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PhD thesis.

STRATEGIES TO ENHANCE PERFORMANCE IN GAELIC FOOTBALL PLAYERS BY REDUCING THE RISK OF INJURIES

A thesis submitted to the University of Glasgow

in candidature for the Degree of Doctor of Philosophy in the faculty of Biomedical

and Life Science.

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Declaration

I hereby declare that this thesis has been composed by myself, that the work, of which it is a record, has been done by myself except where assistance has been acknowledged, that it has not been submitted in any previous application for a higher degree and that all sources of information have been specifically acknowledged by means of references.

Micheál Newell

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Summary

Attempts to implement dedicated evidence-based sports science research in Gaelic Football are challenging. Current structures within Gaelic Football render the sport less conducive to research analysis. The tenet that all Gaelic Footballers "are born not made" still has its adherents in today's management circles. Atavistic attitudes to sport scientific experimentation persist. This doctorate dissertation seeks to address important issues that have the potential to maximise performance in Gaelic Football. The underlying theme of this thesis is to understand the prevalence and aetiology of injury, and the provision of researched suggestions designed to enhance performance.

The first study is a detailed prospective epidemiological study of injuries sustained by Gaelic Football players during a single competitive season (Newell *et al.,* 2006). The design of the study was based on Van Mechelen's (1992) model of 'sequence of prevention of sports injuries'. To date there has been no prospective epidemiological study of injuries in Gaelic Football. Two of the main findings arising from the injury surveillance study were the high incidence of hamstrings injury and the frequency of injuring occurring in the final quarter of training and games (Newell *et al.,* 2006).

As a follow-up to the initial injury surveillance study (Newell *et al.,* 2006), the next phase of study focussed on the aetiology of hamstrings injuries and in particular to investigate if hamstrings muscle strength or functional hamstrings/quadriceps ratio (H:Q ratio) is a predictor of hamstrings injury in Gaelic Football.The linear regression model fitted to the functional H:Q data identified two players as potential hamstrings injury candidates, one of whom

sustained a hamstrings injury during the playing season. A subsequent intervention programme aimed at reducing the incidence of hamstrings injury was devised but team managers were generally unwilling to embrace an intervention as they did not wish, as they saw it, to interfere with components which were essential for player preparation.

Dehydration is a recognised risk factor for injury, although the direct evidence linking dehydration and injury has not been established. The goal of the next phase of research was to investigate the fluid and electrolyte balance of individual elite (Newell *et al.*, 2008) and club Gaelic Football players and devise personal hydration strategies, as a means of controlling the potential impact of dehydration while prospectively recording injuries.

The two hydration studies (conducted in warm and cool conditions) have shown that changes to pre and post training body mass (using weigh scales), assessing pre-training hydration status (using a refractrometer, and reagent strips), and monitoring of the amount of fluids consumed during training (individualised drinks bottles) can help determine individual hydration requirements. The results of both studies indicated: a wide variation in sweat rates and fluid and electrolyte balance, evidence of pre and post dehydration, and that a single hydration strategy, based on published guidelines, is unlikely to be suitable for an entire team. Conducting regular testing during varying environmental conditions will help to establish a routine for fluid intake for all situations. Both studies provide support for an enlarged dedicated epidemiological research study to provide direct evidence linking dehydration to injury. However a study of this magnitude would require the full support of the Gaelic Football Association.

Publications

Research findings from this thesis have been published in the following journals:

Newell, Grant, Newell, MacFarlane (2008). Fluid and Electrolyte Balance in Elite Gaelic Football Players. Irish Medical Journal, 101 (8): 236-239.

Newell, Grant, Newell, MacFarlane (2008). Fluid and Electrolyte Balance in Elite Gaelic Football Players. Paper presented to Royal College of Surgeons in Ireland Conference in Sport and Exercise Medicine, Dublin. Winner of O'Flanagan Prize for best original Scientific Paper.

Newell, Grant, Henry, Newell (2006) Incidence of Injury in Elite Gaelic Footballers. Irish Medical Journal, 99(9): 269-271.

Newell, Grant, Henry, Newell (2004) Incidence of Injury in Elite Gaelic Footballers: Preliminary Findings. Paper presented to Royal College of Surgeons in Ireland Conference in Sport and Exercise Medicine, Dublin.

Newell, Grant, Henry, Newell (2004) Gaelic Football Injury Study. Paper presented at Association of Chartered Physiotherapists in Sports Medicine Conference, Derry, Ireland.

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Introduction

Gaelic Football is a high intensity contact field game. It is the most popular sport in Ireland with matches shown live on television and crowds in excess of 80,000 attending the All-Ireland Final. It is an indigenous sport that retains a strictly amateur status and ethos. Competition is restricted to 32 elite teams competing for two national awards. In comparison with other Football codes, Gaelic Football has not expanded worldwide.

It is a field game played by two teams normally for thirty-five minutes each side. Each team is composed of fifteen players, six defenders, six forwards, two midfielders and a goalkeeper. The pitch is similar to a rugby pitch; the length of the pitch is between 140-160 yards and between 84 and 100 yards wide with 'H' shaped goal posts at either end (Appendix 1).

Physiologically, Gaelic Football is comparable to Soccer, Rugby Union, and Australian Rules Football (Table 1.1). It is characterised by intermittent short dynamic body movements such as sprinting, sudden acceleration or deceleration, and turning (Keane *et al.*, 1993). The average age of elite (Inter County) Gaelic Football players is 24 years (McIntyre, 2005), with an average body mass of 79.9kg ± 8.2. The values for vertical jump performance of elite players range from 51.6cm ± 6.5 (Keane *et al.*, 1997). These values are similar to those published for professional Soccer players (41± 6cm), Australian Rules Football players (42.5± 8.8), and Rugby Union backs (55 ±5) (Table 1.1). According to McIntyre (2005) midfield Gaelic Football players had significantly greater vertical jumping ability than backs and forwards respectively. Estimates for maximal oxygen uptake ($\dot{V}O_2$ max) for elite Gaelic Football players range from 58.8 ± 3.8 ml·kg^{-1}·min^{-1} (Reilly and Doran, 1999). In general, the values for Gaelic Football players are similar to those published for professional Soccer players (63 ± 4.8 ml·kg^{-1}·min^{-1}), Australian Rules Players (57.8 ± 3.4 ml·kg^{-1}·min^{-1}) and Rugby Union backs (59.8 ± 16.9 ml·kg^{-1}·min^{-1}) (Table 1.1).

Table 1.1 *Physiological Profiles of Gaelic Football Players*

	Gaelic Football	Soccer	Australian Rules Football	Rugby Union (backs)
Height (m)	1.83 ±0.05 Reilly, 2000	1.81 ± 0.08 Henderson *et al.*, 2009	1.86 ±0.06 Pyne *et al.*, 2005	1.81±0.05 Brooks, 2005
Body Mass (kg)	79.9± 8.2 Reilly & Doran, 2001	75.8 ± 94, Henderson *et al.*, 2009	89.2 ± 11, Gabbett, 2002	89.5±6.7 Brooks, 2005
Vertical jump (cm)	51.6 ± 6.5 Keane *et al.*, 1997	41 ± 6 Henderson *et al.*, 2009	42.5 ± 8.8 Gabbett, 2002	55±5 Duthie *et al.*, 2003
Sprint 10m	1.89sec ± 0.17 Reilly and Doran, 2001	1.82 ± 0.3 seconds Wisloff *et al.*,2004	1.86± 0.06 (17) Young *et al.* 2005.	1.87+0.10 Walsh *et al.*, 2007
$\dot{V}O_2$ max ml·kg^{-1}·min^{-1}	58.8 ± 3.8 Reilly & Doran, 1999	63.0±4.8 Greig & Walker, 2007	57.8 ± 3.4 Pyne *et al.*, 2005	59.8 ± 16.9 Duthie *et al.*, 2003

Using heart rate as a measure of the physiological demand of Gaelic Football, Reilly and Keane (2001, cited in Reilly and Doran, 2001) reported that mean heart rates exceeded 160 beats·min^{-1} for 43% of match play and 26% of training (Table 1.2). Similar mean heart rates have been recorded for professional Soccer players (157 beats·min^{-1}), Australian Rules Players (164 beats·min^{-1}) and Rugby Union backs (161 beats·min^{-1}) (Table 1.2).

Table 1.2 *Physiological Demand of Gaelic Football Match Play*

	Gaelic Football	Soccer	Australian Rules Football	Rugby Union (backs)
Mean Heart Rates (beats·min^{-1})	160 Reilly & Keane, 2001	157 Niyazi., 2005	164 Wisbey *et al*., 2009	161 Cunniffe *et al*., 2009
Distance covered (m)	9131 Keane *et al*., 1993	11008 Small *et al*., 2009	11700 Wisbey *et al*., 2009	7227 Cunniffe *et al*., 2009
Main activity	walking & jogging Keane *et al*., 1993	walking & jogging Small *et al*., 2009	walking & jogging Wisbey *et al*., 2009	Walking & Jogging Doutreloux *et al*., 2002

Keane (1993) analysed the activity of elite Gaelic Football players during games, using time motion analysis, and reported that there were only minor differences between player positions and no significant difference between the amount of distance covered by players in the first and second halves of games. The total distance covered by an elite player was estimated at 8594±1056m. Walking and jogging accounted for two thirds of the total distance. Midfield players covered the greatest distance (9131±977m), followed by defenders (8523±1175m), and attackers (8490±673m), respectively. These values are comparable to the mean distances reported for Soccer players (11008m), Australian Rules Football players (11700m) and Rugby Union backs (7227m) (Table 1.2).

In recent years more dedicated scientific study has focussed on the anthropometrical characteristics, aerobic fitness assessment, explosive power, and physiological responses of players during training and games. Gaelic Football lacks a specific scientific analysis (Table 1.3), and many of the current training methods rely on scientific knowledge borrowed from other codes and adapted for Gaelic Football purposes (Reilly and Doran, 1999).

Table 1.3 *Search Results for Scientific Papers using Medline database*

Sport (Keyword search)	Number of Published Studies
Soccer	2572
Rugby League	156
Rugby Union	226
Australian Rules Football	104
Gaelic Football	21

An important application of sports science is to investigate the methodologies necessary to help athletes and coaches achieve excellence in sport. Knowledge used correctly can enhance the performance of players and the enjoyment for spectators; used incorrectly it has the potential to increase the risk of injury. If maximizing physical performance is the ultimate goal of Gaelic Football training, then ideally the aim of any training programme should be Gaelic Football specific, designed and delivered in a systematic and efficient manner to prepare the athletes for strenuous exertion with minimal risk of injury, while simultaneously allowing for health and recuperation requirements (Bangsbo, 2003; Reilly, 1996; Burke, 1977; Smith, 2003; Scriber, 1978). Furthermore, any attempts to enhance the performance of players through physiological intervention and changes to playing rules and equipment should be based on solid evidence. Sports epidemiology research is providing the scientific basis for developing specific intervention projects aimed at maximising performance and injury prevention. Van Mechelen's Injury Audit Cycle (1992) (Figure 1.1) has been used extensively in Australian Rules Football, Soccer, Rugby Union, and Rugby League.

