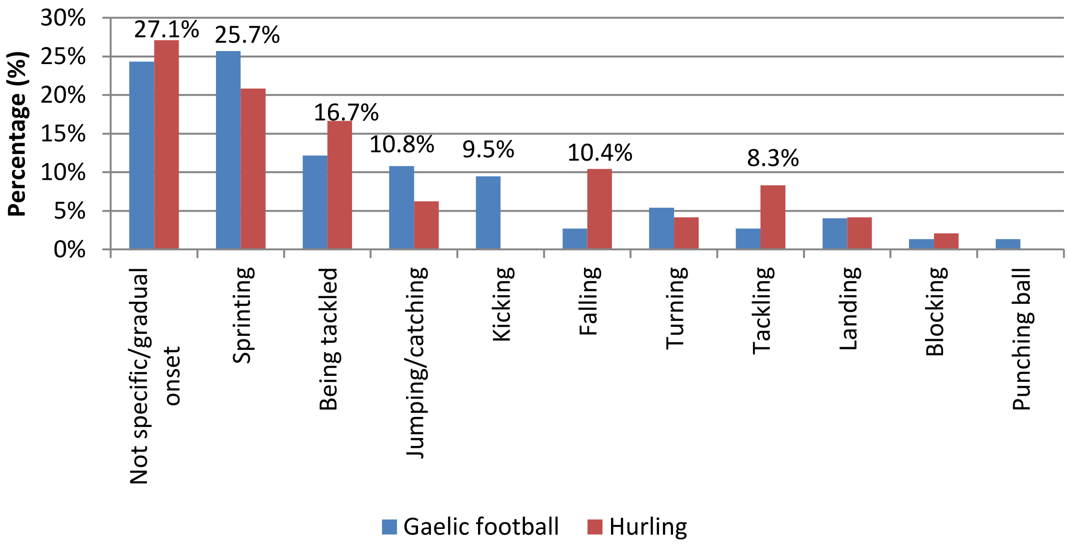

Figure 4.58: Mechanism of injury in adolescent Gaelic footballers and hurlers

4. 3. 4. 3. 2 . Time of Injury

Injuries primarily occurred during training and matches and accounted for a similar percentage in Gaelic footballers and hurlers (Table 4.13). More injuries occurred in the warm up in Gaelic football and in the cool down in hurling.

An independent samples t-test was completed to compare the minutes the injured occurred in Gaelic footballers and hurlers. No significant difference was noted between

Gaelic footballers and hurlers in adolescent (p=0.307) and collegiate participants (p=0.981). The majority of injuries occurred in the second half with 61.8% and 56.0% of injuries occurring in hurlers and Gaelic footballers respectively. Injuries during the 4th quarter were more common in hurling with injuries in the 1st quarter occurring more commonly in Gaelic footballers (Figure 4.59). The percentage of injuries during the 2nd and 3rd quarter was similar in Gaelic footballers and hurlers.

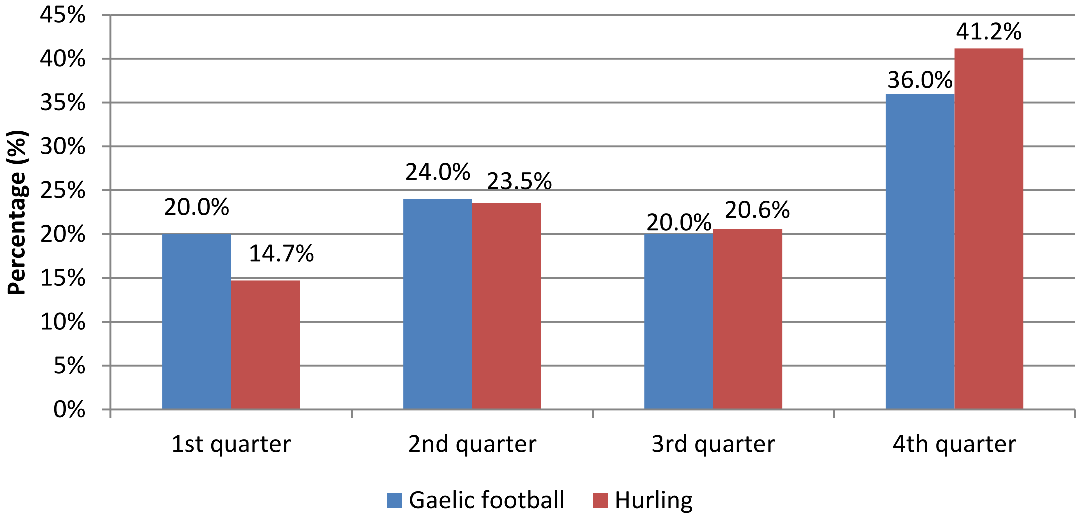

Figure 4.59: Quarter of injury in adolscent Gaelic footballers and hurlers

4. 3. 4. 3. 3 . Foul Play

The majority of injuries did not occur due to foul play. Hurlers received an injury due to foul play (14.3%) more commonly than Gaelic footballers (9.3%). In Gaelic football, 1.3% of injuries were due to an own foul with the rest of Gaelic football injuries and all hurling injuries due to an opponent foul. The majority of foul play that lead to an injury in hurling received a free with the majority of Gaelic footballers receiving a yellow card (Table 4.13).

4. 3. 4. 4. Factors Surrounding the Injury

4. 3. 4. 4. 1 . Relationship between time of year and injury

The percentages of injuries occurring from April to December were similar between Gaelic football and hurling (Figure 4.60). However, injuries to Gaelic footballers were more common in January and March with hurling injuries predominant in February.

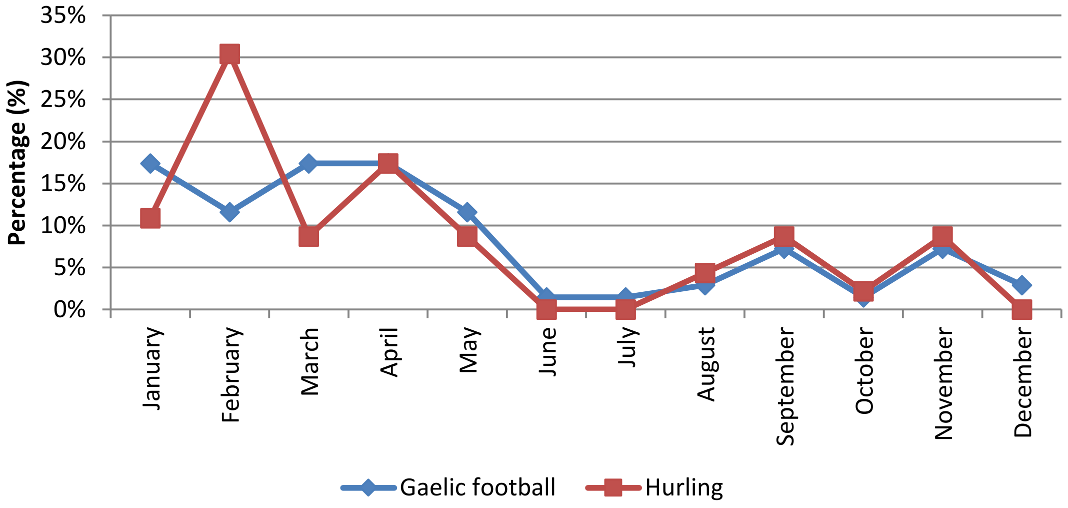

Figure 4.60: Monthly profile of injury in adolescent Gaelic footballers and hurlers

4. 3. 4. 4. 2 . Relationship between relative age group and injury

The majority of Gaelic footballers and hurlers played with their own age group, however Gaelic footballers played at a higher percentage (97.3%) than hurlers (86.0%). Similarly hurlers (14.0%) played in an older age group more commonly than Gaelic footballers (2.7%).

4. 3. 4. 4. 3 . Relationship between playing position and injury

Injuries predominated in backs in Gaelic footballers with a higher percentage of injuries occurring than in hurlers (Figure 4.61). Injuries were more common in hurling to midfielders and goalkeepers in Gaelic football. When taking the adjusted figures for the amount of players in each position into account, injuries in goalkeepers (15.95%) and backs predominated in Gaelic footballers compared to adolescent hurlers (7.9%, 23.7%) and injuries in midfielders primarily occurred in hurlers (43.4%) in comparison to Gaelic footballers (33.9%). A similar percentage of injuries occurred in forwards for both adolescent Gaelic footballers (24.4%) and hurlers (25.0%).

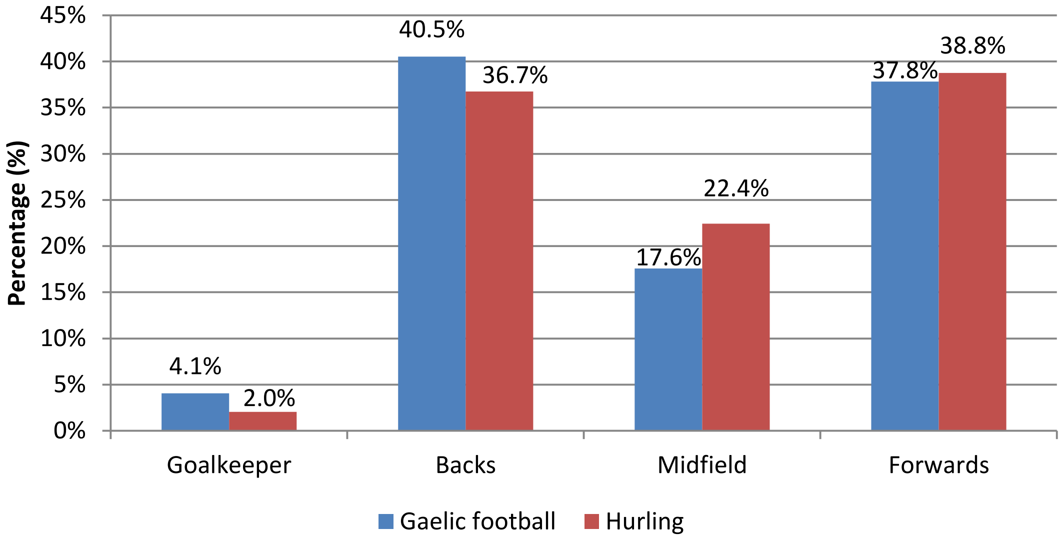

Figure 4.61: Distribution of injuries in different positions in adolescent Gaelic footballers and hurlers

4. 3. 4. 4. 4 . Relationship between a free taking role and injury

The majority of injured participants did not have a free taking role (Table 4.13).

4. 3. 4. 4. 5 . Relationship between playing surface and injury

Injuries occurred more commonly on grass, with more injuries occurring in grass in Gaelic footballers than hurlers (Figure 4.62). Indoor injuries were more frequent in hurlers.

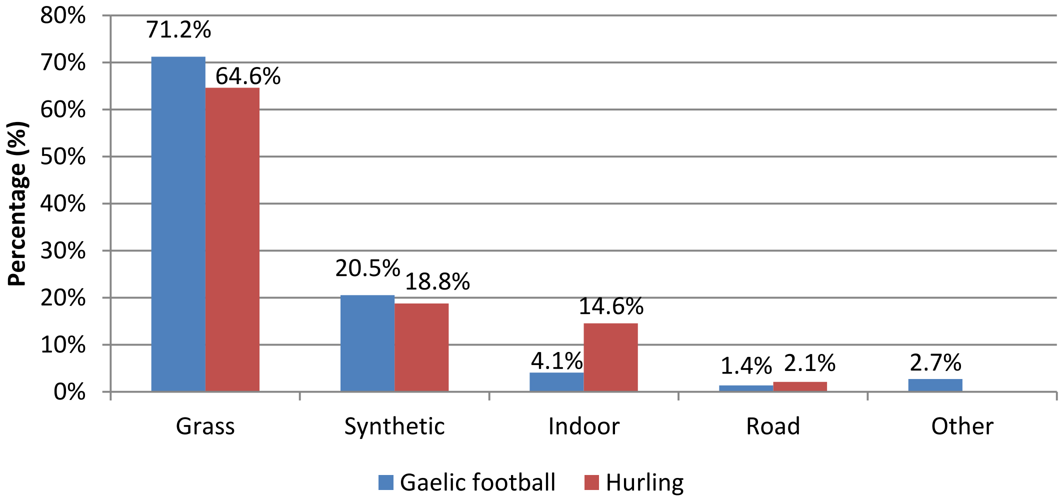

Figure 4.62: Playing surface in adolescent Gaelic footballers and hurlers

4. 3. 4. 4. 6 . Relationship between weather conditions and injury

The temperature was predominantly normal when injuries occurred in both Gaelic football and hurling, however a higher percentage of injuries occurred when the temperature was normal in hurling (Table 4.13). In contrast, Gaelic football injuries occurred in the cold more commonly than hurling. Injuries when the ground was dry were predominant with a higher percentage of hurling injuries occurring on dry ground (Table 4.13). Injury on wet ground occurred more frequently in Gaelic footballers.

4. 3. 4. 4. 7 . Protective Equipment worn

The majority of Gaelic footballers (73.3%) and hurlers (95.9%) wore no extra protective equipment. Mouth guards and ankle strappings were worn by Gaelic footballers and accounted for 80.0% and 20.0% of the protective equipment worn.

4. 3. 4. 5. The injury assessment

4. 3. 4. 5. 1 . Injury examination

The majority of injuries in Gaelic footballers (77.3%) and hurlers (84.0%) were assessed solely by the main therapist in this study. Gaelic footballers (22.7%) were referred on for further assessment by an orthopaedic surgeon more commonly than hurlers (16.0%).

4. 3. 4. 5. 2 . Further Investigations completed

A similar percentage of Gaelic footballers (18.7%) and hurlers (18.1%) required further investigations to be completed. Of these further investigations the majority of Gaelic footballers underwent an MRI scan (42.9%), followed by an X-ray (28.6%) and 28.6% were referred for both an MRI scan and X-ray. In hurlers the majority underwent an X-ray (44.4%), followed by an MRI scan (33.3%) and 22.2% were referred for both an MRI scan and X-ray.

Table 4.13: Summary epidemiology results between adolescent Gaelic football and hurling

	Gaelic football	Hurling
Onset of injury		
Acute	73.3%	73.5%
Overuse	26.7%	26.5%
New and Recurrent injuries		
New	52.7%	66.7%
Early Recurrence (<2 months)	14.9%	8.3%
Late Recurrence (2-12 months)	16.2%	8.3%
Persistent/recurring	16.2%	16.7%
Side of injury		
Right	41.9%	38.8%
Left	50.0%	42.9%
Bilateral	8.1%	18.4%
General distribution of injuries		
Lower body	76.0%	64.0%
Upper body	20.0%	14.0%
Trunk/spine	4.0%	22.0%
Stopped or continued playing after injury		
Stopped playing	66.7%	68.1%
Continued playing	33.3%	31.9%
Severity of injury		
Minor	41.7%	61.7%
Moderate	20.8%	8.5%
Severe	37.5%	29.8%
Contact or non-contact injuries		
Contact	36.0%	36.7%
Non-contact	64.0%	63.3%
Time of injury		
Warm up	17.4%	10.9%
Cool down	2.9%	8.7%
Training/match	79.7%	80.4%
Sanction given if foul play was cause of injury		
Free	40.0%	50.0%
Yellow card	50.0%	41.7%
Red card	10.0%	8.3%
Free taking role in team		
Free taking role	33.3%	24.5%
Not a free taking role	66.7%	75.5%
Temperature during injury		
Normal	62.5%	79.5%
Cold	31.3%	15.4%
Hot	6.3%	5.1%
Weather conditions during injury		
Dry	69.8%	77.8%
Wet	28.6%	16.7%
Frozen	1.6%	5.6%

4. 3. 5. Comparison between Gaelic football and hurling injuries in collegiate participants

Further analysis of the results of the epidemiology of Gaelic football and hurling injuries in collegiate participants was assessed.

4. 3. 5. 1. Injury Incidence in collegiate Gaelic footballers and hurlers

Further analysis on the total, training and match injury rates of collegiate Gaelic footballers and hurlers were completed (Table 4.14). The total injury incidence was found to be the same in Gaelic football and hurling. Match injuries accounted for a higher injury incidence than training in both Gaelic football and hurling however the match injury incidence in hurling was substantially higher.

Table 4.14: Injury incidence in collegiate Gaelic footballers and hurlers

Injuries per 1,000 hours	Gaelic football		Hurling	
	Incidence Rate	95% CI	Incidence Rate	95% CI
Total	13.303	11.084-15.523	14.695	10.303-19.088
Training	7.020	5.243-8.796	7.177	3.861-10.492
Match	42.716	33.236-52.196	59.808	36.363-83.253

4. 3. 5. 2. The Injury Description

4. 3. 5. 2. 1 . Onset of injury

Acute injuries were more common and accounted for a similar percentage of injuries in Gaelic football and hurling (Table 4.15). New injuries were most common in both Gaelic football and hurling and accounted for a similar percentage of injuries (Table 4.14). Early recurrence (<2 months) of injuries was more common in Gaelic football and late recurrence (2-12 months) was predominant in hurlers with a similar percentage of persistent injuries.

4. 3. 5. 2. 2 . Side of injury

Injuries to the right hand side were more common in Gaelic football with left hand side injuries more common in hurling (Table 4.15).

4. 3. 5. 2. 3 . Body parts injured

Lower body injuries were predominant in both Gaelic footballers and hurlers; Gaelic footballers had a higher incidence of lower body injuries than hurling (Table 4.15). Hurlers had more upper body and head/face injuries than Gaelic footballers with a similar percentage of injuries occurring in the trunk/spine.

With regard to the regional distribution of injuries, injuries to the shoulder, hip/groin/thigh, and trunk/spine were more common in hurling (Figure 4.63). This was further demonstrated by Figure 4.64 as hurlers had a higher incidence of injuries to the shoulder, hamstring, quadriceps, pelvis and groin and lower. In contrast, injuries to the knee, shin/calf/ankle/foot and forearm/wrist/hand were predominant in Gaelic footballers which corresponded to a higher percentage of injuries to the knee, ankle, forearm, wrist and hand and fingers. Notably, injuries to the hip were more common in Gaelic footballers than hurlers.

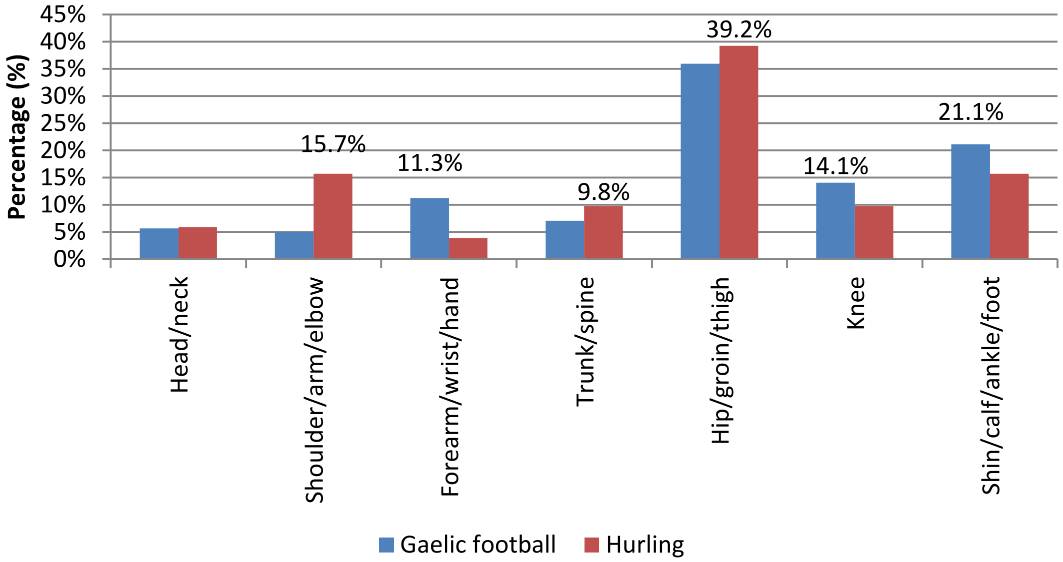

Figure 4.63: Regional distribution of injuries in collegiate Gaelic footballers and hurlers

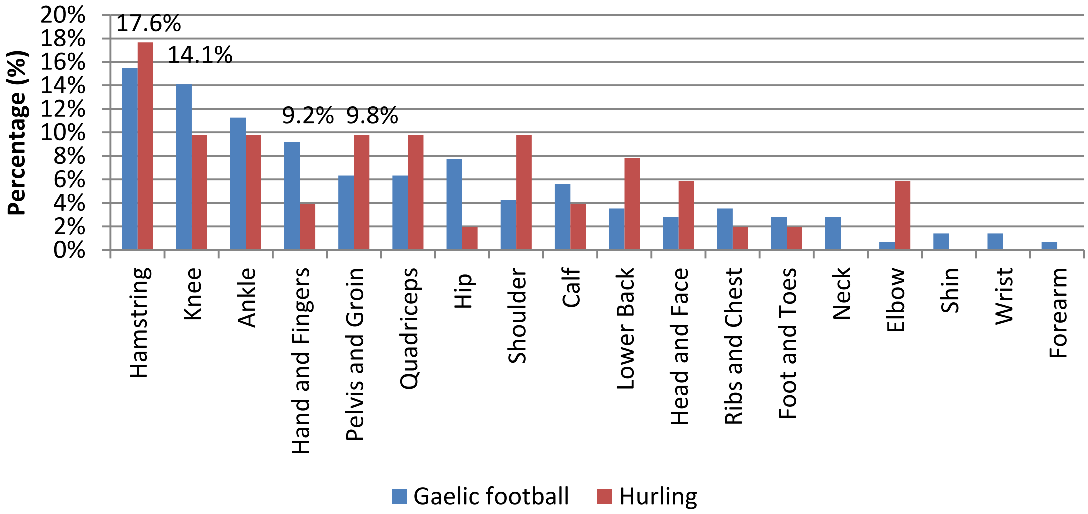

Figure 4.64: Body parts injured in collegiate Gaelic footballers and hurlers

4. 3. 5. 2. 4 . Nature of injury

The percentage of muscle and ligament injuries was similar in Gaelic football and hurling (Figure 4.65). Contusions and strains were more common in Gaelic football and muscle tightness was predominant in hurling (Figure 4.66). Fractures were more prevalent in Gaelic football which may be linked to the higher incidence of bone injuries in Gaelic football. Tendon injuries were more common in hurling and corresponded to a higher predominance of tendinopathy in hurlers.

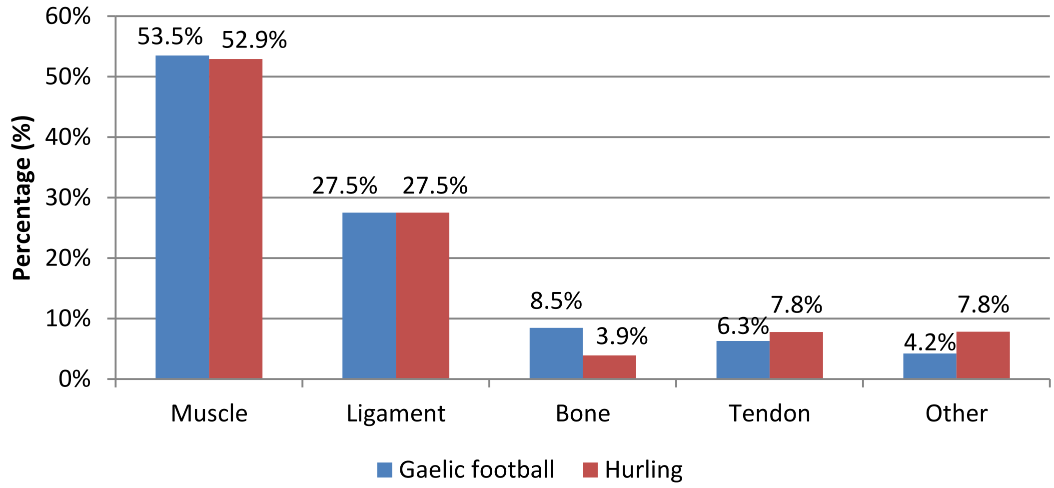

Figure 4.65: General nature of injury in collegiate Gaelic footballers and hurlers

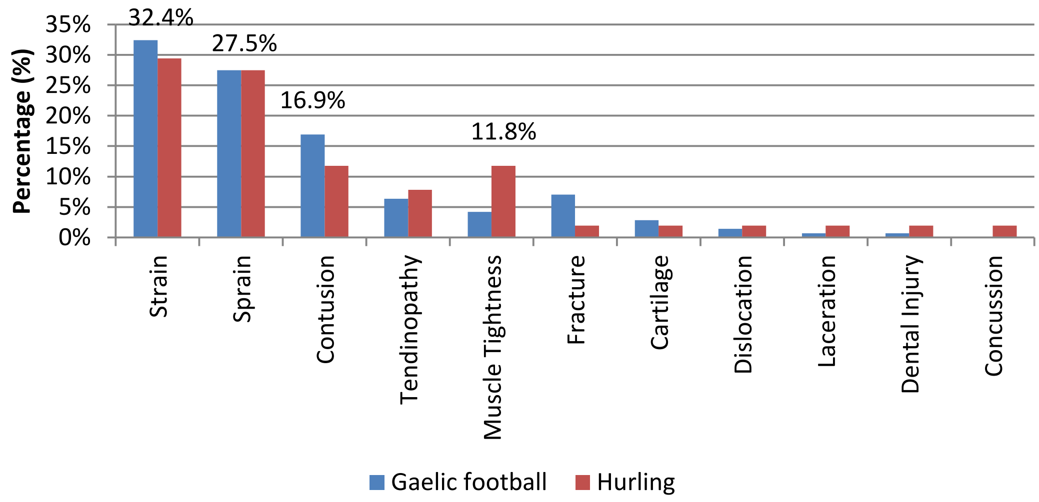

Figure 4.66: Nature of injury in collegiate Gaelic footballers and hurlers

4. 3. 5. 2. 5 . Severity of Injury

Collegiate participants predominantly stopped playing and training after the injury occurred. However, hurlers tended to carry on training and playing more commonly than Gaelic footballers after the injury occurred (Table 4.15). Both minor and severe injuries were predominant in hurlers, however moderate injuries were more common in Gaelic footballers (Table 4.15). No significant difference was noted between the days missed from light training (p=0.197), full training (p=0.152) and full fitness (p=0.130) between injured Gaelic footballers and hurlers. The majority of Gaelic footballers (88.0%) and hurlers (94.1%) did not require surgery after injury. 7.0% of Gaelic footballers and 5.9% of hurlers required surgery during the season, with 4.9% of Gaelic footballers undergoing surgery after the season had ended.

4. 3. 5. 3. The Injury Event

4. 3. 5. 3. 1 . Mechanism of Injury

Gaelic footballers had a higher percentage of contact injuries whereas hurlers had an increased amount of non-contact injuries (Table 4.15). Of the non-contact injuries, injuries due to overuse were more common in hurlers and accounted for 17.6% of all injuries with only 9.2% of Gaelic football injuries due to overuse. The percentage of non-contact acute injuries was similar and accounted for 43.0% and 43.1% in Gaelic footballers and hurlers respectively. Contact with another player was predominant in contact injuries and accounted for 28.9% of injuries, followed by the playing surface (11.3%), football (6.3%), apparatus (0.7%) and assault and violence (0.7%). In hurling, contact with another player was also most common (25.5%), followed by a hurley (11.8%), sliother (2.0%) and assault and violence (2.0%). Landing, jumping/catching, kicking and blocking were all predominant in Gaelic footballers (Figure 4.67). In contrast, being tackled and turning were more common in hurlers. In fact, tackling (being tackled and tackling) accounted for 29.4% of injuries in hurlers compared to 20.6% in Gaelic footballers.

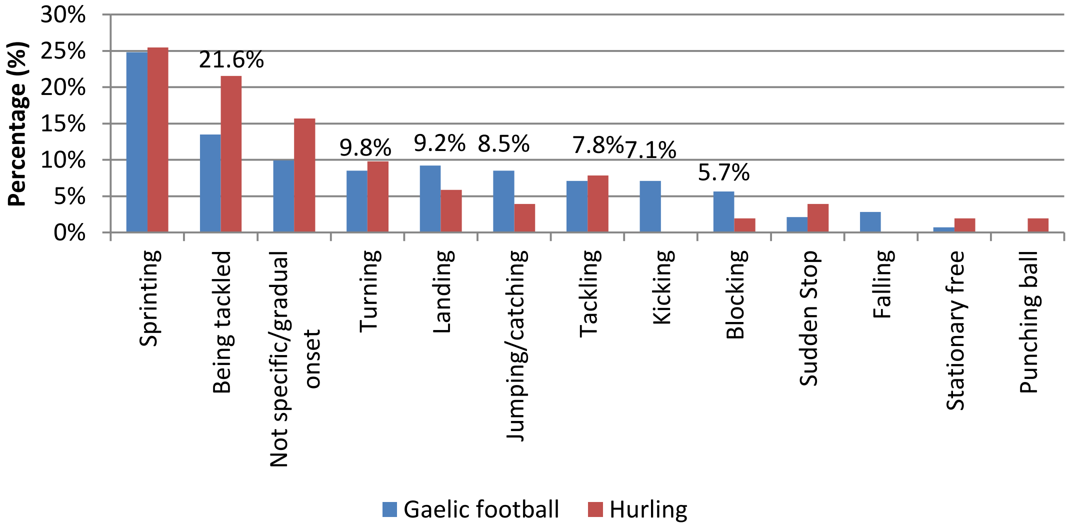

Figure 4.67: Mechanism of injury in collegiate Gaelic footballers and hurlers

4. 3. 5. 3. 2 . Time of Injury

Injuries primarily occurred during training and matches, however a higher incidence of injuries occurred in the warm-up and cool down in Gaelic football (Table 4.15). No significant difference was noted between the minutes the injury occurred between Gaelic footballers and hurlers when an independent samples t-test was completed ($p=0.981$). The majority of injuries occurred in the second half with 71.3% and 67.5% of injuries occurring in Gaelic footballers and hurlers respectively. Injuries in that occurred during the 4th quarter were similar in Gaelic footballers (48.5%) and hurlers (48.6%) (Figure 4.68). Injuries during the 1st quarter and 3rd quarter are more common in Gaelic footballers and in the 2nd quarter for hurlers.

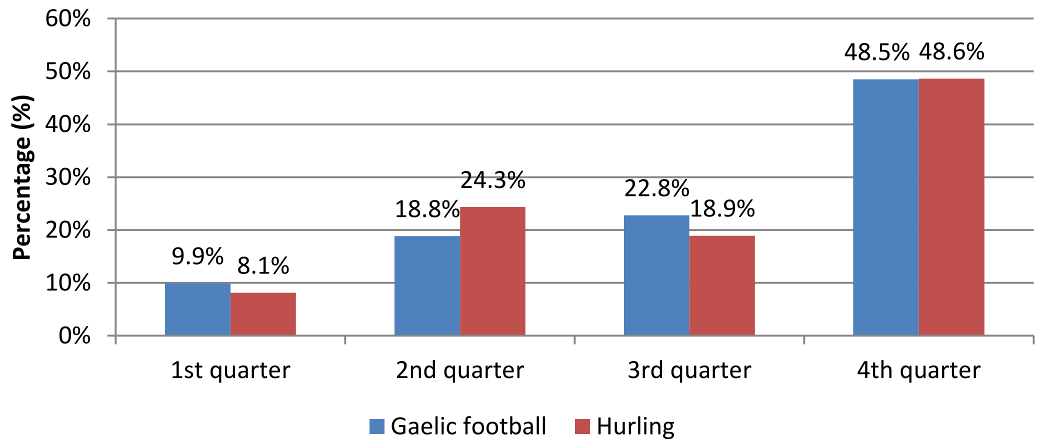

Figure 4.68: Quarter of injury in collegiate Gaelic footballers and hurlers

4. 3. 5. 3. 3 . Foul Play

The majority of injuries did not occur due to foul play. Gaelic footballers received an injury due to foul play (7.0%) more commonly than hurlers (2.0%). In Gaelic football, injuries occurred due to an opponent and own foul to the same percentage (3.5%). Only the injured Gaelic footballers reported the sanction given by the referee with a free being most commonly issued (50.0%), followed by a yellow card (37.5%) and a red card (12.5%).

4. 3. 5. 4. Factors Surrounding the Injury

4. 3. 5. 4. 1 . Relationship between time of year and injury

The percentages of injuries occurring from March to August were similar between Gaelic football and hurling (Figure 4.69). Injuries to hurlers were more common in October and February however injuries to Gaelic footballers were predominant in January, September, November and December.

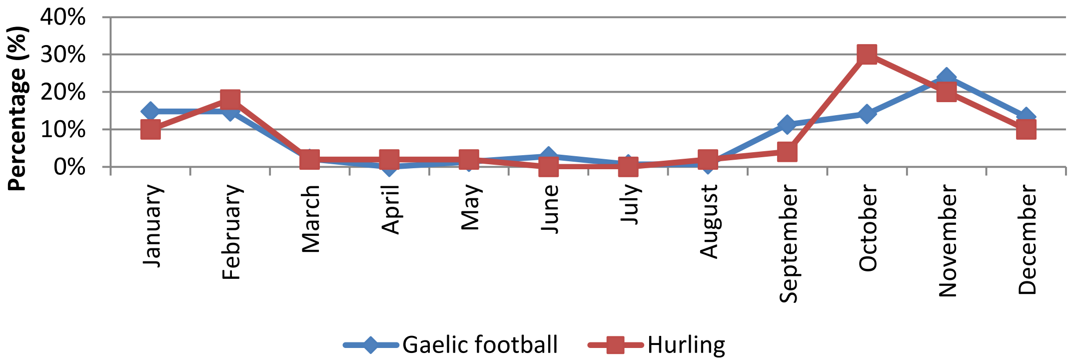

Figure 4.69: Monthly profile of injury in collegiate Gaelic footballers and hurlers

4. 3. 5. 4. 2 . Relationship between relative age group and injury

The majority of Gaelic footballers and hurlers played with their own age group, however hurlers played at a higher percentage (94.1%) than Gaelic footballers (92.3%). Similarly Gaelic footballers (7.7%) played in an older age group more commonly than hurlers (5.9%).

4. 3. 5. 4. 3 . Relationship between playing position and injury

Injuries to backs (47.1%) and forwards (45.1%) were more common in hurlers (Figure 4.70). Injuries to goalkeepers (10.6%) and midfielders (14.8%) were predominant in Gaelic footballers. When taking the adjusted figures for the amount of players in each position into account, injuries to goalkeepers (34.8%) predominated in collegiate Gaelic footballers, followed by midfielders (24.3%), forward (21.6%) and backs (19.3%). In collegiate hurlers, injuries to backs (38.7%) predominated, followed by forwards (37.1%), midfielders (14.5%) and goalkeepers (9.7%).

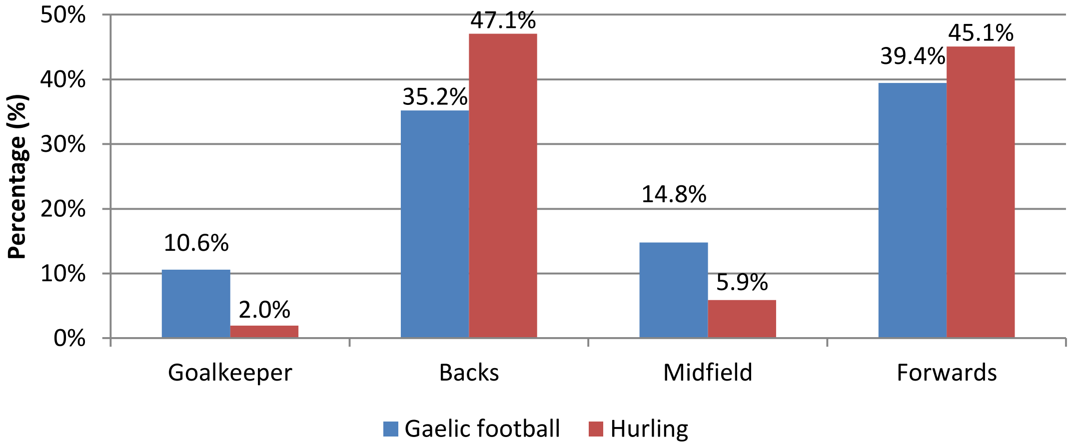

Figure 4.70: Distribution of injuries in different positions in collegiate Gaelic footballers and hurlers

4. 3. 5. 4. 4 . Relationship between a free taking role and injury

The majority of injured participants did not have a free taking role with hurlers (86.3%) predominantly not having a free taking role compared to Gaelic footballers (Table 4.15).

4. 3. 5. 4. 5 . Relationship between playing surface and injury

Injuries occurred more commonly on grass, with more injuries occurring in grass in hurlers than Gaelic footballers (Figure 4.71). Synthetic injuries were more frequent in Gaelic footballers.

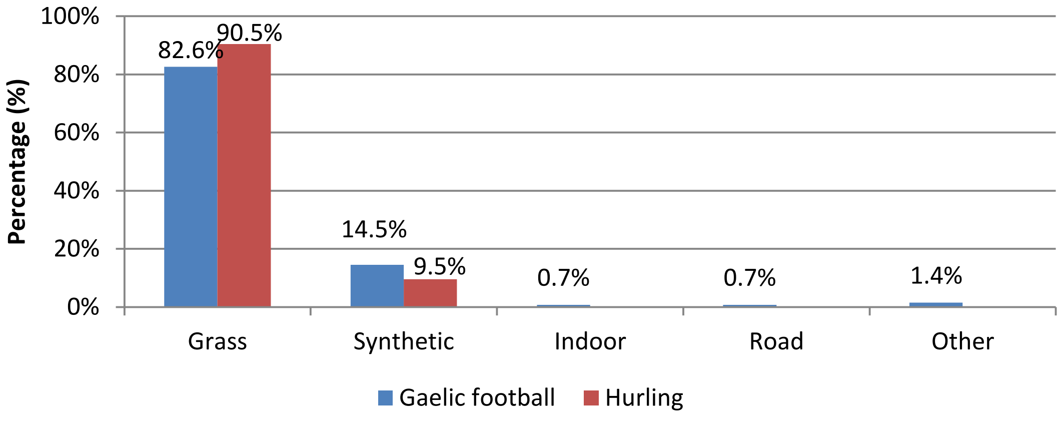

Figure 4.71: Playing surface in collegiate Gaelic footballers and hurlers

4. 3. 5. 4. 6 . Relationship between weather conditions and injury

The temperature was predominantly normal when injuries occurred in both Gaelic football and hurling, however a higher percentage of injuries occurred when the temperature was normal in hurling (Table 4.15). In contrast, Gaelic football injuries occurred in the cold more commonly than hurling. Injuries when the ground was dry were predominant with a higher percentage of hurling injuries occurring on dry ground (Table 4.15). Injury on wet ground occurred more frequently in Gaelic footballers.

4. 3. 5. 4. 7 . Protective Equipment worn

The majority of Gaelic footballers (76.1%) and hurlers (96.1%) wore no extra protective equipment. All hurlers that wore protective equipment wore an ankle strapping. Mouth guards (70.6%), ankle strapping (20.6%), wrist taping (2.9%), patellar taping (2.9%) and thumb tapping (2.9%) were worn by Gaelic footballers.

4. 3. 5. 5. The injury assessment

4. 3. 5. 5. 1 . Injury examination

The majority of injuries in Gaelic footballers (79.6%) and hurlers (90.2%) were assessed solely by the main therapist in this study. Gaelic footballers (20.4%) were referred on for further assessment by an orthopaedic surgeon more commonly than hurlers (9.8%).

4. 3. 5. 5. 2 . Further Investigations completed

Gaelic footballers (31.0%) required further investigations to be completed more commonly than hurlers (23.5%). Of these, the majority of Gaelic footballers underwent an MRI scan (36.4%), followed by an X-ray (31.8%) , an X-ray and MRI scan (25.0%), an X-ray and CT scan (4.5%) and a blood work assessment (2.3%). In hurlers, the majority underwent an X-ray and MRI (41.7%), followed by an X-ray (33.3%) and an MRI scan (25.0%).

Table 4.15: Summary epidemiology results between collegiate Gaelic football and hurling

	Gaelic football	Hurling
Onset of injury		
Acute	78.9%	76.5%
Overuse	21.1%	23.5%
New and Recurrent injuries		
New	76.6%	78.4%
Early Recurrence (<2 months)	8.5%	2.0%
Late Recurrence (2-12 months)	2.1%	9.8%
Persistent/recurring	12.8%	9.8%
Side of injury		
Right	56.9%	47.9%
Left	36.5%	43.8%
Bilateral	6.6%	8.3%
General distribution of injuries		
Lower body	71.1%	64.7%
Upper body	16.2%	19.6%
Trunk/spine	9.2%	9.8%
Head/face	3.5%	5.9%
Stopped or continued playing after injury		
Stopped playing	85.1%	80.4%
Continued playing	14.9%	19.6%
Severity of injury		
Minor	34.8%	37.3%
Moderate	29.8%	17.6%
Severe	35.5%	45.1%
Contact or non-contact injury		
Contact	47.9%	39.2%
Non-contact	52.1%	60.8%
Time of injury		
Warm up	5.3%	2.4%
Cool down	4.5%	0.0%
Training/match	90.2%	97.6%
Sanction given if foul play was cause of injury		
Free	50.0%	0%
Yellow card	37.5%	0%
Red card	12.5%	0%
Free taking role in team		
Free taking role	31.0%	13.7%
Not a free taking role	69.0%	86.3%
Temperature during injury		
Normal	61.2%	73.8%
Cold	35.7%	19.0%
Hot	3.1%	7.1%
Weather conditions during injury		
Dry	63.8%	75.0%
Wet	35.4%	22.5%
Frozen	0.8%	2.5%

4. 3. 6. Comparison between fresher and senior injuries in Gaelic footballers

Further analysis of the results of the epidemiology of fresher and senior injuries in Gaelic footballers was assessed.

4. 3. 6. 1. Injury Incidence in fresher and senior Gaelic footballers

Higher total, training and match injury rates were found in fresher Gaelic footballers compared to senior players (Table 4.16). A higher match incidence rate occurred in both fresher and senior Gaelic footballers.

Table 4.16: Injury incidence in fresher and senior Gaelic footballers

Injuries per 1,000 hours	Fresher		Senior	
	Incidence Rate	95% CI	Incidence Rate	95% CI
Total	14.668	11.568-17.768	10.743	7.823-13.664
Training	8.640	4.140-6.390	7.323	4.657-9.988
Match	54.347	39.984-68.711	26.136	15.454-36.817

4. 3. 6. 2. The Injury Description

4. 3. 6. 2. 1 . Onset of injury

Acute injuries were more common in both fresher and seniors however senior players received more overuse injuries (Table 4.17). New injuries were more common in both fresher and senior Gaelic footballers; with senior players experiencing more early recurrence (<2 months), late recurrence (2-12 months) and persistent injuries (Table 4.17).

4. 3. 6. 2. 2 . Side of injury

Injuries to the right hand side were more common in senior players with injuries to the left hand side more common in fresher Gaelic footballers (Table 4.17). Bilateral injuries accounted for a similar percentage of injuries in both fresher and senior Gaelic footballers.

4. 3. 6. 2. 3 . Body parts injured

Lower body injuries were predominant in both fresher and senior Gaelic footballers (Table 4.17). However, senior players were found to have a higher percentage of lower body injuries; with upper body and trunk/spine injuries occurring more commonly in freshers. A similar percentage of head/face injuries occurred in fresher and senior Gaelic footballers.

Injuries to the forearm/wrist/hand, shin/calf/ankle/foot and head/neck/face were more common in fresher participants (Figure 4.72). This was further demonstrated by the predominance of hand and finger, calf, head/face and neck injuries in fresher Gaelic footballers (4.73). Injuries to the knee and shoulder/arm/elbow were more common in senior participants (Figure 4.72) and this was further demonstrated by the predominance of knee and shoulder injuries in senior Gaelic footballers (Figure 4.73).

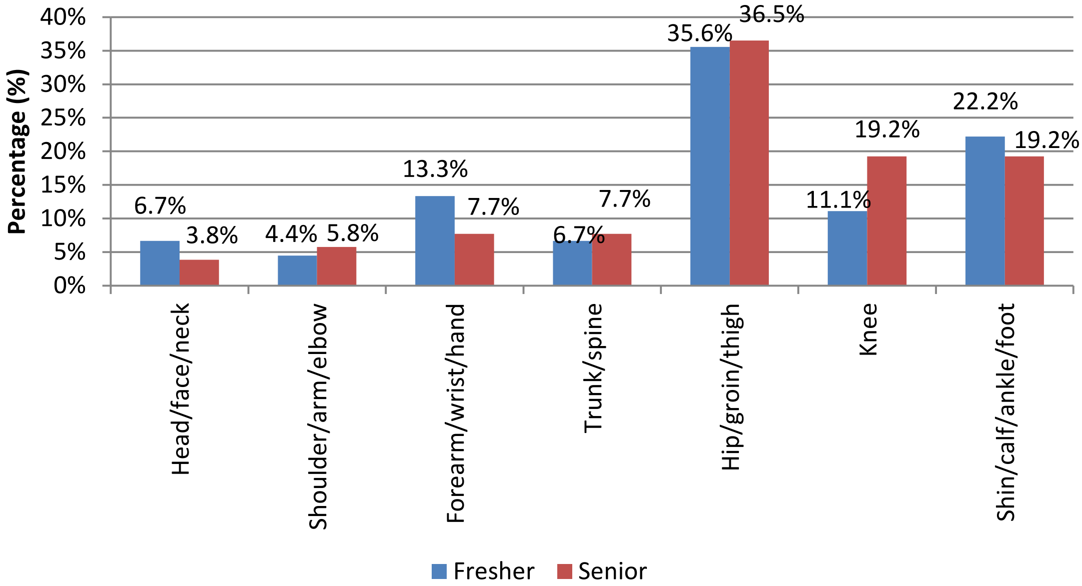

Figure 4.72: Regional distribution of injuries in fresher and senior Gaelic footballers

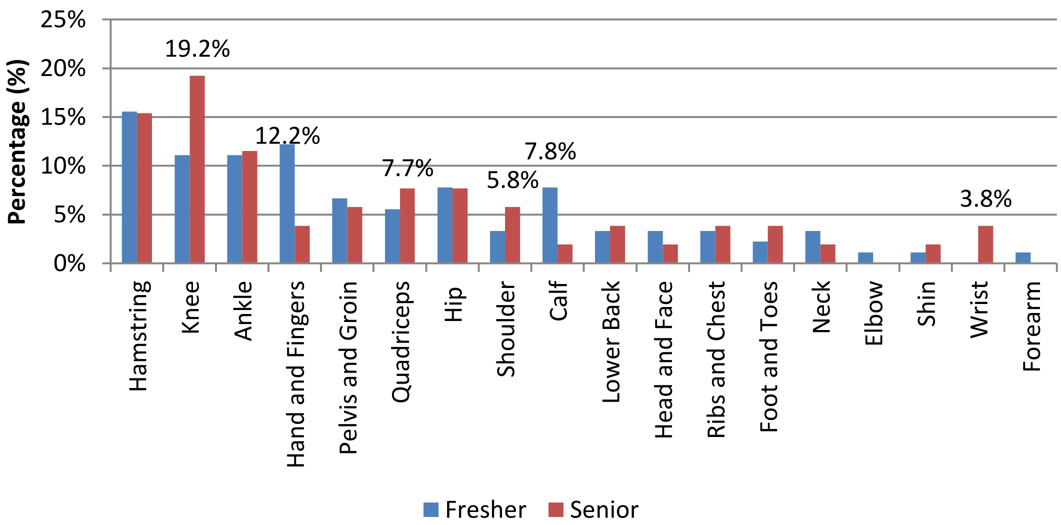

Figure 4.73: Body parts injured in fresher and senior Gaelic footballers

4. 3. 6. 2. 4 . Nature of injury

Muscle injuries were predominant in fresher Gaelic footballers (Figure 4.74) which corresponds to the substantially higher percentage of muscle contusions in fresher Gaelic footballers, however muscle strains and muscle tightness was more common in seniors (Figure 4.75). Ligament and bone injuries were more common in senior players which accounts for the higher incidence of strains and fractures in senior Gaelic footballers.

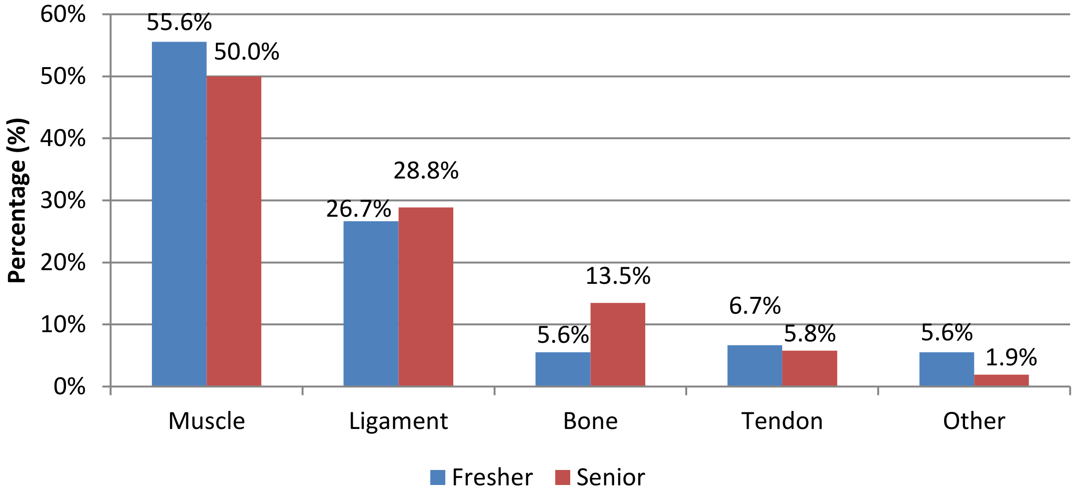

Figure 4.74: General nature of injury in fresher and senior Gaelic footballers

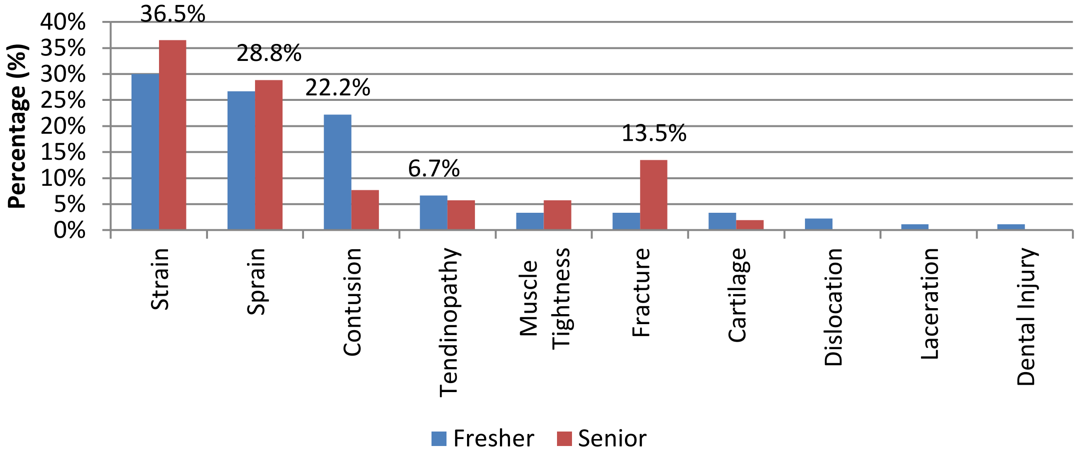

Figure 4.75: Nature of injury in fresher and senior Gaelic footballers

4. 3. 6. 2. 5 . Severity of Injury

The majority of fresher and senior Gaelic footballers stopped playing and training after the injury occurred with freshers predominating (Table 4.17). Both fresher and senior Gaelic footballers sustained a similar percentage of moderate injuries however freshers and seniors predominantly receiving minor and severe injuries respectively (Table 4.17). No significant difference was noted between the days missed from light training ($p=0.543$) between fresher and senior Gaelic footballers. However, fresher players were found to have significantly lower days missed from full training ($p<0.0001$) and full fitness ($p<0.0001$) compared to senior Gaelic footballers. The majority of fresher (92.2%) and senior (80.8%) Gaelic footballers did not require surgery after injury. 5.6% of fresher and 3.8% of senior Gaelic footballers required surgery during the season, with

2.2% of freshers and 15.4% of senior players undergoing surgery after the season had ended.

4. 3. 6. 3. The Injury Event

4. 3. 6. 3. 1 . Mechanism of Injury

Fresher and senior Gaelic footballers had a similar percentage of contact and non-contact injuries with non-contact injuries predominating (Table 4.17). Of the non-contact injuries, 10.0% of fresher and 7.7% of senior Gaelic football injuries were overuse in nature and 42.2% and 44.2% were non-contact acute injuries in fresher and senior Gaelic footballers respectively. Of the fresher contact injuries, the majority were due to contact with another player (30.0%), a football (8.9%), the playing surface (4.0%) and assault or violence (1.1%). The majority of senior contact injuries were due to contact with another player (21.2%), the playing surface (17.3%), apparatus (3.8%), and football (1.9%). Sprinting, jumping/catching, kicking and landing were more common in senior Gaelic footballers however being tackled and turning were predominant in fresher Gaelic footballers (Table 4.17). Tackling (being tackled and tackling) was more common in fresher (24.4%) than senior Gaelic footballers (13.7%).

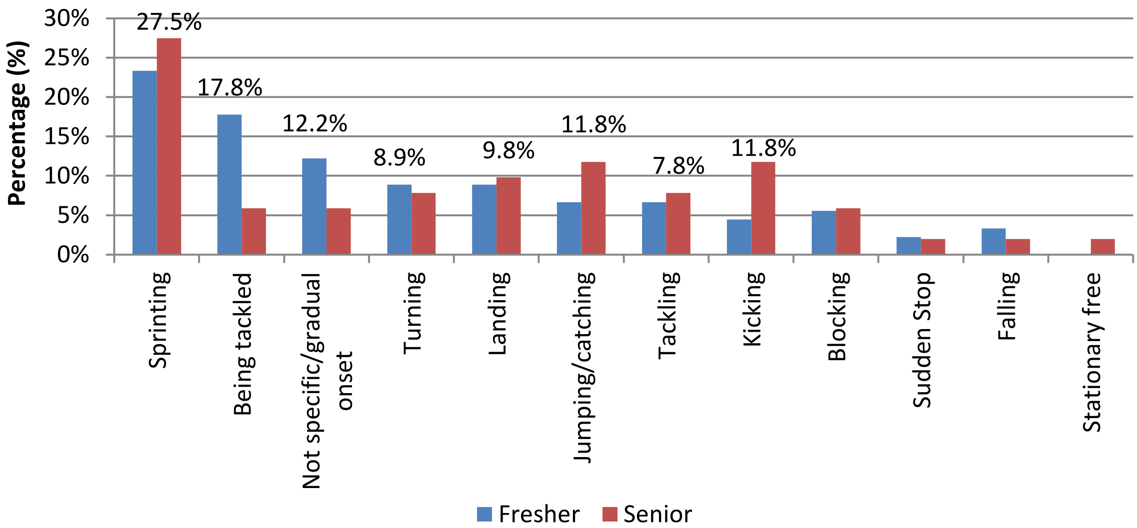

Figure 4.76: Mechanism of injury in fresher and senior Gaelic footballers

4. 3. 6. 3. 2 . Time of Injury

Injuries primarily occurred during training and matches with a higher percentage of these injuries occurring in fresher Gaelic footballers (Table 4.17). Injuries during the warm up were predominant in senior Gaelic footballers. An independent samples t-test was completed to compare the minutes the injury occurred in fresher and senior Gaelic footballers. No significant difference was noted between the minutes the injury occurred in fresher and senior Gaelic footballers (p=0.726). The majority of injuries occurred in the second half with 67.8% and 76.2% of injuries occurring in fresher and senior Gaelic footballers respectively. Injuries during the 4th and 2nd quarter were more common in fresher Gaelic footballers with injuries during the 3rd quarter more common in senior Gaelic footballers (Figure 4.77). The percentage of injuries during the 1st quarter was similar in both fresher and senior Gaelic footballers.

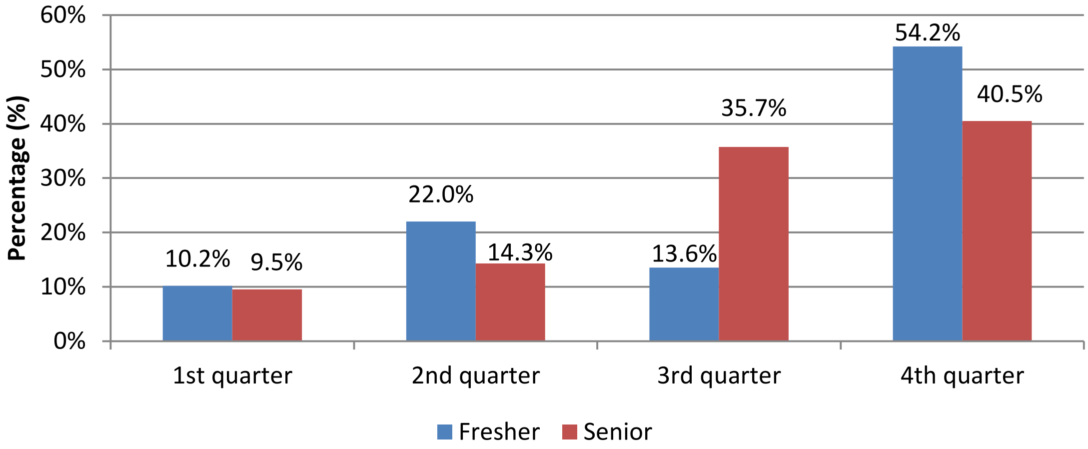

Figure 4.77: Quarter of injury in fresher and senior Gaelic footballers

4. 3. 6. 3. 3 . Foul Play

The majority of injuries did not occur due to foul play with senior Gaelic footballers (20.8%) sustaining injuries due to foul play more than freshers (13.2%). Opponent fouls accounted for 6.1% of fresher and 8.3% of senior injuries with 4.1% and 12.5% of injuries were caused by own fouls by fresher and senior Gaelic footballers respectively. The sanction given in injuries that occurred to fresher Gaelic footballers was predominantly a free however in senior Gaelic footballers a free and a yellow card was most common (Table 4.17).

4. 3. 6. 4. Factors Surrounding the Injury

4. 3. 6. 4. 1 . Relationship between time of year and injury

Injuries to senior Gaelic footballers were more common in February, March, June, July, October however fresher Gaelic footballers had a higher percentage in September and November (Figure 4.78).

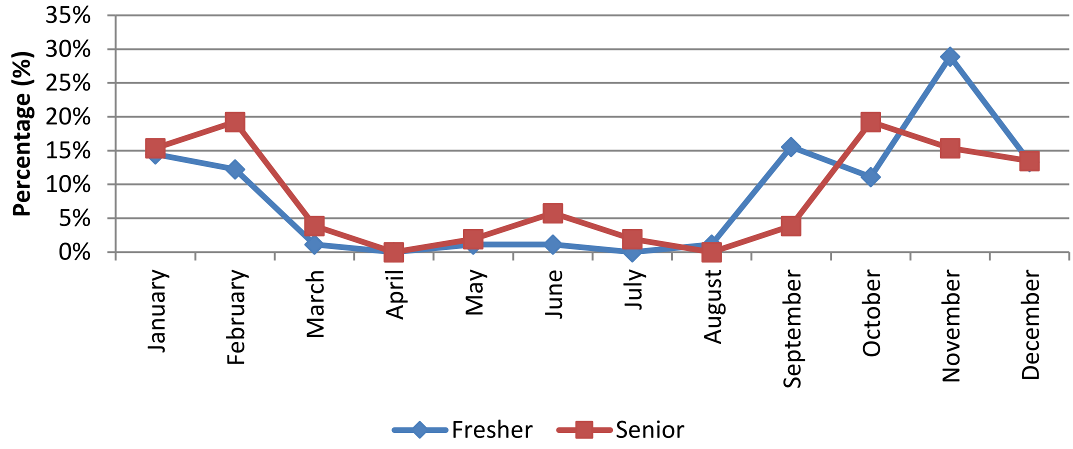

Figure 4.78: Monthly profile of injury in fresher and senior Gaelic footballers

4. 3. 6. 4. 2 . Relationship between relative age group and injury

The majority of fresher and senior Gaelic footballers played with their own age group, however senior players played at a higher percentage (96.2%) than fresher Gaelic footballers (90.0%).

4. 3. 6. 4. 3 . Relationship between playing position and injury

Injuries predominated in forwards in senior Gaelic footballers and backs in fresher Gaelic footballers (Figure 4.79). When taking the adjusted figures into account, injuries primarily occurred in goalkeepers (31.7%) in fresher Gaelic footballers, with backs (22.9%), midfielders (22.9%) and forwards (22.3%) displaying a similar percentage of injuries. In contrast, senior players presented with a similar percentage of injuries in goalkeepers (27.8%) and forwards (27.2%), followed by backs (23.2%) and midfielders (21.9%).

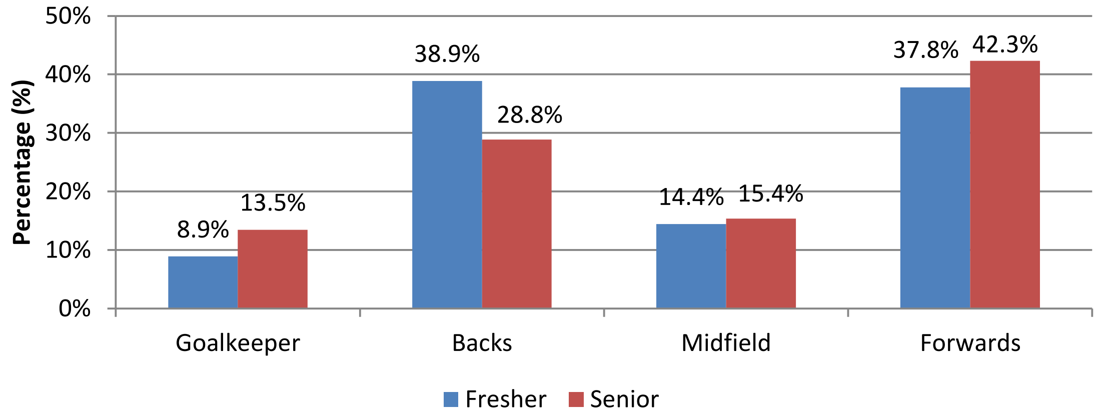

Figure 4.79: Distribution of injuries in different positions in fresher and senior Gaelic footballers

4. 3. 6. 4. 4 . Relationship between a free taking role and injury

The majority of injured participants did not have a free taking role (Table 4.17).

4. 3. 6. 4. 5 . Relationship between playing surface and injury

Injuries occurred more commonly on grass, with more injuries occurring in grass in senior Gaelic footballers (Figure 4.80). Injuries that occurred on synthetic surfaces were more frequent in fresher Gaelic footballers.

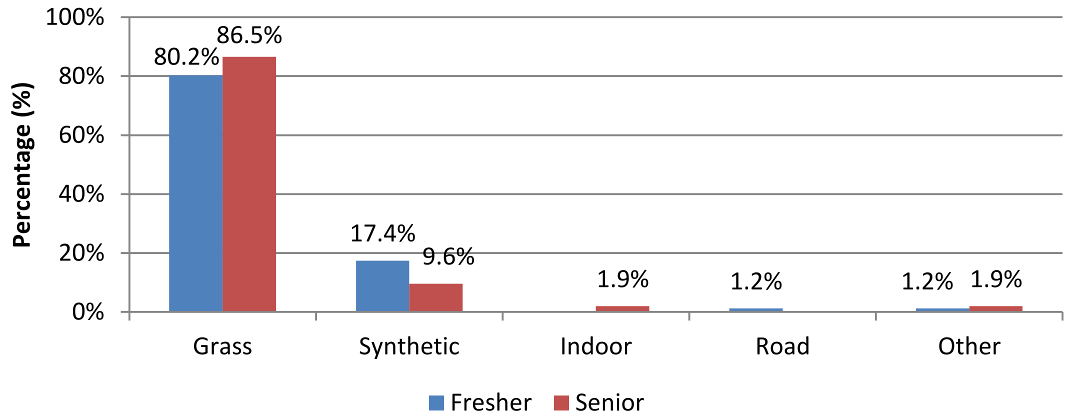

Figure 4.80: Playing surface in fresher and senior Gaelic footballers

4. 3. 6. 4. 6 . Relationship between weather conditions and injury

The temperature was predominantly normal in fresher Gaelic footballers and cold in senior Gaelic footballers (Table 4.17). A similar percentage of injuries occurred during hot weather. Injuries when the ground was dry were predominant in fresher Gaelic footballers and in wet ground in senior Gaelic footballers (Table 4.17).

4. 3. 6. 4. 7 . Protective Equipment worn

The majority of fresher (81.1%) and senior Gaelic footballers (67.3%) wore no extra protective equipment. In fresher Gaelic footballers, mouth guards (64.7%) were the most commonly worn protective equipment followed by ankle strapping (23.5%), patellar strapping (5.9%) and thumb strapping (5.9%). In senior Gaelic footballers mouth guards (76.5%) were also the predominant protective equipment worn followed by ankle strapping (17.6%) and wrist strapping (5.9%).

4. 3. 6. 5. The injury assessment

4. 3. 6. 5. 1 . Injury examination

The majority of injuries in fresher (83.3%) and senior (73.1%) Gaelic footballers were assessed solely by the main therapist in this study. Senior Gaelic footballers (26.9%)

were referred on for further assessment by an orthopaedic surgeon more commonly than fresher Gaelic football (16.7%).

4. 3. 6. 5. 2 . Further Investigations completed

Senior Gaelic footballers (44.2%) required further investigations to be completed more commonly than fresher Gaelic footballers (23.3%). Of these further investigations the majority of senior Gaelic footballers underwent an MRI scan (43.5%), followed by an X-ray and MRI (30.4%), an X-ray (25.7%). In fresher Gaelic footballers, the majority underwent an X-ray (42.9%), followed by a MRI scan (28.6%), an X-ray and MRI scan (19.0%) and an X-ray and CT scan (9.5%).

Table 4.17: Summary epidemiology results between fresher and senior collegiate Gaelic footballers

	Fresher	Senior
Onset of injury		
Acute	82.2%	73.1%
Overuse	17.8%	26.9%
New and Recurrent injuries		
New	81.1%	68.6%
Early Recurrence (<2 months)	6.7%	11.8%
Late Recurrence (2-12 months)	1.1%	3.9%
Persistent/recurring	11.1%	15.7%
Side of injury		
Right	54.7%	60.8%
Left	38.4%	33.3%
Bilateral	7.0%	5.9%
General distribution of injuries		
Lower body	68.9%	75.0%
Upper body	17.8%	13.5%
Trunk/spine	10.0%	7.7%
Head/face	3.3%	3.8%
Stopped or continued playing after injury		
Stopped playing	80.0%	94.1%
Continued playing	20.0%	5.9%
Severity of injury		
Minor	50.0%	7.8%
Moderate	30.0%	29.4%
Severe	20.0%	62.7%
Contact or non-contact injuries		
Contact	47.8%	48.1%
Non-contact	52.2%	51.9%
Time of injury		
Warm up	0.0%	14.0%
Cool down	4.9%	4.0%
Training/match	95.1%	82.0%
Sanction given if foul play was cause of injury		
Free	80.0%	40.0%
Yellow card	20.0%	40.0%
Red card	0.0%	20.0%
Free taking role in team		
Free taking role	30.0%	32.7%
Not a free taking role	70.0%	67.3%
Temperature during injury		
Normal	70.4%	45.8%
Cold	25.9%	52.1%
Hot	3.7%	2.1%
Weather conditions during injury		
Dry	71.3%	52.0%
Wet	28.8%	46.0%
Frozen	0.0%	2.0%

4. 3. 7. Analysis of senior hurling injuries

Nine injuries occurred in fresher hurlers during the course of this prospective study, thus due to the small amount of injuries that occurred in this population, further analysis of the results of the epidemiology of senior hurling injuries was solely assessed.