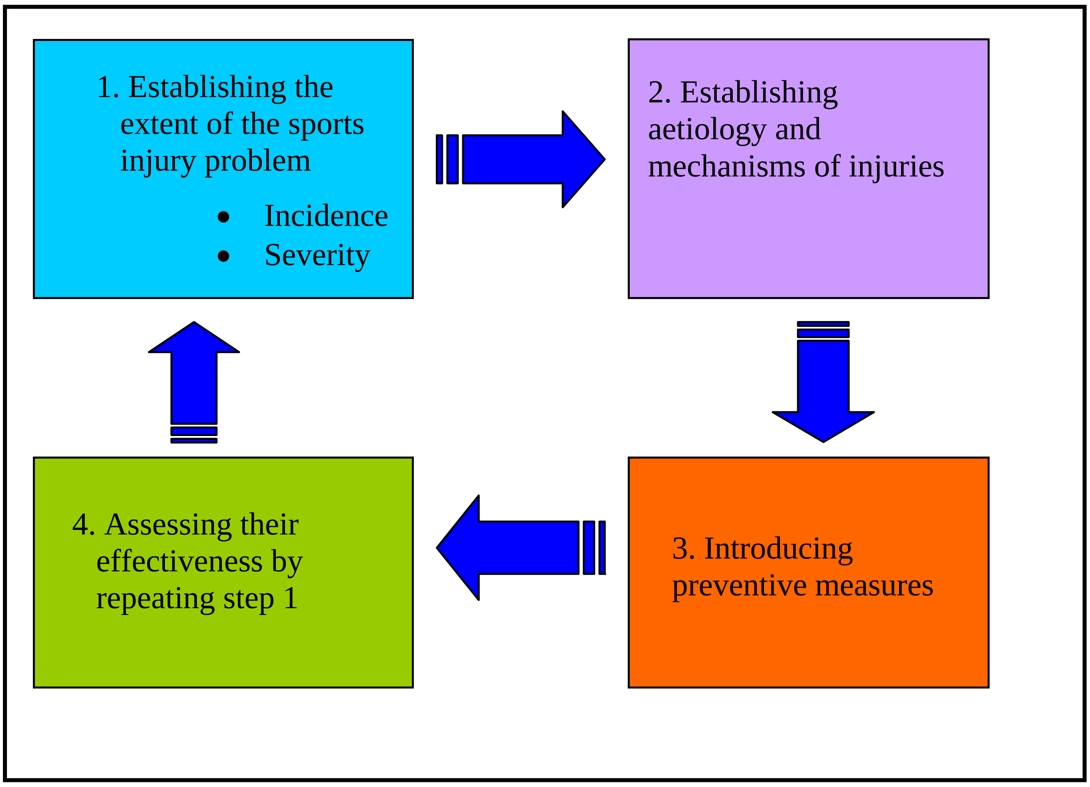


Figure 1.1 The 'sequence of prevention' of sport injuries (Van Mechelen *et al.*, 1992)

The injury surveillance data generated by this model and the specific knowledge of incidence, nature, aetiology, and severity of injuries have provided the bases for enhanced training techniques, maximising performance, injury prevention, and player welfare (Ekstrand *et al.,* 1983; Seward *et al.,* 1993; Arnason *et al.,* 1996; Caraffa *et al.,* 1996; Hawkins and Fuller, 1999; Hewett *et al.,* 1999; Heidt *et al.,* 2000; Orchard and Seward 2002; Mandelbraum, 2003; Brooks *et al.,* 2006). FIFA for example, have recently released a new best-practice guide to warm-ups for Soccer (FIFA 11+). This document and video contains a series of dynamic movements aimed specifically at helping to reduce the incidence of injury in Soccer. The guide is based on results from research investigating the incidence of injury in professional Soccer.

While it is accepted that the physical and contact nature of the field-based games inevitably lead to a degree of risk which will be associated with a certain number of unavoidable injuries, injury surveillance studies have raised concerns about the increasing incidence of injury and the associated medical and financial costs (Seward *et al.,* 1993; Orchard *et al.,* 1997; Bennell *et al.,* 1998; Cromwell *et al.,* (2000); Hawkins *et al.,* 2001; Verrall *et al.,* 2001; Arnason *et al.,* 2004; Woods 2004; Seward *et al.,* 1993; Brooks *et al.,* 2005). Injury prevention has become a major public health issue.

According to best practice models, in order to achieve reliable and comparable injury surveillance data, a detailed comprehensive prospective epidemiological study of injuries sustained over one season is required. Since the early 1990’s most of the studies on the incidence of injuries in Soccer have been designed prospectively. In their paper on the influence of definition and data collection on the incidence of injuries in Soccer, Junge and Dovarak (2001) recommend that the incidence of Football injury be studied for an entire year including the pre-season training and that the timing (pre-season or competition period) and circumstance (game, training) of the injury be documented. From the perspective of injury prevention, it is particularly important to know the body part injured, the nature of the injury and a measure of injury severity. Furthermore, individual exposure to injury must be recorded. Only by calculating the injury incidence per player per hour of participation can true comparisons of the risk of injury for different sports be established (Van Mechelen *et al.*, 1997, Orchard, 2002).

To date there has been no prospective epidemiological study of injuries in Gaelic Football. Previous efforts to conduct similar research have used retrospective studies that relied on subjects to recall their injuries. Subject numbers were low, and in most cases the incidence rate of injury could not be determined, making it difficult to compare data with other sports codes (McGrath and Watson, 1998; Cromwell *et al*., 2000). For a game that is considered to be the most popular sport in Ireland, the lack of data on injury incidence, nature, and severity of injury in Gaelic Football and the resulting risks and cost of participation, are serious omissions which should be addressed.

Attempts to implement dedicated evidence-based sports science research in Gaelic Football are challenging. Current structures within Gaelic Football render the sport less conducive to research analysis. The small number of published research studies is a reflection of this. By and large this is due to a combination of factors: firstly, a limited number of elite teams contesting for honours, a lack of international competition, the playing season is short (January to September, and even less for non-successful teams). In addition squads must comply with an enforced off-season break during the months of November and December. During this period elite teams are not allowed to train collectively. The off-season break was introduced to help prevent ‘burn out’. It was considered that multiple commitments to club, college, and elite teams significantly increased the risk of injury. Also it is difficult for a researcher to gain access to players. Participation in scientific research largely depends on the cooperation of individual team managers and medical staff. There are no national directives on the matter issued by the governing body, as is common in other field sports. The tenet that all Gaelic Footballers “are born not made” still has its adherents in today’s management circles. Atavistic attitudes to sport scientific experimentation persist.

Conducting experimental studies presents an even greater challenge, as some managers show a reluctance to allow their players act as a control group for intervention studies. Time allocated to data collection is considered to impinge adversely on tight training schedules. To date, published research focuses mainly on elite players (often to facilitate comparisons with players participating in other sports codes at their highest levels), the number of subjects tends to be quite low, and suggested recommendations may not be appropriate for club level (recreational) players, the vast majority of the Gaelic Football playing population.

This doctorate dissertation seeks to address important issues that have the potential to maximise performance in Gaelic Football. In keeping with the spirit of Van Mechelen's Injury Audit Cycle (1992) (Figure 1.0) concerning an integrated approach to injury prevention, the aims of this thesis were as follows:

- To conduct a comprehensive prospective epidemiological study of the injuries sustained in Gaelic Football over an entire season.

- To follow up the initial injury surveillance study with an exploration of the aetiology and mechanism of the most frequently occurring injury.

- To investigate the fluid and electrolyte balance of elite and recreational club Gaelic Football players.

The underlying theme of this thesis is to understand the prevalence and aetiology of injury, and the provision of researched suggestions designed to enhance performance. The results will be of benefit to coaches, players, and officials at all levels of Gaelic Football. The aims are to rectify gaps identified in the literature review and to provide evidence-based scientific information for current and future practice.

Because of the cited difficulties of conducting scientific inquiry in Gaelic Football, namely the restricted access to players and the associated time constraints, it proved impossible to complete all phases of Van Mechelen's

Injury Audit Cycle (1992). The focus therefore is not on a single coherent theme but rather on four original and innovative field-based studies specific to Gaelic Football. These are presented in separate chapters and each chapter includes the relevant literature review. Two of the research studies have already being published in medical journals; in addition one of the studies was awarded a prize for best original presentation at Royal College of Surgeon's in Ireland Sports and Exercise Medicine Conference.

Chapter 1

Study 1:

Profile of Injuries in

Elite Gaelic Football Players

1.1 Introduction

Successful Gaelic Football performance depends on the ability to perform repetitive intermittent high-intensity exercise and to display excellent cognitive function for decision making as well as proper execution of complex skills. Although a team may be uniform, it is important to stress that there are marked differences between individual players with regard to performance. Differences in strength and speed may be obvious, differences in physiological functioning requirements maybe more subtle. Gaelic Football players are prone to injury as the game requires intermittent short and quick movements such as sprinting, sudden acceleration or deceleration, and turning. In addition the physical and contact nature of the game inevitably leads to a degree of risk which will also be associated with a certain number of unavoidable injuries. Failing to allow for physiological adaptation and recognising individual response to training can have negative effects on endurance performance, cognitive functioning, and an increased the risk of injury (Kvist, 1994).

Sports epidemiology research is providing the scientific evidence for developing specific intervention projects aimed at maximising performance and injury prevention particularly in Australian Rules Football, Soccer, Rugby Union, and Rugby League (Ekstrand *et al.,* 1983; Seward *et al.,* 1993; Arnason *et al.,* 1996; Caraffa *et al.,* 1996; Hawkins and Fuller, 1999; Hewett *et al.,* 1999; Heidt *et al.,* 2000; Orchard and Seward 2002; Mandelbraum, 2003; Brooks *et al.,* 2006). To date there has been no epidemiological study of injuries in Gaelic Football. Previous efforts to conduct similar research have used retrospective studies that relied on subjects to recall their injuries. Subject numbers were low, and in most cases the incidence rate of injury could not be determined, making it difficult to compare data with other sports codes (McGrath and Watson, 1998; Cromwell *et al*., 2000; Wilson *et al.*, 2007). The lack of evidence based data on incidence of severity of injury makes it difficult to identify the underlying aetiology of injury and effective preventive methods, and rehabilitation is more challenging (Worrell, 1994, Mason *et al.*, 2007). For a game that is considered to be the most popular sport in Ireland, with matches shown live on television, and crowds in excess of 80,000 people at the All-Ireland Final, the lack of data on injury incidence, nature, and severity of injury in Gaelic Football and the resulting risks and cost of participation, are serious omissions which need to be addressed.

According to best practice models, in order to achieve reliable and comparable injury surveillance data, a detailed comprehensive prospective epidemiological study of injuries sustained over one season is required. The aim therefore of this study was to undertake a comprehensive epidemiological study of the injuries sustained by Elite Gaelic Footballers over an entire season (January 2004-Sept 2004). The results will establish a platform for further studies, particularly with regard to intervention as an aid to injury prevention, as well as assisting in the strategic planning of many different aspects of Gaelic Football.

1.2 Literature Review

1.21 Injury Epidemiology and Injury Surveillance

Epidemiology comes from the Greek terms: epi (upon), demos (people) and logos (study). It is the study of what is upon, or befalls a people or population. It is recognised all over Europe and elsewhere of the importance of detailed injury reports as an aid to injury prevention (Bird *et al.*, 1998). As stated by Walter *et al.,* (1985):

> *Unless sports and athletic associations are prepared to implement epidemiological studies, the factors that could eliminate or reduce both the numbers and severity of injuries received by sports participants will remain undefined. A detailed prospective study is the first step in approaching injury prevention.*

The establishment of a flow chart to provide guidance on the various steps to help reduce injury is deemed to be of help. Van Mechelen (1992) has produced such a chart which is of help to the researcher in the specific sport in question. According to the sequence of prevention chart (Figure 1.1), also known as an audit cycle for conducting injury surveillance, the first step is to establish the incidence and severity of injury.

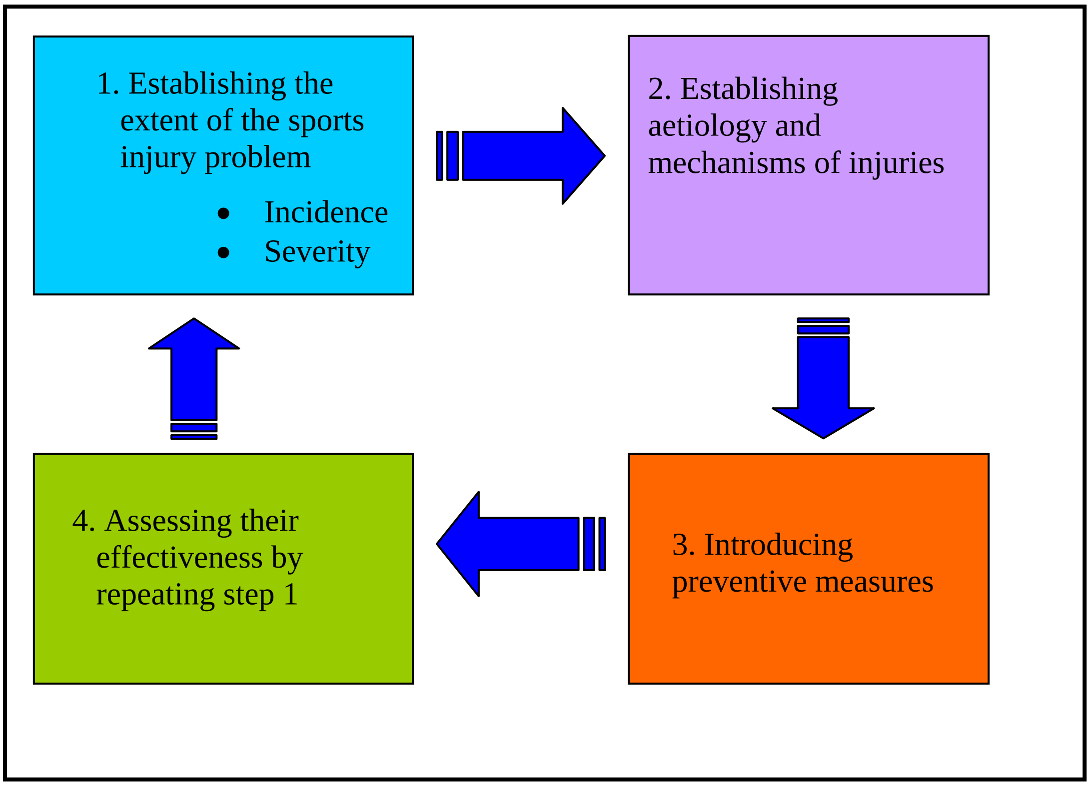


Figure 1.1 The ‘sequence of prevention’ of sport injuries (Van Mechelen *et al.*, 1992)

1.22 Incidence of injury

The incidence of injury, also known as the injury rate, is the number of new injuries in a specific period divided by the total number of players exposed to injury (the population at risk). Thus the risk per player per year is equal to the number of new injuries during one year among the total population at risk (Van Mechelen, 1992, Dvorak and Junge, 2000). This definition of injury rate implies that every player is equally exposed to injury; however this is not the case as the risk of injury may vary according to, the position played, the actual rather than the average amount of time played, the nature and intensity of activity during training or games (Inklaar, 1994).

The incidence rate is a measure of the rate at which new injuries occur during a specified time in a defined population (Figure 1.2).

Incidence rate:

$$\frac{\text{The number of new events during a specified time period}}{\text{The number of the population at risk}} \times K$$

Figure 1.2 Calculation of Incidence rate (the ratio is transformed to a common metric by multiplying by a convenient multiple of 10 (usually 1000) represented by the constant K in the above equation)

Incidence of injury or injury rates have been expressed in a variety of ways across the sports science literature. Early studies on injuries in high school American Football reported injury rates as a percentage of the total number of injuries recorded, or as the number of injuries per 100 players (Mueller *et al.*, 1996). For example, a study of high school American Football found that 62% of recorded injuries occurred in training and only 38% in games. Comparisons were made based on these percentages of injuries and concluded that players were at a greater risk of injury while training than rather than in games. It would be expected that a greater number of injuries occur in training as teams tend to have six times more training sessions than games and participatory rates are usually higher in training sessions than in games. However it is important to note that using a percentage breakdown of total injuries is not a rate and therefore has no relation to estimating risk.

Studies investigating injury at collegiate level American Football reported their results as injuries per 1000 athlete exposures (A-E's). An A-E occurs each time a player takes part in a practice or game, thus being exposed to injury. This expression of injury rate gives a more accurate picture of injuries compared to studies that recorded injuries in terms of the number of injuries per 100 athletes. Table 1.4 shows the different injury rates for various collegiate sports in America using three different reporting systems:

- The National Athletic Injury/Illness Reporting System (NAIRS)
- The NCAA Injury Surveillance System (ISS)
- The Athletic Injury Monitoring System (AIMS)

Of these, the NCAA is the most widely used injury reporting form in America. These data collection systems are basically similar in format. They use the same definition of a reportable injury, data are provided by on-site athletic trainers and injury rates reported as cases per 1000 athlete-exposures. Consequently it is possible to summarise and compare the results from these injury collection systems.

Table 1.4 *Injury rates for various sports from three national data collection systems (McKeag et al., 1994)*

	Injury rate/1000 Athlete-exposures		
Sport	**NAIRS**	**ISS**	**AIMS**
Basketball	7.0	5.0	
Field Hockey	5.4	4.9	
American Football	10.1	6.6	6.6
Ice Hockey	9.1	5.7	
Soccer	9.8	7.7	

Examination of Table 1.4 shows that American Football and Soccer have the highest reported injury rates. Secondly the inherently violet nature of American Football and the physically demanding aspects of both games coupled with the speed, strength and size of the players combine to make American Football and Soccer high risk sports (Mueller *et al.*, 1996). The older NAIRS system reported an injury rate of 10.1 (per 1000 athlete exposures) for American Football, more recent studies by the ISS and Aims have calculated the injury rate at 6.6. The calculation of athletic exposures was based on the sum of training and game exposures, rather than calculating them separately. Results for injury rates based on game and training exposures when calculated separately for different American college sports NCAA study (1990) is shown below (Table 1.5). The relative risk of injury was calculated by dividing the rate of injury in games by the rate of injury in training.

Table 1.5 *Injury rates in Training and Games in US College Sports (McKeag et al., 1996)*

	Injury rate/1000 Athlete-exposures		
Sport	**Training**	**Games**	**Relative Risk (Games / Training)**
Basketball	4.1	8.9	2.2
Field hockey	3.8	8.4	2.2
American Football	4.1	35.6	8.7
Ice Hockey	2.5	16.2	6.5
Soccer	4.5	19.2	4.3

The injury rate for American Football in this instance is 4.1 per 1000 Athletic-Exposures (A-E's) in training and 35.6 per 1000 A-E's in games. The relative risk of injury in games compared to training is 8.7 (calculated by dividing the competition rate by the practice rate). This indicates that an individual player is 8.7 times as likely to be injured in a game than in a training session, even though the data show that the majority (57%) of the injuries occur in training (as normally a team has five or six times more training sessions than matches and usually more players participate in training than in matches). Similarly in Soccer, the game injury rate is 4.3 times higher than the training rate.

Again unfortunately, this definition of injury rate implies that every player is equally exposed to injury, however this is not the case as the risk of injury may vary according to, the position played, the actual rather than the average amount of time played, the nature and intensity of activity during training or games (Inklaar, 1994). Also this estimation of injury rate does not take into account the varying number of games and practices across teams thereby making it difficult to compare injury rates.

The incidence of injury can be calculated more precisely if the actual amount of time spent in training or games of is considered. The risk of injury (the probability that an individual will be injured) per exposure is defined as the number of new injuries divided by the time all players spent in games and training sessions (Lindenfeld *et al.,* 1988). Incidence is expressed by many researchers as the number of injuries per 1000 hours of sports participation (exposure). Thus the risk of injury per 1000 hours of games is calculated as follows (Figure 1.3):

$$\frac{\text{The number of injuries in games}}{\text{The total hours in games}} \times 1000$$

Similarly the risk of injury per 1000 hours of training is calculated as:

$$\frac{\text{The number of injuries in training}}{\text{The total hours in training}} \times 1000$$

Figure 1.3 Calculation of risk of injury per 1000 hours training and games

Studies in Soccer have documented the individual amount of training and games for each individual player (Arnason *et al.,* 1996, Engstrom *et al.,* 1990, Peterson *et al.,* 2000), while in other Soccer studies the exposure time has been estimated by multiplying the number of players by the hours of participation per week and the weeks per season (Hawkins and Fuller 1999, Inklaar, 1999). As a result, exposure time is overestimated and the real incidence of injury is underestimated.

As Junge and Dvorak (2001) indicated, studies that do not differentiate between training and games, may not yield a true incidence rate of injury as more time is spent in training than in games and thus injuries incurred during training will increase the incidence per game hour. Furthermore such incidence rates cannot be compared with those recorded during a tournament. If activity and exposure time are not examined, the true risk of an injury cannot be determined.

Only by calculating the injury incidence per player per hour of participation, can comparison of the risk of injury for different sports be made (Van Mechelen *et al.,* 1997, Orchard 2002). De Loes (1995) reported the relative incidence of injury for a number of different sports in Switzerland based on exposure time and the number of injuries (relative risk was calculated by dividing the total number of injuries by the total hours of exposure for each sport). The study involved 350,000 youths participating annually in sport. Ice hockey, handball, and Soccer had the highest injury rates and gymnastics the lowest rates of injury (Table 1.6).

Table 1.6 *The relative incidence of injury for different sports* (de Loes, 1995)

Sport	No. of Injuries	% of injuries	No. of participants	Hours of Exposure	Incidence Rates (No of injuries/ Hours of Exposure)
Ice hockey	1570	21.1	29,911	1,824,535	8.6
Handball	1052	8.1	30,876	1,452,907	7.2
Soccer	7264	55.8	192,690	10,973,085	6.6
Wrestling	105	0.8	4,927	167,085	6.3
Hiking	821	6.3	76,149	2,308,797	3.6
Basketball	243	1.9	15,094	693,952	3.5
Volleyball	152	1.2	13,739	500,631	3.0
Alpine skiing	502	3.9	58, 960	1,667,207	3.0
Alpinism	126	1.0	21,398	434,133	2.9
Judo	102	0.8	17,837	442,361	2.3
Fitness training	296	2.3	57,068	1,726,600	1.7
Athletics	268	2.1	43,448	1,646,962	1.6
Gymnastics	90	0.7	12,441	602,524	1.5
Other sports	425	3.3	114,836	3,986,578	1.1
Total	13016	100.3	689,374	28,427,357	4.6

1.23 Severity of Injury

Injury severity is defined according to the length of incapacity. It is usually calculated as time lost from training and games participation through injury. Normally it is classified in three categories, although some studies use four categories (Table 1.7).

Table 1.7 *Classifications of Injury Severity*

Injury Classification	**Author**
Minor (1-7 days) Moderately serious (8-21 days) Serious (over 21 days lost or permanent damage)	Schlatmann *et al.*, 1986
Minor (no further treatment required) Moderate (some further treatment required) Serious (referral to hospital)	Finch, 1997
Minor (if able to return to game/training in which injury occurred) Mild (if missed one week) Moderate (if missed two weeks) Severe (if missed more than two weeks)	McManus, 2000
Minor (absence from sport < 1 week) Moderate (absence from sport 1-3 weeks) Severe (absence from sport > 4 weeks)	Sandelin *et al.*, 1985
Nature of injury, Duration and nature of treatment Sports time lost Working time lost Permanent damage Costs of sporting injury	Van Mechelen, 1997

However before any injury recordings can take place, it is important to have a clearly defined and workable definition of injury.

1.24 Definition of Injury

The extent to which sports injuries can be assessed accurately depends on the definition of the sport injury and the method used to record injuries (Junge and Dvorak, 2001; Inklaar, 1994). For all the sports injury studies detailed in the scientific literature there are as many definitions for injury. Currently, there is no universally accepted or uniform definition of a sports injury (Finch, 1997). Most definitions have recommended that some time loss from training and/or games as a result of injury is necessary for an incident to be counted as an injury (Table 1.8).

In the most recently published studies in Soccer, a player was defined as injured if he or she was unable to participate in the next or at least one training session or game (Arnason *et al.*, 1996; Hawkins and Fuller, 1999). However this definition as pointed out by Junge and Dvorak (2000), has some limitations. First, its application depends on the frequency of training and games. An injured player might participate in the training sessions but his performance might be handicapped or his exercise programme might be modified. Secondly, players who train only twice a week have a greater chance of recovering before the next training session than players who train every day.

Not all definitions of injury record all examples of injury. For example, injuries often occur that can be considered mild and players may be in a position to return immediately to training and games after seeking medical treatment. Consequently injury definitions have a very strong influence on the injury incidence reported by studies. When it comes to describing injuries, it is important to provide a distinction between traumas and overuse injury. Van Mechelen (1992) suggested that an injury be defined as acute, if it is caused by a single incident of macro trauma and as overuse, if it is a consequence of repetitive micro traumas.