4. 3. 7. 1. Injury Incidence in senior hurlers

Further analysis on the total, training and match injury rates of senior hurlers was assessed with a higher incidence of injury occurring in matches than training (Table 4.18).

Table 4.18: Injury incidence in senior hurlers

Injuries per 1,000 hours	Senior	
	Incidence Rate	95% CI
Total	16.528	11.530-21.527
Training	6.427	3.060-9.795
Match	55.096	30.949-79.243

4. 3. 7. 2. The Injury Description

4. 3. 7. 2. 1 . Onset of injury

Acute injuries (76.2%) were more common in senior hurlers than overuse injuries (23.8%). New injuries were more common in senior hurlers followed by late recurrence (2-12 months), persistent injuries and early recurrence (<2 months) (Table 4.19).

4. 3. 7. 2. 2 . Side of injury

Injuries to the right and left hand side were similar in senior hurlers (Table 4.19).

4. 3. 7. 2. 3 . Body parts injured

Lower body injuries were predominant in senior hurlers, followed by upper body injuries, trunk/spine injuries and head/face injuries (Table 4.19). Injuries to the hip/groin/thigh predominated (Figure 4.81) and this corresponded to a higher percentage of hamstring, quadriceps and pelvis and groin injuries (Figure 4.82). Injuries to the ankle, shoulder, knee and lower back were also common.

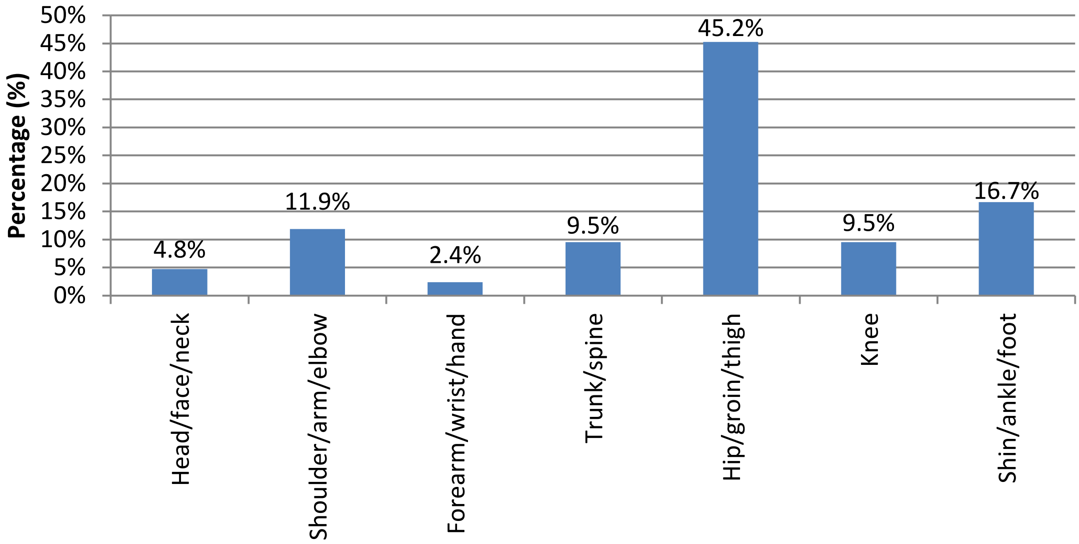

Figure 4.81: General distribution of injuries in senior hurlers

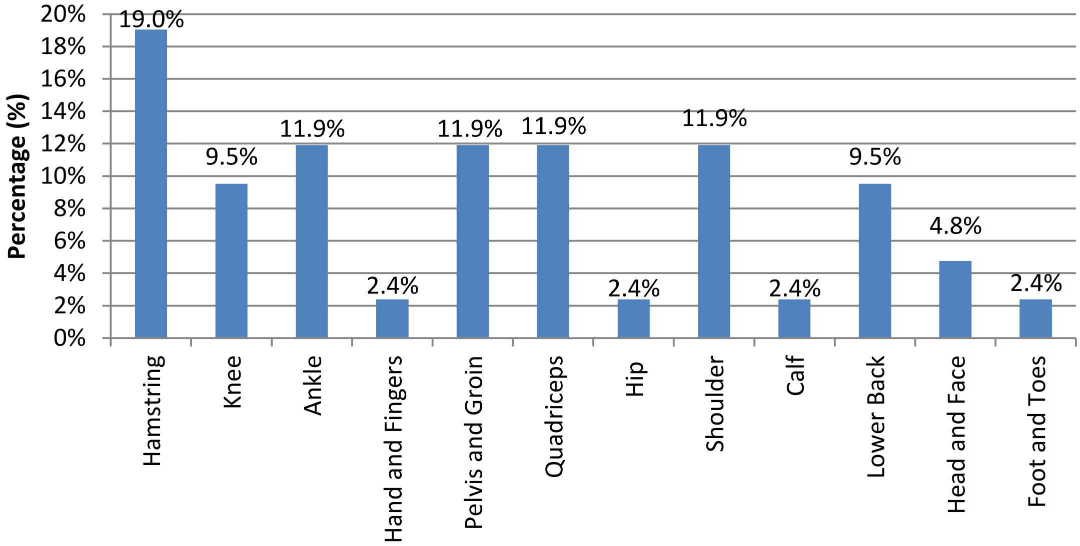

Figure 4.82: Body parts injured in senior hurlers

4. 3. 7. 2. 4 . Nature of injury

Muscle injuries were predominant in senior hurlers (Figure 4.83) which corresponds to the higher percentage of strains, muscle contusions and muscle tightness in senior hurlers (Figure 4.84). Ligament injuries were also common and were demonstrated by the high percentage of sprain injuries in senior hurlers.

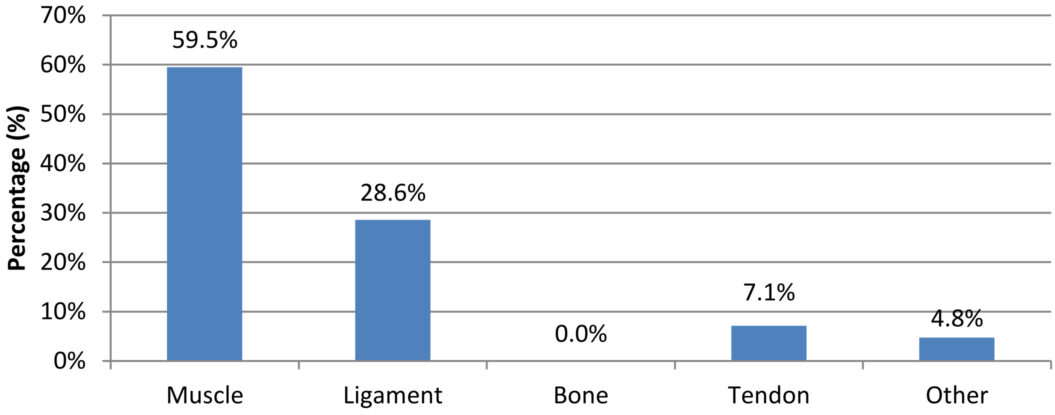

Figure 4.83: General nature of injury in senior hurlers

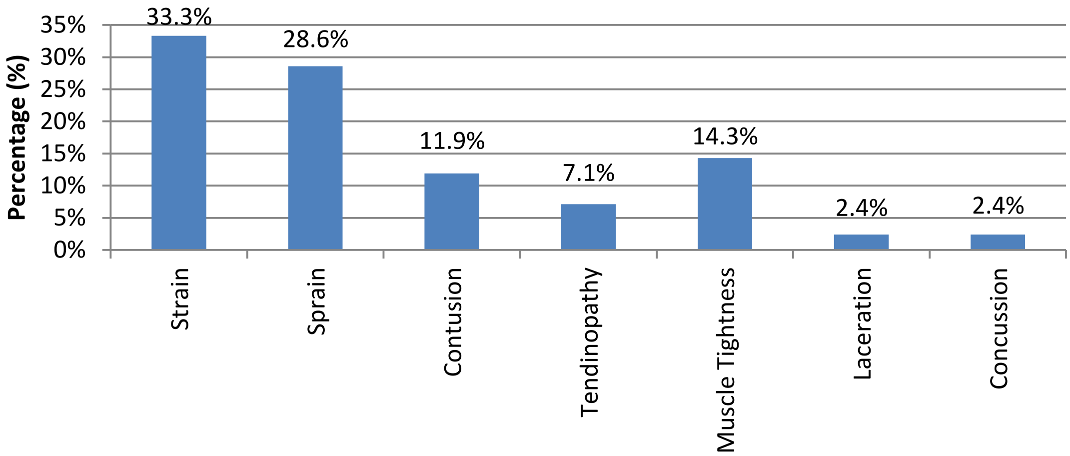

Figure 4.84: Nature of injury in senior hurlers

4. 3. 7. 2. 5 . Severity of Injury

The majority of senior hurlers stopped playing and training after the injury occurred (83.3%) with only 16.7% of senior hurlers continuing playing after the injury. Severe injuries predominated in senior hurlers, followed by minor and moderate injuries (Table 4.19). The average days missed from light training were 19.25±20.09, from full training were 20.75±21.62 and from full fitness were 21.82±21.95. The majority of senior hurlers did not require surgery after injury (97.6%) with only 2.4% requiring surgery during the season.

4. 3. 7. 3. The Injury Event

4. 3. 7. 3. 1 . Mechanism of Injury

Senior hurlers primarily sustained non-contact injuries (64.3%) with only 35.7% of injuries contact injuries. Of the non-contact injuries 9.5% of injuries were overuse in nature and 54.8% of injuries were non-contact acute injuries. Of the contact injuries, the majority were due to contact with another player (26.2%), followed by contact with the playing surface (21.4%), sliother (4.8%) and a hurley (2.4%). Sprinting, being tackled, turning, landing and tackling predominated in senior hurlers (Figure 4.85). Tackling (being tackled and tackling) accounted for 28.5% of injuries.

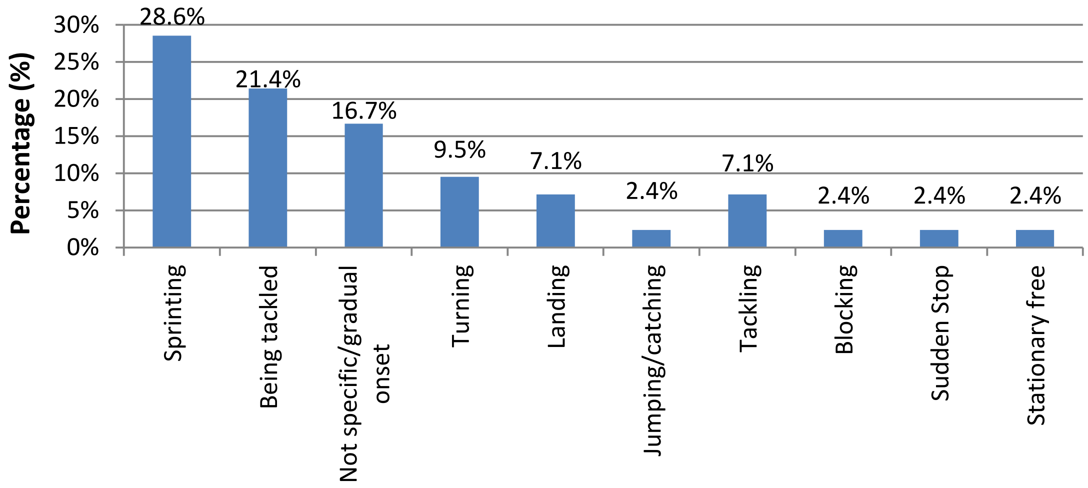

Figure 4.85: Mechanism of injury in senior hurlers

4. 3. 7. 3. 2 . Time of Injury

Injuries primarily occurred during training and matches (97.1%) with only 2.9% of senior hurlers sustaining an injury in the warm up. The mean minutes the injury occurred were 38.32±17.68. The majority of injuries occurred during the second half (71.0%) with injuries during the 4th quarter predominating (54.8%) (Figure 4.86).

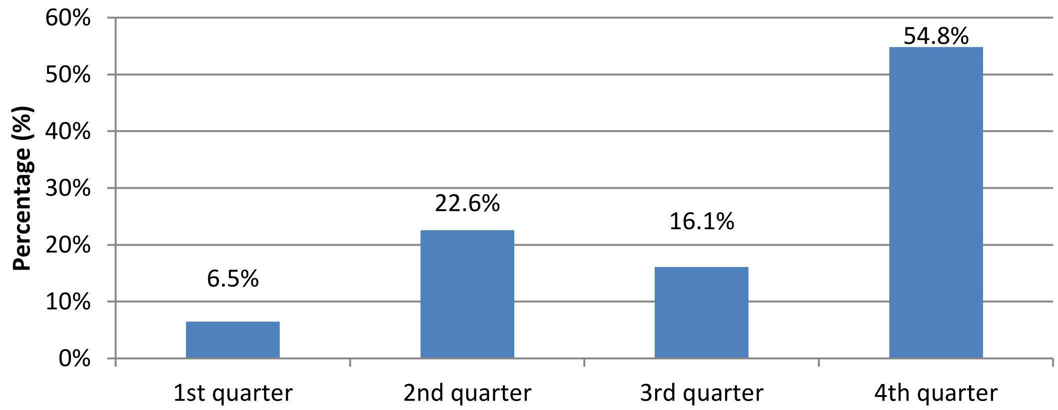

Figure 4.86: Quarter of injury in senior hurlers

4. 3. 7. 3. 3 . Foul Play

No injuries sustained by senior hurlers were due to foul play.

4. 3. 7. 4. Factors Surrounding the Injury

4. 3. 7. 4. 1 . Relationship between time of year and injury

Injuries to senior hurlers were more common in October, followed by November, February, December and January (Figure 4.87).

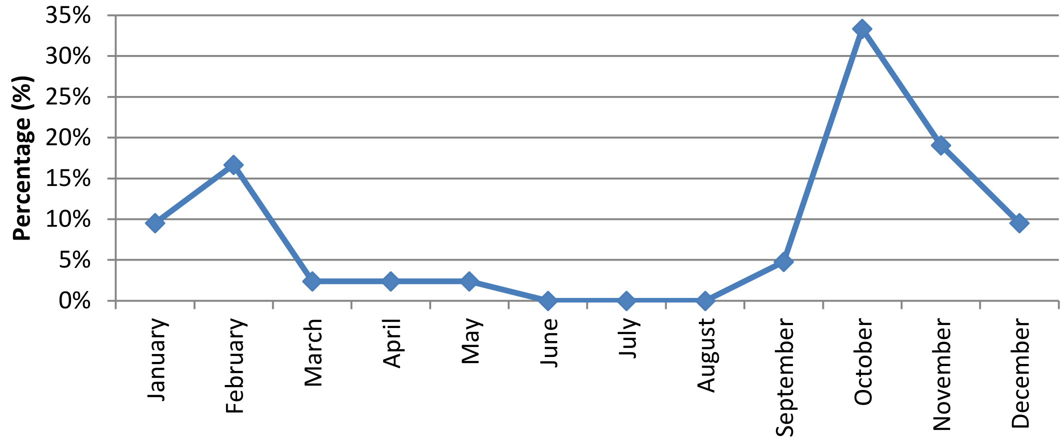

Figure 4.87: Monthly profile of injuries in senior hurlers

4. 3. 7. 4. 2 . Relationship between relative age group and injury

The majority of senior hurlers played with their own age group (97.6%) and only 2.4% played with an older age group.

4. 3. 7. 4. 3 . Relationship between playing position and injury

Injuries to backs and forwards predominated in senior hurlers (Figure 4.88).

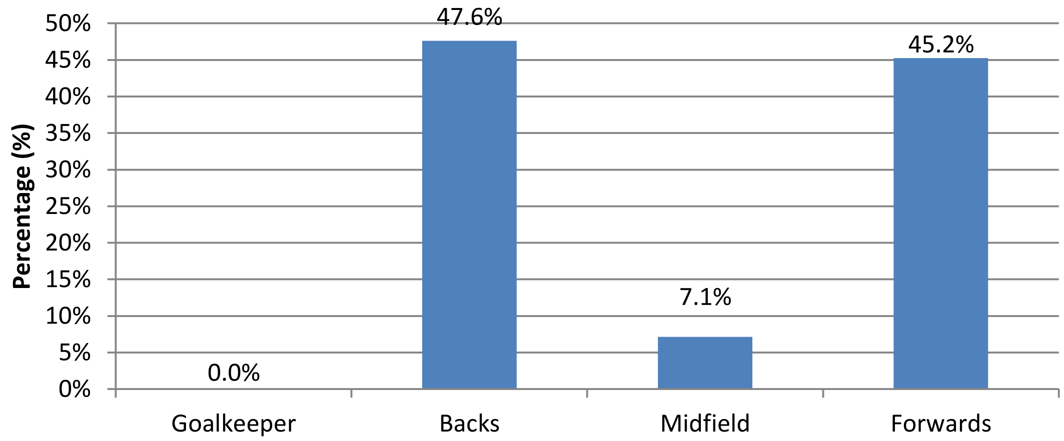

Figure 4.88: Distribution of injury in different positions in senior hurlers

4. 3. 7. 4. 4 . Relationship between a free taking role and injury

The majority of injured participants did not have a free taking role (83.3%) (Table 4.19).

4. 3. 7. 4. 5 . Relationship between playing surface and injury

Injuries predominantly occurred to senior hurlers on grass (91.2%) with 8.8% of injuries sustained on synthetic turf.

4. 3. 7. 4. 6 . Relationship between weather conditions and injury

The temperature was predominantly normal and the ground was most commonly dry in senior hurlers (Table 4.19).

4. 3. 7. 4. 7 . Protective Equipment worn

The majority of senior hurlers (95.2%) wore no extra protective equipment. Ankle strapping was the only protective equipment worn by 4.8% of senior hurlers.

4. 3. 7. 5. The injury assessment

4. 3. 7. 5. 1 . Injury examination

The majority of injuries in senior hurlers (95.2%) were assessed solely by the main therapist in this study. Only 4.8% of injuries were referred on for further assessment by an orthopaedic surgeon.

4. 3. 7. 5. 2 . Further Investigations completed

Senior hurlers required further investigations to be completed in 16.7% of injuries. Of these further investigations the majority underwent an X-ray and MRI scan (57.1%), followed by an MRI scan (28.6%) and an X-ray (14.3%).

Figure 4.89: Summary epidemiology results in senior hurlers

	Senior
Onset of injury	
Acute	76.2%
Overuse	23.8%
New and Recurrent injuries	
New	81.0%
Early Recurrence (<2 months)	2.4%
Late Recurrence (2-12 months)	9.5%
Persistent/recurring	7.1%
Side of injury	
Right	42.9%
Left	45.2%
Bilateral	9.5%
General distribution of injuries	
Lower body	71.4%
Upper body	14.3%
Trunk/spine	9.5%
Head/face	4.8%
Stopped or continued playing after injury	
Stopped playing	83.3%
Continued playing	16.7%
Severity of injury	
Minor	38.1%
Moderate	19.0%
Severe	42.9%
Contact or non-contact injuries	
Contact	35.7%
Non-contact	64.3%
Time of injury	
Warm up	2.9%
Cool down	0.0%
Training/match	97.1%
Free taking role in team	
Free taking role	16.7%
Not a free taking role	83.3%
Temperature during injury	
Normal	79.4%
Cold	14.7%
Hot	5.9%
Weather conditions during injury	
Dry	79.4%
Wet	20.6%
Frozen	0.0%

4. 4. Discussion

The aim of this study was to implement a high quality, standardised epidemiological study to prospectively examine the incidence of injury in adolescent and collegiate Gaelic footballers and hurlers. The amount of published epidemiological studies in Gaelic games is small in comparison to international sports, with only six studies in Gaelic football and two in hurling. Not only do these studies vary in their research design, study length, definition of injury and reporting procedures, they also have primarily focused on elite adult players (Murphy et al., 2012b, Murphy et al., 2012a, Newell et al., 2013, Cromwell et al., 2000) with a severe lack of research in the non-elite, adolescent or collegiate population (Junge and Dvorak, 2000, Fuller et al., 2007c, Fuller et al., 2006, Brooks and Fuller, 2006, Chalmers, 2002). In fact, no epidemiological data is available on adolescent hurling injuries, collegiate injuries and only a single study has been published on adolescent Gaelic football injuries (Watson, 1996b) despite the fact a large proportion of those playing Gaelic games are within these poorly examined populations. As the assessment of adolescent injuries was completed during school, this study also aimed to establish the epidemiology of injuries in 4th and 5th year males during one academic year in five schools that primarily played Gaelic football and hurling which is representative of a large proportion of schools in Ireland.

4. 4. 1. Sports Played

Two thirds of all adolescents primarily played Gaelic games, which is expected, as Gaelic games are predominant Irish sports, with over 2,300 sporting clubs throughout Ireland (GAA, 2013). Gaelic football was also found to be primarily played in a cohort of school aged adolescents in Ireland, however hurling was not as common (Watson, 1996b). Soccer was also a predominant sport in school participants, followed by rugby, basketball, gymnastics, athletics and gym work. Gym work was not noted in Watson (1996b)'s study in Irish adolescents, which could be due to the recent increase in popularity and availability of gyms to adolescents and adults that want to increase fitness and build muscle mass and may not be involved in organised sport. Adolescent and collegiate participants primarily played Gaelic football than hurling and approximately 20% of adolescents played Gaelic football and hurling in equal measure.

4. 4. 2. Injury Incidence

Over a third of all adolescent and collegiate participants were at risk of sustaining an injury in one academic year or season. In addition, the repeat incidence proportion demonstrated that over a quarter of all injured participants, received another or multiple injuries that season. Previous injury has been highlighted as the most predominant risk factor for re-injury, which may explain this high rate of re-injury. Players may be returning to sport with substantial deficits in strength, range of motion and proprioception which may increase the risk of sustaining another injury in the injured or different area (Maffey and Emery, 2006, Garrick, 2004). Thus, players should be encouraged to complete a comprehensive rehabilitation programme prior to return to sport in order to reduce the risk of re-injury.

A substantially higher injury incidence was found in collegiate participants than the similar incidence found in adolescents and adolescent Gaelic footballers and hurlers. A higher incidence of collegiate than high school injuries has been demonstrated in both American football (Shankar et al., 2007) and wrestling (Yard et al., 2008a). This increased injury rate in collegiate participants has been attributed to increased match exposure time, higher level of competition which requires players to become more skilled and stronger which can increase the physicality of the game and possible age related deficits such as reduced range of motion (Shankar et al., 2007, Yard et al., 2008a, Arnason et al., 2004).

A substantially higher incidence of injury occurred during matches than training in all participants. This is despite the fact that adolescent and collegiate participants spent 6.5 and 4.8 times as much time in training than matches. This is similar to the findings reported by numerous studies in the epidemiology of injuries in both Gaelic football (Murphy et al., 2012b, Wilson et al., 2007, Newell et al., 2006, Watson, 1996b) and hurling (Murphy et al., 2012a, Watson, 1996a). This higher incidence in matches can be attributed to the higher intensity, physicality and effort put in due to competiveness in a match setting as training is a controlled and supervised session (Murphy et al., 2012b, Wilson et al., 2007). Adolescent Gaelic footballers and hurlers displayed a similar training injury rate as school Gaelic footballers observed by Watson (1996b) (3.106 per 1,000 hours). In contrast, Watson (1996b) found a higher injury incidence in matches than adolescent Gaelic footballers and hurlers in the present study. Collegiate Gaelic footballers displayed a higher training injury rate than observed in elite adults as described by Murphy et al. (2012b) (4.05 per 1,000 hours) and Newell et al. (2006)(5.5 per 1,000 hours) and also than non-elite adults as reported by Wilson et al. (2007) (5.8 per 1,000 hours). However, collegiate Gaelic footballers presented with a lower match injury rate than elite (61.86 and 64.0 per 1,000 hours) and non-elite adults (51.2 per

1,000 hours) (Murphy et al., 2012b, Newell et al., 2006, Wilson et al., 2007). This lower match incidence rate in collegiate hurlers could be due to the lower level of play in collegiate Gaelic football in comparison to elite county and adult club football games. Similarly, collegiate hurlers displayed a slightly higher training injury rate than adult teams observed by Murphy et al (5.3 per 1,000 hours) and Watson (1996a) (4.383 per 1,000 hours). Conversely, the present study found that collegiate hurlers (59.808 per 1,000 hours) displayed a substantially higher match injury rate than Watson (1996a) (34.247 per 1,000 hours) but almost half the match injury rate reported by Murphy et al. (2012a) (102.5 per 1,000 hours). The vast differences in the injury rates observed could be due to differences in age group, methodology and injury definitions utilised.

The incidence of training injuries that occurred in adolescent and collegiate Gaelic footballers and hurlers were similar, which has also been noted by Murphy et al. (2012a) in adult Gaelic footballers and hurlers. In contrast, both adolescent and collegiate hurlers displayed higher injury rates than Gaelic footballers for match injuries; this was also observed by Murphy et al. (2012a) where hurlers reported a match injury rate of 102.5 injuries per 1,000 hours in comparison to 51.2-61.2 injuries per 1,000 hours reported by Newell et al. (2006) and Wilson et al. (2007). The higher incidence of match injuries in hurlers could be due to the enhanced physicality of hurling, as contact between player to player, player to hurley and player to sliother can commonly occur (Murphy et al., 2012a). In addition, hurlers are reportedly less fit than Gaelic footballers as the nature of the game requires a high skill level which is a huge focus in training, thus, the increased demands of a match situation may cause a higher risk of injury in hurlers (Murphy et al., 2012a). This lower fitness has been further suggested as hurlers have demonstrated a higher percentage body fat, lower aerobic fitness, speed endurance and upper body strength than Gaelic footballers (McIntyre, 2005).

Adolescent Gaelic footballers presented with a higher match injury rate than high school soccer players (7.15 injuries per 1,000 hours) (Yard et al., 2008b), with collegiate Gaelic footballers displaying a higher match injury rate than community level Australian rules football (20 injuries per 1000 hours) (Braham et al., 2004) and professional soccer players (27.7 injuries per 1,000 hours) (Hawkins and Fuller, 1999). Similarly, collegiate hurlers displayed a higher match injury rate than male collegiate lacrosse players (12.58 injuries per 1,000 hours) (Dick et al., 2007), with adolescent hurlers displaying a higher total injury rate than adolescent lacrosse under 15 boys (Hinton et al., 2005).

Fresher Gaelic footballers displayed a higher total, training and match injury rate than senior Gaelic footballers. This could be due to the increased intensity and physicality placed on freshers in their first year competing in a higher level of competition. In addition, a large proportion of freshers may be starting to begin strength and conditioning programmes for the first time which could perhaps lead to increased risk of injury due to lack of familiarity with the movements and techniques required. This increased injury risk is noteworthy as it would seem prudent to implement an injury prevention programme in fresher players. Senior hurlers displayed a similar total, training and match as fresher Gaelic footballers which can be attributed to the higher incidence of injury in hurlers.

4. 4. 3. The injury description

4. 4. 3. 1. Onset of injury

Acute injuries were predominant, with a similar percentage of overuse injuries noted in adolescents in the present study and in adolescents (median age 16) in American high schools (18%) (Cuff et al., 2010). Gaelic footballers and hurlers also demonstrated alike percentages of acute injuries in both the adolescent and collegiate populations respectively. In addition, collegiate hurlers in the present study displayed similar overuse injuries as elite adult hurlers (19%) (Murphy et al., 2012a). Fresher Gaelic footballers demonstrated a higher percentage of acute injuries than senior players which could be due to poor technique of the younger less experienced players. The higher percentage of overuse injuries in senior Gaelic footballers, that was also evident in senior hurlers, could be due to their higher training age and increased likelihood of previous injury. This theory was further supported as 68.6% of injuries in senior Gaelic footballers were new in comparison to 81.1% of injuries in fresher Gaelic footballers.

While new injuries predominated, a much higher percentage of new injuries occurred in collegiate players. In fact, 41.1% and 41.8% of all injuries reported in adolescents and adolescent Gaelic footballers and hurlers are actually re-injuries. This high rate of re-injury could be due to adolescents returning to sport too quickly without adequate rehabilitation, persistent training errors, poor technique or an unaddressed cause of the initial injury (DiFiori, 1999). In addition, 14.9% of Gaelic football and 8.3% of hurling injuries in adolescents occurred within two months of returning from the original injury.

This was slightly higher than the reported early recurrence rates reported in elite adult Gaelic footballers (6.8%) (Murphy et al., 2012b). Adolescent Gaelic footballers demonstrated a higher incidence of recurrent injuries than hurlers and this was found to higher than reported in elite adult Gaelic footballers (23% and 30%) and hurlers (14.6%) (Murphy et al., 2012b, Cromwell et al., 2000, Murphy et al., 2012a). In contrast, collegiate Gaelic footballers and hurlers displayed similar recurrent injuries as recounted in present literature. A similar percentage of new injuries occurred in collegiate Gaelic footballers and hurlers however slightly more new injuries occurred in adolescent hurlers in comparison to Gaelic footballers. Murphy et al. (2012b) observed a similar percentage of new injuries in elite adult Gaelic footballers (74.7%) as collegiate Gaelic footballers in the present study. In contrast, Murphy (2012a) demonstrated a higher percentage of new injuries in elite adult hurlers (85.4%) in comparison to collegiate hurlers in the current study. Wilson et al. (2007) however displayed a lower amount of new injuries in non-elite Gaelic footballers (65%) which was more alike the values that was displayed in the adolescents. Thus, it is evident that recurrent injuries are a serious issue in adolescents and coaches and parents must ensure that players are adequately rehabilitated prior to returning to sport.

4. 4. 3. 2. Side of injury

A similar percentage of injuries occurred between the right and left sides. Injuries occurred predominantly to the right and left side with a smaller amount occurring bilaterally. Adolescent hurlers had a larger amount of bilateral injuries in comparison to adolescent Gaelic footballers and this could be related to the higher percentage of lower back pain presenting in hurlers than Gaelic footballers. The side of injury was assessed in order to assess if dominance is related to injury sides. However this study found that injuries are somewhat evenly distributed and so may not be related to dominance. This could be due to the increased focus in Gaelic games in enhancing skill levels on both sides to improve performance.

4. 4. 3. 3. Body part injured

Injuries predominantly occurred in the lower limb and accounted for approximately one third of all injuries in adolescent and collegiate participants which is similar to the 70-77% of injuries reported in Gaelic football and 70.1% reported in hurling (Cromwell et al., 2000, Murphy et al., 2012b, Wilson et al., 2007, Newell et al., 2013, Murphy et al., 2012a). Adolescent and collegiate Gaelic footballers and hurlers demonstrated a similar percentage of upper body injuries however a lower percentage was observed in secondary school adolescents.

Adolescents and adolescent Gaelic footballers and hurlers presented with the same top five injured body parts however they differed slightly in the order of prevalence; the knee was the most commonly injured body part in both populations, however the ankle, hamstring, lower back and pelvis and groin were the most common injured body parts in decreasing occurrence in adolescents and the lower back, ankle, hamstring and pelvis and groin in adolescent Gaelic footballers and hurlers. The most commonly injured body parts differed between Gaelic footballers and hurlers in adolescents. Lower back pain was the most common body part injured in adolescent hurlers and was far more predominant than in Gaelic footballers; this may have caused the increased percentage of trunk and spine injuries in hurlers in comparison to Gaelic footballers. Watson et al. (1996b) also observed a lower incidence of back injuries in school Gaelic footballers (10%) than school hurlers as reported in the present study, however this was still lower than observed in adolescent hurlers in the current study. The higher incidence of lower back pain in hurlers could be due to the twisting nature of the sport when swinging the hurley to hit the slioter, the increased physicality of the game of hurling and tight hamstrings which can affect pelvic and lumbar positioning (Balague et al., 1999). Adolescent hurlers also had a higher incidence of lower back pain than collegiate hurlers in the present study and also to adult hurlers (11%) as reported by Watson (1996a); this higher rate of injury could be due to poor posture in adolescent males (Balague et al., 1999). Male adolescents tend to present with increased thoracic kyphosis that can lead to consequential lumbar hyper-lordosis which could possibly cause lower back pain (Balague et al., 1999). This is noteworthy as no prior studies have captured information on adolescent hurling injuries and so this high incidence of lower back pain has not been noted before. Knee injuries was the most common injuries in adolescent Gaelic footballers and second most common in adolescent hurlers which contrasts to a previous study in school Gaelic footballers where knee injuries were found to be far from predominant (1996b). The high incidence of knee injuries in adolescent Gaelic footballers and hurlers could be related to twisting and turning which are inherent movements in Gaelic games and are commonly noted as common mechanisms of injury. Poor neuromuscular control has been identified as a risk factor for knee injuries, and a high level of poor neuromuscular control has been noted in adolescents in this PhD (Chapter 3); this can lead to knee valgus occurring during these twisting and turning movements and so lead to knee injury (Weeks et al., 2012). Gaelic footballers presented with a higher percentage of hamstring injuries in comparison to hurlers which can be linked to the higher incidence of lower limb injuries in Gaelic footballers compared to hurlers. Hamstring injuries in adolescent Gaelic footballers was also found to be more predominant than the 6.5% of hamstring strains reported by Watson et al. (1996b) in school Gaelic footballers. The higher incidence of hamstring injuries could be due to Gaelic football recently turning into more of a running game with players working their way up the pitch with a series of short passes that require its players to cover longer distances. However, in hurling the use of the hurley allows for quick passes of the slioter to further areas of the pitch which reduces the amount of running required. In addition, the predominance of hamstring tightness noted in Chapter 3 may also contribute to the high incidence of hamstring injuries. Ankle injuries were common in both Gaelic footballers and hurlers and were the third most common injury sustained by both populations. However previously Watson (1996b) has reported a higher percentage of ankle injuries (15.1%) in school Gaelic footballers. The predominance of ankle injuries could be due to poor landing technique and balance (Plisky et al., 2006, Clark et al., 2010) and may be related to the poor balance noted in the Y balance and single leg squat screening tests in Chapter 3. A similar percentage of pelvis and groin injuries occurred in both hurlers and Gaelic footballers which is expected as groin injuries have been shown to be predominant in sports that require quick acceleration and changes of direction which are inherent skills in both Gaelic sports (Maffey and Emery, 2007). In addition, the high incidence of pelvis and groin pain in adolescent Gaelic footballers and hurlers could be due to the anecdotal large amounts of training reported at this age, adolescents commonly play over a few age groups and may take part in multiple sports. In fact, 19.2% of all adolescent Gaelic footballers and hurlers played both sports to an equal level. A similar percentage of injuries was found in the present study and school Gaelic footballers (9.5%) as reported by Watson (1996b); surprisingly no injuries to the hand and finger were reported by adolescent hurlers in the present study. The large amount of hand-ball contact that occurs in Gaelic football may also predispose this area to injury (Brown et al., 2013). The lack of injuries in adolescent hurlers is surprising as hurlers have the same hand-ball contact as Gaelic footballers and also would theoretically be more at risk of injury due to certain plays in the game of hurling such as when a player jumps to catch the sliother, other players are permitted to swing to hit the sliother with the hurley which could clearly leave the hand and finger predisposed to injury. Thus hurlers may not have reported hand and finger injury as they may have felt the injury was not serious enough to warrant reporting and may not have prevented the players from continuing to play sport or limit their performance.