Table 1.8 *Definitions of Injury*

Injury Definition	**Sport**	**Author(s)**
Any physical or medical condition that prevents a player from participating in a regular season match.	Australian Rules Football	Orchard *et al.*, 2002
An injury was defined as an incident occurring during scheduled games or practices and causing the player to miss the next game or practice session.	Rugby Union and Soccer	Bathgate *et al.*, 2002, Soderman *et al.*,2001, Ekstrand and Gillquist, 1983
The reportable injury is one that limits athletic participation for at least the day after the day of onset.	All Sports	National Athletic Injury Registration System (NAIRS) in the USA.
Any injury which caused a player to miss playing time during a match or be unable to be selected in a match or participate in a training session.	Australian Rules Football	Orchard, 1993
Any sudden trauma occurring during practice or games that led to examination and treatment by a physician.	Soccer	Jouka *et al.*, 2001
Any incident that required the player to miss at least one game or scheduled team practice, or to seek medical attention.	Rugby Union	Quarrie *et al.*, 2001
An injury occurring in scheduled games or training sessions causing the player to interrupt the game or training and to contact the physiotherapist/doctor.	Soccer	Luthje *et al.*, 1996
A rugby injury was defined as an injury sustained on the field during a competitive match, during a practice match, or during other training activity directly associated with rugby Football, which prevented the player from training or playing rugby from the time of the injury or from the end of the match or practice in which the injury was sustained.	Rugby Union	Garraway and Macleod, 1995
One sustained during training or competition resulting in restricted performance or time lost from play.	Gaelic Football	Cromwell *et al.*, 2000
A player was defined as injured if he was unable to participate in a match or training session because of an injury incurred in Soccer. The player was defined as injured until he was able to comply fully with all instructions given by the coach.	Soccer	Arnason *et al.*, 1996
Any injury as a result of participation in sport with one or more of the following consequences: A reduction in the amount or level of activity A need for (medical) advice or treatment Adverse social or economic effects	All Sports	Council of Europe, 1989

1.25 Injury Studies in Sports

Most team sports have been examined in the scientific literature at some point in time with regard to estimating the number of injuries occurring. It is often a case of do we look back, i.e. a retrospective study, or do we look forward, i.e. a prospective study? Retrospective studies usually employ some form of questionnaire and ask subjects to recall injuries that occurred over a particular period.

Other field games similar to Gaelic Football have conducted injury surveys. The Australian Football League conducted its first comprehensive study in 1983 and has conducted a continuous injury survey since 1992 with the injury rates published annually (Orchard and Seward 2002; Seward *et al.*, 1993). The NFL in America has conducted an official inquiry survey for over twenty years. Injury rates have been recorded for Rugby Union, (Bathgate *et al.*, 2002; Bird *et al.*, 1998; Garraway and Macleod 1995; Hughes and Fricker 1994; Quarrie *et al.*, 2001) as well as Rugby League (Gabbett, 2000).

With the growth in popularity of Soccer throughout the world, Soccer injuries have become the object of increasing medical interest. The most recent publication was a comprehensive audit of injuries by the Football Association in England (Hawkins *et al.*, 2001). Player injuries were annotated by club medical staff at 91 professional Soccer clubs. The study was rolled out to all clubs following a preliminary study involving four professional clubs (Hawkins and Fuller, 1999). The template for the injury surveillance study has subsequently been applied to English youth Football academies (Price *et al*., 2004). Studies investigating the aetiology of injuries, particularly hamstrings injuries have been commissioned as a direct result of findings from the injury surveillance studies. While numerous epidemiological studies on injuries in elite and recreational level Soccer have been conducted (Table 1.9), comparison of these studies is problematic because of differences in population size and demographics, levels of play, and the definition of reporting of injuries.

Nevertheless some general trends regarding injury patterns in male adult Soccer can be observed. The incidence rates for injury in training, ranges from 1.5 to 7.6 while that recorded for games ranges from 13 to 35.5. In the majority of these studies the incidence has been calculated for 1000 hours of games as well as 1000 hours of training. The values for youth Soccer players (Table 1.10) range from 3.6 to 4.1 per 1000 hours training, and between 14.4 and 37.8 per 1000 hours in games.

Table 1.9 *Epidemiological Studies on the Incidence of Injury in Male Soccer Players (from Soccer Injuries, A Review on Incidence and Prevention, Dvorak and Junge, 2000)*

No. of Players	Level	Age	Study Period	Injuries per 1000 hours			Authors
				Games	Training	G&T*	
306	Elite	16-38	1 season	24.6		2.1	Arnason *et al.*,2004
1 team	Elite		1991-97	30.3		6.5	Ekstrand *et al* .,2004
310	Elite	17-38	1 season	25.9		5.2	Hägglund *et al.*, 2001
237	Elite	18-38	1 season	35.5		2.9	Morgan and Oberlander, 2001
21	Elite	>18	1 year	18.9			Peterson *et al.*, 2000
17	Amateur	>18	1 year	21.6			
108	Elite		3 seasons	25.9		3.4	Hawkins and Fuller, 1999
84	Elite	18-34	1 season	34.8		5.9	Arnason *et al.*, 1996
101	High level	19-60	1 season	21.7			Inklaar *et al.*, 1996
144	Low level	19-60	1 season	11.7			
263	Elite	17-35	1 season	16.6		1.5	Luthje *et al.*, 1996
19	Elite	21-28	1 year	19.8		4.1	Poulsen *et al.*, 19991
	Low level	24-30	1 year	20.7		5.7	
64	Elite	24 (mean)	1 season	13		3	Engstrom *et al.*, 1990
135	Elite	17-38	1 season	21.8		4.6	Ekstrand and Tropp, 1990
144	Low level		1980	14.6		7.5	Ekstrand *et al.*, 1983,
34	High level	>18	1 season	18.5		2.3	Neilsen and Yde, 1989
59	Low level	>18	1 season	11.9		5.6	

*Note: G & T = Games and Training

Table 1.10 *Epidemiological Studies on the Incidence of Injury in Male Youth/Adolescent Soccer Players (from Soccer Injuries, A Review on Incidence and Prevention, Dvorak and Junge, 2000)*

No. of Players	Level	Age	Study Period	Injuries per 1000 hours Games	Training	G&T*	Authors
145	Schoolboy	14-18	1 season	16.2	3.7		Junge *et al.*, 2004
46	Academy	14-19	1 season	18.7	4.1		
70	Academy	14-16	1 year	15.8			Petersen *et al.*, 2000,
23	Low level	14-16	1 year	37.8			
75	Adolescent	13-14	6 months	12.8			Inklaar *et al.*,1996
78	Adolescent	15-16	6 months	16.1			
79	Adolescent	17-18	6 months	28.3			
496	Schoolboy	12-18	1 Year			3.7	Schmidt-Olsen *et al.*,1991
152	Adolescent	6-18	1 season			5.6	Yde and Nielson, 1990
30	Youth	16-18	1 season	14.4	3.6		Nielson and Yde,1989

*Note: G & T = Games and Training

1.26 Injury Studies in Gaelic Football

Inadequate attention has been given to injury prevention in Gaelic Football (Reilly and Doran, 2001). Despite the popularity of Gaelic Football and high participatory rates in Ireland, to date there have been very few studies on injuries. Some of these studies have been individual case studies (Table 1.11), others have compared injuries in Gaelic Football with similar codes and categories of sport (endurance, non-contact, or explosive sports), (Table 1.11a), some studies have grouped Gaelic Football injuries with the other main game of the Gaelic Athletic Association, Hurling (Table 1.11b), and reference has been made to Gaelic Football injuries in the incidence of sports related injuries reporting to hospital accident and emergency centres (Table 1.11c).

Previous injury data on Gaelic Football are from insurance, general practitioners, and hospital records (O' Sullivan and Curtin, 1989; Lynch and Rowan, 1997; Walsh, 2002) (Table 1.11c). These types of records tend to account for only serious injuries while overuse injuries usually tend to be recorded at a doctor's clinic (Junge and Davorak, 2001). Where possible, Gaelic Football injury studies will be described using the following criteria: methods used, level of players, timescale of study, injury classification used, findings, and conclusions.

Table 1.11 *Injury Studies in Gaelic Football*

Sports Classification	Injury Type	No of subjects	Level	Study period	Author
Gaelic Football	All	88	Elite	6 months	Cromwell *et al.*, 2000
Gaelic Football	Ankle	80	Elite & Recreational	4 years	Watson, 1999
Gaelic Football	All	150	Youths	7 months	Watson, 1996
Gaelic Football	All	87	Recreational		McGrath and Watson, 1998
Gaelic Football	Hamstrings		Elite & Recreational		Hennessy and Watson, 1993
Gaelic Football	All		Elite & Recreational	12 months	Mc Carthy, 1971

Table 1.11a *Sports Injury Studies including Gaelic Football*

Sports Classification	Injury Type	No of subjects	Level	Study period	Author
Contact sports	All		Elite & Recreational	1 year	Watson, 1993
Contact sports	All	86	Elite & Recreational	2 years	Watson, 2001

Table 1.11b *Sports Injury Studies in Gaelic Games (Gaelic Football and Hurling)*

Sports Classification	Injury Type	No of subjects	Level	Study period	Author
Gaelic Football and Hurling	Facial	332	All	1 year	Carroll *et al.*, 1995

Table 1.11c *Sports Injury Studies including Gaelic Football recorded at GP and Hospital Departments*

Sports Classification	Injury Type	No of subjects	Location	Study period	Author
All Sports	All		General Practice	1 year	Walsh, 2002
All Sports	Hand		A&E clinic	1 year	O'Sullivan and Curtin, 1989
All Sports	Eye		Eye casualty department	1 year	Lynch and Rowan, 1997

Watson (1993) investigated the incidence of sports injuries in Ireland over a twelve month period for different categories of sport, endurance, contact, non-contact, or explosive sports (Table 1.11a). The average athlete sustained 1.17 acute and 0.93 overuse injuries per year, and the incidence of acute injuries per 10,000 hours of participation was highest in the contact sports including Gaelic Football.

McGrath and Watson (1998) conducted a study involving eighty-seven Gaelic Football club players of different grades, elite players and club players, to investigate the incidence and risk of injury (Table 1.11). This retrospective study compiled over one season (January to August), defined injury as ‘a mishap occurring during, or as a result of, competition or training that resulted in incapacity to train or complete normally’. The mean incidence of injury was 51.5 injuries per 10,000 hours of participation. Although there was no significant difference between the two groups of players in the incidence of injury per 10,000 hours of participation or per 10,000 hours of training, club players (non-elite) had a significantly higher incidence of injury (185.2 ± 164.4 per 10,000 hours) in competitive matches than the elite players (114.5 ±137.5 per 10,000 hours). The mean risk of injury to players was 159.4 days per 10,000 hours of participation.

Watson (1999) linked the incidence of ankle sprains to the physical characteristics of players. Injuries sustained by eighty male elite and club Gaelic Footballers over a four-year period were recorded (Table 1.11). Subjects were physically examined by the author and participated in physical tests prior to the start of the study. The results of this prospective study found that subjects who sustained ankle sprains had a greater height, lower body mass index, a higher incidence of postural defects of the ankle and knee, and a higher incidence of defective lower-limb proprioception. McCarthy (1971) when analysing chronic injuries in Gaelic Football, deemed the knee, the ankle, and the acromioclavicular joint to be at most risk due to the inherent contact-nature of game. The author considered that few chronic disabilities result form Gaelic Football.

Hennessy and Watson (1993) investigated flexibility and posture assessment in relation to hamstrings injury (Table 1.11). They compared Gaelic Football players to hurling and Rugby Union players. They reported that spinal lordosis rather than inflexibility was observed predominantly in the group of players with a previous history of hamstrings injury. The authors recommended giving greater attention to the regular assessment of player's posture in games.

The most recent study of Gaelic Football injuries by Crowell *et al.,* (2000) employed a retrospective recording of injuries from a sample of one hundred and seven elite Gaelic Football players from six county teams in Ireland (Table 2.8). Their definition of injury was defined as 'one sustained during training or competition resulting in restricted performance or time lost from play'. This was also the definition of injury used by Watson *et al.,* (1996) when they investigated injuries to schoolboy Gaelic Footballers. In the study by Crowell *et al.,* (2000) the subjects were asked to complete questionnaires detailing injuries sustained during the previous six months (January to June). Players' physical characteristics and time spent training and participation in other sports were recorded. A total of 88 out of the 107 players sustained injuries during the study period. The most common injuries were soft tissue injuries, muscle 3%, ligament, 32%, and tendon 16%. Injuries to the ankle (20%), knee (13%), hamstrings (13%), and shoulder (12%) were the most common. Of the injuries recorded, 62% were sustained during games and 35% during training. The most common cause of injury was collisions and twist/turn. 46% of players continued to play despite sustaining an injury, however the vast majority of players (93%) who continued to play were restricted in their performance. Injury incidence was reported as 1.78 injuries per subject per calendar year, a figure similar (1.76) to that reported by Watson (1993).

In their study of Gaelic Football Injuries, Wilson et al., (2007) interviewed players each month to collect data on their injury experience. 61 club (recreational) players from seven individual teams participated in the study. A total of 90 injuries were recorded in the six month study period. Of the total injuries recorded, 71% were injuries to the lower limbs. The most common sites of injury were ankle (13%) hamstrings (12%) and quadriceps (12%) respectively. Tackling, being tackled by an opponent, sprinting, and turning were the principle mechanisms of injury. According to the authors the injury rate was 13.5/1000 hours exposure to Gaelic Football, while the relative risk of injury was nearly 9 times greater in games (51 per 1000 hours) than in training (5.8 per 1000 hours). Of the total number of injuries sustained in games, 57% were sustained in the second half and there was an increased risk of injury as the game progressed.

While the number of subjects in the study by Wilson et al., (2007) was also low, the prospective methods used to record data provides some useful information on injury rate and allows for comparison with injury data from other sports codes. However the authors did not include data on the injuries to compare and contrast injuries sustained in training to those sustained in matches respectively.

Overall their results indicated that the majority of injuries tend to be soft tissue injuries to the lower limbs with collision accounting for the most common cause. Their findings are similar to the results of injury studies of the popular professional sports similar such as Soccer, Rugby Union, American Football, and Australian Rules Football (Rahnama *et al.,* 2002; Hawkins *et al.,* 2001; Arnason *et al.,* 1996; Hughes and Fricker, 1994; Inklaar, 1994; Ekstrand *et al.*, 1983; Seward *et al.,* 1993).

Limitations of Previous Gaelic Football Injury Studies

Both Cromwell *et al.,*'s (2000) and McGrath and Watson's (1998) were retrospective studies that relied on subjects to recall their injuries. In the case of McGrath and Watson (1998) the players were personally interviewed at the end of the season. This type of study has obvious limitations. The reliability of retrospective studies assessments is limited by the effects of memory such as recall bias (Twellaar *et al.,* 1996) and inaccuracies in remembering exactly the amount of time spent participating in physical activity (Kuhn *et al.,* 1997). It is difficult to gain a valid assessment of an injury that relies solely on player recall. Also the definition used to define injury is subject to interpretation, as players may interpret the same injury in different ways. For example one player may take a bruise to the leg as part of the game, and not report the injury, whereas another player may consider this a significant injury. The numbers of subjects in both studies were low, and in the study by Cromwell *et al.,* (2000) the incidence rate of injury could not be determined, thereby making it difficult to compare data with other sports codes (Junge *et al.,* 2002; Van Mechelen *et al.,* 1992; Walter *et al.,* 1985).

1.27 Injury Audits and Surveillance

Since the early 1990's most of the studies on the incidence of injuries in Soccer have been designed prospectively. In their paper on the influence of definition and data collection on the incidence of injuries in Soccer, Junge and Dovarak (2001) recommend that the incidence of Football injury be studied for an entire year including the pre-season training and that the timing (pre-season or competition period) and circumstance (game, training, overuse) of the injury be documented. From the perspective of injury prevention, it is particularly important to know the body part injured, the nature of the injury and a measure of injury severity.

The recent injury audits conducted by the English Football Association are an example of good practice. Injuries were recorded prospectively in conjunction with individual player exposure time to injury in training and games. The injury reporting form was well constructed and although very detailed it was considered to be user friendly by participating physiotherapists. At the end of each month, clubs were required (according to a directive from the English FA) to submit the top copy of all completed forms (the bottom copy was retained by the club for their own records) to the study headquarters. The dual approach of prospectively recording injuries and exposure to injury simultaneously, facilitated a powerful epidemiological study of injury.

1.28 Intervention and Reduction in Incidence of Injury

Having established incidence and severity rates, studies in Soccer have shown that through intervention, the incidence of injury can be reduced (Table 1.12). A study by Ekstrand *et al.,* (1983) evaluated an injury prevention programme in male Soccer players. Six teams were selected for an injury intervention programme and the other six teams in the league acted as the control group. The devised programme for injury prevention under the direction of the team doctor and physiotherapist included the modification of training, strapping of joints where instability was a problem, the provision of special training shoes for winter training, shin guards, and controlled rehabilitation from injury. During a six month follow-up period, the players in the intervention group reported 75% fewer injuries than those in the control group.

A similar intervention study by Junge *et al.,* (2002) looked at injury incidences amongst male youth Soccer players. A specific prospective intervention and education programme for players and coaches was devised including appropriate warm-ups, the inclusion of exercises designed to improve knee and ankle joint stability, coordination, reaction time, and endurance, together with adequate rehabilitation and the promotion of fair play. Physiotherapists supervised the activities performed as well as assisting with the rehabilitation of injured players. Following a one-year study period, the authors reported that 21% fewer injuries were sustained by players who participated in the injury prevention programme.

Table 1.12 Studies on the prevention of injury in Soccer players (from Soccer Injuries, A review on Incidence and Prevention, Junge and Dvorak, 2004)

Study	Country	Intervention group	Control group	Sex	Age	Type of Injury	Intervention	Result
Ekstrand et al., 1983	Sweden	6 teams	6 teams	M	17-37	All time-loss injuries	Multi-model intervention programme	Fewer injuries in the intervention than in the control group
Heidt et al., 2000	USA	42 Players	258 players	F	14-18	All time-loss injuries	Frappier Acceleration Programme	Significantly lower incidence of injury in the trained than in the untrained group
Junge et al., 2002	Switzerland	101 players	93 players	M	14-19	All injuries	Multi-model intervention programme	Fewer injuries in the intervention than in the control group
Tropp et al., 1985	Sweden	60 players and 65 players with previous ankle problems	171 players	M	Senior	Ankle sprains	Use of orthosis or ankle disk training	Both techniques reduce the frequency of ankle sprains in players with previous history of ankle sprains
Surve et al., 1994	South Africa	117 players without and 127 players with previous ankle sprains	260 players	M	Senior	Ankle sprains	Instruction to wear a semi-rigid orthosis on the previously sprained ankle or on the dominant ankle	A semi-rigid orthosis significantly reduced the incidence of recurrent ankle sprains in players with previous history of ankle sprains
Söderman et al., 2000	Sweden	62 players	78 players	F	21	Traumatic time loss injuries of the lower extremities	Balance board training	No preventive effect on severe knee injuries or ankle sprains
Caraffa et al., 1991	Italy	40 teams	20 teams			ACL injuries	Proprioceptive training	Significant reduction of ACL injuries
Hewett et al., 1999	USA	97 players	193 players	F	High school age	Serious knee injuries	Pre-season neuromuscular training programme	A trend toeards a higher incidence in the untrained group than in the trained group
Askling et al., 2003	Sweden	15 players	15 players	M	25	Hamstring strains	Training with eccentric overload	Fewer injuries in the training than in the control group

Heidt *et al.*, 2000 investigated the effects of a seven week pre-season conditioning programme on the occurrence of injuries in 42 female high school Soccer players, randomly selected from a group of 300 players. The students participated in an intervention programme that included sport-specific cardiovascular conditioning, strength and flexibility exercises, and speed and agility training. During the one-year observation period, the untrained group had a significantly higher incidence of injury (34%) compared with the intervention group (14%).

Intervention studies that target specific injuries such as knee and ankle injuries have reported significantly lower incidence of ACL injuries in the intervention group compared to the control group (Caraffa *et al.*, 1996; Mandelbraum, 2003). Neuromuscular training programmes designed to increase muscular strength and decrease landing forces have reported a significantly lower incidence of serious knee injuries in intervention groups than in untrained groups (Hewett *et al.*, 1999). The use of semi-rigid orthosis can help reduce the incidence of ankle sprains especially in players with a history of previous ankle sprains (Surve *et al*., 1994, cited in Junge and Dvorak 2004).

It has been pointed out in the literature, the need for more scientific research into injuries associated with playing sports (Junge and Davorak 2001), and in particular Gaelic Football (Reilly and Doran 2001). To date there has been no epidemiological study of injuries in Gaelic Football. The few studies that have been conducted had inherent disadvantages including study design (studies were retrospective), data relied on players having to recollect their injuries, (recall bias), small number of subjects (80-107 players), and no involvement of team physiotherapists. For a game that is considered to be the most popular sport in Ireland, with matches shown live on television, and crowds in excess of 80,000 people at the All-Ireland Final, the lack of injury data in Gaelic Football and the resulting risks and cost of participation, are serious omissions which need to be addressed. For these reasons the aim of study 1 of this thesis was to undertake a comprehensive epidemiological study of the injuries sustained by Elite Gaelic Footballers over an entire season. The injury surveillance form would collect information about:

- The characteristics of the injured person
- The type of Gaelic Football activity at the time of injury
- The time of the injury
- The playing surface
- The playing/training surface conditions
- Equipment used when injury sustained
- The body region injured
- The nature of the injury
- The cause or mechanism of injury
- The particular activity initiating the injury
- The severity of the injury

The results will establish a platform for further studies particularly with regard to intervention as aid to injury prevention, as well as assisting in the strategic planning of many different aspects of Gaelic Football including:

- Insight into the causes and mechanisms of injury by identifying possible risk factors
- Identification and monitoring of priority areas for injury prevention
- Quantification of the risks of various types, frequencies, and intensities of Gaelic Football activities
- Evaluation of policy with regard to injury prevention and rehabilitation protocols
- Improvements to equipment and education and training programmes
- The development of specific trends, the rationale for rule changes
- Determine the effectiveness of preventive measures (on a local or national scale) whether they are rule changes, new or modified equipment, or modifications of training techniques
- Provide an overview of long-term injury trends in Gaelic Football

1.3 Methods

Ethics approval for the study was obtained from the ethics committees of Glasgow University, the National University of Ireland, Galway, and the Irish College of General Practitioners.

1.30 Pilot Study

A pilot study was conducted during the months of June and July 2003, prior to the commencement of the main study the following January (2004). The purpose of the pilot study was to test the feasibility and logistical aspects of the proposed main study in particular the submission of detailed injury surveillance data and player activity data (participation rates in training and games). The success of the main study depended on the active participation and cooperation of team physiotherapists.

Three physiotherapists attached to elite Gaelic Football teams based in the north of Ireland, the south of Ireland, and the west of Ireland were approached to participate in the pilot study. These particular teams were chosen as they were amongst the favourites to win the All-Ireland Championship that year and consequently there was a strong probability that they would be playing Gaelic Football during the months of June and July and potentially right through to the end of September. It later transpired that two of the three teams selected contested the All-Ireland Final that year.

A study pack was sent out to the three participating physiotherapists following the initial meeting. The study pack consisted of a book of Injury Report forms specifically designed for Gaelic Football, a corresponding book of Activity Schedule forms, together with a detailed instructions and pre-paid envelopes. Also included were information sheets for players (Appendix 3) and a feedback questionnaire (Appendix 4).

Completed Injury Report Forms and Weekly Activity Schedules were received from all three participating teams for the duration of the pilot study (June and July inclusive). The Activity Report Form although concise proved to be time consuming when coupled with completing the Injury Report Form. It was recommended to allocate the Activity Report form to a member of the management team as he would be in attendance at all of the team's activity (training and games).

1.31 Study Design

Following a review of the pilot study, two meetings were arranged with senior members of the Gaelic Athletic Association's Medical and Players Welfare Committee. This committee is largely made up of medical professionals many of whom are ex Gaelic Football players. At each meeting the members were given a detailed presentation of the proposed Injury Study. The purpose of the meetings was two fold, firstly to gauge the opinion of the members and to seek an endorsement for the study; and secondly to receive a letter of recommendation from the committee requesting all (32) elite Gaelic Football teams in Ireland to participate in the study. The project was duly endorsed together with financial support of five thousand euros for three years.