Collegiate players presented with similar common injuries as adolescent Gaelic footballers and hurlers, with hamstrings the most predominant site of injury, followed by the knee, ankle, hand and fingers, with the pelvis and groin and quadriceps accounting for the same amount of injuries. The hip/groin/thigh was by far the most principal regional injury noted. Hamstring injuries were predominant in Gaelic games, with hurlers sustaining slightly more hamstring injuries than Gaelic footballers. This is similar to other studies in Gaelic games, where the hamstring was the most commonly reported site of injury accounting for 6.5-24% of injuries (Murphy et al., 2012b, Wilson et al., 2007, Newell et al., 2013, Watson, 1996b, Cromwell et al., 2000, Brown et al., 2013, Murphy et al., 2012a, Watson, 1996a). In fact, Murphy et al. (2012b) reported that the hamstring was the site of 52% of all muscle injuries in elite Gaelic footballers. The possible predisposition for hamstring injuries in Gaelic games could be related to sprinting, which has been identified by the current and other studies as a common mechanism for injury (Wilson et al., 2007). Sprinting is a high velocity action which places high stresses on the hamstring muscle as it crosses over two joints, thus if any inherent flexibility or strength issues exist within the muscle this may predispose the player to injury (Woods et al., 2004, Gabbe et al., 2006). Collegiate Gaelic footballers and hurlers sustained a high percentage of knee injuries, which was slightly lower than those noted in adolescents, and is similar to the 8-13% of injuries noted in adult Gaelic footballers and 7.4-9% in hurlers (Murphy et al., 2012b, Wilson et al., 2007, Newell et al., 2006, Cromwell et al., 2000, Murphy et al., 2012a, Watson, 1996a). Ankle injuries were also common in collegiate Gaelic footballers and hurlers, and report a similar percentage of injuries as adult Gaelic footballers (10-13.3%) and hurlers (9%) (Murphy et al., 2012b, Wilson et al., 2007, Newell et al., 2006, Murphy et al., 2012a, Watson, 1996a) However, Cromwell et al. (2000) reported a much higher incidence of ankle injuries than collegiate Gaelic footballers in the current study. Hip injuries were common in collegiate Gaelic footballers and hurlers and accounted for a slightly higher percentage of injuries than reported in adult Gaelic footballers by Murphy et al. (2012b) (3.1%) and Wilson et al. (2007) (4%). This high frequency of hip injuries may be related to the poor hip mobility noted during the overhead squat and single leg squat in collegiate players in Chapter 3. Pelvis and groin injuries were slightly more common in collegiate hurlers than Gaelic footballers, however the percentage of injuries were similar to those described in adult Gaelic footballers (7-9.4%) and hurlers (9%) (Murphy et al., 2012b, Wilson et al., 2007, Newell et al., 2006, Cromwell et al., 2000, Murphy et al., 2012a). Upper body injuries were slightly more prevalent in collegiate hurlers than Gaelic footballers however shoulder/elbow/forearm injuries had a much higher incidence in hurlers than Gaelic footballers. The prevalence of upper body injuries in collegiate hurlers was similar to adult hurlers (15.2%) (Murphy et al., 2012a). Quite a large variance of upper body injuries is noted in Gaelic football, with collegiate Gaelic footballers reporting a similar percentage of upper body injuries as Murphy et al. (2012b) (11.3%), a slightly higher incidence than Newell et al. (2006) (5%) and lower than Cromwell et al. (2000) (23%). Shoulder injuries occurred more often in hurlers than Gaelic footballers, however adult Gaelic footballers have higher reported injuries to this region (6.2-12%) (Cromwell et al., 2000, Newell et al., 2013, Murphy et al., 2012b) and shoulder, arm and elbow injuries only accounted for 2.9% of all injuries in adult hurlers (Murphy et al., 2012a). The prevalence of shoulder injuries could be due to the high physicality of the game where shouldering (a type of charge lead by the shoulder against the shoulder of the opponent) is a permitted method of tackling. Overuse injuries to the shoulder could be caused by the high catching and carrying of the ball that are inherent skills required in both hurling and Gaelic football (Cromwell et al., 2000). In addition, the reduced shoulder range of motion found in collegiate Gaelic players in Chapter 3 may also predispose the shoulder to injury. Similar to adolescents, collegiate Gaelic footballers presented with a higher percentage of hand and finger injuries than hurlers and this was much higher than the 1.5% of injuries noted in adult Gaelic footballers (Murphy et al., 2012b).

Fresher and senior Gaelic footballers presented with similar percentages of hamstring, ankle and hip injuries. Senior players sustained a higher percentage of knee injuries than fresher players, which may be related to the poorer score found in senior players for knee valgus during the overhead squat, while this difference did not reach significance, the increased knee valgus could have predisposed senior players to an increased risk of knee injuries. Hand and fingers injuries were more common in fresher’s than senior players.

4. 4. 3. 4. Nature of injury

Muscle injuries predominated in participants (53.3-57%) which was slightly higher than observed in adult male Gaelic players in previous studies (33-49.1%) (Murphy et al., 2012a, Murphy et al., 2012b, Cromwell et al., 2000). Strains were the most common specific nature of injury noted and these predominated in the hamstring, pelvis and groin, quadriceps and calf. In addition, muscle tightness and contusions were the third and fourth most common nature of injuries found in adolescents, however contusions were more common in collegiate players and muscle tightness was only the fifth most common nature of injury noted. Muscle tightness occurred quite frequently in lower back and pelvis and groin injuries which were quite predominant in adolescents, which may explain the higher proportion of muscle tightness in adolescent than collegiate participants. In addition, all neck injuries were due to muscle tightness in adolescents. Watson (1996b) found that school Gaelic footballers presented with far fewer contusions (6.5%) than observed in adolescents, however a similar percentage of contusions was found in adult Gaelic footballers (13-17%) (Murphy et al., 2012b, Brown et al., 2013, Cromwell et al., 2000). Contusions were predominate in the quadriceps, hips, foot and toes, ribs and chest, wrist and shoulders which are all areas on the extremities or on the trunk which are left susceptible to injury. Ligament injuries and sprains were the second most common nature of injury noted in all populations studied; however collegiate participants presented with a higher proportion of ligament injuries and sprains than school participants. Ligament injuries presenting in the adolescents was similar to those reported in school Gaelic footballers (23.2%) (Watson, 1996b). Ligament injuries in collegiate participants was similar to those reported by Cromwell et al. (2000) in adult Gaelic footballers (32%) and higher than adult Gaelic footballers (13.2%) as reported by Murphy et al. (2012b) and adult hurlers (15.2%) (Murphy et al., 2012a). Sprains were predominant in the ankle and knee and were also quite common in the upper limb, especially to the shoulder, wrist, hand and fingers and elbow. Serious injuries were not particularly common, and a similar percentage of fractures and dislocations occurred in participants. The percentage of fractures in the current study was similar to those mentioned in male Gaelic footballers (4.4-10%) and hurlers (7.4%) (Murphy et al., 2012b, Wilson et al., 2007, Cromwell et al., 2000, Murphy et al., 2012a). Fractures occurred predominantly in the wrist, ankle, hand and fingers, head and face however they also were noted in the shin, foot and toes. Since the introduction of a rule change by the GAA for mandatory helmet use in hurling the amount of facial fractures and dental injuries has reduced dramatically. However it has been reported that some hurlers still modify their protective faceguards by removing bars which they feel can improve their vision and comfort; however this reduces the protection to the face (Murphy et al., 2010). Osgood Schlatter’s disease is an injury that occurs only in the adolescent population and it accounted for 1.8% of injuries in adolescents and a slightly higher percentage of 2.4% in adolescent Gaelic footballers and hurlers. As expected there was no incidence of Osgood Schlatter's disease reported in the collegiate population as this injury would have resolved by the time participants attended college. A very low prevalence of concussions were reported for adolescents (0.5%) and collegiate Gaelic footballers and hurlers (0.5%) which is far lower than expected in sports with such high physicality, however is similar to the reported concussion rates in adult male hurlers (0.5%) (Murphy et al., 2012a). Current studies have noted a decrease in concussions since the introduction of mandatory helmet usage (as demonstrated by the 3% of concussions found by Watson (1996a) prior to the rule change), however since Gaelic footballers wear no additional head protection, the low incidence reported may be attributed to a low reporting of concussions. Participants may not have adequate knowledge of the symptoms of concussion and may not recognise its occurrence or may be fearful of missing playing time.

A higher percentage of muscle injuries occurred in adolescent hurlers than Gaelic footballers that may be related to the higher percentage of muscle tightness and contusions and the corresponding higher percentage of lower back pain in hurlers. The increased incidence of contusions is expected as hurling is quite a physical game with contact constantly occurring between players and the hurley. Conversely, strains predominated in Gaelic footballers and is higher than previously reported in school aged Gaelic footballers (21%) (Watson, 1996b). The high incidence of strains in Gaelic footballers can be attributed to the corresponding higher percentage of hamstring injuries. Ligament injuries and sprains also predominated in Gaelic footballers which also could be attributed to the corresponding higher percentage of ankle injuries. The percentage of sprains in adolescent Gaelic footballers was similar to the 22.3% reported by school Gaelic footballers, however adolescent hurlers reported substantially less sprains (Watson, 1996b). A similar percentage of muscular and ligamentous injuries occurred in collegiate Gaelic footballers and hurlers, however contusions were slightly more predominant in Gaelic footballers, which contrasts to the higher incidence in hurlers noted in the adolescent population. Muscle tightness was also higher in hurlers, as was similarly noted in the adolescent population. Bone injuries occurred more frequently in Gaelic footballers which may be related to the higher percentage of fractures. While the percentage of fractures in collegiate Gaelic footballers is slightly higher or similar to the percentage reported in previous studies on adult Gaelic footballers (4 – 10%) (Murphy et al., 2012b, Wilson et al., 2007, Cromwell et al., 2000), the percentage of fractures in collegiate hurlers was far lower than reported in male adult hurlers (7.4%) (Murphy et al., 2012a) Although hurlers have additional protection in the form of helmets, Gaelic footballers wear no additional protection and so the design of additional protection should be seriously considered as a prevention strategy. Tendon injuries were slightly more common in hurlers and this was similar to the reported tendon injuries in adult Gaelic footballers (9.2%) and hurlers (6.9%) (Murphy et al., 2012b, Murphy et al., 2012a).

Muscle injuries were predominant in fresher Gaelic footballers which may be related to the considerably higher proportion of contusions in fresher players. Senior hurlers presented with a similar percentage of contusions as Gaelic footballers. However, senior Gaelic footballers presented with a higher incidence of strains and muscle tightness than fresher Gaelic footballers. This higher incidence of strains in senior participants could be related to the higher percentage of quadriceps and shoulder injuries. Senior hurlers presented with a similar percentage of strains as Gaelic footballers, however a higher amount of muscle tightness was noted in hurlers which can be attributed to the higher proportion of lower back injuries in senior hurlers. Sprains were slightly more predominant in senior Gaelic footballers than fresher Gaelic footballers and were similar to the incidence of sprains reported in senior hurlers.

4. 4. 3. 5. Severity of injury

The majority of participants stopped playing after sustaining an injury, however almost two fifths of adolescent Gaelic footballers and hurlers carried on playing and did not take time off sport to allow the injury to heal, which is higher than both school adolescents and collegiate players. Collegiate hurlers were found to continue playing and training more commonly than Gaelic footballers, which could be related to the anecdotally “hardier” mentality of hurlers. Fresher Gaelic footballers also more commonly played on and may be under pressure to perform to compete for selection or secure a sport scholarship, and so may be unwilling to stop playing in comparison to senior players that may have already cemented their role in the team. While this study observed a lower percentage of players continuing to play on despite injury than reported by Cromwell et al. (2000) in elite male adult Gaelic footballers (46%), a substantial amount of players continued to play through injury. Thus, player and coach education, especially to adolescents, hurlers and fresher players, is essential as a prevention strategy to explain the importance of healing and rehabilitation, to reduce the effects of the injury and prevent re-injury, as players may be under pressure to continue playing due to the high frequency of matches and fear of losing their place on the team (Cromwell et al., 2000).

Minor (0-7 days) injuries were predominant in school adolescents closely followed by severe injuries (>22 days) and moderate injuries (8-21 days). Strains, sprains and fractures primarily lead to a severe injury, with minor injuries commonly occurring due to muscle tightness, contusions, tendinopathy and Osgood Schlatter's disease which are injuries that don't require either an extended period of time out from sport or players may be able to continue playing through the injury. Hurlers presented with a much higher amount of minor injuries which could be attributed to the larger percentage of muscle tightness and contusions in hurlers. The higher proportion of moderate and severe injuries in Gaelic footballers can be linked to the higher incidence of strains, sprains and cartilage injuries in adolescents Gaelic footballers. The mean days lost from sport before full fitness was slightly lower in the current study than in adolescent Gaelic footballers (34.3±37.1) (Watson, 1996b). However the current study displayed a higher mean days lost from sport before taking place in light training and full training than the 13.9±15.2 days of restricted activity in school Gaelic footballers as reported by Watson (1996b). Despite the differences in the amount of minor, moderate and severe injuries in Gaelic footballers and hurlers, no significant difference was found between Gaelic footballers and hurlers in mean days missed from light training, full training or full fitness ($p>0.05$).

The severity of injury in collegiate participants was distributed slightly more evenly as severe injuries occurred most frequently, followed closely by minor and moderate injuries. The difference between adolescent and collegiate players could be that collegiate participants are more prone to more moderate and serious injuries such as strains and sprains or were willing to take the appropriate length of time away from sport to recover fully from the injury. Similar to adolescents, minor injuries predominantly occurred in contusions, muscle tightness, tendinopathy and lacerations with strains commonly resulting in a moderate severity of injury and sprains and fractures causing a severe injury. The higher incidence of sprains resulting in moderate injuries in collegiate participants could be due to a larger proportion of Grade 1 injuries which with appropriate treatment and rehabilitation would generally allow participants to return to sport return within 3 weeks (Brukner and Khan, 2006). Collegiate hurlers presented with a higher proportion of minor and severe injuries however Gaelic footballers displayed a higher incidence of moderate injuries. Unfortunately, the severity of injury has been defined in a number of different manners in different epidemiology of injury studies in Gaelic games which makes comparisons between studies difficult. Collegiate Gaelic footballers presented with a far higher percentage of minor injuries in the current study than the 13.2% and 10% reported in adult Gaelic footballers by Murphy et al. (2012b) and Newell et al. (2013) respectively. However, Cromwell et al. (2000) observed a similar percentage of minor injuries in adult Gaelic footballers (38%) as reported in the current study. Collegiate hurlers presented with a slightly smaller percentage of minor injuries than adult hurlers (45%) (Murphy et al., 2012a). The percentage of moderate injuries that occurred in Gaelic footballers and hurlers was less than those reported in adult Gaelic footballers (56%), however the amount of severe injuries reported in adult Gaelic footballers (34%) was similar to the percentage of severe injuries noted in collegiate Gaelic footballers but lower than those in collegiate hurlers (Newell et al., 2013). The mean days lost from sport from full fitness before full fitness was higher in collegiate participants than reported by Watson (1996a) in adult hurlers (20.3±19.3). Notably fresher participants returned to full training and full fitness significantly quicker than senior Gaelic footballers, which can be explained by the much higher incidence of minor injuries in fresher players and severe injuries in senior players.

The majority of players did not require surgery due to their injury, which is expected as only a certain amount of serious injuries would require surgical intervention. Collegiate Gaelic footballers and senior Gaelic footballers underwent surgery more commonly than hurlers and fresher Gaelic footballers. This higher proportion is not surprising as a higher percentage of senior players presented with serious injuries. There is no data available on the rate of injuries that required surgery in Gaelic games in this population, and this information is important as players that undergo surgery can lose time from school, college or work, may incur significant costs related to the surgery for players and also places extra burden on insurance companies and hospitals. Thus injury prevention programmes and strategies that target these severe injuries are necessary.

4. 4. 4. The injury event

4. 4. 4. 1. Mechanism of injury

Non-contact injuries predominated, however the percentage of contact injuries was higher in collegiate participants. Collegiate Gaelic footballers presented with a lower percentage of non-contact injuries and collegiate hurlers a similar percentage in the current study as the 60% and 67.8% reported in adult Gaelic footballers by Newell et al. (2013) and Murphy et al. (2012b); unfortunately no information on the distribution of contact and non-contact injuries was noted in the studies on adult hurlers (Murphy et al., 2012a, Watson, 1996a). The predominance of non-contact injuries in Gaelic games is not surprising as strains and sprains are the two most predominant natures of injury and these do not occur commonly due to contact. Nonetheless a significant number of contact injuries occurred in Gaelic games, which is anticipated due to the physicality of these games (Cromwell et al., 2000).

Adolescent Gaelic footballers and hurlers presented with a higher amount of overuse injuries than school adolescents and collegiate Gaelic footballers and hurlers. Adoelscent Gaelic footballers sustained a slightly higher percentage of overuse injuries than hurlers, which was slightly higher than the 13.5% of overuse injuries reported by Watson (1996b) in school aged Gaelic footballers. Collegiate Gaelic footballers presented with far fewer overuse injuries than hurlers and had a similar incidence to collegiate Gaelic footballers. Thus fresher hurlers presented with more overuse injuries than collegiate Gaelic footballers and senior hurlers, however due to their low numbers in the current study, further investigations into this topic is recommended. Thus collegiate Gaelic footballers and senior hurlers presented with far fewer overuse injuries than the 17.4% of injuries reported in adult Gaelic footballers or 19% in adult hurlers (Murphy et al., 2012b, Murphy et al., 2012a). Contact with another player was predominant and accounted for approximately one fifth of all injuries in participants, and could be attributed to tackling. Thus the introduction of protective padding or protective equipment requires further research and development (Murphy et al., 2012a). Assault and violence was an uncommon cause of injury (0.5-2.4%) which demonstrates the low level of unruly behaviour in Gaelic games.

With regard to the specific mechanisms of injury a substantial proportion of adolescent and collegiate participants had no specific mechanism of injury, as the injury came on gradually, which is due to overuse injuries. Sprinting was a predominant cause of injury which is similar to the 26.8% reported by Murphy et al. (2012b) in adult Gaelic footballers. Sprinting was a mechanism of injury more commonly noted in adolescent Gaelic footballers than hurlers which could be related to the increased incidence of hamstring strains in adolescent Gaelic footballers. In contrast, collegiate Gaelic footballers and hurlers presented with a similar amount of injuries due to sprinting. The sudden acceleration/deceleration that is required in Gaelic games, excessive loading placed on the body's tissues in such a high intensity movement and coupled with this possible poor strength or poor flexibility of muscles in participants may all predispose tissues to injury during sprinting (Newell et al., 2013, Murphy et al., 2012b, Gabbe et al., 2006, Woods et al., 2004). Injuries commonly occurred during tackling with a similar percentage of injuries reported in adult Gaelic footballers (27.8%) (Wilson et al., 2007). Being tackled resulted in an higher amount of injuries than tackling the opposition which was also reported by Wilson et al. (2007). Injuries during tackling were more predominant in hurling than Gaelic football and fresher Gaelic footballers sustained more injuries during tackling than senior Gaelic footballers. While tackling has been shown to be a common mechanism of injury, one of the biggest attractions of Gaelic games, especially in hurling, is the physicality of the game as players are not only permitted to aggressively tackle the opposition to win possession of the ball but are also allowed to use a shoulder to shoulder hit on their opposition when competing to win possession of the ball (Murphy et al., 2012b). Thus any prevention strategies such as possible rule changes must be feasible and must not change the inherent nature of the game itself, otherwise it will receive high resistance from players, coaches and the sporting body itself and so will not have the desired effect, to reduce the amount of injuries (Finch, 2006). Turning and landing were also frequent mechanisms of injury in participants. The current study reported a lower percentage of injuries occurring during turning than observed by Murphy et al. (2012b)(12%), Wilson et al. (2007)(13.3%) and Cromwell et al. (2000)(18%). Landing injuries in collegiate Gaelic footballers and hurlers was similar to the 7.1% reported in adult Gaelic footballers (Murphy et al., 2012b). Knee and ankle injuries predominantly occur during these movements. Turning injuries were slightly more common in hurlers than Gaelic footballers; whereas conversely, injuries occurred more frequently during landing in collegiate Gaelic footballers than collegiate hurlers which can be attributed to the higher percentage of ankle injuries in Gaelic footballers.

4. 4. 4. 2. Time of injury

As expected, the vast majority of injuries occurred during training and matches and not in the warm up or cool down. The mean minutes an injury occurred were similar in all three populations studied and no significant difference was noted between participants. Previous research in Gaelic games has found that as a match or a training session progresses, the likelihood of an injury occurring increases (Wilson et al., 2007, Murphy et al., 2012b, Murphy et al., 2012a) and this was supported by the current study. The majority of injuries occurred in the second half in adolescent Gaelic footballers and hurlers at a similar rate to the 56.9-60.8% reported in adult Gaelic footballers and hurlers (Wilson et al., 2007, Murphy et al., 2012b, Murphy et al., 2012a). However, injuries occurred far more predominantly in the second half in collegiate participants than in adolescent Gaelic footballers and hurlers in the current study or adult Gaelic footballers and hurlers (Wilson et al., 2007, Murphy et al., 2012b, Murphy et al., 2012a). Injuries predominated in the 4th quarter in participants and similar to injuries in the second half, school adolescents and adolescent Gaelic footballers and hurlers displayed a similar percentage of injury and collegiate participants presented with a higher percentage of injury than those reported in adult Gaelic footballers and hurlers (29.3-38%) (Wilson et al., 2007, Murphy et al., 2012a, Newell et al., 2013). This increased risk of injury as the match progresses is primarily attributed to fatigue, which can reduce motor coordination, neuromuscular control and affect muscle mechanics especially at the end of matches as fatigued players may drastically increase their efforts in order to ensure they win the match (Wilson et al., 2007, Hawkins et al., 2001, Bahr and Holme, 2003). Poor conditioning of players and poor coach education could further increase the susceptibility of injury as anecdotally, some coaches tend to structure their sessions to complete speed work and sprints at the end of sessions; this requires fatigued players to complete a number of high intensity activities and so in order to develop a comprehensive prevention strategy, coach education must be provided to combat these issues (Newell et al., 2013). Some changes to the game itself may also help reduce the risk of injury in the later stages of the game, such as dividing the game into four quarter rather than two halves to introduce more breaks in the game or the introduction of rolling substitutes and removing the limitation of the amount of substitutes that are allowed on the pitch per game; this would give players increased opportunities to rest throughout the match and reduce fatigue (Wilson et al., 2007).

Senior Gaelic footballers and senior hurlers presented with a higher incidence of injuries in the second half of the game than fresher Gaelic footballers which could be attributed to the older senior players becoming fatigued more than the fresher players. The current study also found a relatively high percentage of injuries occurring in the second quarter in both adolescent and collegiate Gaelic footballers and hurlers which was similar to the 29.1% of injuries reported by Murphy et al.(2012b). This predominance of injuries in the second quarter could be due to players becoming fatigued just before half time. In fact, when visually estimating the time players became injured during the second quarter a large proportion of the injuries occurred nearing half time.

4. 4. 4. 3. Foul Play

Foul play was involved in double the amount of injuries in school adolescents and adolescent Gaelic footballers and hurlers than in collegiate participants. While foul play was more predominant in adolescents it was still far below the 34.8% observed in school Gaelic footballers by Watson (1996b). In addition, foul play and recklessness was found to be the highest contributors to injury in Irish adolescents in sport in a paper published in 1984 (Watson, 1984). Thus, it would seem that while the amount of injuries in adolescents has reduced in recent times, possibly due to stronger enforcement of the rules of play, injuries relating to foul play in adolescents are more prevalent than collegiate players but also account for a tenth of all injuries. Consequently, further research on foul play and its relationship to injury, including establishing the attitudes and perceptions of foul play in adolescent players is required. Collegiate participants demonstrated fewer injuries related to foul play than adult Gaelic footballers (10.0%) (Wilson et al., 2007) and vastly less injuries than reported in adult hurlers (41.1%) (Watson, 1996a). However, the study on adult hurlers was completed in 1996 and so the injuries related to foul play may have decreased, similar to those observed in school Gaelic footballers. Adolescent and collegiate Gaelic footballers presented with a higher proportion of injuries related to foul play than adolescent and collegiate hurlers. This has not been noted in previous research and perhaps indicates that further enforcement of the rules may be required in Gaelic football. Senior Gaelic footballers also presented with a higher percentage of injuries related to foul play than fresher players. Surprisingly almost half of collegiate injuries related to foul play occurred when the injured participant themselves fouled or attempted to foul an opposing player. This is an essential result to impart to collegiate players to ensure they understand the increased risk of injury they are not only placing on the opposing player, but also on themselves.

Red cards were rarely used as a sanction in foul play related to injury, with the majority of participants who completed the foul receiving a free or a yellow card. Senior players on the other hand presented with a higher proportion of red cards, which could be related to the higher proportion of injuries related to foul play in senior players which would increase the chances of senior players receiving a more serious sanction. In order to reduce the risk of injury due to foul play, referees should be encouraged to enforce the rules more strongly and the rules should be examined to allow more red cards to be given out to those who flout the rules and increase the risk of injury to themselves and other players. Education to coaches and players should be provided to explain the link between foul play and injury to not only the opposing player but the participant who fouls; this may reduce the rate of professional fouls that are used to improve the chances the team has of winning the match.

4. 4. 5. Factors surrounding the injury

4. 4. 5. 1. Relationship between time of year and injury

The majority of injuries occurred during the season which can be attributed to the increased amount of matches during this period. Both the current study and previous research have shown that there is an increased risk of injury during matches, this is primarily credited to the increased intensity during matches and the higher physical and physiological stresses played on players during match situations (Murphy et al., 2012b, Murphy et al., 2012a, Yung et al., 2007). Injuries during preseason and offseason were not as common.

Injuries predominantly occurred at the beginning of the calendar year in adolescents; the incidence of injury decreased significantly over the course of the summer months and increased again nearing the end of the year. Injuries during February predominated, followed by April, January and March. Injuries during January and February correspond to preseason in underage club Gaelic games, thus the increased risk of injury during these months correspond to the previously mentioned increased demands being placed on the body's tissues due to the increased training load and possible under conditioning of players (Takemura et al., 2007, Cromwell et al., 2000). This increased demand was further exemplified by the fact that overuse injuries were most common in February and January. In addition, adolescent hurlers demonstrated a far higher percentage of injuries during February than Gaelic footballers. Similar to adolescent Gaelic footballers and hurlers, elite Gaelic footballers and hurlers have increased susceptibility of injury during April, this corresponds to the beginning of the competitive season for both adolescent and adult participants and so enhanced demands are placed on the body which can lead to soft tissue failure and injury (Cromwell et al., 2000). The decreased injury rate during the summer could be due to the reduced amount of matches during the summer as underage teams tend to suspend training and matches over the summer holidays (Crowley and Condon, 1989). In addition, the current study assessed injuries during the school term and did not have access to participants during the summer months, therefore, only injuries that were still reducing performance or causing players to miss sport were reported in September and so this study may not have accurately assessed injuries throughout the full year. Injuries to collegiate Gaelic footballers and hurlers predominated at the end of the calendar year and the bringing of the year and reduced dramatically from March to August. Injuries primarily occurred during November, followed by October, February, January and December. This increased incidence of injury at the end and beginning of each calendar year coincides with the collegiate season which begins in September and ends in early March. Thus there was a spike in injuries occurring during October/November and January/February. The increased risk of injury in October/November corresponds to preseason training and the start of the competitive collegiate season. In addition, players would concurrently be playing club or county football depending on their skill level and so they would be at the end or just finished their club season. In fact, overuse injuries were most common in October and November in collegiate participants which may be related to this increased demand placed on players. In addition, this susceptibility to injury in the month of October was far higher in collegiate hurlers than Gaelic footballers. The collegiate competitive season tapers out in early March and so the increased risk of injury during January and February could be related to the increased importance of matches nearing the end of the collegiate season. It is paramount the team wins each and every match as it is a knock out structure, therefore not only are these games played at great intensity and competiveness, players may also be prone to playing through injuries as they are so close to the end of the collegiate competitive season. Senior Gaelic footballers and hurlers displayed an increased rate of injury in November and February. Senior players would be more likely to be starting players with their club teams than fresher players, and November corresponds to the end of the club season usually of successful teams or counties and the beginning of the collegiate competitive season, and February corresponds to the end of the collegiate season and beginning of the club season. Thus a seasonal bias in Gaelic games would seem to occur and it is essential that the governing body of Gaelic games critically assess the structures of the collegiate, club and county seasons to ensure players are not forced into playing continuously throughout the year without an off season which may predispose to injury.

4. 4. 5. 2. Relationship between age group and injury

The vast majority of injuries occurred when players were playing within their own age group. Restrictions are not in place at present to prevent younger players playing in older age levels within Gaelic games. Thus, younger players would possibly be at risk of increased susceptibility to injury when playing in an older age group as there would not be fair competition between the players as the opposition may be taller, heavier and the younger player may be unable to withstand the greater physicality that may occur (Helsen et al., 2005). While a small amount of injuries occurred while playing in an older age group, adolescent hurlers and fresher players exhibited a higher percentage of injuries while playing with an older age group, and so may be at an increased risk of injury however further research is required in order to fully address this possible risk factor for injury.

4. 4. 5. 3. Relationship between playing position and injury

Backs and forwards presented with a higher percentage of injuries than goal keepers or midfielders. However, in each Gaelic team there are six backs and forwards, two midfielders and only a single goalkeeper, thus the chances of backs and forwards sustaining an injury is higher as there are more players in this position. Thus, in order to adjust for this discrepancy and truly compare between positions, the amount of injuries was divided by the number of players in that position. Murphy et al. (2012b) adjusted their figures for this discrepancy by standardising the frequency of injury against the number of players registered to each position, this may be easy to do when assessing elite players however when examining adolescent or collegiate players they commonly change position depending on the age group, team or opposition they are playing and so would not exclusively be playing in the same position throughout the year. When the adjusted figures are taken into account, goalkeepers presented with the highest injury proportion than any other position. Wilson et al. (2007) also found that goalkeepers had a higher injury rate than half forwards or half backs in adult Gaelic footballers. Goalkeeper’s risk of injury is commonly overlooked as they are not outfield players; however they are required to tackle, twist, turn and may need to dive more frequently than other positions. Midfielders were found to have the highest injury proportion in adolescent Gaelic footballers and hurlers, which is similar to adult Gaelic footballers (Murphy et al., 2012b). Midfielders are required to cover large portions of the field, jump and catch high balls repeatedly and are expected to both defend and attack during the match, thus they are placed under a higher level of intensity and physicality than other playing positions (McIntyre, 2005).

The injured body parts varied slightly between positions and between adolescent and collegiate players. Adolescent goalkeepers presented primarily with ankle and lower back injuries and collegiate goalkeepers demonstrated a high proportion of knee injuries, followed by hand and fingers and lower back injuries. The hand and finger injuries can be attributed to catching the football and sliother, and lower back injuries may be related to diving to save goals. Adult goalkeepers in Gaelic football were similarly reported to present with knee and finger injuries (Newell, 2011). Adolescent backs predominantly sustained knee, lower back and ankle injuries and collegiate backs presented with hamstring, quadriceps and ankle. Adolescent forwards sustained knee ankle and hamstring injuries, similarly collegiate forwards underwent knee, hamstring and ankle injuries. Correspondingly in adult Gaelic footballers the hamstring, knee and ankle injuries were most common, thus outfield players seem to be susceptible to injuries in these locations (Newell, 2011). Adolescent midfielders commonly presented with injuries to the knee, lower back and calf. In contrast, collegiate midfielders commonly presented with hamstring, ankle and knee. Similar to collegiate midfielders, adult midfielders in Gaelic football presented with ankle, hamstring and knee injuries (Newell, 2011). Thus it would seem that the hamstring, ankle and knee are predominant injuries in backs, forwards and midfielders with goalkeepers differing in the most commonly injury body parts. In addition, the prevalence of sprains, strains, contusions and muscle tightness in all adolescent and collegiate positions may be related to this predominance of hamstring, ankle and knee injuries and so it may be beneficial to adapt injury preventative strategies in goalkeepers to focus on the different injuries sustained.

4. 4. 5. 4. Relationship between free taking role and injury

The majority of adolescent and collegiate participants that became injured were not free takers. However both adolescent and collegiate Gaelic footballers presented with a higher percentage of injury to free takers than hurlers. Thus, Gaelic footballers who have a free taking role within the team may be at a slightly higher risk of injury as they would need to practice their free taking repeatedly in sessions to enhance their skill level in this technique. Therefore, theoretically they may become fatigued as they must complete this motion repeatedly especially if they undergo poor training techniques and do not rest between repeated actions. In addition, in a match situation the free taker may be required to cover more distances to get to the place where free must be taken and then return to their own position. In elite teams there may be a number of free takers however in the adolescent teams especially at the lower level there may only be one or two free takers on the team and so they would be under pressure to complete their own role and this role. Thus, education should be provided to free takers and coaches to ensure that if they are completing unsupervised sessions practicing their free taking or if they are completing the practice during training, that they rest between repetitions and do not overload the same muscles repeatedly.

4. 4. 5. 5. Relationship between playing surface and injury

Injuries primarily occurred on grass more commonly in collegiate players than in adolescent participants and this high rate of injury is most likely due to the fact that grass is the predominantly used and traditional surface for Gaelic games. The percentage of injury in the current study is lower than the 97% of injuries noted on grass in unpublished data on adult Gaelic footballers (Newell, 2011). Injuries occurred on synthetic or AstroTurf more commonly in adolescents than collegiate participants. Astroturf has begun to be used more frequently in Gaelic games as they can be used in all weathers. Collegiate and fresher Gaelic footballers presented with a higher rate of injuries when playing on synthetic turf than collegiate hurlers and senior Gaelic footballers; however this could be related to these teams utilising synthetic pitches more frequently. Astroturf is harder than grass and has previously been identified as a possible risk factor for injury as harder ground increases the impact and loading placed on body's tissues (Orchard, 2002, Takemura et al., 2007, Skovron et al., 1990, Nigg and Segesser, 1988). Further research on the relationship between synthetic turf and injury in Gaelic games is required to comprehensively assess its possible influence on injury, especially as the use of synthetic turf is increasing in clubs across the country.

Injuries during road running were more common in adolescent hurlers than adolescent Gaelic footballers and collegiate players. Adolescent hurlers may be attempting to improve their fitness levels by running on roads during preseason or outside of supervised training sessions. Thus education on appropriate methods to increase their fitness and advice such as substituting running on grass as it reduces the impact played on the body's tissues can be helpful to reduce injuries (van Mechelen, 1992). Information on training load and how to slowly increase the running distance and intensity in order to prevent overload on tissues would be helpful (Berg, 2003).

Injuries that occurred indoors were more prominent in adolescent participants especially adolescent hurlers and these were commonly injuries that occurred during P.E. in the hall or in the gym. Adolescent Gaelic players have started to undergo gym work at a younger age than was previously done in the past. These players may be unfamiliar with the movements required with a lot of the exercises and so be at greater susceptibility to injury especially if they undertake these exercises in an unsupervised environment.

Thus, adolescent participants should be taught the functional movements required with minimal or no external weights in a supervised environment as an injury prevention strategy.

4. 4. 5. 6. Relationship between weather conditions and injury

As the majority of injuries occurred outdoors in participants, weather conditions and its effect on the ground and playing surfaces is important to note. The temperature during injury was primarily normal, followed by cold, which is expected as Ireland has quite a tepid temperature. The higher percentage of injuries that occurred in cold weather in collegiate players could be related to their playing season, as the majority of competitive matches are held between October to early March which is essentially winter time. School adolescents displayed a higher percentage of injuries that occurred in a hot temperature than adolescent and collegiate Gaelic footballers and hurlers which may be due to the different sports played with possible different structures to their season.

Pitches were primarily dry when any injury occurred and this was far higher than the percentage of injuries that occurred in dry/hard ground in adult Gaelic footballers (43%) (Cromwell et al., 2000). Dry or hard ground can predispose to injury as it places greater external forces on the body's tissues and produces faster running speeds and quicker movements which may increase susceptibility to injury (Orchard, 2002, Takemura et al., 2007). Wet weather during the injury event was lower than in adult Gaelic footballers (39%) (Cromwell et al., 2000). Wet weather may predispose to injury as it may cause players to slip and fall, or the muddy ground conditions may cause players to become stuck in the less yielding surface and when a player is turning place increased forces on the knee which has been identified as a possible mechanism of serious knee injuries such as ACL tears (Lee and Garraway, 2000, Brukner and Khan, 2006). Previous research has cited the state of the pitch as a common cause of injury in both adolescent and adult Gaelic footballers which highlights the need for further research on the relationship between the weather and the state of pitch to injury (Watson, 1996b, Cromwell et al., 2000).

4. 4. 5. 7. Protective equipment

The majority of adolescent and collegiate participants did not wear protective equipment during training or matches. In fact, the vast majority of adolescent hurlers and collegiate hurlers wore no protective equipment more commonly than adolescent and collegiate Gaelic footballers. Fresher Gaelic footballers and senior hurlers also presented with a high proportion of players not wearing protective equipment in comparison to senior Gaelic footballers. This is a worrying, as Gaelic games are physical sports with a high risk of injury. Protective equipment is commonly used in other sports and further research on protective equipment is necessary in Gaelic games to develop equipment that may reduce the risk of injury. The introduction of padding to reduce the risk of muscle contusion which have been found to be prevalent in school aged and collegiate Gaelic footballers and hurlers in the present study may also be beneficial (Wilson et al., 2007). Mouth guards were the most commonly worn protective equipment and the introduction of the mandatory use of mouth guards in all age groups in Gaelic football is a welcome move to prevent injury. Ankle strappings were also common in both Gaelic football and hurling which can be linked to the predominance of ankle injuries in Gaelic games and players may be using strapping as a method of reducing the risk of recurrent ankle injury (Murphy et al., 2003). Preventative taping other than ankle taping was rare, especially in hurlers, where no other preventative strapping was reported in both adolescent and collegiate hurlers. Gaelic footballers reported an extremely small proportion of patellar, thumb and wrist taping. Thus, education on protective equipment should be provided to players and coaches, especially to hurlers and fresher Gaelic footballers, and instruction on the importance of preventative taping and its benefits in reducing the risk of injury would be beneficial (Murphy et al., 2003).

4. 4. 6. The injury assessment

4. 4. 6. 1. Injury examination and further investigations completed

Approximately one fifth of all participants were referred on to an orthopaedic surgeon for further assessment on their injury. Gaelic footballers and senior Gaelic footballers were referred on more commonly than hurlers and fresher Gaelic footballers. This has severe implications for the GAA, as the GAA insurance scheme would be required to cover the extra cost of an orthopaedic assessment. In addition, further investigations were ordered for between 21.7-29.0% of adolescent and collegiate participants which also are costly but necessary. X-rays and MRI scans were the most common further investigations required with also a large amount of participants sent for both an MRI scan and an X-ray. Thus, a large proportion of injuries, especially in collegiate participants, required further investigation, which not only increases the cost associated with the injury to the player themselves and the GAA, it also increases the demands on the emergency departments and referral system for scans. Therefore preventative programmes to reduce the risk of injury may be critical in reducing the need for further investigations in Gaelic games which would reduce the associated costs.

4. 4. 7. Limitations to the study

Similar to Study 1, the use of only two colleges may have caused a certain amount of bias, as the training events and loads within each college may have been similar. In addition, only 4th and 5th year adolescents were assessed in the current study, so further research is needed on injury epidemiology in younger adolescents. This study utilised student therapists to assess injuries. Ideally qualified therapists should assess injuries in epidemiological studies, however this was not feasible, as the collegiate population did not have qualified therapists working with the teams and a large proportion of their training and match sessions occurred at the same time throughout the week. Therefore to accurately collect injury data, it was necessary to utilise student therapists as the qualified therapist completing this study was unable to attend all sessions. In order to minimise the possible negative effect of utilising student therapists, as detailed previously, the qualified therapists met weekly with the student therapists and went through all injuries they viewed. If the student therapists were unsure of any aspect of the injury the qualified therapist re-assessed the injury again.

4. 4. 8. Conclusion

This study provided comprehensive epidemiological information on injury in populations that have yet to be studied in great detail. Injuries were found to be prevalent, with collegiate players presenting with a higher incidence of injury than adolescent players. Over a third of all adolescent and collegiate participants are at risk of injury in one year and over a quarter of injured participants at risk of developing a subsequent injury throughout the year. Injuries occurred more frequently in matches in all populations and hurlers presented with a higher match injury rate. Fresher Gaelic footballers had an increased training and match injury rate than senior Gaelic footballers. Lower limb injuries predominated, with the hamstring, knee and ankle most commonly injured and injuries to the lower back common in adolescent hurlers. Thus comprehensive injury prevention strategies based on this epidemiology of injury presented should be designed for adolescent and collegiate Gaelic footballers and hurlers.

Chapter 5. Risk factors for injury in adolescent and collegiate Gaelic footballers and hurlers

5. 1. Introduction

A risk factor for injury is defined as any entity that contributes to the occurrence of sports injuries and are subdivided into modifiable and non-modifiable risk factors (Maffey and Emery, 2006, Meeuwisse et al., 2007). Modifiable risk factors for injury are factors that can be improved through the implementation of an injury prevention programme or strategy e.g. flexibility, balance, core stability, biomechanical factors (Bradley and Portas, 2007, Cowley and Swensen, 2008, Plisky et al., 2006, Meeuwisse et al., 2007). Non-modifiable risk factors for injury on the other hand, are those that are unable to be altered to reduce the likelihood of injury taking place e.g. age, gender, previous injury (Meeuwisse et al., 2007). Current research identifying risk factors for injury in sport tend to utilise research designs, statistical analysis and sample sizes that are less than ideal. Therefore cohort studies with large sample sizes utilising appropriate statistical analysis is recommended, as cohort studies are considered superior due to their prospective nature, strong analytical design and ability to provide an accurate measure of relative risk (Brooks and Fuller, 2006, Goldberg et al., 2007, Bahr and Holme, 2003).

Identifying causative factors for injury in Gaelic games is critical, as this has not been analysed in detail as of yet. Only five studies have examined risk factors for injury in Gaelic games, four of these studies assessed a small number of risk factors for a single injury (ankle, hamstring, hand) (Watson, 1999, O'Sullivan et al., 2008, Lowther et al., 2012, Falvey et al., 2013) and only a single study assessed a larger number of risk factors to all possible injuries; however this was not inclusive of only Gaelic sports, as soccer was also analysed which may have confounded the results (Watson, 2001). Of the five studies that assessed risk factors for injury in Gaelic games, two were case control studies where injured participants were compared to uninjured participants (Lowther et al., 2012, O'Sullivan et al., 2008). Thus these were retrospective in nature, open to bias and unable to decisively state that any differences noted between the injured and uninjured participants were due to deficits that were present prior to the injury occurring, not consequential after the injury occurred (Lowther et al., 2012, O'Sullivan et al., 2008, Bahr and Holme, 2003). One study implemented a retrospective cross sectional study utilising telephone interviews with hurlers who had previously presented at an emergency department; this study design is susceptible to a bias towards serious injuries such as fractures (Falvey et al., 2013). Merely two studies prospectively assessed a number of possible risk factors for injuries in Gaelic games; however only

Watson (2001) established the risk factors for injury in all possible injuries as Watson et al. (1999) analysed ankle injuries only.

As demonstrated, there is a severe lack of good quality, prospective research on risk factors for injury in all injuries that can occur in Gaelic games. Without this essential information, sufficient injury prevention programmes and strategies are unable to be developed. Thus, the aims of this study were:

1) To identify the risk factors of injury for region (lower body, upper body and trunk) in school adolescents, adolescent Gaelic footballers and hurlers and collegiate Gaelic footballers and hurlers

  Sub-aim 2) To determine cut off points to identify participants at risk of injury in each region (lower body, upper body and trunk) for school adolescents, adolescent Gaelic footballers and hurlers and collegiate Gaelic footballers and hurlers.

3) To determine the risk factors for injury in commonly injured body parts in school adolescents, adolescent Gaelic footballers and hurlers and collegiate Gaelic footballers and hurlers

  Sub-aim 4) To determine cut off points to identify participants at risk of injury in each of the commonly injured body parts for school adolescents, adolescent Gaelic footballers and hurlers and collegiate Gaelic footballers and hurlers.

5. 2. Methods

A prospective cohort study was implemented to assess the risk factors for injury in school adolescents, adolescent Gaelic footballers and hurlers and collegiate Gaelic footballers and hurlers.

5. 2. 1. Subjects

795 male participants that played Gaelic football and hurling were recruited. Adolescents (n=452) were recruited as detailed in Section 3.2.1 and 4.2.1. As previously described in Chapter 4, schools recruited in this study primarily played Gaelic football and hurling, however all students in the class were assessed, so the current study captured information on the risk factors for injury not only specifically in Gaelic football and hurling but also in 4th and 5th year students in a sample of Irish secondary schools. 293 adolescents played Gaelic football and hurling only. Collegiate participants (n=343) were recruited from male fresher and senior collegiate Gaelic football and hurling teams (Section 3.2.1. and 4.2.1.).

5. 2. 2. Experimental protocol

A prospective cohort study was implemented to assess the risk factors for injury in adolescent and collegiate Gaelic players. All participants underwent a musculoskeletal pre-participation screening at the beginning of the year (Section 3.2.3). Injuries to these participants were then tracked, and any injury that occurred was assessed by a therapist for the full school year or full collegiate season (Section 4.2.3.). The injury diagnosis, description and injury event was recorded in great detail in the injury report form (Appendix P). The following variables were related to regional location of injury and body part injured:

- Age
- BMI
- Active knee extension results
- At risk AKE cut off point >70°
- Navicular drop results
- Navicular drop >10mm
- Navicular drop asymmetry >3mm
- Normalised Y balance results
- Y balance test asymmetry ≥4cm
- Y balance test ≤94% leg length
- Y balance test ≤89% leg length
- Overhead squat individual criteria
- Overhead squat overall impression
- Single leg squat individual criteria
- Single leg squat overall impression
- Scapular control results
- Alternative push up test results
- Internal rotation of shoulder
- External rotation of shoulder
- Total range of motion asymmetry >5°
- Internal range of motion on the non-dominant side >20° than the dominant side

5. 2. 3. Data Processing and statistical analysis

All results were inputted into Microsoft excel (2010) where the data was checked, mistakes were corrected and missing values were coded. Following this the results were inputted into the statistical package R. Missing values were replaced using the random forest model. Slight, moderate and severe results for the categorical screening data were aggregated to increase predictive power, as the occurrence for each was small when analysing them separately.

Multinomial Regression Model was initially attempted to identify the model to best predict injury in the lower body, upper body and trunk. The risk factors for the head were not assessed due to the low occurrence of injuries in this region. Based on the results of Chapter 3, Multinomial Regression Model was also used to assess the risk factors for injury in the following common body parts injured: hamstring, knee, ankle, lower back, pelvis and groin, quadriceps and shoulder.

As there were a large number of independent variables, it was decided to generate a statistically driven model using stepwise selection[2] to prevent overfitting of the model and selection of the most informative variables. Informative variables are those that: 1) lead to a better discrimination between "injured" and "not injured" and so have higher accuracy and produce a better model fit and 2) variables that add original information to the model and do not contain information that is redundant. Multi-collinearity would then be assessed and if highly correlated variables were found, the variables with the least predictive power would be removed. Following that, a theoretically driven model would be completed utilising possible risk factors for injury that have been suggested in published literature. However, complete and quasi-complete separation was found for each of the statistically driven and theoretically driven models.

Reducing the amount of independent predictor variables within the model has been identified as a method to address complete or quasi-complete separation (Boyle, 1996). Therefore, the "region injured" dependant variable was recoded into three separate variables: lower body injury present, upper body injury present and trunk injury present. The "body parts injured" dependant variable was recoded into seven separate variables for each of the commonly injured body parts mentioned previously. Logistic regression

[2] Corrected Akaike's Information Criterion (AICc criterion) and leave-one-out cross validation methods were also used to generate a statistically driven model however similarly complete and quasi-complete separation was found using these methods.

was then completed for each of the ten dependant variables, and specially selected variables were chosen for each dependant variable based on the theoretical risk factors for injury to that region or body part. Unfortunately, the regression models that produced high overall accuracy displayed high specificity but extremely low sensitivity and so were unable to accurately predict injury in the population. In addition, each of the individual predictor variables was not significant within the overall model.

Thus the data was then entered into the statistical package SPSS (version 20). Further recoding of data was completed to generate dichotomous variables where average and excellent scores were aggregated to compare to a poor score for the overall impression of the squat, single leg squat and core stability test. Univariate analysis was completed to identify any risk factors for injury in each region and commonly injured body part. An independent samples t-test was completed to identify any significant differences between injured and uninjured participants for each of the dependant variables for all continuous independent variables, including: age, BMI, hamstring flexibility, navicular drop, balance (reach distance, percentage reach distance with regard to leg length, difference between right and left legs), internal rotation and external rotation of the shoulder. The effect size was determined using eta squared (Equation 3.2. Section 3.2.6.1). The chi square test for independence was completed on categorical independent variables including: knees over toes, knee valgus, toe out, hip flexion, trunk flexion and overall impression for the squat and single leg squat, core stability, winging of scapulae, control of scapulae when lifting, control of scapulae when lowering and symmetry of scapulae. In addition, categorical variables for identifying participants at risk of injury using previously reported cut off points were assessed, including: navicular drop greater than 10mm (Plisky et al., 2007, Buist et al., 2010, McPoil et al., 2008, Bennett et al., 2001), navicular drop difference between feet greater than 3mm (Plisky et al., 2007), hamstring flexibility less than 70° (Shimon et al., 2010), balance less than 89% of leg length (Butler et al., 2013b), balance less than 94% of leg length (Plisky et al., 2006), total range of motion greater than 5° between shoulders (Wilk et al., 2011) and non-dominant internal range of motion greater than 20° than the dominant shoulder (Wilk et al., 2011). Relative risk (RR) (ratio of the rate of injury in those identified with an issue in the screening, to the rate of injury in those with no issue noted in the screening (Bahr and Holme, 2003)) and the 95% Confidence Intervals was presented for any significant differences demonstrated by the chi square test for independence.

Receiver operating characteristic (ROC) curve was used to identify the optimal cut-off points for BMI, hamstring flexibility, navicular drop, balance, internal and external rotation of the shoulder to identify those at risk of injury (Hajian-Tilaki, 2013). The area under the curve (AUC) is a value that combines the sensitivity and specificity measures to describe the inherent accuracy of the cut-off points (Hajian-Tilaki, 2013). Cut-off points were only created when the AUC was greater than 0.6, as values below this demonstrate low overall accuracy, with a value of 0.5 equalling chance (Zou et al., 2007). In addition, only the cut-off points that resulted in producing a significant Chi square test of independence, differentiating between injured and uninjured were reported. Likelihood ratios were calculated as they quantity how much the measure improves the likelihood of making the correct prediction for injury or absence of injury. Sensitivity and specificity were also calculated to assess the accuracy of the cut-off points identified and a cut-off point with low sensitivity indicates that it is unable to accurately predict participants that will sustain an injury in the following season, with low specificity signifying that the cut-off point is unlikely to accurately predict participants that will not sustain an injury in the following season. The following cross-tabulation explains the factors used to calculate sensitivity and specificity:

Table 5.1: Cross-tabulation for sensitivity and specificity analysis

	Injury occurred	**Injury did not occur**
Issue present	True positive	False positive
No issue present	False negative	True negative

Sensitivity: Sensitivity (how accurate the measure is in predicting injury correctly) was measured using the following calculation:

$$\text{Sensitivity} = \frac{\text{True positives}}{\text{True positives} + \text{False negatives}}$$

Equation 5.1: Calculation of Sensitivity

Specificity: Specificity (how accurate the measure is in predicting the absence of injury correctly) was measured using the following calculation:

$$\text{Specificity} = \frac{\text{True negatives}}{\text{True negatives} + \text{False positives}}$$

Equation 5.2: Calculation of Specificity

Positive Likelihood Ratio: Positive likelihood ratio (improvement of likelihood of correctly predicting the presence of injury) was measured using the following calculations:

$$\text{Positive Likelihood Ratio} = \frac{\text{Probability that participant with an issue develops an injury}}{\text{Probability that participant without an issue devops an injury}}$$

Equation 5.3: Calculation of Positive Likelihood Ratio

As sensitivity and specificity have already been calculated it is easier to calculate positive likelihood ratio using the following calculation:

$$\text{Positive Likelihood Ratio} = \frac{\text{Sensitivity}}{\text{1 - Specificity}}$$

Equation 5.4: Calculation of Positive Likelihood Ratio using Sensitivity and Specificity

Negative Likelihood Ratio: Negative likelihood ratio (improvement of likelihood of correctly predicting the absence of injury) was measured using the following calculations:

$$\text{Negative Likelihood Ratio} = \frac{\text{Probability that participant with an issue does not develop an injury}}{\text{Probability that participant without an issue does not devop an injury}}$$

Equation 5.5: Calculation of Negative Likelihood Ratio

As sensitivity and specificity have already been calculated it is easier to calculate negative likelihood ratio using the following calculation:

$$\text{Negative Likelihood Ratio} = \frac{\text{1 - Sensitivity}}{\text{Specificity}}$$

Equation 5.6: Calculation of Negative Likelihood Ratio using Sensitivity and Specificity

5. 3. Results

5. 3. 1. Risk factors for region of injury

5. 3. 1. 1. Lower body Injuries

5. 3. 1. 1. 1 . School adolescents

With regard to the categorical predictor variables, excessive trunk flexion during the squat ($\chi^2(1)=14.10$, $p<0.0001$, RR=2.57, 95% CI: 1.48-4.46), inadequate hip flexion in the left single leg squat ($\chi^2(1)=4.82$, p=0.03, RR=1.65, 95% CI=1.03-2.66), and poor balance ($\chi^2(1)=6.59$, p=0.01, RR=1.49, 95% CI=1.10-2.02) and overall impression ($\chi^2(1)=12.99$, $p<0.0001$, RR=1.75, 95% CI=1.29-2.37) in the right single leg squat occurred significantly more often in school adolescents that developed a lower body injury the following season. No significant difference was found between those that developed a lower body injury and those that did not, for age, BMI, hamstring flexibility, navicular drop and balance ($p>0.05$). In addition, ROC curves were completed for all continuous independent variables. All AUC values were below 0.6 for BMI, hamstring flexibility, navicular drop and balance, thus cut off points to predict injury were unable to be identified.

5. 3. 1. 1. 2 . Adolescent Gaelic footballers and hurlers

Poor overall impression on the right ($\chi^2(1)=7.96$,p=0.005, RR=1.82, 95% CI=1.20-2.77) and left single leg squat ($\chi^2(1)=4.16$,p=0.04, RR=1.56, 95% CI=1.02-2.39), poor balance in the right single leg squat ($\chi^2(1)=4.91$, p=0.03, RR=1.61, 95% CI=1.06-2.45) and excessive trunk flexion during the squat ($\chi^2(1)=11.40$, p=0.001, RR=3.64, 95% CI=1.52-8.69) occurred significantly more often in those that subsequently developed a lower limb injury. No significant difference was found for age, BMI, hamstring flexibility, navicular drop and balance ($p>0.05$) and ROC curves produced AUC values below 0.6, thus cut-off points were unable to be generated.

5. 3. 1. 1. 3 . Collegiate Gaelic footballers and hurlers

Significantly more collegiate players that developed lower body injuries presented with inadequate hip flexion in the right single leg squat ($\chi^2(1)=3.98$, p=0.04, RR=1.50, 95% CI=1.00-2.27). No significant difference was found for age, BMI, hamstring flexibility, navicular drop and balance ($p>0.05$) and ROC curves displayed AUC values below 0.6.

5. 3. 1. 2. Upper body Injuries

5. 3. 1. 2. 1 . School adolescents

No significant difference between school adolescents with an upper body injury and the uninjured was found for: winging, control of scapulae when lifting, control of scapulae when lowering, symmetry of scapulae, at risk participants with total range of motion greater than 5° between sides or at risk participants with non-dominant internal range of motion greater than 20° than the dominant side. However internal rotation on the right ($p=0.005$, effect size=0.02) and left side ($p=0.01$, effect size=0.01) were found to be significantly lower in those that sustained an upper body injury with a small effect size. External rotation was not significantly different in those that developed an upper body injury ($p>0.05$).

ROC curves were completed for internal and external rotation of the shoulder, however the AUC values were below 0.6. With regard to BMI, an AUC value of 0.60 was reported, and the ROC curve suggested that participants with ≥21.7kg/m^2 were at risk of injury. The chi square test of independence demonstrated that significantly more participants with ≥21.7 kg/m^2 BMI during the screening developed an upper body injury ($\chi^2(1)=5.69$, $p=0.02$, RR=2.61, 95% CI=1.15-5.92). However, this cut off point for BMI represents a sensitivity of 64.0%, specificity of 56.4%, positive likelihood ratio of 1.46 and negative likelihood ratio of 0.64 which indicates low overall accuracy.

5. 3. 1. 2. 2 . Adolescent Gaelic footballers and hurlers

No significant difference between adolescent Gaelic players and uninjured players for the scapular control test and previously reported cut off points for shoulder mobility. Internal rotation on the left side ($p=0.03$, effect size=0.02) was found to be significantly lower in those that sustained an upper body injury that season with a small effect size. The AUC values for BMI, internal rotation and external rotation were all below 0.6.

5. 3. 1. 2. 3 . Collegiate Gaelic footballers and hurlers

No significant difference between collegiate players that subsequently developed an upper body injury using the chi square test of independence for categorical independent variables and independent samples t-test for the continuous independent variables was found. The AUC values in the ROC curves were all below 0.6.

5. 3. 1. 3. Trunk Injuries

5. 3. 1. 3. 1 . School adolescents

No significant difference was noted between those that developed a trunk injury and the uninjured for: hip flexion, trunk flexion, knee valgus and toe out for the squat and single leg squat, and poor overall impression for the squat, single leg squat and core stability. No significant difference between those identified as at risk using previously reported cut-off points for hamstring flexibility (<70°) and navicular drop (>10mm and side to side difference >3mm) was found. Participants identified as at risk due to non-dominant shoulder internal range of motion greater than 20° than the dominant side developed a trunk injury significantly more frequently than those not at risk ($\chi2(1)=4.35$, $p=0.03$, RR=2.33, 95% CI=1.04-5.22). Trunk injuries were found to occur significantly more commonly in older adolescents ($p=0.02$, effect size=0.01). BMI, hamstring flexibility, navicular drop and balance was not found to be significantly different in school adolescents that developed trunk injuries and those that did not ($p>0.05$). In addition, the AUC values for BMI, hamstring flexibility, navicular drop, internal and external rotation of the shoulder were all below 0.6.

5. 3. 1. 3. 2 . Adolescent Gaelic footballers and hurlers

Participants identified as at risk due to non-dominant shoulder internal range of motion greater than 20° than the dominant side developed a trunk injury significantly more frequently than those not at risk ($\chi^2(1)=4.40$, $p=0.04$, RR=3.08, 95% CI=1.03-9.26). Trunk injuries also occurred significantly more frequently in older adolescents ($p=0.002$, effects size=0.03) and those with reduced left external rotation ($p=0.04$, effect size=0.02) with a small effect size. The AUC values for BMI, hamstring flexibility, navicular drop and balance were all below 0.6.

5. 3. 1. 3. 3 . Collegiate Gaelic footballers and hurlers

No significant difference was found between collegiate players that developed a trunk injury and those that did not for hip flexion, trunk flexion, knee valgus and toe out for the squat and single leg squat and poor overall impression for the squat, single leg squat and core stability. No significant difference between those identified as at risk using previously reported cut-off points for hamstring flexibility, navicular drop and shoulder mobility was found. In addition, BMI, hamstring flexibility, navicular drop and shoulder mobility was not found to be significantly different in collegiate Gaelic footballers and hurlers that developed trunk injuries ($p>0.05$) and the AUC values from the ROC curves were all below 0.6.

5. 3. 2. Risk factors for commonly injured body parts

5. 3. 2. 1. Hamstring Injuries

5. 3. 2. 1. 1 . School adolescents

Poor overall impression of the left (χ^2 (1)=4.72, p=0.03, RR=2.69, 95% CI=1.06-6.79) and right single leg squat (χ^2(1)=13.768, p<0.0001, RR=7.14, 95% CI=2.10-24.32) were found to be significantly higher in those that developed a hamstring injury. No significant difference were found for core stability, the individual aspects of the squat and single leg squat and those identified as at risk with regard to hamstring flexibility, navicular drop and balance. No significant difference in hamstring flexibility was noted in those that received a hamstring injury and the uninjured (p>0.05). AUC values from ROC curves were below 0.6 for BMI, hamstring flexibility, navicular drop and balance and so cut off points were unable to be identified for hamstring injuries school adolescents.

5. 3. 2. 1. 2 . Adolescent Gaelic footballers and hurlers

Poor overall impression for the squat (χ2(1)=5.12, p=0.02, RR=5.12, 95% CI=1.05-24.93), right single leg squat (χ2(1)=15.01, p<0.0001, RR=2.98, 95% CI=2.53-3.51) and left single leg squat (χ2(1)=16.98, p<0.0001, RR=3.26, 95% CI=2.73-3.88) occurred significantly more frequently in those that subsequently developed a hamstring injury. Hamstring injuries occurred more commonly in those with reduced anterior percentage leg length for balance (p=0.01, effect size=0.03). Cut-off points were unable to be generated for BMI, hamstring flexibility, navicular drop and balance.

5. 3. 2. 1. 3 . Collegiate Gaelic footballers and hurlers

No significant difference was found for the categorical independent variables between the uninjured and participants that sustained a hamstring injury. Posteriolateral percentage of leg length for balance was found to be significantly lower in collegiate players that developed a hamstring injury (p=0.01, effect size=0.03). Cut-off points were unable to be calculated for BMI, hamstring flexibility, navicular drop and balance.

5. 3. 2. 2. Knee Injuries

5. 3. 2. 2. 1 . School adolescents

A significantly higher amount of participants identified as at risk of injury due to a navicular drop greater than 10mm on the right (χ^2(1)=5.46, p=0.02, RR=2.20, 95% CI=1.12-4.34) and left side (χ^2(1)=5.20, p=0.02, RR=2.22, 95% CI=1.10-4.45) were found to develop a knee injury in the following season. Poor balance during the right single leg squat occurred more frequently in those that developed a knee injury ($\chi^2(1)=9.86$, $p=0.002$, RR=3.02, 95% CI=1.46-6.27). No significant difference was noted for age, BMI, balance and hamstring flexibility.

ROC curves displayed AUC values below 0.6 for BMI, hamstring flexibility and balance. However, the navicular drop on the right and left side was 0.61 and the ROC curve identified a cut-off point of 7mm on the right and 6mm on the left. The chi square test of independence displayed that significantly more participants with ≥7mm on the right ($\chi^2(1)=4.86$, $p=0.03$, RR=2.26, 95% CI=1.07-4.79) and ≥6mm on the left ($\chi^2(1)=4.80$, $p=0.03$, RR=2.34, 95% CI=1.06-5.17) during the screening developed a knee injury during the subsequent season. The ≥7mm cut off point on the right foot represents a high sensitivity of 71.0%, relatively low specificity of 49.6%, positive likelihood ratio of 1.41 and negative likelihood ratio of 0.59. The ≥6mm cut off point on the left foot represents a high sensitivity of 72.4%, relatively low specificity of 48.7%, positive likelihood ratio of 1.41 and negative likelihood ratio of 0.57.

5. 3. 2. 2. 2 . Adolescent and Collegiate Gaelic footballers and hurlers

Adolescent and collegiate players that developed a knee injury did not perform significantly worse in any of the categorical and continuous independent variables ($p>0.05$) during the preseason screening. In addition, ROC curves were unable to generate accurate cut-off points for BMI, hamstring flexibility, navicular drop and balance as a predictor for knee injury.

5. 3. 2. 3. Ankle Injuries

5. 3. 2. 3. 1 . School adolescents

Trunk flexion ($\chi^2(1)=5.14$, $p=0.02$, RR=6.90, 95%CI=1.00-50.42) and toe out ($\chi^2(1)=4.16$, $p=0.04$, RR=2.20, 95% CI=1.01-4.79) during the squat occurred significantly more frequently in those that developed an ankle injury than uninjured participants. No significant difference in balance was noted between those that developed an ankle injury and those that did not ($p>0.05$). In addition the ROC curves displayed AUC values below 0.6 for balance, BMI, hamstring flexibility and navicular drop.

5. 3. 2. 3. 2 . Adolescent Gaelic footballers and hurlers

No significant difference was found for the categorical independent variables between the uninjured and participants that sustained an ankle injury. ROC curves were unable to identify cut-off points and no significant difference was noted in those that developed an ankle injury for balance, BMI, hamstring flexibility and navicular drop.

5. 3. 2. 3. 3 . Collegiate Gaelic footballers and hurlers

Poor balance in the left single leg squat ($\chi 2(1)=3.89$, $p=0.04$, RR=1.39, 95% CI=1.30-1.49) was significantly more predominant in collegiate players that subsequently developed an ankle injury. No significant difference between those that developed an ankle injury was noted for balance, BMI, hamstring flexibility and navicular drop. ROC curves were unable to generate adequate cut-off points for balance, BMI, hamstring flexibility and navicular drop.

5. 3. 2. 4. Lower back Injuries

5. 3. 2. 4. 1 . School adolescents

Inadequate hip flexion ($\chi^2(1)=4.75$, $p=0.03$, RR=3.05, 95% CI=1.05-8.87) during the squat occurred significantly more commonly in those that subsequently developed a lower back injury. Lower back injuries occurred more commonly in older adolescents ($p=0.04$, effect size 0.01). AUC values displayed by each of the ROC curves for BMI, hamstring flexibility, navicular drop and balance were all either too low or unable to differentiate using the chi square test between injured and uninjured participants.

5. 3. 2. 4. 2 . Adolescent and Collegiate Gaelic footballers and hurlers

No categorical or continuous independent predictors were found to be significantly different between those that developed a lower back injury in both adolescent and collegiate Gaelic footballers and hurlers. In addition the ROC curves were not able to generate cut-off points that significantly displayed a difference between injured and uninjured.

5. 3. 2. 5. Pelvis and Groin Injuries

5. 3. 2. 5. 1 . School adolescents

No categorical variables were found to be significantly higher in those that subsequently developed a pelvis and groin injury. Those that became injured had significantly lower posteriomedial balance as a percentage of their leg length ($p<0.001$, effect size=0.04). The AUC produced by the ROC curves were less than 0.6 for BMI, hamstring flexibility, navicular drop and balance.