Separate meetings were also held with the provincial secretaries of the Gaelic Athletic Association requesting their assistance with the collection and forwarding of completed Player Activity Report Forms. It was considered that if each provincial secretary was aware of the project he might encourage the teams from their province to participate. Secondly, in order to reduce the risk of data being lost in the post (particularly as each team could be submitting up to thirty nine weekly envelopes), it was considered beneficial to the workings of the project if completed weekly Activity Report Forms were submitted to one central provincial location and then subsequently dispatched en masse at the end of each month to the project leader. By using this process, the secretary could monitor the return of completed report forms (each team were assigned their own unique study code envelopes) and contact the project leader and relevant teams directly if forms were not forth coming.

The managers, physiotherapists, and members of the management team of each of the thirty two elite Gaelic Football teams were contacted and informed about the project and requested to participate. The first contact was via a letter and this was followed up with a meeting and a telephone call. A flow chart for the procedures involved in setting up the study is shown in Figure 1.4. The workings of the project were explained and all parties were given detailed instructions on how to complete the relevant forms. Samples of completed forms were distributed together with the contact details for the project leader.

Similar meetings were also held with the physiotherapists working with each team. Meetings took place on an individual basis throughout Ireland. As ultimately the success of the study relied on the active and voluntary participation of the team's physiotherapists, the majority of whom were self-employed with limited free time between running their own clinics and their involvement with Gaelic Football teams, a monthly prize draw was scheduled as an incentive for physiotherapists to submit completed Injury Report Forms as requested.

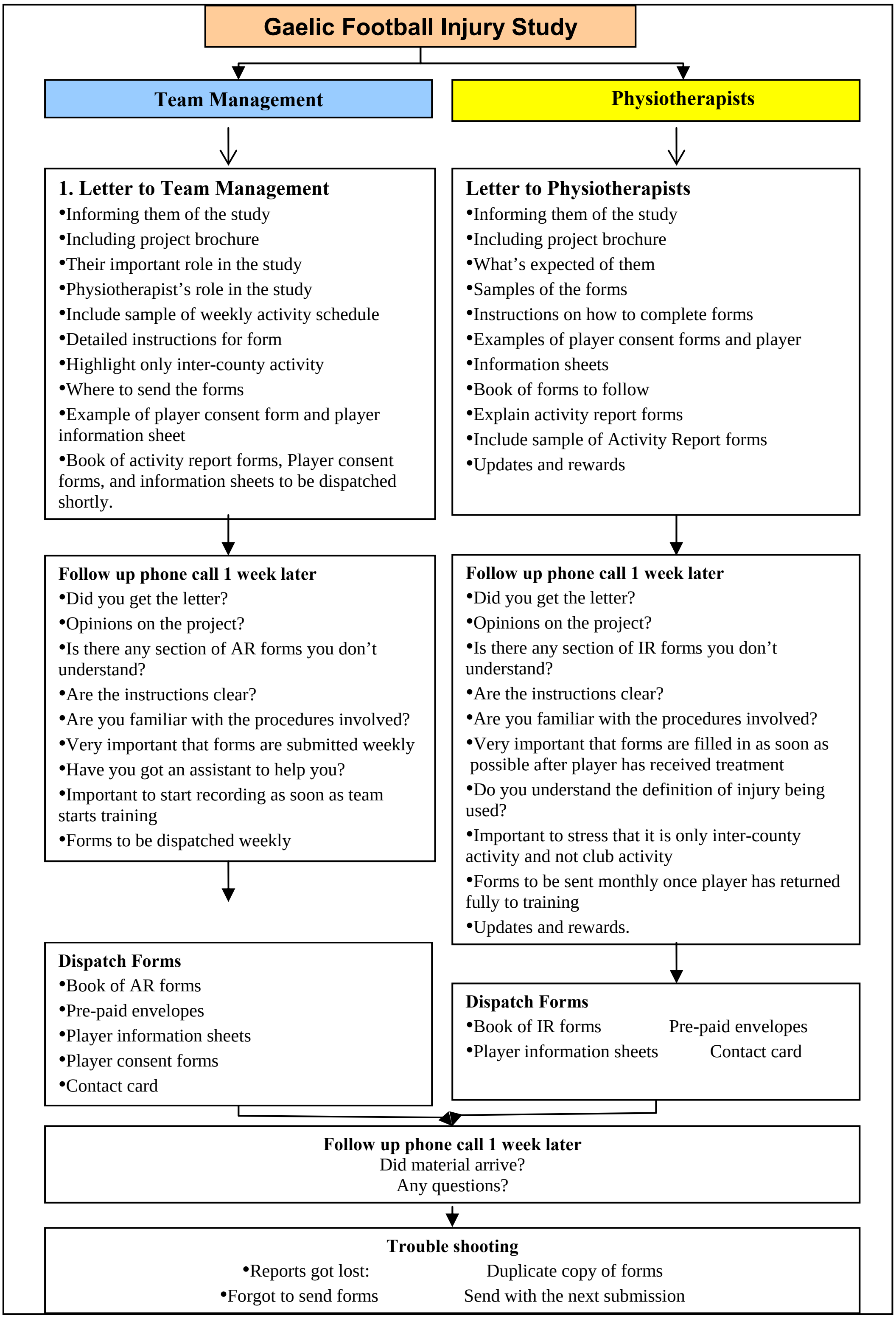


Figure 1.4 Flow Chart of Injury Study Design and Procedure

Of the thirty two teams contacted, eighteen teams agreed to participate. This total was reduced to sixteen teams as two teams dropped out after the first month, one manager decided to dispense with the team's physiotherapist, while another team's physiotherapist emigrated shortly after the project started. All four provinces and league divisions were represented by teams in the study.

Data collection began in January 2004 (pre season) and continued throughout the season through to the end of September of that year. The Weekly Activity schedules were submitted by a member of the management team at the end of each week to one of four provincial offices. Completed forms were grouped and dispatched at the end of every month to the study office. Injury report forms were submitted directly to the study office by participating physiotherapists at the end of each month for the duration of their team's involvement in the League and up until the team's elimination from the All-Ireland Championship (Figure 1.5).

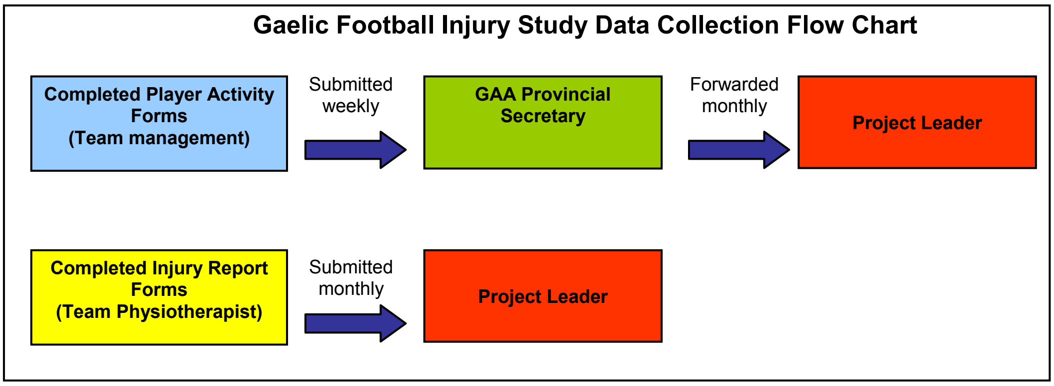


Figure 1.5 Flow Chart of Data Collection for Injury Study

1.32 Subjects

A total of 16 teams agreed to participate in the study. All subjects (n=511) were male between 18 and 36 years of age and members of Senior Inter County (elite) Gaelic Football teams. There was country wide representation as data were obtained from teams based in the north of Ireland (Ulster), in the south of Ireland

(Munster), in the east of Ireland (Leinster), and in the west of Ireland (Connaught). All players were informed of the study and signed the corresponding consent form.

The project was divided into two sections:

1. Injury Reporting
2. Weekly Activity

1.33 Injury Reporting

This involved the recording of injuries sustained by players while playing Gaelic Football with their County Team. A detailed injury reporting form was used to record injuries by the team's physiotherapist and completed forms were submitted on a monthly basis. Pre-paid envelopes were included with the book of forms to facilitate a speedy return of completed forms.

1.34 Weekly Activity

This section dealt with individual player's weekly activity schedule, documenting the time spent training and playing matches. Data were recorded by members of the coaching staff attached to each team and submitted on a weekly basis. Pre-paid envelopes were included with the book of forms. This information was used to calculate the risk of injury per hour of training and also per hour of competition/matches.

For the purpose confidentiality, players were not named. Instead they were allocated a research number prior to the commencement of the study and retained the same number through the remainder of the research project. A player consent form and an information sheet were distributed to each player at the start of the study period outlining the nature and purpose of the project (Appendix 3). Players were free to withdraw at any stage.

1.35 Definition of Injury

As stated previously the extent to which sports injuries can be assessed accurately depends on the definition of the sport injury and the method used to record injuries (Junge and Dvorak, 2001; Inklaar, 1994). Currently, there is no universally accepted or uniform definition of a sports injury (Finch, 1997). For the purpose of this study an injury was defined as:

> *'One sustained during training or a game and which prevented the injured player from participating in normal training or games for more than 48 hours, not including the day of injury'* (Hawkins et al., 2001).

This is the same definition used by Hawkins *et al*., (2001) in their recent epidemiological study of injuries in professional Soccer, and has been successfully used as a template for subsequent injury audits (Price *et al*., 2004, Brooks *et al.,* 2005). The benefits of using this definition include, it accounts for any time loss from training and/or games as a result of injury and it facilitates comparison with other injury studies that have used the same definition of an injury.

Also this study purposely dealt only with acute injuries and did not include past injury history. Secondly, the study dealt with injuries resulting from inter-county activity (training/playing). If a player was unable to participate in training or a game as a result of an injury sustained while playing with his local club, this information was recorded on the injury report form. The player was defined injured until the club medical staff cleared him for participation in full training or match play.

1.36 Severity of Injury

The severity of injury used in this study was defined as minor (<1 week), moderate (1-3 weeks), and severe (>3 weeks), (Bathgate *et al.*, 2002).

1.37 Injury Reporting Form

The injury form used in the study (Figure 1.6) consisted of seven sections and was designed to be user friendly and aimed at gaining data with the minimum of time required for completion. The study only included injuries sustained while playing or training, and does not include home accidents or illness, e.g. influenza. It was requested that as much information relating to the injury sustained should be entered onto the Injury Report Form as soon as is practical following the injury. All injuries were recorded as separate injuries. All completed Injury Report Forms (white copy) were returned on a monthly basis (end of each month) in the pre-paid envelope provided. The carbonised copy (coloured) was retained by the physiotherapist for reference.

<u>Section 1. Injury Information:</u>

This section included background details on the injury including:

- The time of day that injury occurred
- The playing surface
- Whether a player was injured in training or in a game

- The time period in the training session or game when injury happened
- The underfoot playing conditions
- The type of footwear worn by the player at the time of injury
- Details of any protective equipment worn by the player

Section 2. Body Region Injured

Persons completing this section of the form were asked to name the body region injured and highlight it on the picture provided; as well as indicating if the injured area was the player's dominant side (predominant kicking/hand passing side) or non dominant side.

Section 3.Supplementary Information

This section was designed to record the effects of injury on a player's participation in training or games. It was considered under three categories:

(1) Players who stopped participation immediately,

(2) Players who stopped later, and

(3) Players who completed training/games.

Information was also sought on player activity prior to the commencement of training and games, particularly if a player participated in a cool down at the end of the previous activity, a warm up prior to playing a game, and whether the player was subject to a late fitness test prior to a game (Late fitness test prior to game is defined as less than 24 hours prior to the game in which the injury occurred).

Section 4. Nature of Injury

This section of the injury report form required a diagnosis of the injury by the team's physiotherapist. Thirteen of the most popular categories were included in the form; if the nature of the injury sustained was not listed, a separate section was included to allow for specification. The objective of the report form was to gather specific details of the nature of injury; consequently the category 'overuse' injury was deliberately omitted from this section as it is a vague term and open to interpretation.

Section 5. Mechanism/Cause of Injury

Individuals completing this section of the form were asked to indicate if the cause of injury was as a result of contact, or non-contact, and if foul play was involved. Possible contact and non-contact causes were detailed and reporters were asked to tick any boxes that applied.

Section 6. Additional Comments

There was a comments section at the bottom of the form to allow for any other relevant information concerning the player's injury. If the injury was a recurrent injury, it was noted in this section.

Section 7. Date of Return to Full Injury

The date that a player was able to participate fully in training or games was recoded. Only then could the injury reporting form be submitted. The date of return to injury provided details of the severity of injury, i.e. minor (<1 week), moderate (1-3 weeks), and severe (>3 weeks). An example of a completed form is shown below (Figure 1.7).

Gaelic Football Injury Reporting Form

Date:__________________ **Team:**____________

Player Code:____________ **Age:**____________

Position: GK ☐ B ☐ M ☐ F ☐

1. Injury Information

Team: **County** ☐ **Club** ☐

Time: Morning ☐ Afternoon ☐ Evening ☐

Playing/ Training Surface

Grass ☐ Indoor/ gym ☐ Astro ☐

Activity: Training ☐ Game ☐

Training: (Occurrence)		**Game:**	
Warm up	☐	Warm up	☐
0- ¼	☐	0-17 mins	☐
¼- ½	☐	18-35 mins	☐
½- ¾	☐	36-53 mins	☐
¾- End	☐	54-70 mins	☐
Cool Down	☐	Extra time	☐
Length of Session		Cool Down	☐
(Mins) ________			

Playing / Training Surface Conditions

Dry ☐ Wet ☐ Hard ☐ Muddy ☐ Icy/Frozen ☐

Type of footwear

Studs ☐ Moulded ☐ Blades ☐ Runners ☐

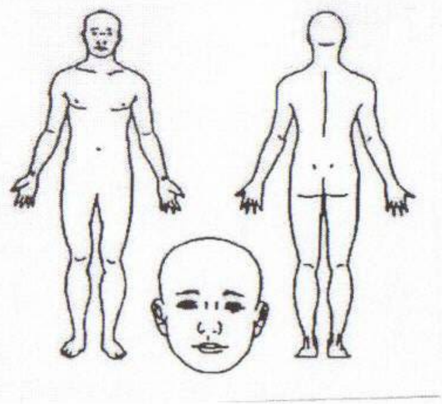
Protective Equipment

Was protective equipment worn on the injured body part? Yes ☐ No ☐

If Yes:

Mouthgaurd ☐ Strapping ☐ Joint Support ☐

2. Body Region Injured



Bodypart/s________________________

____

____

____

Dominant Side ☐ Non Dominant side ☐

Bilateral ☐ Not Applicable ☐

3. Supplementary Information

Cessation of playing / training
Immediately ☐ Later (during game/ training) ☐
Completed game/ training ☐

Warm up prior to playing game ☐

Late fitness test prior to game ☐

4. Nature of Injury

Abrasion/ graze	☐	Open wound / laceration / cut	☐
Dislocation	☐	Bruise / contusion	☐
Strain e.g. muscle tear	☐	Fracture	☐
Sprain e.g. ligament tear	☐	Blisters	☐
(Grade: 1 ☐ 2 ☐ 3 ☐)	☐	Concussion	☐
Respiratory problem	☐	Unspecified medical condition	☐
Cardiac problems	☐	Loss of consciousness	☐
Other	☐	Please specify:	

5. Mechanism / Cause of Injury

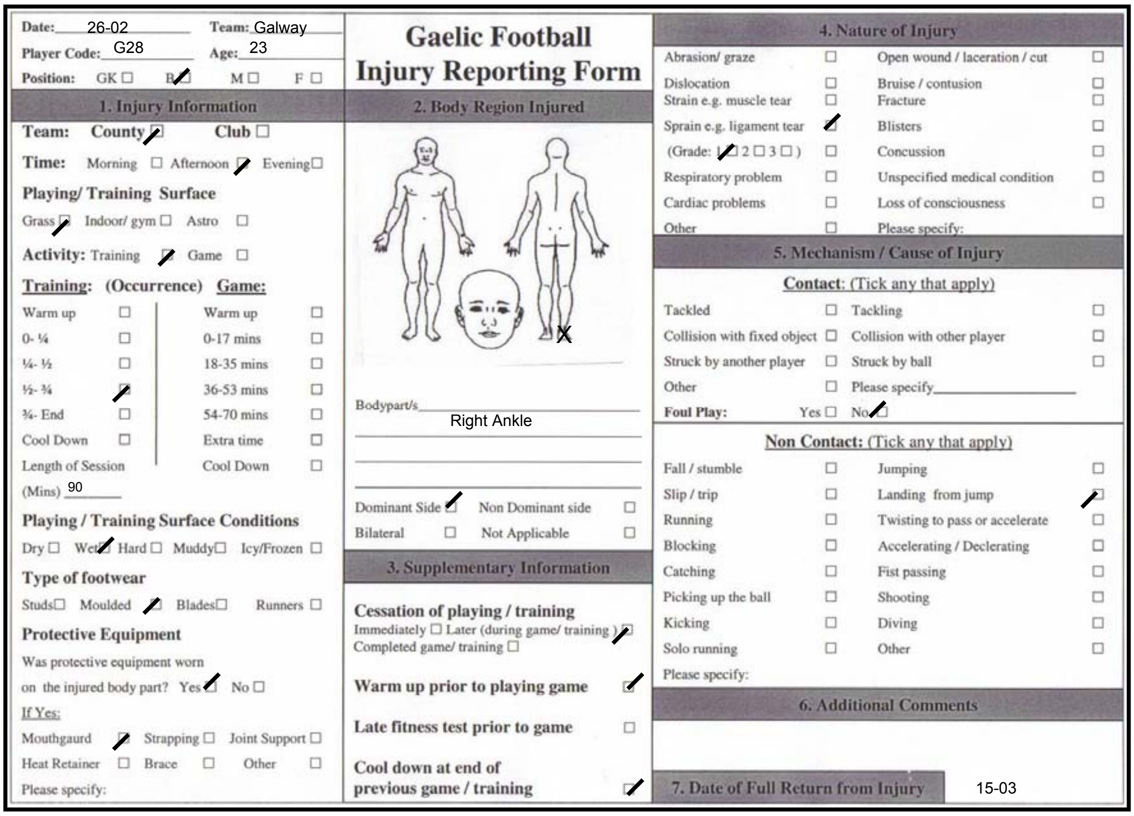
Contact: (Tick any that apply)

Tackled	☐	Tackling	☐
Collision with fixed object	☐	Collision with other player	☐
Struck by another player	☐	Struck by ball	☐
Other	☐	Please specify____________	
Foul Play:	Yes ☐	No ☐	

Non Contact: (Tick any that apply)

Fall / stumble	☐	Jumping	☐
Slip / trip	☐	Landing from jump	☐
Running	☐	Twisting to pass or accelerate	☐
Blocking	☐	Accelerating / Declerating	☐
Catching	☐	Fist passing	☐
Picking up the ball	☐	Shooting	☐
Kicking	☐	Diving	☐
Solo running	☐	Other	☐
Please specify:			

6. Additional Comments



Date: 26-02 Team: Galway
Player Code: G28 Age: 23
Position: GK ☐ B ☑ M ☐ F ☐

Gaelic Football Injury Reporting Form

1. Injury Information

Team: County ☑ Club ☐
Time: Morning ☐ Afternoon ☑ Evening ☐
Playing/ Training Surface
Grass ☑ Indoor/ gym ☐ Astro ☐
Activity: Training ☑ Game ☐

Training: (Occurrence)		Game:	
Warm up	☐	Warm up	☐
0- ¼	☐	0-17 mins	☐
¼- ½	☐	18-35 mins	☐
½- ¾	☑	36-53 mins	☐
¾- End	☐	54-70 mins	☐
Cool Down	☐	Extra time	☐
Length of Session (Mins) 90		Cool Down	☐

Playing / Training Surface Conditions
Dry ☐ Wet ☑ Hard ☐ Muddy ☐ Icy/Frozen ☐
Type of footwear
Studs ☐ Moulded ☑ Blades ☐ Runners ☐
Protective Equipment
Was protective equipment worn on the injured body part? Yes ☑ No ☐
If Yes:
Mouthgaurd ☑ Strapping ☐ Joint Support ☐
Heat Retainer ☐ Brace ☐ Other ☐
Please specify:

2. Body Region Injured

Bodypart/s Right Ankle

Dominant Side ☑ Non Dominant side ☐
Bilateral ☐ Not Applicable ☐

3. Supplementary Information

Cessation of playing / training
Immediately ☐ Later (during game/ training) ☑
Completed game/ training ☐
Warm up prior to playing game ☑
Late fitness test prior to game ☐
Cool down at end of previous game / training ☑

4. Nature of Injury

Abrasion/ graze	☐	Open wound / laceration / cut	☐
Dislocation	☐	Bruise / contusion	☐
Strain e.g. muscle tear	☐	Fracture	☐
Sprain e.g. ligament tear	☑	Blisters	☐
(Grade: 1 ☑ 2 ☐ 3 ☐)	☐	Concussion	☐
Respiratory problem	☐	Unspecified medical condition	☐
Cardiac problems	☐	Loss of consciousness	☐
Other	☐	Please specify:	

5. Mechanism / Cause of Injury

Contact: (Tick any that apply)

Tackled	☐	Tackling	☐
Collision with fixed object	☐	Collision with other player	☐
Struck by another player	☐	Struck by ball	☐
Other	☐	Please specify	

Foul Play: Yes ☐ No ☑

Non Contact: (Tick any that apply)

Fall / stumble	☐	Jumping	☐
Slip / trip	☐	Landing from jump	☑
Running	☐	Twisting to pass or accelerate	☐
Blocking	☐	Accelerating / Declerating	☐
Catching	☐	Fist passing	☐
Picking up the ball	☐	Shooting	☐
Kicking	☐	Diving	☐
Solo running	☐	Other	☐
Please specify:			

6. Additional Comments

7. Date of Full Return from Injury 15-03

Figure 1.7 Example of Completed Injury Report Form

1.38 Weekly Activity Report Form

The purpose of the Activity Report Form (Figure 1.8) was to record the time spent by each player participating in training and games, as well as the matches/ training sessions missed due to injury. For the purpose of this study, each week was taken as Monday-Sunday. The form consisted of the week number and the days of the week listed in order form Monday to Sunday respectively. Three activities were listed for each day of the week as follows: (1) Training, (2) Match, and (3) Other.

Week no:	**Gaelic Football Weekly Activity Report**: Please tick one of the following; **T**: Training **M**: Match **O**: Other						
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	T□ M□ O□	T□ M□ O□	T□ M□ O□	T□ M□ O□	T□ M□ O□	T□ M□ O□	T□ M□ O□
Time in Mins:							
	Indicate **ONLY** players who **did not participate fully** in training or matches by entering one of the following codes:						
Player Code	**I**: Injured **PT**:Taking part in partial training	**C**:Club related injury	**SK**:Sick/ill **W**:Working	**N**:No reason given	**S**:Sub (Came on)	**SN**:Sub not used	
1							
2							
3							
4							
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Figure 1.8 Weekly Activity Report Form

The appropriate box was ticked for any activity that took place on that particular day. Secondly for each day the time spent engaged in the particular activity was also recorded. Each player was listed along the left-hand margin of the form according to their study code number. Only players who did not participate fully in training or matches were recorded on the form using one of the following categories:

(1) I (Injured)

(2) PT (Taking part in partial training)

(3) S (Sick)