5. 3. 2. 5. 2 . Adolescent and Collegiate Gaelic footballers and hurlers

No significant difference between those that developed a pelvis and groin injury and those that didn't was noted for the categorical and continuous independent variables in adolescent and collegiate players ($p>0.05$). The ROC curve was unable to generate cut-off points for BMI, balance, hamstring flexibility and navicular drop.

5. 3. 2. 6. Quadriceps Injuries

5. 3. 2. 6. 1 . School adolescents, Adolescent Gaelic footballers and hurlers and Collegiate Gaelic footballers and hurlers

No significant differences between those that developed a quadriceps injury and the uninjured participants was found for either the categorical or continuous variables ($p>0.05$). The ROC curve produced AUC values less than 0.6 for BMI, hamstring flexibility, navicular drop and balance.

5. 3. 2. 7. Shoulder Injuries

5. 3. 2. 7. 1 . School adolescents

Poor control of the right scapula when lifting ($\chi^2(1)=4.29$, $p=0.04$, RR=3.46, 95% CI=1.00-12.07) and left ($\chi^2(1)=5.94$, $p=0.02$, RR=4.55, 95% CI=1.19-17.35) was more common in those that developed a shoulder injury. Internal rotation on the left side was significantly lower in those that became injured ($p=0.01$, effect size=0.01). Internal and external rotation displayed AUC values below 0.6 in the ROC curves and so cut off points to determine risk of shoulder injuries in school adolescents was unable to be completed. However, BMI displayed an AUC of 0.62 and the ROC curve identified a cut-off point of $\geq 21.6kg/m^2$. The chi square test of independence demonstrated that significantly more participants with $\geq 21.6kg/m^2$ BMI during the screening developed an upper body injury the subsequent season ($\chi^2(1)=4.76$, $p=0.03$, RR=4.70, 95% CI=1.01-21.90). However, this cut off point for BMI represents a high sensitivity of 80.0%, relatively low specificity of 54.8%, positive likelihood ratio of 1.77 and negative likelihood ratio was 0.36 which indicates a small overall accuracy.

5. 3. 2. 7. 2 . Adolescent Gaelic footballers and hurlers

No significant difference for the scapulae control test was noted in those that developed a shoulder injury and players that did not. However, internal rotation on the left side was significantly lower in those that sustained a shoulder injury ($p=0.001$, effect size=0.04). Cut off points were unable to be generated using the ROC curves.

5. 3. 2. 7. 3 . Collegiate Gaelic footballers and hurlers

Poor control when lifting scapulae on the left side ($\chi 2(1)=4.21$, $p=0.04$, RR=3.68, 95% CI=1.00-13.98) was more common in those that developed a shoulder injury. No significant difference was found for BMI, internal and external rotation of the shoulder. Cut off points were unable to be generated using the ROC curves.

5. 3. 3. Summary of Risk factors for injury

5. 3. 3. 1. Summary of Risk factors for injury in the Lower body

The risk factors for injury in the lower body region and the commonly injured body parts in the lower body are presented in Table 5.2.

5.2: Summary of Risk factors for injury in the Lower body, Hamstring, Knee, Ankle, Quadriceps and Pelvis and Groin

Variable	Lower Body			Hamstring			Knee			Ankle			Pelvis and Groin			Quadriceps		
	S	A	C	S	A	C	S	A	C	S	A	C	S	A	C	S	A	C
Squat																		
Overall impression					✓													
Toe out										✓								
Trunk flexion	✓	✓								✓								
Single leg squat																		
Overall impression	✓	✓		✓	✓													
Hip flexion	✓		✓															
Balance	✓	✓					✓					✓						
Navicular drop																		
Navicular drop at Risk >10mm							✓											
Balance																		
Anterior reach (%LL)					✓													
Posteriomedial reach (%LL)													✓					
Posteriolateral reach (%LL)						✓												

5. 3. 3. 2. Summary of Risk factors for injury in the Upper body and Shoulder

The risk factors for injury in the upper body region and the commonly injured body parts in the upper body are presented in Table 5.3.

5.3: Summary of Risk factors for injury in the Upper body and Shoulder

	Upper Body			Shoulder		
	S	A	C	S	A	C
Scapular Control						
Control of scapulae when lifting				✓		✓
Shoulder Mobility						
Internal rotation	✓	✓		✓	✓	
BMI						
BMI Cut off	✓			✓		

5. 3. 3. 3. Summary of Risk factors for injury in the Trunk and Lower back

The risk factors for injury in the trunk region and the lower back are presented in Table 5.4.

5.4: Summary of Risk factors for injury in the Trunk and Lower back

Variable	Trunk			Lower back		
	S	A	C	S	A	C
Shoulder Mobility						
External rotation		✓				
Non-dominant internal ROM >20° than dominant	✓	✓				

5. 4. Discussion

The aim of this study was to identify risk factors for injury in school adolescents, adolescent and collegiate Gaelic footballers and hurlers to pave the way for the development of injury prevention strategies in these under-researched populations. To date there has been no research on the risk factors for injury in school adolescents and adolescent Gaelic footballers and hurlers, and merely two studies examining collegiate Gaelic games. Just five studies have examined the causative factors for injury in Gaelic games, however they were limited by research design (Lowther et al., 2012, O'Sullivan et al., 2008, Falvey et al., 2013), retrospective nature (Lowther et al., 2012, O'Sullivan et al., 2008, Falvey et al., 2013), low sample sizes (Lowther et al., 2012, O'Sullivan et al., 2008, Watson, 1999, Watson, 2001, Falvey et al., 2013) and focus on a single injury (Watson, 1999, O'Sullivan et al., 2008, Lowther et al., 2012, Falvey et al., 2013). This study aimed to abide by recommended research by utilising a cohort study with a large sample size and implementing high quality statistical analysis to measure relative risk of injury (Brooks and Fuller, 2006, Goldberg et al., 2007, Bahr and Holme, 2003).

5. 4. 1. Risk factors for injury in the lower body

Poor squatting technique was identified as the primary risk factor for injury to the lower body, in particular the hamstring, knee, ankle and lower back. School participants and adolescent Gaelic footballers and hurlers with poor overall impression for the single leg squat presented with a 1.7-1.8 and 2.7-7.1 times increased risk of lower body and hamstring injury, respectively. In addition, poor overall impression during the squat resulted in a 5.1 times increased risk of hamstring injury in adolescent Gaelic footballers and hurlers. While squatting techniques itself has not been compared to injury rate, the squat as part of the FMS has been. A poor score of 14 or lower in the FMS has been demonstrated to predict injury to a greater extent than in the current study with four times as many lower limb injuries occurring in female collegiate athletes (Chorba et al., 2010) and eleven times as many in adult professional American football players (Kiesel et al., 2011). The squat movement examines global movement patterns that incorporate many risk factors for injury, including range of motion, strength, control, endurance, coordination, balance and neuromuscular control of all the individual joints working in synchrony to complete a functional movement (Kivlan and Martin, 2012, Butler et al., 2010). It challenges the body’s mobility and stability in order to control and move the ankle, knee and hip joints in a bilateral, symmetrical and functional manner (Cook et al., 2006a, Butler et al., 2010). Thus, the overhead squat and single leg squat is an essential component to any pre-participation screening, and injury prevention programmes should focus on ensuring Gaelic players have adequate squatting technique. While the squat and single leg squat examine identical movement patterns, the overall impression of the single leg squat has been identified more commonly in this study as a predisposing factor to injury. This could be attributed to the fact that it's unilateral movement may highlight certain subtle dysfunctions that may be passed over in the overhead squat (Whatman et al., 2012). Balance during the single leg squat also plays a superior part in the unilateral movement than the squat which may also have contributed.

Individual components of the single leg squat and overhead squat were also identified as predisposing factors to injury. Excessive trunk flexion during the squat was linked to 2.6 and 3.6 times as many lower body injuries in school adolescents and adolescent Gaelic footballers and hurlers. In addition, excessive trunk flexion amounted to 6.9 times as many ankle injuries in school adolescents only. Excessive trunk flexion during the squatting motion commonly occurs due to an anterior tilted pelvis which may be attributed to tight hip flexors (Brukner and Khan, 2006). As a large amount of musculature attaches to the pelvis, the positioning of the pelvis in a less than ideal position and consequential placement of the lumbar spine into excessive lordosis may affect the kinematic patterns of the lower body and predispose to injury. It is also noteworthy that excessive trunk flexion was only evident in the adolescents. Thus injury prevention programmes that target stretching of the psoas major in adolescents may help reduce lower body injury.

Inadequate hip flexion during the single leg squat predisposed school adolescents and collegiate Gaelic players to 1.5 and 1.7 times as many lower body injuries, respectively. In addition, inadequate hip flexion during the overhead squat was linked to 3.1 times as many lower back injuries in school adolescents. The depth of the squatting movement indicates the range of mobility available at the hip joint (Cook, 2010, Frohm et al., 2012). Reduced hip mobility during functional tasks such as landing can increase loading to the lower body and so predispose to injury (Silvers and Mandelbaum, 2007).
In addition, inadequate hip flexion during the overhead squat was linked to 3.1 times as many lower back injuries in school adolescents. Sjolie (2004) also reported reduced hip mobility as a predisposing factor to lower back injury in adolescents (14.7 years) using goniometric measurements. The authors attributed reduced hamstring flexibility as the

cause of the poor mobility and poor hamstring flexibility was also noted in adolescents in the current study's pre-participation screening.

Toe out during the squat resulted in 2.2 times as many ankle injuries in school adolescents. Toe out is a compensation strategy to achieve adequate dorsiflexion which replicates gait. The participant's feet tilt outwards to pronate and achieve the required range of dorsiflexion. It has been well documented that reduced dorsiflexion commonly occurs after ankle injury (Brukner and Khan, 2006, Hertel, 2000), and so previous ankle injury may predispose to future injury, not only because of adaptations to proprioceptive factors but also reduced dorsiflexion (Hertel, 2000). However, this reduction in dorsiflexion may not solely be due to previous injury and may be an inherent risk factor. In fact, Tabrizi et al. (2000) found that a significantly lower dorsiflexion was noted in the uninjured ankle in children that sustained an ankle injury compared to an uninjured control group ($p<0.001$). Thus, injury prevention programmes that increase dorsiflexion utilising mobilisations and a stretching programme for the gastrocnemius and soleus may help reduce ankle injury.

School adolescents and adolescent Gaelic footballers and hurlers with poor balance during the single leg squat presented with 1.5-1.6 times as many lower body injuries. This was similar to elite Australian footballers where poor balance lead to twice as many injuries (Hrysomallis et al., 2007), but far lower than high school female basketball players, where poor balance using the star excursion balance test corresponded to 6.5 times as many lower body injuries (Plisky et al., 2006). Poor balance during the single leg squat was related to 3 times as many knee injuries in school adolescents and 1.4 times as many ankle injuries in collegiate Gaelic footballers and hurlers. This result is similar to adult Gaelic footballers, where Watson (1999) identified reduced lower limb proprioception as a risk factor for ankle injury, however it is lower than reported in high school basketball players where 7 times as many ankle injuries occurred (McGuine et al., 2000). As previously mentioned, the single leg squat incorporates a functional assessment of balance. The Y balance test is extremely time consuming in comparison to the other screening tests, if the pre-participation screening is under severe time constraints, the findings of this study indicate that the single leg squat alone may be a sufficient measure of balance. Regarding the Y balance test, significantly lower anterior and posteriolateral balance was noted in adolescent and collegiate Gaelic footballers and hurlers that subsequently developed a hamstring injury. In addition, significantly lower posteriomedial balance was found in school adolescents that developed pelvis and groin injuries. Thus, while it would seem the Y balance test may identify participants with poor balance that can affect injury rates further up the kinetic chain, the effect size was low for each of the significant differences noted. Interestingly, the biceps femoris which is a hamstring muscle is primarily active during the posteriolateral reach in the Y balance test (Plisky et al., 2006), which corresponds to the low posteriolateral balance noted in collegiate players that developed a hamstring injury.

School adolescents with a navicular drop of ≥10mm were 2.2 times more likely to develop a knee injury in the following academic year (right foot: sensitivity=54.8%, 66%, left foot: sensitivity=51.7%, specificity=68.9%). Excessive pronation has been frequently identified as a predisposing factor to ACL injury (Beckett et al., 1992) and patellofemoral pain syndrome (Barton et al., 2010, Barton et al., 2011). Excessive pronation can cause corresponding internal tibial and femoral rotation which places the knee into a valgus position and can place tension on the ACL and cause increased pressure on the lateral aspect of the patellofemoral joint due to the increased quadriceps angle (Bonci, 1999, Picciano et al., 1993, Barton et al., 2010). Thus, this effect on knee positioning and patellofemoral joint mechanics is essential to address in injury prevention programmes developed for school adolescents. The ROC curve suggested that a lower cut off point of ≥6-7mm for the navicular drop in school adolescents may be more beneficial. The use of these cut off points increased the relative risk of knee injury very slightly to 2.3. While the sensitivity of these cut off points was high (71.0-72.4%), the specificity was relatively low (48.7-49.6%). Similarly while the sensitivity of the proposed cut-off points were higher than the ≥10mm cut off point previously reported, the specificity was lower. Thus, further analysis on the optimal cut off point for navicular drop in adolescents is required.

Poor hamstring flexibility was not found to predispose to hamstring injury, which is similar to community level Australian football (Gabbe et al., 2005) and soccer (Arnason et al., 2004) which are field sports similar to Gaelic games. This is not in line with commonly held beliefs and was not expected, as a large proportion of adolescents and collegiate players presented with poor flexibility during the screening and hamstring injuries were frequent, especially in collegiate players. In addition, previous research has noted that adult Gaelic footballers displayed significantly reduced hamstring flexibility in the injured limb compared to the uninjured; however the research design used was limited, as it was unable to ascertain the presence of poor hamstring flexibility prior to injury occurrence (Lowther et al., 2012). Thus, further prospective research is needed to focus specifically on possible risk factors for hamstring injury such as hamstring strength, gluteal muscle activation and neurological issues.

5. 4. 2. Risk factors for Upper body Injury

Poor control of the scapulae during lifting in the scapular control test lead to 3.5-4.5 and 3.7 times as many shoulder injuries in school adolescents and collegiate Gaelic footballers and hurlers. Poor scapular control has been identified as a risk factor for injury in upper body sports (Wang and Cochrane, 2001, Thomas et al., 2010, Ellenbecker et al., 2012), however this is the first study to identify poor scapular control as a risk factor for injury in Gaelic games. Poor control of the scapulae during lifting affects the scapulae position during movement, which in turn may affect the normal functioning of the shoulder complex and could cause narrowing of the subacromial space and prevent the acromion from rotating out of the way of the humeral head which may cause impingement and impaired motion of the upper limb (Wang and Cochrane, 2001, Thomas et al., 2010).Thus prehabilitation to correct any shoulder protraction by stretching the pectoralis minor muscle, strengthen the thoracic spine and shoulder muscles and address any problems with muscle activation patterns would be beneficial to reduce this risk of injury. No significant difference was noted for control of scapulae during the downward motion of the test, however this may be because the muscles are working eccentrically and any malalignments present are very pronounced (Kibler et al., 2002). If a participant has a malalignment present during the upward motion, it would tend to be more severe in nature, and so more likely to cause a shoulder injury.

Internal rotation was found to be significantly reduced in school adolescents and adolescent Gaelic players that developed upper limb and shoulder injuries, and this impairment has previously been identified as a predisposing factor (Wang and Cochrane, 2001). In fact, cut-off points were developed to identify the rate of reduced internal rotation to injury; however these focused on upper body sport where a large focus was asymmetry between sides and its relationship to dominance. Baseball players were found to be twice as likely to become injured with reduced internal rotation of greater than 20° and pitchers with a total rotational deficit of greater than 5° had a higher injury rate (Wilk et al., 2011). However these cut-off points were not found to differentiate between the injured and uninjured in the present study. Reduced internal rotation may occur due to chronic eccentric stress placed on the posterior capsule of the shoulder; this can consequently cause thickening of this capsule which in turn may alter the range of motion of the shoulder (Thomas et al., 2010). In addition, the eccentric loading may also cause tightness of the posterior rotator cuff muscles which may further restrict internal range of motion (Thomas et al., 2010). These adaptations may change the biomechanical movement patterns of the shoulder and so predispose to injury. In fact, it has been reported that athletes with reduced internal rotation commonly present with abnormal scapulae positioning (Thomas et al., 2010). Thus these should ideally be included in any injury prevention programme designed. It has also been noted that high school players have significantly higher internal rotation then collegiate players (Thomas et al., 2010) and so theoretically collegiate players should be more predisposed to upper limb and shoulder injury. In contrast, this study found a significantly reduced internal rotation in adolescents only, however it is noteworthy that the effect size was small.

ROC curves in school adolescents suggested a cut-off point of ≥21.7 kg/m^2 and ≥21.6kg/m^2 BMI during the screening were at risk of developing an upper body and shoulder injury, respectively. In fact, school adolescents with a BMI greater than the cut-off point were 2.6 times and 4.7 times more likely to sustain an upper body and shoulder injury, respectively. However, while these cut-off points increased the relative injury risk greatly and displayed high sensitivity (64.0% and 80.0%), particularly for shoulder injuries, the specificity of the cut-off points were quite low (64.0% and 54.8%). Contradictory evidence has been published on the effect of high BMI on injury in adolescents. Obese adolescents have been reported to have a 34% increased risk of injury (Richmond et al., 2012), however this was not supported in other studies (Lowry et al., 2007, Kemler et al., 2014) possibly because obese adolescents have extremely low physical activity levels and are less likely to get into situations where injury may occur. High BMI places extra physical stress on body structures, particularly during high impact contact sports like Gaelic games, requiring the body to absorb large forces which may predispose to soft tissue and joint injury (Richmond et al., 2012). BMI has also been linked to poor motor coordination (Foss et al., 2012) and reduced balance, as the uneven weight distribution may affect the players stable base and the increased pressure on the feet may affect somatosensory ability (Ku et al., 2012). However, as BMI is a crude predictor of body composition (Heyward, 2006), especially in the physically active population (Richmond et al., 2012), further research is needed to compare more gold standard assessments of body composition (skinfolds, DEXA scans) to injury.

5. 4. 3. Risk factors for Trunk Injury

Limited risk factors for trunk injury were identified in this study, which is expected as the screening primarily focused on predicting injury in lower and upper body injuries as these are most predominant in Gaelic games (Murphy et al., 2012b, Murphy et al., 2012a). Internal rotation of ≥20° less than the non-dominant shoulder lead to 2.3 times more trunk injuries in school adolescents and 3.1 times as many in adolescent Gaelic footballers and hurlers. This risk factor for injury was not expected, as previously it has been proposed as a risk factor for shoulder injury only (Wilk et al., 2011). The reduced internal rotation and asymmetry between sides may be due to issues with the shoulder stabilisers which attach to the thoracic spine and anterior positioning of the shoulder. This may cause corresponding muscle tightness in these muscles, which could lead to pain in the upper aspect of the trunk.

5. 4. 4. Limitations to the study

Despite the fact that this study (school adolescents=452, adolescent Gaelic players=293, collegiate Gaelic players=343) had a far higher sample size than previous risk factor studies in Gaelic football and hurling (n=18, 44, 80, 102, 163) (Lowther et al., 2012, O'Sullivan et al., 2008, Watson, 1999, Watson, 2001, Falvey et al., 2013) and a similar and slightly higher sample size to other similar cohort studies in soccer (n=306) (Arnason et al., 2004), Australian rules football (n=126) (Gabbe et al., 2005) and rugby (n=258) (Quarrie et al., 2001), the ideal multivariate statistical analysis was unable to be completed due to complete and quasi complete separation. This can be due to the high amount of risk factors examined, and the relatively low amount of cases of injury found, particularly in the specific body parts injured. Despite the fact this study had a similar amount of injuries in comparable cohort studies that utilised multivariate statistics (such as Arnason et al. (2004), Gabbe et al. (2005) and Quarrie et al. (2001)), and even when only risk factors identified as significant using univariate analysis were examined, an accurate model was still unable to be completed. It was then necessary to complete univariate analysis only, which is considered inferior to multivariate analysis as it does not account for interactions and confounding factors between predisposing factors (Meeuwisse, 1994, Bahr and Holme, 2003). However practically, a trade-off exists between ideal methodology and accurate data collection and a large sample size. In order to identify very small risk factors for injury in this population, a power calculation suggested a sample size of almost 3,000 participants. In reality, this would be outside the scope of this PhD, as to screen and track 3,000 participants would be extremely time consuming, expensive, require a far larger amount of testers which may affect the reliability of the screening and recruitment of participants would have been exceptionally difficult. This study used the gold standard method of data collection which is a prospective cohort study with medical professionals assessing injuries weekly. For the scope of this PhD, in order to recruit the vast amount of participants ideally required, a retrospective research design for injury tracking would have been needed, which is considered inferior to prospective studies as it is less reliable due to recall bias and imprecise estimations of duration of activity (Junge and Dvorak, 2000, Inklaar, 1994). Future research however could address these issues by partnering with the GAA and acquire funding to recruit a large amount of therapists to screen and track injuries in adolescent and collegiate Gaelic players. To date, most elite county teams and adult club teams have designated therapists attending all matches and most training sessions, however this is not the case in adolescent and collegiate players and funding would need to be in place to facilitate this.

In addition, other predisposing factors that were not measured in the screening may influence injury rates in adolescent and collegiate Gaelic footballers and hurlers to a greater degree than those assessed. Other possible risk factors such as previous injury, posture, fitness levels, weather conditions and ground conditions may predispose to injury and should be assessed in future research. As this is the first study of its kind to assess risk factors for injury in Irish adolescents and adolescents Gaelic players, further research is needed to consider the effect of maturation on neuromuscular control, balance, flexibility, strength and mobility which are assessed in the screening, as this may have a corresponding effect on injury risk. Training load may also be important to quantify, particularly in Irish adolescents, as it is evident from this research that some are playing a large number of sports with a number of teams which may contribute to an increased injury risk. Unfortunately training diaries implemented in this study had an extremely low compliance (Section 4.2.4.3.) and so future research should ideally utilise incentives or other objective methods of capturing training information (e.g. SenseCam, accelerometers, pedometers) in order to examine the training load in this population. Training diaries provide a huge amount of contextual information on the activity completed, and examine not only the duration, intensity and frequency of training that can also be assessed using other objective measures, but furthermore aim to provide information on the type of training, sessions completed, footwear worn, training surfaces, training environment, weather and travel time in this study, which would have allowed the analysis of these possible predisposing factors to injury. While an objective measure such as an accelerometer has been frequently used to assess physical activity levels in adolescent populations and may be beneficial to objectively capture training duration and intensity, accelerometers are unable to; capture the contextual information about the training activity itself, cannot measure activities with little torso movement such as cycling and must be removed in contact sport which limits their use in Gaelic games. This study assessed injury rate for a single academic year or season, which may not have captured the influence that neuromuscular defects identified in the screening have on injury rates over subsequent seasons and its effect on overuse or repetitive injuries. Thus further research assessing possible risk factors for injury over a longer prospective period of time would be advantageous.

5. 4. 5. Conclusion

A number of predisposing factors to injury were identified. Poor squatting technique was found to be the primary risk factor for lower body injury. Poor squatting technique was also found to predispose to hamstring injuries in school adolescents and adolescent Gaelic footballers and hurlers. Reduced internal rotation of the shoulder and higher BMI during the pre-season screening was significantly more common in those that sustained upper body and shoulder injuries in school adolescents and adolescent Gaelic footballers and hurlers. High BMI was also found to predispose to upper body and shoulder injury in school adolescents. Control of the scapulae when lifting during the scapular control test was a risk factor to shoulder injury in school adolescents and collegiate players. Poor balance was noted as a predisposing factor to hamstring injury in adolescent and collegiate Gaelic footballers and hurlers, and poor balance during the single leg squat to ankle injury in collegiate players. A navicular drop of ≥10mm was identified as a risk factor for knee injury in school adolescents; however ROC curves suggested that in adolescents a lower cut off point of between 6-7mm may be more appropriate. As there has been no previous research in school adolescents and adolescent Gaelic footballers and hurlers, and limited published data on risk factors for injury in collegiate players, injury prevention programmes that address the predisposing factors identified in this study should be developed to reduce injury rates.

Chapter 6. Thesis Summary, Conclusion and Directions for Future Research.

6. 1. Thesis summary

While there are numerous benefits to playing sport, an inherent risk of injury exists. There is currently a lack of epidemiological and risk factor for injury studies in Gaelic games, particularly in the adolescent and collegiate populations. In addition, there is very little normative data for screenings in these populations.

A comprehensive musculoskeletal pre-participation screening using simple field based tests, with minimal and inexpensive equipment, specific to Gaelic games was developed in Study 1. It was necessary to adapt some of the common screening tests and develop scoring systems to ensure suitability in a screening setting. The developed and adapted screening tests demonstrated excellent inter-tester reliability and good-to-excellent intra-tester reliability (Appendix A).

Normative data for adolescent and collegiate Gaelic footballers and hurlers was established to develop a standardised reference of results from Study 1. Some neuro-musculoskeletal deficiencies were identified using the screening: poor hamstring flexibility, balance, scapular control and squatting technique were noted. Poor hamstring flexibility was predominant; however the extent of this flexibility issue was worse in adolescent Gaelic footballers and hurlers. Senior players presented with a higher BMI than fresher collegiate participants. Older players were found to have better core stability, and collegiate players were shown to have significantly better core stability than adolescent players. While adolescents presented with an increased incidence and severity of winging, issues with controlling the scapulae when lowering and symmetry were common in both populations. Adolescent players displayed greater internal and external range of motion in the shoulders than collegiate participants. Approximately a third of adolescent and collegiate participants were found to have a navicular drop of greater than the 10mm cut off point which may indicate excessive pronation. Adolescents performed worse in the overhead squat than collegiate participants; however this was reversed for the single leg squat. Both adolescent and collegiate participants tended to perform poorly in the individual aspects of the single leg squat including knees over toes and knee valgus; however collegiate participants performed worse than adolescents in hip flexion and trunk flexion. Poor balance was found to occur commonly in both adolescent and collegiate participants, however the issue varied depending on the cut off points utilised.

Study 2 found that injuries are prevalent in Gaelic games, with over a third of all adolescent and collegiate participants at risk of injury in one year and over a quarter of injured participants at risk of developing a subsequent injury throughout the year. Collegiate participants displayed a higher rate of injury than adolescents. There was an increased injury rate during matches than training in all participants with hurlers presenting with a higher match injury rate. Fresher Gaelic footballers had an increased training and match injury rate than senior Gaelic footballers. Acute and new injuries predominated, with a higher percentage of recurrent injuries in adolescent participants, especially adolescent Gaelic footballers. Lower limb injuries were predominant, with the hamstring, knee and ankle injuries most common. Injuries to the lower back were far more common in hurling, especially in adolescent hurlers. Muscle injuries predominated, with strains the most common nature of injury, especially in the hamstring and pelvis and groin. Contusions occurred more commonly in collegiate participants, especially in the quadriceps and hips. In contrast, muscle tightness was more common in adolescents, especially in the lower back and pelvis and groin. Ligament injuries and strains were the second most common injury and these commonly occurred in the ankle and knee. Adolescent hurlers developed muscle tightness and contusions more commonly than Gaelic footballers; however Gaelic footballers presented with strains and sprains more frequently. Minor injuries occurred most frequently in adolescents, with severe injuries most common in the collegiate population. In addition, fresher Gaelic footballers reported a much higher rate of minor injuries than senior Gaelic footballers. Non-contact injuries predominated, with injuries frequently occurring during sprinting and tackling. Injuries occurred primarily in the second half, particularly in the 4th quarter of the session, especially in collegiate participants. In adolescent players, injuries predominantly occurred at the beginning of the calendar year, decreased significantly over the course of the summer months and increased again nearing the end of the year. In collegiate participants, injuries predominated at the end of the calendar year and the beginning of the year and reduced dramatically from March to August.

Study 3 identified a number of risk factors for each region and specific body parts. Poor squatting techniques were identified as a risk factor for lower body injury in all three populations. Poor overall impression and poor balance in the single leg squat and excessive trunk flexion in the squat were identified as a risk factor in school adolescents and adolescent Gaelic footballers and hurlers. In school adolescents and collegiate

Gaelic players, inadequate hip flexion during the single leg squat was noted as a risk factor for lower body injury. Reduced internal rotation was found to occur more commonly in school adolescents and adolescent Gaelic players that sustained upper body injuries in the subsequent season. School adolescents identified as at risk during the screening due to non-dominant internal range of motion ≥20° than the dominant side sustained upper body injury more frequently. In addition, adolescent Gaelic footballers and hurlers with reduced external rotation developed trunk injuries more frequently. Poor overall impression in the single leg squat was identified as a risk factor for hamstring injury in school adolescents and adolescent Gaelic footballers and hurlers; with poor overall impression also a risk factor for injury in adolescent Gaelic players only. In addition, reduced posteriomedial balance as a percentage of leg length was noted as a risk factor for hamstring injury in collegiate Gaelic players. Predisposing factors to knee injuries in school adolescents were poor balance during the single leg squat and a navicular drop of greater than 10mm. Poor balance during the single leg squat was found to be a risk factor for ankle injury in collegiate Gaelic players, whereas excessive trunk flexion and toe out during the squat was a predisposing factor in school adolescents. No risk factors for injury were identified for the knee, lower back, quadriceps and pelvis and groin in adolescent and collegiate Gaelic footballers and hurlers. Control of the scapulae when lifting during the scapulae control test was noted as a predisposing factor to shoulder injury in school adolescents and collegiate players, with reduced internal rotation of the shoulder also identified in school adolescents and adolescent Gaelic footballers and hurlers. Cut off points were only able to be generated in school adolescents, with ROC curves identifying a BMI of ≥21.7kg/m^2 and 21.6kg/m^2 as a cut off point for increased risk of upper body and shoulder injuries, respectively. A navicular drop of ≥7mm and ≥6mm on the right and left feet increased the risk of sustaining a knee injury in the subsequent season.

6. 2. Conclusion

A review of literature indicated the need for comprehensive epidemiological and risk factor for injury studies in adolescent and collegiate Gaelic players. In addition, there is a lack of normative data available for musculoskeletal pre-participation screening tests, and the tests proposed are limited for use in screenings, with varied reliability and complicated, expensive equipment. Normative data was presented, with hamstring flexibility, balance, scapular control and squatting technique identified as areas requiring improvement. The reliability of screening tests designed within this thesis found good-to-excellent absolute and relative inter-tester and intra-tester reliability. Injuries were found to be prevalent, with 4.873 and 14.512 injuries per 1,000 hours noted in adolescent and collegiate Gaelic footballers and hurlers, respectively. Injuries to the lower body were predominant, especially to the hamstring, knee and ankle. However lower back injuries were common in adolescent participants, particularly adolescent hurlers. A number of risk factors for injury were identified, which indicates the likely benefit of implementing a pre-participation screening. The trauma, pain and loss of function experienced during injury is substantial, and this initial research in adolescent and collegiate Gaelic players indicates it is essential that effective injury prevention strategies are developed. Injury prevention programmes that particularly tackle neuromuscular deficits identified in the screening, in particular poor squatting technique and neuromuscular control is required to reduce the incidence of injury.

6. 3. Directions for future research and recommendations

This study presents initial research in the identification of the epidemiology and risk factors for injury in these previously overlooked adolescent and collegiate Gaelic populations; thus there is a clear need for further research.

Musculoskeletal pre-participation screenings

- The current study focused on 4th and 5th year adolescents that primarily played Gaelic football and hurling. Further research is needed in younger adolescents (1st-3rd year) and children in order to develop a comprehensive normative bank of data as a reference. In addition, the assessment of normative data in other sports commonly played by adolescents in Ireland should be completed.
- Based on the findings from the screening in the adolescent and collegiate populations, poor hamstring flexibility, scapular control, balance and squatting techniques (neuromuscular control, hip flexor flexibility and education on technique) are common and those that are identified as at risk should undertake injury prevention programmes.
- Criterion validity of the tests used in the screening should ideally be established as only content validity was assessed in this study. In particular three dimensional analysis should be completed for the scapular control test, overhead squat and single leg squat. The alternative push up tests should be compared to gold standard core muscle electromyography activity during higher and lower scores.

Epidemiology of injury

- Based on the epidemiological findings, an injury prevention programme should be developed for adolescent and collegiate Gaelic footballers and hurlers to reduce injury. This injury prevention programme should focus on common injuries such as hamstring, knee and ankle injuries and severe injuries. To establish the effectiveness of the injury prevention programme, the injury rate, epidemiology and the costs related to injury should be re-assessed.
- Further analysis on the aetiology of injury in commonly injured areas such as the hamstring, knee and ankle and related mechanisms of injury including sprinting, twisting/turning and landing is needed.
- Further research on the aetiology of lower back injuries in adolescent hurlers is needed as this has not been undertaken in previous research.
- Further research on tackling (being tackled and tackling) and its relationship to injury should be assessed, as it has been identified as a common mechanism of injury in Gaelic games. Possible rule changes may be suggested to reduce the incidence of injuries occurring during tackling. In addition, educating coaches and players on the importance of appropriate technique during tackling and adequate physical conditioning alongside the introduction of specific skill sessions in training on tackling may reduce injuries.
- Aside from the mandatory use of helmets in hurling and mouth guards in Gaelic football, very little if any protective equipment was utilised in Gaelic games. The attitudes of players to protective equipment should be established, and protective equipment such as protective padding, specifically related to Gaelic games, should be designed. The effectives of this protective equipment should then be assessed to see if injuries that occur due to contact or contusions are reduced.
- An increased amount of injuries occurred nearing the end of sessions which may be related to fatigue. Further analysis on the occurrence of fatigue in Gaelic games should be completed. The GAA should consider the introduction of more than two halves during matches, rolling substitutes or removal of the limitation of substitutes. Further research on these possible methods to combat fatigue should be completed.
- Seasonal bias has been noted by this study and it is essential the GAA critically assess the structure of school, club, county and collegiate seasons to ensure players are not playing continuously throughout the year without an adequate

offseason. Further research on the effects of the current structure on injury and risk of overtraining should be completed.

Risk factors for injury

- Further research on the risk factors of injury over a longer prospective period of time is required to assess the effects of the predisposing factors on injury development, especially for overuse and repetitive injuries.
- While this study examined a large number of risk factors for injury, future research should observe the effect of other possible risk factors for injury not captured in this study in adolescent and collegiate Gaelic footballers and hurlers, such as previous injury, training load, fitness levels, weather conditions, ground conditions, posture etc.
- As this is the first study assessing risk factors for injury in adolescents, further research is needed to consider the effect maturation has on neuromuscular control, balance, flexibility, strength and mobility as this may affect injury risk.
- Training load is important to quantify in these populations, as it is evident from this initial research that adolescents in particular are playing numerous sports which may contribute to an increased risk of injury. Training diaries had an extremely low compliance in the current study, thus further analysis with incentives to participants may assist the quantification of training load in this population.
- While hamstring flexibility was not found to predispose to injury in this study, the overall low flexibility levels in the adolescent and collegiate players is noteworthy. Further prospective research focusing specifically on the risk factors for injury to the hamstring, which is a common injury in Gaelic games, is required.
- This study proposed cut-off points that indicate a high BMI in adolescents can predispose to upper body and shoulder injury. However, as BMI is a crude predictor of body composition, especially in those that are physically active, further research utilising better measures of body composition such as skinfolds and DEXA scans to injury is needed.
- A limited number of risk factors for injury were identified in collegiate Gaelic footballers and hurlers. Thus further investigation is needed to examine the predisposing factors to common injuries found in this research to facilitate the design of a more applicable injury prevention programme.

In summary, there is a clear need for the development of appropriate and effective injury prevention strategies in adolescent and collegiate Gaelic footballers and hurlers. As this is initial research, longer prospective epidemiological studies should be implemented, risk factors for injury should be completed in a larger population and further analysis on the aetiology of common injuries should be completed. Injury prevention programmes should be designed and proposed, and the attitudes and opinions of adolescent and collegiate players, coaches and parents to these strategies should be established. The effectiveness of these strategies should than be assessed. A novel approach to implementing adolescent injury prevention programmes could be in schools rather than during Gaelic games training sessions. Physical education classes provide an opportunity for adolescents to complete comprehensive programmes in a controlled manner, as it is mandatory for them to attend school. Similarly the benefits of these programmes could be implemented in all adolescents rather than focused in Gaelic games only. However further analysis of this possibility is needed.

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Appendices

Appendix A. **Reliability of the Overhead Squat, Single leg squat, Active knee extension test, Alternative push up test and Scapular control test**

A.1. Introduction

The musculoskeletal pre-participation screening identifies possible modifiable risk factors for injury which can aid in the development of a suitable injury prevention strategy and injury prevention programme to reduce the likelihood of an athlete receiving an injury in the impending season (Maffey and Emery, 2006). In order to accurately assess the susceptibility of an athlete to injury, it is imperative that all tests in the musculoskeletal screening have minimal measurement error to prevent imprecise results occurring. High reliability (high consistency of the test or measurement) is essential for each test in the screening in order to confidently interpret the results of the testing. In reality a certain amount of error exists in any measurement and a measure should be deemed reliable if it has an acceptable level of measurement error (Hopkins, 2000).

Despite the importance of reliability in tests in a screening, Hopkins (2000) has noted that reliability studies in the sports medicine context are rarely completed with a high methodological and statistical standard. In addition, reliability studies in current literature have focused on either absolute (the degree of variation between repeated results in a group of participants) or relative (the degree that a participant maintains the same position in the group during repeated testing) reliability when analysing their results or tended to implement methodologies that solely measure inter-tester reliability (the degree of similarity between measurements taken by different testers) or intra-tester reliability (consistency of the same tester capturing the same test result when testing repeatedly) of the tests (Atkinson and Nevill, 1998, Hayen et al., 2007, Eliasziw et al., 1994). Within sports medicine research the most commonly used and recommended measures to assess absolute and relative reliability are the ICC and SEM statistics (Hayen et al., 2007). The ICC assesses the variation between cases in relation to the total variation in all observations in a sample; i.e. the greater the variation between or within testers the smaller the ICC value (Frohm et al., 2012). If no reliability exists the ICC value will equate to 0, if there is no variation within or between testers an ICC value of 1 will occur (Frohm et al., 2012). SEM on the other hand looks at the repeated measurements and their relationship with the mean of the results. The SEM is beneficial as it is expresses in the units of the tested variable which allows researchers to understand the magnitude of measurement error within the test (Atkinson and Nevill, 1998).

Thus this study aims to implement a reliability study with high methodology and statistical analysis in order to accurately assess the inter-tester reliability and intra-tester reliability of a number of tests utilised in the musculoskeletal pre-participation screening developed for this thesis. The chosen tests in this reliability study were the tests developed by the lead researcher and expert group (alternative push up test, scapular control test) or the tests where the lead researcher and expert group designed new scoring systems (overhead squat, single leg squat). Tests were developed or adapted because no gold standard, clinically feasible and reliable tests or scoring systems were available in published research for core stability, scapular control and squatting techniques. Inherent issues were present in the published tests in these areas including: measurements undertaken in a static position that do not assess the component in a functional manner that replicates the demands placed on the body during sporting movements, prone to biasness as the tests themselves are open to compensation strategies, take a significant time to complete, unclear definitions, widely variable and complicated scoring systems and required expensive equipment that is not readily available in the clinical setting. Thus the expert group developed or adapted tests that combated each of these issues that were noted in current published tests. In addition, the reliability of the active knee extension test will be established, as ambiguity in the reliability of this test exists in current research due to large variations in the methodology and equipment used. Reliability studies have assessed the active knee extension testing using various equipment including a cross bar, stabilisation belts, cloth straps, inclinometers, goniometers, video assessments and lift and raise instruments (Gabbe et al., 2004, Sullivan et al., 1992, Gajdosik and Lusin, 1983, Gajdosik et al., 1993, Norris and Matthews, 2005, Rakos et al., 2001, Worrell and Perrin, 1992, Shimon et al., 2010). Thus the lead researcher felt it was necessary to establish the reliability of the field based active knee extension test utilised in this study as it used an inclinometer and a straight standing pole and so its reliability has yet to be established.

A.2. Methods

A.2.1. Subjects

Fifteen physically active male Gaelic football and hurlers (19.46±0.63) were recruited from a convenience sample of students in Athlone Institute of Technology. All participants were free from any orthopaedic or neurological disorders. Participants were required to avoid sporting activity on both testing days. All participants attended an information session where the testing procedure was fully explained. Ethical approval was granted prior to the study starting date by Dublin City University Ethics committee.

A.2.2. Experimental Protocol

Prior to testing, all participants were required to return a signed informed consent form. All testing was completed in a rehabilitation room with the same equipment and set up used on both days. Testing was completed in 10 minute blocks per participant. All three testers measured the same test at the same time, however no talking or comparison of results was allowed between testers. This method reduced the subject differences that may occur between tests and allowed a comprehensive analysis of the differences testers have at rating the exact same motion in a test. This could not be completed for the active knee extension test however as it required each tester to measure the movement with an inclinometer, thus for this test each tester measured the motion behind a curtain away from the view of other testers. Two testing sessions occurred a week apart on a Wednesday afternoon. Each participant was required to return the following week at the same time and same day.

A.2.2.1. Testers

Three testers qualified as therapists with experience in screening were chosen to assess reliability in this study. Tester 1 was the main researcher in this study with extensive experience designing and implementing screenings. Tester 2 was a member of the core undergraduate research team that completed the earlier testing in Study 1 who had subsequently graduated. Tester 3 was a qualified therapist with over 8 years' experience working with sports teams and experience in screenings.

All testers underwent three training sessions. The testers were initially given a presentation on the purpose, the instructions and scoring system of each of the tests in the testing protocol. In addition, photographs were provided in this presentation of possible and common mistakes made by participants. A manual of testing instructions and the scoring system for each test was given to each tester to study. Following this a demonstration of each of the tests was provided. Common mistakes made by both the testers and participants during each test were highlighted. Furthermore testers underwent three separate practice sessions where they practised each tests on a sample group of collegiate participants. Testers were encouraged to critique each other's scoring technique and the main researcher in this study assessed the ability of each tester to adequately score each test prior to the screening.

A.2.2.2. Testing protocol

Figure A.1 displays the testing order for each participant at each testing station. The tests assessed in this reliability study were developed or adapted by the research team and included the overhead squat, single leg squat, alternative push up test, active knee extension test and scapular control test. The research team developed the scapular control test, the scoring system for the overhead squat and single leg squat and adapted the methodology of the active knee extension test and alternative push up test. The tests are described in Section 3.2.4.3.

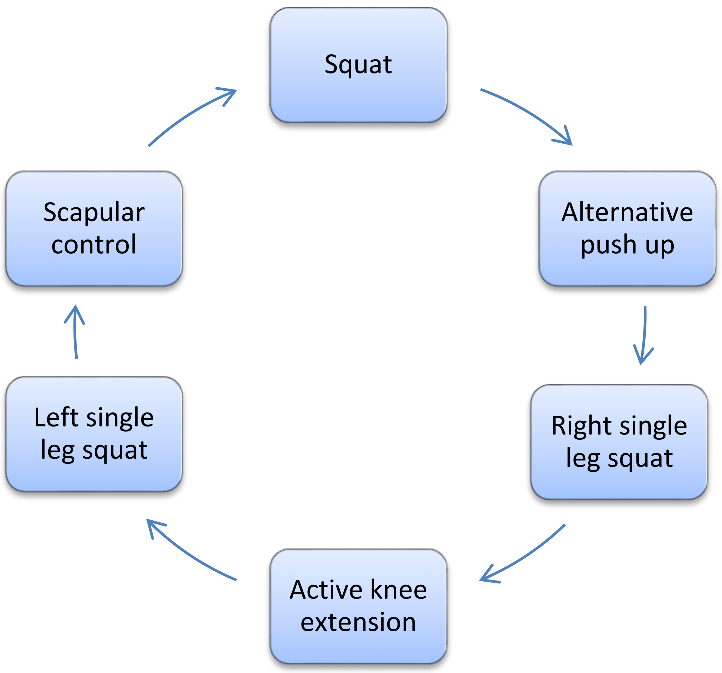

Figure A.1: Testing procedure for Reliability study

A.2.3. Data Processing and Statistical Analysis

Both inter-tester reliability (the degree of similarity between measurements taken by different testers) and intra-tester reliability (consistency of the same tester capturing the same test result when testing repeatedly) was assessed (Hayen et al., 2007, Eliasziw et al., 1994).

Intraclass correlation coefficient (ICC) was used to assess relative reliability i.e. the degree that a participant maintains the same position in the group during repeated testing. The ICC was assessed utilising a two way random effects model as in our model each tester assessed every participant and the testers are a sample of the testers used in the future. Absolute agreement rather than consistency of the three samples was used as it is a more stringent method of assessing reliability. This study classified reliability according to Fleiss (2011) and these values are displayed in Table A.1.

Table A.1: Classification of reliability ICC values

Reliability Classification	ICC value
Excellent	>0.75
Good	0.40-0.75
Poor	<0.40

Standard error of measurement (SEM) was used to assess absolute reliability i.e. the degree of variation between repeated results in a group of participant. SEM was calculated using the following formula:

$$SEM_X = S_T \sqrt{(1 - r_{xx})}$$

When S_T is the standard deviation of the test scores and r_{xx} is the reliability coefficient

Equation A.1: Calculation of Standard Error of Measurement

This study identified that for the active knee extension test a SEM of ≥2° was clinically significant. For the overhead squat, single leg squat, alternative push up test and scapular control test a SEM of ≥1 was clinically significant.

A.3. Results

For this study ICC was classified according to Fleiss (2011) with poor reliability <0.40, good reliability 0.40-0.75 and excellent reliability >0.75. A SEM of ≥1 for the overhead squat, single leg squat, alternative push up test and scapular control test was considered clinically significant and ≥2° for the active knee extension test.

A.3.1. Reliability of the Overhead Squat

Excellent inter-tester and intra-tester reliability was found for each of the individual criteria and the overall impression of the overhead squat (Table A.2). The SEM was found to be less than clinically significant in each of the individual criteria and the overhead impression of the overhead squat.

Table A.2: The overhead squat: inter- tester and intra-tester reliability

Individual Criteria	Inter-tester		Intra-tester	
	ICC	SEM (°)	ICC	SEM (°)
Knee over toes	0.926	0.056	0.851-0.958	0.009-0.054
Knee Valgus	1	0	1	0
Knee Varus	1	0	1	0
Toe out	0.960	0.032	0.926	0.025-0.094
Toe in	1	0	1	0
Hip Flexed	0.850	0.027	0.899-0.955	0.010-0.044
Trunk Flexed	0.941	0.040	0.859-0.935	0.024-0.070
Balance	1	0	1	0
Overall Impression	1	0	0.978	0.006

All measures were ordinal data. Scoring ranged from 0-3

A.3.2. Reliability of the Single leg squat

Excellent inter-tester and intra-tester reliability was found for each of the individual criteria and the overall impression in the single leg squat on the right and left legs (Table A.3). The SEM was found to be less than clinically significant in each of the individual criteria and the overhead impression for the single leg squat on both legs.

Table A.3: The single leg squat: Inter- tester and intra-tester reliability

Individual Criteria		Inter-tester		Intra-tester	
		ICC	SEM	ICC	SEM
Knee over toes	R	0.937	0.041	0.947-0.952	0.010-0.011
	L	0.945	0.029	0.821-0.904	0.029-0.059
Knee Valgus	R	0.951	0.027	0.817-0.879	0.032-0.060
	L	0.967	0.007	0.750-1	0-0.047
Knee Varus	R	1	0	1	0
	L	1	0	1	0
Toe out	R	0.924	0.034	0.759-0.833	0.038-0.069
	L	0.895	0.013	0.788-1	0-0.021
Toe in	R	1	0	1	0
	L	1	0	1	0
Hip Flexed	R	0.948	0.018	0.785-0.921	0.026-0.087
	L	0.947	0.018	0.785-0.909	0.028-0.087
Trunk Flexed	R	0.868	0.059	0.857-0.909	0.028-0.053
	L	0.962	0.024	0.947-1	0-0.021
Balance	R	0.920	0.023	0.851-1	0-0.036
	L	0.941	0.020	0.833-1	0-0.038
Overall Impression	R	0.977	0.006	0.975-1	0-0.007
	L	1	0	0.972-1	0-0.007

All measures were ordinal data. Scoring ranged from 0-3

A.3.3. Reliability of the Active knee extension

The active knee extension test demonstrated excellent inter-tester and intra-tester reliability as demonstrated in Table A.4. The SEM in both inter-tester and intra-tester reliability was found to be less than clinically significant.

Table A.4: Active knee extension: inter-tester and intra-tester reliability

Side	Inter-tester Reliability		Intra-tester Reliability	
	ICC	SEM (°)	ICC	SEM
Right (°)	0.982	0.235	0.782-0.886	0.642-1.422
Left (°)	0.993	0.288	0.787-0.937	0.309-1.219

All measures were in degrees

A.3.4. Reliability of the Alternative push up test

Excellent inter-tester reliability was reported as demonstrated in Table A.5 with a very high intra-class correlation value and extremely low SEM value demonstrated for the alternative push up test. With regard to intra-tester reliability good to excellent intra-class correlation coefficient was determined with an SEM that is not clinically significant.

Table A.5: Alternative push up test: inter-tester and intra-tester reliability

Inter-tester Reliability		Intra-tester Reliability	
ICC	SEM	ICC	SEM
0.978	0.012	0.729-0.898	0.048-0.115

All measures were ordinal data. Scoring ranged from 0-4

A.3.5. Reliability of the Scapular control test

Excellent ICC values were found for inter-tester reliability and good to excellent intra-tester reliability in the Scapular control test (Table A.6). The SEM was not found to be clinically significant for inter-tester and intra-tester reliability.

Table A.6: Scapular control test: inter-tester and intra-tester reliability

Scapular control test		Inter-tester		Intra-tester	
		ICC	SEM	ICC	SEM
Winging	R	0.952	0.018	0.656-0.904	0.014-0.082
Winging	L	0.977	0.006	0.720-0.920	0.013-0.074
Control of Scapula when lifting	R	1	0	1	0
Control of Scapula when lifting	L	1	0	1	0
Control of Scapula when lowering	R	0.909	0.024	1	0
Control of Scapula when lowering	L	0.980	0.005	0.632-0.750	0.047-0.085
Symmetry between both scapulae		0.933	0.021	0.600-0.759	0.069-0.119

All measures were ordinal data. Scoring ranged from 0-3

A.4. Discussion

The reliability of selected tests developed or adapted by the researchers in the screening was investigated in this study. High reliability of tests is imperative to accurately assess the susceptibility of an athlete to injury. In order to complete a comprehensive analysis of the reliability of these tests, both inter- tester (between tester) and intra-tester (multiple assessments by the same tester) reliability must be established using statistical analysis that assesses both absolute (ICC statistic) and relative reliability (SEM statistic) (Hayen et al., 2007, Eliasziw et al., 1994, Atkinson and Nevill, 1998). The results indicate that the selected tests have high inter-tester and intra-tester reliability.

A.4.1. Reliability of the overhead squat

Six studies analysed the reliability of the overhead squat as described by Cook (2010), four studies examined inter-tester reliability (Schneiders et al., 2011, Minick et al., 2010, Shultz et al., 2013, Teyhen et al., 2012) and three investigated intra-reliability (Smith et al., 2013, Frohm et al., 2012, Teyhen et al., 2012). Four out of the six studies utilised the kappa or the weighted kappa coefficient to assess reliability, with only two studies utilising the ICC statistic and none analysed both absolute and relative reliability. Since these studies utilised the deep squat described in the FMS protocol, it assessed a general analysis of the overall impression of the squat and did not examine the reliability of the individual criteria assessed in the squat. Excellent inter-tester reliability for the overall impression of the overhead squat was found in the present study, similar to the excellent inter-tester agreement observed by Schneiders et al. (2011) (κ=1.00) and Minick et al. (2010) (κ=0.80). In addition, Schultz et al.(2013) (Kα =0.41), Minick et al. (2010) (κ=0.64) and Teyhen et al. (2012) (0.68) reported lower inter-tester reliability than the current study. The intra-tester reliability reported in the current study was found to be similar to the excellent reliability reported by Smith et al. (2013) (ICC=0.82-0.90) and higher than Teyhen et al. (2012) (κ=0.76) and Frohm et al. (2012) (ICC=0.73). The present study demonstrated excellent inter and intra-tester reliability in each of the individual criteria of the overhead squat and low SEM values that were far below the 1 value indicated as clinically significant however comparison against other reliability studies was not possible as other scoring systems did not examine the individual criteria. This high reliability may be attributed to the clear and well defined instructions for the test and scoring system utilised. In addition, the minimal equipment utilised may also have contributed to a reduction in measurement error in the testing procedure. The analysis of the individual criteria of the scoring system demonstrated that hip flexion had the lowest inter-tester reliability with knees over toes and hip flexion demonstrating the lowest intra-tester reliability. Thus, the definition of the differentiation between a minor, moderate and severe score for both hip flexion and knees over toes may need to be further clarified and highlighted to the testers during the familiarisation process. While these criteria reported the lowest reliability results they still produced excellent inter and intra-tester reliability.

A.4.2. Reliability of the single leg squat

Very few studies have assessed the reliability of a single leg squat in a screening in this manner, with only a single study examining the inter-tester reliability (Poulsen and James, 2011) and two studies investigating the intra-tester reliability (Poulsen and James, 2011, Frohm et al., 2012). Excellent inter-tester reliability was found for the overall impression which is higher than the good reliability (κ=0.68) reported in Poulsen et al. (2011). Similarly, excellent intra-tester reliability for the overall impression was noted, which is higher than the fair to excellent reliability demonstrated in Poulsen et al. (2011) and moderate reliability reported in Frohm et al. (2012). Excellent inter and intra-tester reliability of the individual criteria was demonstrated in the single leg squat, however similar to the overhead squat, it is not possible to compare to other studies and only the overall impression is measured. The high reliability of the single leg squat is similar to those discussed in the overhead squat as the instructions, scoring system and equipment requirements were similar.

A.4.3. Reliability of the active knee extension

The reliability of the active knee extension test has been examined, with seven studies assessing inter-tester reliability (Gabbe et al., 2004, Sullivan et al., 1992, Norris and Matthews, 2005, Rakos et al., 2001, Webright et al., 1997, Worrell and Perrin, 1992, Hamid et al., 2013) and eight studies investigating intra-tester reliability (Gabbe et al., 2004, Sullivan et al., 1992, Gajdosik et al., 1993, Gajdosik and Lusin, 1983, Webright et al., 1997, Worrell and Perrin, 1992, Shimon et al., 2010, Hamid et al., 2013). The current study found excellent inter and intra-tester reliability with the SEM statistic observed to be below the 2° value deemed clinically significant in this study which is similar to the excellent inter and intra-tester reliability found in all the reliability studies to date. However, the majority of these previous studies utilise many methods to achieve high reliability in this test, such as cross bars, straps and belts, to ensure appropriate positioning of the patient throughout the test (Lowther et al., 2012, Gajdosik and Lusin, 1983, Gajdosik et al., 1993, Worrell and Perrin, 1992, O'Connor et al., 2011). However, the methodology used in these studies are not practical, as the apparatus used is complex, takes time to set up, is not available in most clinical settings, may require therapists to build the equipment themselves and in some methodologies may require two testers to conduct the test (Hamid et al., 2013). Thus, the AKE test completed in this manner is not a simple field test that can be implemented with a large number of participants in a variety of settings as is recommended in screenings (Maffey and Emery, 2006). The AKE methodology in the current study required very little equipment; a vertical side bar as a reference point for the hip at 90°, a plinth and an instrument underneath the opposite leg to ensure the corresponding knee was bent to 20°. The thigh position was held in place by the participants themselves with the participants monitoring the motion of the femur to ensure it was kept in place, this position was corrected if needed by the tester as recommended by Norris and Matthews (2005). Thus this was easily adaptable in different settings and was less time consuming as methodologies suggested in previous studies. The two reliability studies that utilised the most similar methodologies used in the present study was Norris and Mathews (2005) that used no equipment and examined inter-tester reliability and Shimon et al. (2010) that used a "lift and raise" unit that utilised a straight line as a reference point for the thigh similar to the current study and investigated intra-tester reliability. The present study demonstrated a higher inter-tester reliability than Norris and Mathews (2005) (ICC=0.76) and similar intra-tester reliability as Shimon et al. (2010) (ICC=0.94). Thus the addition of simple, readily available equipment appears to enhance the reliability of the active knee test in comparison to the use of no equipment as demonstrated in the Norris and Mathews (2005) methodology.

A.4.4. Reliability of the alterative push up test

Five studies assessed the reliability of the trunk stability push up test which is the original version of the adapted alternative push up test. Of these reliability studies, four assessed inter-tester reliability (Schneiders et al., 2011, Minick et al., 2010, Shultz et al., 2013, Teyhen et al., 2012) and only two assessed intra-tester reliability (Teyhen et al., 2012, Smith et al., 2013). In fact, only a single study investigated both inter and intra-tester reliability (Teyhen et al., 2012). Three out of the five studies utilised the kappa (κ) or the weighted kappa coefficient to assess reliability in categorical data (Teyhen et al., 2012, Schneiders et al., 2011, Minick et al., 2010), one study utilised Krippendorff's alpha (Kα) to assess ordinal/interval data (Shultz et al., 2013) and another study utilised the ICC statistic (Smith et al., 2013). None of these studies analysed both absolute and relative reliability.

As the alternative push up test was developed in this study comparisons in this discussion are made to the trunk stability test. The excellent inter-tester reliability found in the current study is consistent with Schneiders et al. (2011) (κ=1.00) and Teyhen et al. (2012) (κ=0.82) and higher than the good and fair reliability reported by Minick et al. (2010) (κ=0.78) and Shultz et al. (2013) (κ=0.31). The present study found good to excellent intra-tester reliability which is consistent with the good to excellent reliability reported by Smith et al. (2013) (ICC=0.88-0.95) and the good reliability noted by Teyhen et al. (2012) (κ=0.68). The current study is superior to studies that scored the test using video-analysis, as it utilises real-time analysis of the test which mimics the method in which the test would be primarily assessed in mass screenings and the clinical setting. In addition, real-time analysis allows the tester to view the movement from all angles and is not limited by the 2d nature of video analysis. Both Minick et al. (2010) and Shultz et al. (2013) videotaped the testing process and testers had the capability to replay the test as many times as needed in order to score the test, which may have provided a false higher reliability score than actually occurs during real time testing which is the primary method of screenings (Teyhen et al., 2012, 2011). The high inter-tester and intra-tester reliability could be attributed to the simplicity of the test; it is an easy and quick test to execute and requires no equipment which removes the risk of equipment error influencing the reliability of the test. In addition, it has an extremely clear scoring system that reduces the possibility of error between testers and sessions (Shultz et al., 2013).

A.4.5. Reliability of the scapular control test

Five studies assessed the reliability of visual assessments of scapular asymmetry that could be utilised in a screening. Five studies assessed inter-tester reliability (Kibler et al., 2002, Ellenbecker et al., 2012, Uhl et al., 2009, McClure et al., 2009) with only a single study examining intra-tester reliability (Kibler et al., 2002). The inter-tester reliability in the current study was found to be excellent, with a high ICC value and low SEM value that was below clinically significant in all individual components of the scapular control test. The inter-tester reliability observed in the current study was found to be substantially higher than those noted in other similar reliability studies that utilised a visual estimation of scapular control. Fair to good inter-tester reliability (κ=0.31, 0.42) was observed in Kibler et al.(2002), poor to fair reliability (κ=0.186, 0.245) in

Ellenbecker et al. (2012) and moderate reliability was noted in Uhl et al. (2009) (κ=0.44), McClure et al. (2009) (κ=0.57, 0.54) and Uhl et al. (2009) (κ=0.41). The present study reported lower intra-tester reliability (good to excellent) than inter-tester reliability which could be attributed to day to day variation in the results of the tests (Atkinson and Nevill, 1998). Low intra-tester reliability is clinically significant as athletes commonly undergo a period of prehabilitation to reduce the effects of the issues noted in the screening and the screening is repeated following this to assess the effectiveness of the prevention strategy. Low intra-tester reliability may affect the consistency of the results and so therapists may be unsure of whether any viewed improvements are due to the prevention strategy alone or was the difference due to this day to day variation. However, the reported intra-tester reliability in this study is higher than the moderate reliability reported by Kibler et al. (2002) (κ=0.49, 0.59).

The lower reliability scores produced in other reliability studies could be attributed to a number of methodological issues including: inadequate familiarisation sessions, complicated scoring systems, poorly defined definitions of scapular dyskinesis and the individual components of this, or the use of video analysis rather than live examinations (Kibler et al., 2002, McClure et al., 2009, Uhl et al., 2009). Video analysis was used in three out of the five reliability studies which could have prevented testers from viewing the scapulae from different angles and may have contributed to the error observed in these studies (Kibler et al., 2002). The familiarisation session utilised in this study was intensive and comprised of three intensive sessions which is far more than utilised in other reliability studies; in fact, Kibler et al. (2002) only utilised a 10 minute familiarisation session. The current researchers felt a stronger focus on teaching the testers the test was necessary, because assessing scapular dyskinesis is challenging as they are required to consider 3 rotational and 2 translations of movement simultaneously due to the complex 3 dimensional pattern of motion that occurs during dynamic motion (Uhl et al., 2009, McClure et al., 2009).

A.4.6. Limitations to study

There a number of limitations in the present study. The tests developed and adapted in this study are subjective in nature and so a certain amount of measurement error will exist. Researchers commonly utilise complex and expensive equipment to objectively measure performance in tests to reduce this measurement error however the aim of this study was to propose simple field based screening tools that require minimal or inexpensive equipment to ensure therapists have the ability to implement this test extensively. In addition, the high reliability demonstrated in this study shows that with appropriate training therapists can implement this subjective test reliably with minimal measurement error. Another limitation to this study is the lack of comparison of the squat, single leg squat, active knee extension test and scapular control test with gold standard three dimensional kinematic analysis using electromagnetic tracking devices and the alternative push up test with core muscles electromyography activity during higher and lower scores in this test. Thus the current researchers recommend that further research assess the validity of the screening tests against gold standard methods.

A.4.7. Conclusion

All tests examined in this study produced high levels of inter-tester and intra-tester reliability, and so therapists can be satisfied when utilising these tests in a screening that the results of these tests can be interpreted with minimal error. The results in this study can be confidently generalised to the physically active and sporting population as it utilised multiple testers over two sessions using physically active and sporting participants. In addition, all tests were assessed using real-time analysis which mimics real life screenings. The three comprehensive preparatory sessions that testers were required to undergo prior to testing, indicate that they were sufficient to adequately train testers to a high standard to administer the tests reliably. These three sessions involved a presentation on the purpose, the instructions and scoring system of each of the tests, visual demonstrations and photographs of common mistakes and poor techniques completed during testing by the testers and participants and provided testers with adequate time to practice administering and scoring the tests. The clear instructions and well defined scoring systems may have also reduced the error in the testing procedures and so have contributed to high inter-tester and intra-tester reliability in each of the tests examined. The tests assessed were simple to execute and required minimal equipment which also may have reduced the error in measurement in the tests.

Appendix B. **Plain Language Statement**

Project Title:

The Epidemiology and Risk Factors Related to Injury in school aged and collegiate Gaelic Footballers and Hurlers.

This study will be undertaken at _______________ school. The principal investigators are Dr Noel McCaffrey (017008187/ noel.mccaffrey@dcu.ie), Dr Kieran Moran (017008011/ kieran.moran@dcu.ie) and Siobhán O Connor (0861639016/ siobhan.oconnor27@mail.dcu.ie)

The aim of the project is to analyse patterns of injuries and risk factors that might cause injury in young Gaelic Footballers and Hurlers with a view to ultimately designing a strategy to help prevent these injuries from occurring. In order to do this we will invite your child to take part in three main ways:

1) A once off clinical examination will take place in ___________ school by a Certified Athletic Rehabilitation Therapist (A.R.T.C.). This examination will involve tests for balance, flexibility, core strength, neuromuscular control and foot function.
2) The participant will be asked to fill in an online Training Diary within _____________ school that details his participation in all sports.
3) The participant will be asked to report all injuries that he develops and if necessary, attend a free medical assessment of the injury by a Certified Athletic Rehabilitation Therapist or Doctor within ____________ school.

This study may contribute in an important way to developing a strategy to help prevent injuries in Gaelic Football and Hurling. The study has been approved by the DCU Research Ethics Committee. This approval guarantees that all records in relation to every participant will be securely stored in DCU and that confidentiality of all participants will be strictly respected.

<u>Project Title:</u>

The Epidemiology and Risk Factors Related to Injury in school aged and collegiate Gaelic Footballers and Hurlers.

This study will be undertaken at ________________. The principal investigators are Dr Noel McCaffrey (017008187/ noel.mccaffrey@dcu.ie), Dr Kieran Moran (017008011/ kieran.moran@dcu.ie) and Siobhán O Connor (0861639016/ siobhan.oconnor27@mail.dcu.ie)

The aim of the project is to analyse patterns of injuries and risk factors that might cause injury in collegiate Gaelic Footballers and Hurlers with a view to ultimately designing a strategy to help prevent these injuries from occurring. In order to do this we will invite you to take part in three main ways:

1) A once off clinical examination will take place in ____________ by a Certified Athletic Rehabilitation Therapist (A.R.T.C.). This examination will involve tests for balance, flexibility, core strength, neuromuscular control and foot function.
2) The participant will be asked to fill in an online Training Diary that details his participation in all sports.
3) The participant will be asked to report all injuries that he develops.

This study may contribute in an important way to developing a strategy to help prevent injuries in Gaelic Football and Hurling. The study has been approved by the DCU Research Ethics Committee. This approval guarantees that all records in relation to every participant will be securely stored in DCU and that confidentiality of all participants will be strictly respected.

Appendix C. **Informed Consent**

<u>Project Title</u>:
The Epidemiology and Risk Factors Related to Injury in school aged and collegiate Gaelic Footballers and Hurlers.

The principal investigators are Dr Noel McCaffrey (017008187/ noel.mccaffrey@dcu.ie), Dr Kieran Moran (017008011/ kieran.moran@dcu.ie) and Siobhán O Connor (0861639016/siobhan.oconnor27@mail.dcu.ie)

I have been asked to allow my son to participate in this research project. I am aware the project aims to investigate the patterns of injury and risk factors that cause injury in school aged children. I have read the Plain Language Statement which fully explains the project and have been given the opportunity to discuss the project with the investigators. I have also discussed it with my son. Based on this I am satisfied to allow him to participate in the study.

I understand that my son must take part in a once off session in school that assesses his ability to complete certain tasks. I understand that my son must document certain information about his participation in training every week. I understand that if my son recieves an injury he must report this injury and if necessary take part in a free assessment by a qualified medical individual (Sports Medicine Physician or Certified Athletic Therapist and Trainer).

I understand that my child's participation is entirely voluntary. He can withdraw from the study at any time without penalty. Within the provisions of Irish law his data will at all times be confidential. His name will not be revealed but the summary data may be presented and discussed at scientific meetings and may be published in a scientific journal

<u>Signature:</u>

The researchers have provided an opportunity for me to contact them with my questions and concerns, and I have a copy of this consent form. They have discussed the project with my child. My child understands what is involved and is willing to participate. Therefore, I (print name) ______________________ consent to allow my child (print name)____________________to take part in this research project.

<u>Signature of Parent / Guardian:</u> ______________________________

<u>Name of Parent / Guardian (Block Capitals):</u> ____________

<u>Witness:</u> ______________________________

<u>Date:</u> ______________________________

Assent by Child

I understand what is involved in this project. It has been explained to me by the research team and by my parents. I agree to take part

Name of Child ________________________ **Witness**______________________

Signature ________________________ **Date** ______________

Project Title:
The Epidemiology and Risk Factors Related to Injury in school aged and collegiate Gaelic Footballers and Hurlers.

The principal investigators are Dr Noel McCaffrey (017008187/ noel.mccaffrey@dcu.ie), Dr Kieran Moran (017008011/ kieran.moran@dcu.ie) and Siobhán O Connor (0861639016/siobhan.oconnor27@mail.dcu.ie)

I have been asked to participate in this research project. I am aware the project aims to investigate the patterns of injury and risk factors that cause injury in collegiate Gaelic footballers and hurlers. I have read the Plain Language Statement which fully explains the project and have been given the opportunity to discuss the project with the investigators. Based on this I am satisfied to participate in the study.

I understand that I must take part in a once off session that assesses my ability to complete certain tasks. I understand that I must document certain information about my participation in training every week. I understand that if I recieve an injury I must report this injury and if necessary take part in a free assessment by a qualified medical individual (Sports Medicine Physician or Certified Athletic Therapist and Trainer).

I understand that my participation is entirely voluntary. I can withdraw from the study at any time without penalty. Within the provisions of Irish law my data will at all times be confidential. My name will not be revealed but the summary data may be presented and discussed at scientific meetings and may be published in a scientific journal

Signature:

The researchers have provided an opportunity for me to contact them with my questions and concerns, and I have a copy of this consent form. They have discussed the project with my child. My child understands what is involved and is willing to participate. Therefore, I (print name) ______________________ consent to allow my child (print name)___________________to take part in this research project.

Signature: ____________________________________

Name (Block Capitals): ______________________________

Witness: ______________________________

Date: ______________________________

Appendix D. **Scoring Sheet**

Name:____________________________________School/Team:_______________

Dominant Foot/Hand:________________DOB:___________________________

Date of Testing:____________________________

Test	**Results**
Height (cm)	
Weight (kg)	
Foot Length (mm)	
Lower Limb (cm)	

Scapular Control Scoring System	**None (0)**	**Slight (1)**	**Moderate (2)**	**Severe (3)**
Winging Right				
Winging Left				
Control of Scapula when lifting Right				
Control of Scapula when lifting Left				
Control of Scapula when lowering Right				
Control of Scapula when lowering Left				
Symmetry between both scapulae				

Alternative Push Up Test	**Score from 0-4**

Flexibility

Test	**Trial 1 (degrees)**	**Trial 2 (degrees)**	**Trial 3 (degrees)**
Internal Rotation Right			
External Rotation Right			
Internal Rotation Left			
External Rotation Left			
Active Knee Extension Right			
Active Knee Extension Left			

Overhead Squat

Aspect	**Normal (0)**	**Slight (1)**	**Moderate (2)**	**Severe (3)**
Knee over toes				
Knee Valgus				
Knee Varus				
Toe out				
Toe in				
Hip Flexed				
Trunk Flexed				
Balance				
Overall	**Pain (0)**	**Poor (1)**	**Average(2)**	**Excellent (3)**

Impression				

Single Leg Squat RIGHT

Aspect	Normal (0)	Slight (1)	Moderate (2)	Severe (3)
Knee over toes				
Knee Valgus				
Knee Varus				
Toe out				
Toe in				
Hip Flexed				
Trunk Flexed				
Balance				
Overall Impression	**Pain (0)**	**Poor (1)**	**Average(2)**	**Excellent (3)**

Single Leg Squat LEFT

Aspect	Normal (0)	Slight (1)	Moderate (2)	Severe (3)
Knee over toes				
Knee Valgus				
Knee Varus				
Toe out				
Toe in				
Hip Flexed				
Trunk Flexed				
Balance				
Overall Impression	**Pain (0)**	**Poor (1)**	**Average(2)**	**Excellent (3)**

Navicular Drop in (mm)

Action	Navicular Level in mm
Sitting R	
Standing R	
Sitting L	
Standing L	
Difference R	
Difference L	

Y Balance Test

Action	Trial 1 (cm)	Trial 2 (cm)	Trail 3 (cm)
Anterior Right			
Posterior medial Right			
Posterior lateral Right			
Anterior Left			
Posterior Medial Left			
Posterior Lateral Left			

Appendix E. **Description of measurement of anthropometric data**

Height	
Equipment needed	Portable Stadiometer, scoring sheet, pen
Description of test	Participant removes shoes Participant stands up straight with head, back, buttocks, calves and heels against the stadiometer Participant looks straight ahead while tester the head piece of the stadiometer is lowered onto the head until hair is pressed flat on the head Instruct the participant to breathe in deeply
Instructions	Remove shoes Stand up straight with head, back, buttocks, calves and heels against the stadiometer Look straight ahead Breathe in deeply
Trials	1 trial completed
Incomplete trial	Does not remove shoes Does not stand up straight with head, back, buttocks, calves and heels against the stadiometer (leans back or forward) Looks down when the measurement is taken Does not breathe in
Measurement	The measurement is recorded to the nearest millimetre just before the participant breathes out
Weight	
Equipment needed	Calibrated scale, scoring sheet, pen
	Participant removes shoes Participant stands up straight with arms by sides on the the centre of the measuring scales with weight distributed evenly Instruct participant to look straight ahead and not look down
Instructions	Remove shoes Stand up straight with arms by sides on the centre of the measuring scales with weight distributed evenly Look straight ahead
Trials	1 trial completed
Incomplete trial	Does not remove shoes Does not stand fully on the scale (heels or toes off the scale) Looks down at weight dial
Measurement	The measurement is recorded to the nearest kilogram

Appendix F. **Description of Active knee extension test**

Active knee extension	
Equipment needed	Plinth, straight vertical side bar, inclinometer, scoring sheet, pen
Practice session	1 practice demonstration
Description of test	Subject lies on their back on a plinth Place an object under the contralateral knee not being tested in order to ensure the knee is kept in 20° flexion A straight vertical side bar is placed alongside the plinth aligned with the greater trochanter of the leg being tested. The participant is asked to grasp the thigh immediately proximal to the knee being tested with both hands and bring the lateral epicondyle of the femur in line with the vertical bar at the side of the plinth and align (i.e. bring the hip to 90° flexion). The knee is bent to 90° so that it is aligned parallel to the plinth and the participant is instructed to point their toes (i.e. ankle plantarflexed) and keep their head flat on the plinth for the duration of the test. The position of the hip and knee is monitored by the tester throughout the test. The inclinometer is placed on a flat surface and the dial of the inclinometer is rotated so the “0” and arrow aligns with the surface of the fluid. The inclinometer is then placed on the on the tibia immediately below the tibial tuberosity. The participant is instructed to straighten their leg as far as possible until they feel a “strong but tolerable stretch” while keeping their ankle pointed and their thigh aligned to the vertical bar throughout the test. This position is held until the tester instructs the participant to relax back into the starting position.
Instructions	Lie on your back Bend your hip to 90° and keep it parallel to the straight side bar throughout the test by grasping your thigh with both hands Bend your knee to 90° and hold it there as the starting position of the test Straighten your leg as far as possible until you feel a strong but tolerable stretch while keeping your ankle pointed Hold this position until tester tells you to relax
Trials	3 trials on each leg
Incomplete trial	The greater trochanter not aligned to vertical side bar throughout test The hip not flexed to 90° throughout test The knee not bent to 90° in starting position of test The ankle dorsiflexed at any point during the test The neck is flexed at any point during the test If the participant does not hold the end point for long enough for the tester to take a measurement.
Measurement	The measurement is recorded to the nearest degree

Appendix G. **Description of the Internal and External range of motion tests**

Internal range of motion	
Equipment needed	Plinth, inclinometer, scoring sheet, pen
Practice session	1 practice demonstration
Description of test	Subject lies on their back with their right shoulder over the edge of the plinth Bring the arm to 90° abduction Bend the elbow to 90° flexion The inclinometer is placed on a flat surface and the dial of the inclinometer is rotated so the "0" and arrow aligns with the surface of the fluid. The inclinometer is then placed on the dorsal surface of the forearm. While holding the inclinometer in a steady position passively move the forearm forward to put the shoulder into internal rotation until the subject notes a strong but tolerable stretch or the tester feels resistance
Instructions	Lie on your back with your right shoulder over the edge of the plinth Hold your arm and elbow in the position the tester places it in throughout the test Report when you feel a strong but tolerable stretch
Trials	3 trials on each shoulder
Incomplete trial	Arm is not at 90° abduction throughout the test Elbow is not bent to 90° flexion throughout the test
Measurement	The measurement is recorded to the nearest degree

External range of motion	
Equipment needed	Plinth, inclinometer, scoring sheet, pen
Practice session	1 practice demonstration
Description of test	Subject lies on their back with their right shoulder over the edge of the plinth Bring the arm to 90° abduction Bend the elbow to 90° flexion The inclinometer is placed on a flat surface and the dial of the inclinometer is rotated so the "0" and arrow aligns with the surface of the fluid. The inclinometer is then placed on the dorsal surface of the forearm. While holding the inclinometer in a steady position passively move the forearm forward to put the shoulder into external rotation until the subject notes a strong but tolerable stretch or the tester feels resistance
Instructions	Lie on your back with your right shoulder over the edge of the plinth Hold your arm and elbow in the position the tester places it in throughout the test Report when you feel a strong but tolerable stretch
Trials	3 trials on each shoulder
Incomplete trial	Arm is not at 90° abduction throughout the test Elbow is not bent to 90° flexion throughout the test
Measurement	The measurement is recorded to the nearest degree

Appendix H. **Description of the navicular drop test**

Navicular Drop Test	
Equipment needed	Fine-tipped, non-toxic, water soluble marker, ruler, chair, scoring sheet, pen
Practice session	1 practice demonstration
Description of test	Mark the most prominent part of the navicular tuberosity using the marker While the participant is sitting with knees bent to 90°, no pressure on their feet and feet shoulder distance apart, place the foot in subtalar joint neutral by palpating medial and lateral talar depressions with thumb and forefinger and invert and evert the foot until both talar heads are equal Using a ruler measure the level of the previously marked navicular tuberosity from the ground and take note of this measurement in milimeters Participant stands without moving their feet into a relaxed stance with equal weight on both legs Measure and take note of the level of the navicular tuberosity in the standing stance
Instructions	Remove shoes Sit with no weight on legs in a position where you can stand without moving your feet Allow tester to move your foot and hold your foot in the position the testers places it in Stand without moving your feet into a relaxed position as you normally would with your weight equally distributed between both feet
Trials	3 trials on each foot
Measurement	The difference between the sitting and standing navicular tuberosity position is noted in mm The difference between the navicular drop in left and right foot is noted in mm

Appendix I. **Description of the Y balance test**

Y balance test	
Equipment needed	Y balance test kit, scoring sheet, pen
Practice session	4 trials in each of the 3 reach directions on both legs
Instructions	Remove shoes Stand on one leg in the centre of the platform Reach with free leg pushing the target as far forward, to the side and backward while maintaining single leg stance
Trials	3 trials in anterior direction on right leg 3 trials in posteriomedial direction on right leg 3 trials in posteriolateral direction on right leg Then swap legs and complete again
Incomplete trial	Fail to maintain unilateral stance on the platform (e.g. touch down to the floor with the reach foot) Fail to maintain reach foot contact with the reach indicator on the target area while it is in motion (e.g. kick the reach indicator) Use the reach indicator for stance support (e.g. place foot on top of reach indicator Fail to return the reach foot to the starting position under control
Measurement	Maximum reach distance was measured by observing the point where the target stopped i.e. the maximum distance between the most distal part of the foot to the most distal reach distance

Appendix J. **Description of Squat and Single leg squat tests**

Squat	
Equipment needed	Dowel, Pen, scoring sheet
Practice session	1 practice demonstration
Description of test	Subject stands with feet shoulder width apart and toes pointing forwards Grasp dowel in both hands and place it horizontally on top of your head so shoulders and elbows are at 90° The subject maintains an upright torso, and keeps heels and dowel in position and descends as deep as possible Subject holds this position for a count of one and returns to the starting position
Instructions	Stand with feet shoulder width apart Grasp a dowel resting on your shoulders with both hands Assume the starting position by straightening your elbows with the dowel overhead Slowly squat down as far as comfortable keeping heels on the floor Hold this position for a count of one Return to starting position
Trials	3 trials
Measurement	Assess the variables: knees over toes, knee valgus, knee varus, toe out, toe in hip flexed, trunk flexed, balance and overall impression 0-3 rating for each variable For overall impression: 0=pain, 1=poor, 2=average, 3=excellent For all other variables: 0=none, 1=slight, 2=moderate, 3=severe
Single leg squat	
Equipment	Step, scoring sheet, pen
Practice session	1 practice demonstration
Description of test	Participant stands on the right leg with the contralateral leg bent and hip slightly flexed on the left edge of a step Participant outstretches arms to 90° with elbows straight and hands clasped together Participant squats down as far as possible in a controlled manner Participant holds this position for one second and returns to starting position
Instructions	Stand with your right foot on the left edge of a step Outstretch your arms at 90° to the body with your elbows straight and clasp your hands together in front Squat down on your right leg as far as is comfortable Return to standing position in a controlled manner
Trials	3 trials on each leg
Measurement	Assess the variables: knees over toes, knee valgus, knee varus, toe out, toe in hip flexed, trunk flexed, balance and overall impression in each leg 0-3 rating for each variable For overall impression: 0=pain, 1=poor, 2=average, 3=excellent For all other variables: 0=none, 1=slight, 2=moderate, 3=severe

Appendix K. **Description of the Scapular Control test**

Scapular Control	
Equipment needed	Scoring sheet, pen
Practice session	None needed
Description of test	Subject should remove t-shirt and face the wall with their arms by their sides and palms facing their thighs Stand 2-3m behind subject with a clear unobstructed view of the scapulae Instruct subject to slowly abduct their arms to 180° and slowly lower to starting position
Instructions	Remove t-shirt Stand facing the wall with arms relaxed by your sides Slowly lift your arms outwards until your arms touch your ears Slowly return them to the starting position
Trials	3 trials
Incomplete trial	Move their arms too fast through the movement Do not lift their arms fully to their ears and back down to their sides
Measurement	Assess the variables: winging (medial border of scapulae should be flat on their ribs), control when lifting, control when lowering (must lift and lower in a controlled manner with no shaking or abnormal scapulae positioning) and symmetry of scapulae (scapulae must move together throughout the full range of motion with no lagging behind or speeding of a single scapula in relation to the corresponding scapulae). 0-3 rating for each variable and the higher the rating the increased severity of that particular component of scapular dyskinesis 0=none, 1=slight, 2=moderate, 3=severe

Appendix L. **Description of the alternative push up test**

Alternative push up test	
Equipment needed	Athletic tape, scoring sheet, pen
Practice session	1 practice demonstration
Description of test	A straight line of athletic tape is placed along the floor which is used to indicate where subjects must place their hands Subject lies with their face towards the floor with their feet together, hands shoulder distance apart and forehead at the level of the athletic tape. The subject is asked to lift their right leg slightly off the ground to reduce their base of support. The subject is then required to complete a press up while lifting the body as a unit with a straight line between the shoulder, hip and knees with no lag or twisting of the spine or hips and keeping the right leg slightly up off the ground. If the subject can complete this movement sufficiently they receive a rating of 4 and the tests finishes. If they are unable to complete the test sufficiently they are required to repeat the test again with both feet on the ground and their hands at the level of the forehead. If they are able to sufficiently do this they receive a score of 3 and the test finishes. If they are unable to complete the test sufficiently with their hands at the level of the forehead, they must repeat the test with their hands at the level of their chin. If they can adequately complete the test in this position they receive a score of 2 and the tests finishes. If they are unable they receive a score of 1.
Instructions	Lie face down with your feet together and forehead at the level of the athletic tape with hands shoulder distance apart Lift your right leg slightly off the ground Complete one push up and lift your body as a unit If unable to do this complete the push up with hands at the level of the forehead with feet together If unable to do this complete the push up with hands at the level of the chin with feet together
Trials	1-3 trials depending on performance in the test
Measurement	0-4 rating given: 4= Can complete a push up with their hands at the level of their forehead and with their right leg slightly lifted off the ground without lagging or twisting of the spine or hips 3=Can complete a push up with their hands at the level of their forehead and both feet together on the ground. Unable to complete the push up with the right leg lifted off the ground without lagging or twisting of the spine or hips 2= Can complete a push up with hands at the level of the chin and both feet together without lagging or twisting of the spine or hips 1=Unable to complete a push up with hands at the level of the chin with both feet together without lagging or twisting of the spine or hips 0= Experiences pain during the test

Appendix M. **Quartile Results for Height, Weight and BMI in adolescent and collegiate participants**

Height, Weight and BMI: Quartile results in adolescent participants

	Quartiles		
	25th	**50th**	**75th**
Height (m)	1.71	1.76	1.80
Weight (kg)	60.0	66.0	74.0
BMI (kg/m^2)	19.8	21.2	23.1

Height, Weight and BMI: Quartile results in collegiate participants

	Quartiles		
	25th	**50th**	**75th**
Height (m)	1.77	1.81	1.85
Weight (kg)	71.0	76.0	84.0
BMI (kg/m^2)	22.3	23.5	24.8

Appendix N. **Percentile results for flexibility tests in adolescent and collegiate participants**

Flexibility tests: Percentile results in adolescent participants

		10th	20th	30th	40th	50th	60th	70th	80th	90th
Active knee extension (◦)	R	43	50	55	58	62	65	68	72.6	78.1
	L	43.2	49.4	53	56	60	63	67	71	77.3
Internal rotation (◦)	R	57.8	65	70	73	77	83	87	90	97.2
	L	65	73	81	86	91	94	98	103	108
External rotation (◦)	R	65	71	75	80	84	88	93	98	105
	L	76	80	86	88.6	91.5	95	98	101	105

Flexibility tests: Percentile results in collegiate participants

		10th	20th	30th	40th	50th	60th	70th	80th	90th
Active knee extension (◦)	R	50	55	58	61.67	65	68	71.68	75	80
	L	51.9	57	60	63.24	66.67	68.46	82	75	80
Internal rotation (◦)	R	55	60	61.7	68.13	73	78	81.7	87	100
	L	56.33	61.7	66.7	70	78	85	91.67	97	102
External rotation (◦)	R	61.67	68	71.67	78	83.3	89.6	93.8	97.94	105
	L	60	66.67	71	74.58	78	84	88.21	92.8	100

Appendix O. **Quartile results for Y balance test.**

Y balance test: Quartile results for adolescent participants

Variable	Leg	25th	50th	75th
Anterior				
Average reach distance (cm)	Right	61.4	67	73.5
	Left	63	69	76
Average reach difference (cm)		1.7	3.7	6.3
Average reach (%LL)		63.2	69	76.5
Posteriomedial				
Average reach distance (cm)	Right	91	99	105.75
	Left	93	101	108
Average reach difference (cm)		2	4.3	8.7
Average reach (%LL)		93.9	100.8	108.3
Posteriolateral				
Average reach distance (cm)	Right	89.3	98	107
	Left	90	99	106
Average reach difference (cm)		2.3	5.3	8
Average reach (%LL)		91.5	100	108
Composite				
Composite score	Right	85	92	98
	Left	87	93	99
Average reach difference (cm)		1.4	3.5	5.6

Abbreviation: %LL, percentage of leg length.

Quartile results for the Y balance test

Variable	Leg	25th	50th	75th
Anterior				
Average reach distance (cm)	Right	62	67.3	75.7
	Left	63	67	76
Average reach difference (cm)		1.4	3.3	6.4
Average reach (%LL)		61.7	65.8	70.2
Posteriomedial				
Average reach distance (cm)	Right	97.5	104	112.7
	Left	98	104.3	112.7
Average reach difference (cm)		2	4	7.5
Average reach (%LL)		96.6	102	108.2
Posteriolateral				
Average reach distance (cm)	Right	98	105	116.7
	Left	98	105	117
Average reach difference (cm)	N/A	2	4.3	8.3
Average reach (%LL)	N/A	96.5	101.6	109.8
Composite				
Composite score	Right	85	89.8	94.9
	Left	85	90	95.7
Average reach difference (cm)		1	2.5	5

Abbreviation: %LL, percentage of leg length.

Appendix P. **Injury Report Form**

1. Name ______________________________________
Contact No ______________ **Team** _______________
Assessed By ____________________________________

2. Main Sport
□ Gaelic Football □ Hurling
□ Camogie □ Other

3. Usual position / role in team
□ goalkeeper □ corner back □ full Back
□ wing back □ centre back □ midfield
□ wing forward □ centre forward □ corner Forward
□ full forward □ substitute

4. Are you a dead ball kicker? □ Yes □ No

5. What sport were you playing / training for when the injury occurred
□ Gaelic Football □ Hurling
□ Camogie □ Other (detail________)

6. Injury occurred with
□ own age club team □ older age club team
□ own age school team □ older age school team
□ county team (GAA) □ college team
□ representative team (if other sport) □ work team
□ recreational team □ individual activity

7. Injury occurred during
□ preseason □ regular season □ off season

9. Onset of injury
□ gradual onset, no specific time □ sudden onset

10. Injury occurred during (pick one only)
□ team outdoor training □ team indoor training
□ friendly game □ competitive game
□ dead ball kicking session □ specific skills session
□ individual activity □ gradual onset

11. Type of playing surface
□ grass □ synthetic □ indoor □ track
□ road □ beach □ other

12. Weather conditions
Temp: □ cold □ 'normal' □ hot
Surface 1: □ wet / slippy □ dry □ frozen
Surface 2: □ firm / hard □ soft / muddy

13. Time of injury
□ Warm up □ Cool down
□ Minutes of match/training _____

14. Type of injury
□ new injury □ early recurrence (<1 month)
□ late recurrence (2-12 months)
□ persistent / recurring

15. Side of injury
□ Left □ Right □ Bilateral □ N/A

16. Injury mechanism
contact with:
□ other player □ playing surface □ football
□ apparatus □ boundary □ goal-post □ flag
□ hurley □ sliothar □ helmet
□ other person (non-player)

□ non contact □ assault / violence
□ gradual onset (overuse)
□ equipment / clothing (e.g friction burn / blister)
other ______________________________

17. Activity during injury
□ jumping/catching □ landing □ turning
□ running/sprinting □ short kick □ long kick
□ hand pass □ sudden stop □ falling
□ tackling □ being tackled □ blocking
□ dead ball kick/puck □ punching ball □ hooking
□ nil specific

18. Were you wearing any of the following (tick)
□ mouthguard □ strapping (details __________)
□ bracing (details _______________)
□ other protective equipment (details ______)

19. Referee's sanction
□ no foul □ opponent foul □ own foul □ tick
□ yellow card □ red card □ N/A

20. Body part injured and type of injury/injuries
____
____
(Orchard Classification)

21. Injury assessment
examination by
□ doctor □ chartered physiotherapist
□ ATT □ other ______________________

22. Other tests done for current injury
□ X-Ray □ MRI □ Ultra-sound
□ other imaging □ blood works/lab test
other ____________ □ none

23. Did this injury require surgery?
□ Yes during season □ Yes, post season □ No

24. Dates
date of injury ______________
date of completing this form ______________
date of resuming light training ______________
date full training (unable to play) ______________
full fitness (able to play and train) ______________

Appendix Q. **FMS Tests: Purpose, Clinical Implications and Possible Causes**

Test	Purpose	Clinical Implications	Possible causes
Deep squat	Challenges total body mechanics Assesses bilateral, symmetrical, functional mobility of the hips, knees, and ankles. The dowel held overhead assesses bilateral, symmetrical mobility of the shoulders as well as the thoracic spine.	Requires closed kinetic chain dorsiflexion of the ankles Flexion of the knees and hips Extension of the thoracic spine Flexion and abduction of the shoulders.	Limited mobility in the upper torso can be attributed to poor glenohumeral and thoracic spine mobility Limited mobility in the lower extremity including poor closed-kinetic chain dorsiflexion of the ankles or poor flexion of the hips
Hurdle step	Challenges the body's proper stride mechanics during a stepping motion. Requires proper coordination and stability between the hips and torso during the stepping motion as well as single leg stance stability. Assesses bilateral functional mobility and stability of the hips, knees, and ankles.	Requires stance-leg stability of the ankle, knee, and hip as well as maximal closed-kinetic chain extension of the hip. Requires step-leg open-kinetic chain dorsiflexion of the ankle and flexion of the knee and hip. Adequate balance	Poor stability of the stance leg or poor mobility of the step leg. Relative bilateral asymmetric hip mobility issues
In-line lunge	Places the lower extremities in a scissor style position challenging the body's trunk and extremities to resist rotation and maintain proper alignment Assesses hip and ankle mobility and stability Quadriceps flexibility Knee stability.	Requires stance leg stability of the ankle, knee, and hip as well as apparent closed kinetic-chain hip abduction Requires step-leg mobility of hip abduction, ankle dorsiflexion Rectus femoris flexibility Adequate balance	Hip mobility may be inadequate in either the stance leg or the step leg The stance leg knee or ankle may not have the required stability Imbalance between relative adductor weakness and abductor tightness in one or both hips Limitations may also exist in the thoracic spine region which may inhibit the athlete from performing the test properly
Shoulder mobility	Assesses bilateral shoulder range of motion, combining internal rotation with adduction and external rotation with abduction. Requires normal scapular mobility and	Requires shoulder mobility in a combination of movements: Abduction/external rotation Flexion/extension Adduction/internal rotation	External rotation gained at the expense of internal rotation in overhead throwing athletes Excessive development and shortening of the pectoralis minor or latissmuss dorsi

	thoracic spine extension	Requires scapular mobility Requires thoracic spine mobility	muscle can cause postural alterations Scapulothoracic dysfunction resulting in decreased glenohumeral mobility secondary to poor scapulothoracic mobility or stability
Active straight leg raise	Tests ability to disassociate the lower extremity from the trunk while maintaining stability in the torso. Assesses active hamstring and gastro-soleus flexibility while maintaining a stable pelvis and active extension of the opposite leg	Requires functional hamstring flexibility Adequate hip mobility of the opposite leg Lower abdominal stability	Poor functional hamstring flexibility Inadequate mobility of the opposite hip, stemming from iliopsoas inflexibility associated with an anteriorly tilted pelvis
Trunk stability push up	Tests ability to stabilise the spine in an anterior and posterior plane during a closed-chain upper body movement. Assesses trunk stability in the sagittal plane while a symmetrical upper-extremity motion is performed	Requires symmetric trunk stability in the sagittal plane during a symmetric upper extremity movement	Poor stability of the trunk stabilisers
Rotatory stability	Assesses multi-plane trunk stability during a combined upper and lower extremity motion	Asymmetric trunk stability in both sagittal and transverse planes during asymmetric upper and lower extremity movement	Poor asymmetric stability of the trunk stabilizers

Adapted from Cook et al. (2006)

Appendix R. **Reliability of Individual FMS tests**

Test	Tester level	Study	Inter-tester reliability	Intra-tester reliability
Deep squat	Trained	Schneiders et al. (2011)	κ=1.00 100% agreement	NT
	Expert	Minick et al. (2010)	κ=0.64 76.9% agreement	NT
	Novice	Minick et al. (2010)	κ=0.80 87.2% agreement	NT
	Trained	Schultz et al. (2013)	Kα=0.41	NT
	Novice	Teyhen et al. (2012)	κ=0.68	κ=0.76
	Novice & Trained	Smith et al. (2013)	NT	ICC=0.82-0.90
Hurdle step	Trained	Schneiders et al. (2011)	κ=0.80 93% agreement	NT
	Expert	Minick et al. (2010)	κ=0.65 92.3% agreement	NT
	Novice	Minick et al. (2010)	κ=0.65 92.3% agreement	NT
	Trained	Schultz et al. (2013)	Kα=0.95	NT
	Novice	Teyhen et al. (2012)	κ=0.67	κ=0.59
	Novice & Trained	Smith et al. (2013)	NT	ICC=0.30-0.35
In-line lunge	Trained	Schneiders et al. (2011)	κ=0.86 93% agreement	NT
	Expert	Minick et al. (2010)	κ=0.53 79.5% agreement	NT
	Novice	Minick et al. (2010)	κ=0.74 89.7% agreement	NT
	Trained	Schultz et al. (2013)	Kα=0.10	NT
	Novice	Teyhen et al. (2012)	κ=0.45	κ=0.69
	Novice & Trained	Smith et al. (2013)	NT	ICC=0.69-0.78
Shoulder mobility	Trained	Schneiders et al. (2011)	κ=0.94 97% agreement	NT
	Expert	Minick et al. (2010)	κ=0.95 97.4% agreement	NT
	Novice	Minick et al. (2010)	κ=1.00 100% agreement	NT
	Trained	Schultz et al. (2013)	Kα=0.64	NT

	Novice	Teyhen et al. (2012)	κ=0.73	κ=0.68
	Novice & Trained	Smith et al. (2013)	NT	ICC=0.96-0.98
Active straight leg raise	Trained	Schneiders et al. (2011)	κ=0.94 97% agreement	NT
	Expert	Minick et al. (2010)	κ=0.84 92.3% agreement	NT
	Novice	Minick et al. (2010)	κ=0.84 92.3% agreement	NT
	Trained	Schultz et al. (2013)	Kα=0.63	NT
	Novice	Teyhen et al. (2012)	κ=0.69	κ=0.60
	Novice & Trained	Smith et al. (2013)	NT	ICC=0.92-0.95
Trunk stability push up	Trained	Schneiders et al. (2011)	κ=1.00 100% agreement	NT
	Expert	Minick et al. (2010)	κ=0.78 87.2% agreement	NT
	Novice	Minick et al. (2010)	κ=0.87 92.3% agreement	NT
	Trained	Schultz et al. (2013)	Kα=0.31	NT
	Novice	Teyhen et al. (2012)	κ=0.82	κ=0.68
	Novice & Trained	Smith et al. (2013)	NT	ICC=0.88-0.95
Rotatory stability	Trained	Schneiders et al. (2011)	κ=1.00 100% agreement	NT
	Expert	Minick et al. (2010)	κ=0.43 82.1% agreement	NT
	Novice	Minick et al. (2010)	κ=0.54 84.6% agreement	NT
	Trained	Schultz et al. (2013)	Kα=0.25	NT
	Novice	Teyhen et al. (2012)	κ=0.82	κ=0.68
	Novice & Trained	Smith et al. (2013)	NT	ICC=0.62-0.84

NT: Not tested. κ=kappa coefficient used to measure agreement in categorical data
Kα= Krippendorff alpha used as an alternative method to measure agreement if there are more than 2 raters and can assess different types of data (interval, ordinal)
Kα requires a value of .8 to be considered acceptable or .65 if tentative conclusions are deemed acceptable

Appendix S. **Weightings and scoring system of the standard 21 point scale, 100 point research scale and 100 point modified scale in the FMS**

Test	**Specific Criteria**	**Standard (21)**			**Research (100)**			**Modified (100)**		
		3	**2**	**1**	**W1**	**W2**	**W3**	**Obj**	**Comp**	**W**
Deep squat	Performed without a board	✓			✓				✓	
	Hips parallel	✓	✓		✓	2		✓		7
	Tibia/torso parallel	✓	✓		6	2			✓	1
	Knees aligned over toes	✓	✓		4	2			✓	1
	Symmetrical & weight bearing	✓	✓		2				✓	1
	Dowel behind toes	✓	✓		2	2			✓	1
	No lumbar flexion		✓						✓	1
	No external rotation of feet	✓	✓						✓	1
	Heels do not come off floor	✓			✓				✓	1
	Perform without pain	✓	✓	✓	✓	✓	1			
Hurdle Step	Clears Cord	✓	✓		5					
	Hip/knee/ankle aligned	✓			2				✓	1
	Lumbar flexion not noted	✓			1			✓		4
	Dowel stays parallel to ground	✓			1				✓	1
	Ankle remains dorsiflexed	✓							✓	1
	No contact between foot and hurdle	✓	✓		✓					
	Maintains balance	✓	✓		✓					
	Performs without pain	✓	✓	✓	✓		1			
In line lunge	Dowel contacts head/back/sacrum	✓			2					
	Dowel remains in sagittal plane	✓			2					
	No torso movement noted	✓			2				✓	1
	Knee contacts ground behind the heel	✓			2				✓	1
	Rear foot does not externally rotate	✓			2				✓	1
	Lumbar spine remains neutral	✓			2				✓	1
	No forward lean noted	✓			2			✓		6
	Maintains balance	✓	✓		✓					
	Places hands appropriately	✓	✓		✓					

	Front heel remains on the ground	✓			2				✓	1
	Performs without pain	✓	✓	✓	✓		1			
Shoulder Mobility	Fists are within 1 hand length	✓			4			✓		1
	Fists are within 1.5 hand length		✓			2			✓	1
	Fists not within 1.5 hands length			✓						
	Performs without pain	✓	✓	✓	✓	✓	1			
	No pain with impingement test	✓	✓	✓	✓	✓	1			
Straight leg raise	Malleolus between midthigh/ASIS	✓			6			✓		3
	Malleolus between/knee		✓			3				
	Malleolus below knee			✓						
	Opposite hip remains neutral	✓	✓		✓	✓				
	Toes remain pointed up	✓	✓		✓	✓			✓	1
	Knee maintains contact with the board	✓	✓		✓	✓			✓	1
	Performs without pain	✓	✓	✓	✓	✓	1			
Trunk stability push up test	Performs with hands at forehead	✓			12				✓	1
	Performs with hands at chin		✓			6				
	Body is lifted as one unit	✓	✓		✓	✓		✓		2
	Ankles remain dorsiflexed	✓	✓		✓	✓			✓	1
	Performs without pain	✓	✓	✓	✓	✓	1			
	No pain with extension test	✓	✓	✓	✓	✓	1			
Rotatory stability	Balanced ipsilateral	✓			6			✓		5
	Balanced contralateral		✓			3				
	Spine parallel to board	✓	✓		✓	✓			✓	1
	Hips parallel to floor								✓	1
	Knee/elbow in line with the board	✓	✓		✓	✓			✓	1
	Support ankle is dorsiflexed								✓	1
	Knee and elbow touch	✓	✓		✓	✓				
	Minimal trunk flexion is noted		✓			✓				
	Performs without pain	✓	✓	✓	✓	✓	1			
	No pain with flexion test	✓	✓	✓	✓	✓	1			

Table based on Frost et al. (2012)

Appendix T. **Training Diary**