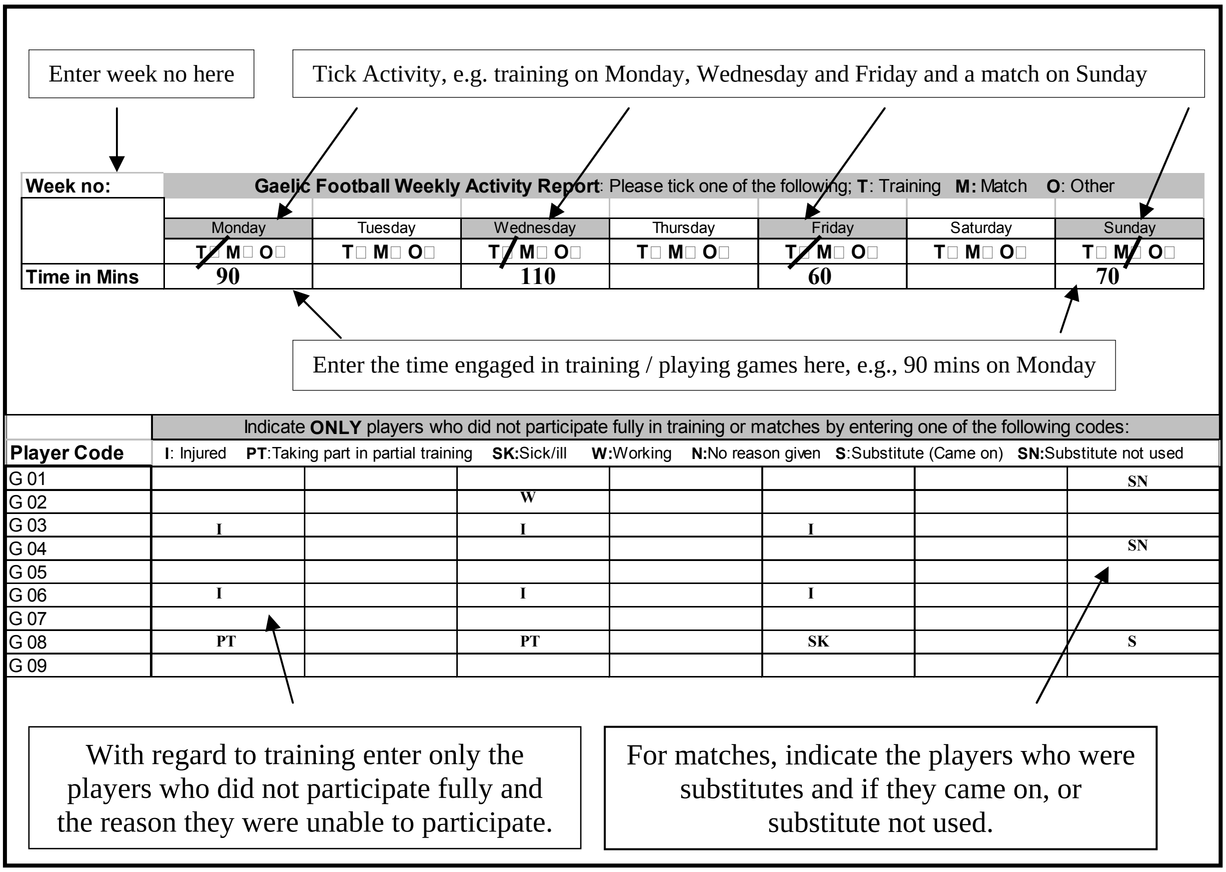
(4) W (Working)

(5) N (No reason given)

(6) S (Substitute came on)

(7) SN (Substitute not used)

An example of a completed form is shown below (Figure 1.9).



Enter week no here

Tick Activity, e.g. training on Monday, Wednesday and Friday and a match on Sunday

Week no:	Gaelic Football Weekly Activity Report: Please tick one of the following; T: Training M: Match O: Other						
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	T M O	T M O	T M O	T M O	T M O	T M O	T M O
Time in Mins	90		110		60		70

Enter the time engaged in training / playing games here, e.g., 90 mins on Monday

Indicate **ONLY** players who did not participate fully in training or matches by entering one of the following codes:

I: Injured **PT**: Taking part in partial training **SK**: Sick/ill **W**: Working **N**: No reason given **S**: Substitute (Came on) **SN**: Substitute not used

Player Code							
G 01							SN
G 02			W				
G 03	I		I		I		
G 04							SN
G 05							
G 06	I		I		I		
G 07							
G 08	PT		PT		SK		S
G 09							

With regard to training enter only the players who did not participate fully and the reason they were unable to participate.

For matches, indicate the players who were substitutes and if they came on, or substitute not used.

Figure 1.9 Example of Completed Weekly Activity Report Form

1.39 Statistical analysis

Graphical and numerical summaries were provided for all response variables of interest. All of the variables of interest were categorical, test of association were performed to test for any association between injury type and other factors of interest. Chi squared test (using a significance level of 0.05) was used if the underlying assumption relating to the expected values were deemed appropriate, otherwise Fishers Exact Test was employed. For binary variables, comparisons of proportion based on the Normal approximation to the Binomial distribution were used as necessary. P-values were reported for those comparisons of specific interest as opposed to comparing all levels of all variables.

1.4 Results

The resulting descriptive and comparative data for the 511 players from the 16 teams that participated in the study are presented below.

1.401 Exposure to Injury

Total exposure time for all Gaelic Football activity throughout the season from January to September was 39785.8 hours. The exposure time in games was 4310.4 hours and 35475.4 hours in training. The hours of exposure per player were 69.4 ($\pm$33.1) in training and 16.8 ($\pm$7.7) in games respectively.

1.402 Total Number of Injuries Recorded

A total of 471 acute injuries were recorded; 195 injuries in training and 276 injuries in games. This represents 0.38 ($\pm$0.27) injuries per player in training, 1.08 ($\pm$0.81) injuries per player in games, and 1.46 ($\pm$0.54) injuries in total, per player per season.

1.403 Incidence of Injury

The overall incidence of injury (total no of injuries/total exposure time *1000) for all teams was 11.8 ($\pm$4.36) per 1000 player hours. The incidence for games was 64 ($\pm$26.5) per 1000 player game hours, and 5.5 ($\pm$2.62) per 1000 player training hours (Table 1.13). The relative risk of injury is 11 times more likely in games than in training; despite the fact that over eight times the amount of time was spent training than in games.

Table 1.13 *Incidence of Injury per 1000h of Gaelic Football Activity*

Activity	No of Injuries	Exposure time	Incidence of Injury per 1000 h Mean (SD)
Training	195	35475.4	5.5 (±2.62)
Games	276	4310.4	64 (±26.5)
Total	471	39785.8	11.8 (±4.36)

1.404 Injuries in Training and Games

A total of 471 injuries were recorded in the study (Figure 1.10). Of the injuries sustained, significantly more injuries occurred in games (276, 59%) than in training (195, 41%) ($p<0.001$). Of all players participating in this study 66% were injured at some stage during the season.

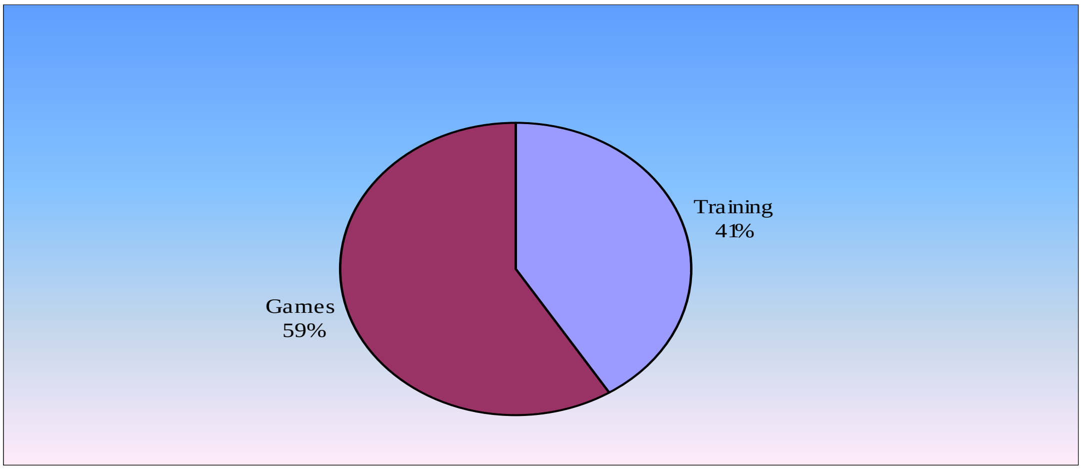


Figure 1.10 Total Injuries Recorded For All Activity (Training and Games).

The results show that the majority of injuries occurred in games.

For most teams, the number of injuries in games was higher than the number of injuries in training (Figure 1.11). However five teams (2, 8, 14, 15, and 16) had a higher number of training injuries than match injuries. These same five teams also had a lower relative risk of injury in games when comparing the incidence of injury (per 1000 hours) for training and games (Figure 1.12).

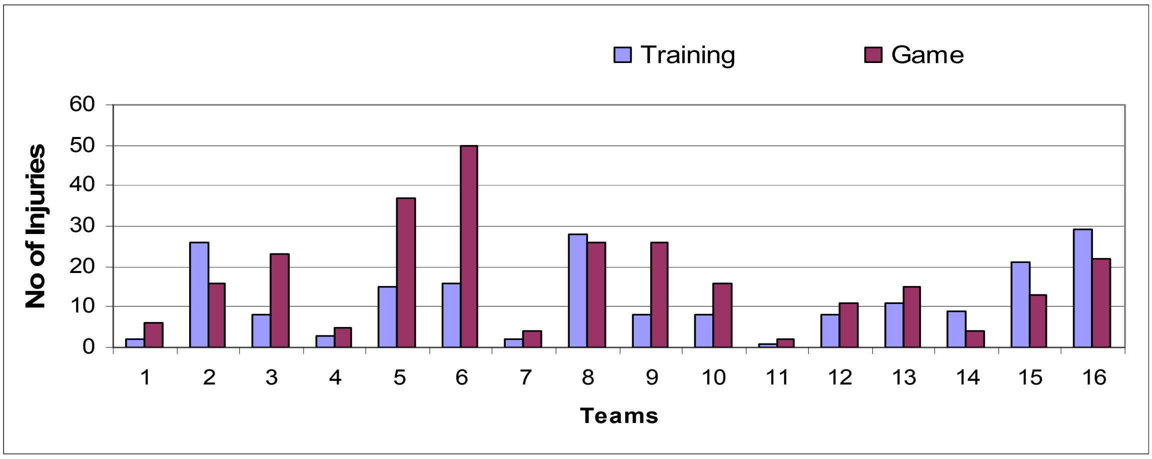


Figure 1.11 Comparison of Training and Game Injuries.

Teams 2,8,14,15, and 16 respectively reported a higher incidence in training than in games, as opposed to the rest of the teams.

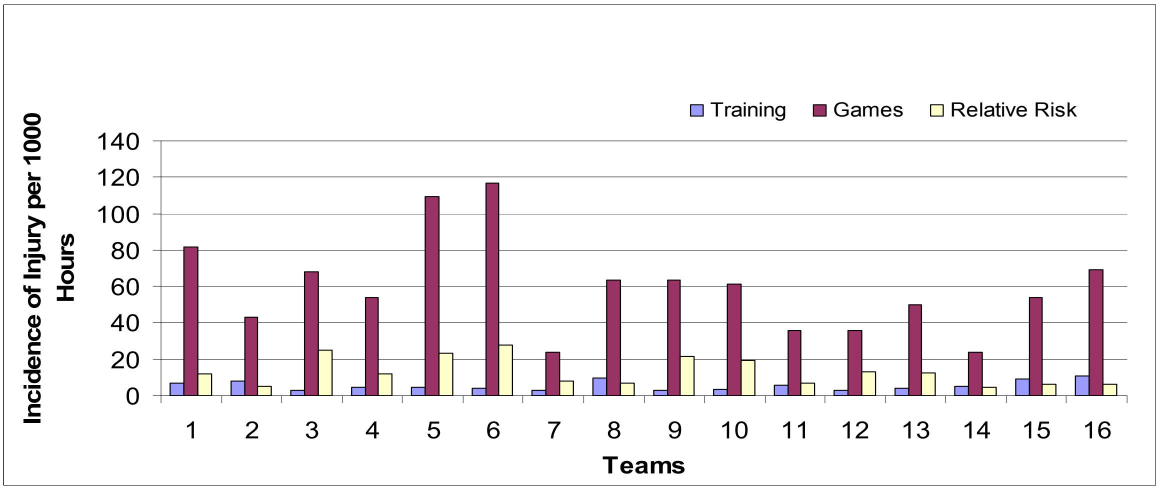


Figure 1.12 Incidence of Injury and Relative Risk of Injury (Games v Training).

Teams 2, 8, 14, 15, and 16 respectively had a lower relative risk of injury when comparing injuries occurring in matches versus injuries occurring in training.

1.405 Monthly Profile of Injury

The numbers of injuries reported each month is shown in Figure 1.13. The highest number of injuries was recorded in January and February (pre-season) for both training and games respectively. As the season progressed the number of injuries declined steadily during the summer months. Hamstrings injuries were consistently the most frequently occurring injury each month followed closely by knee and ankle injuries (Table 1.14).

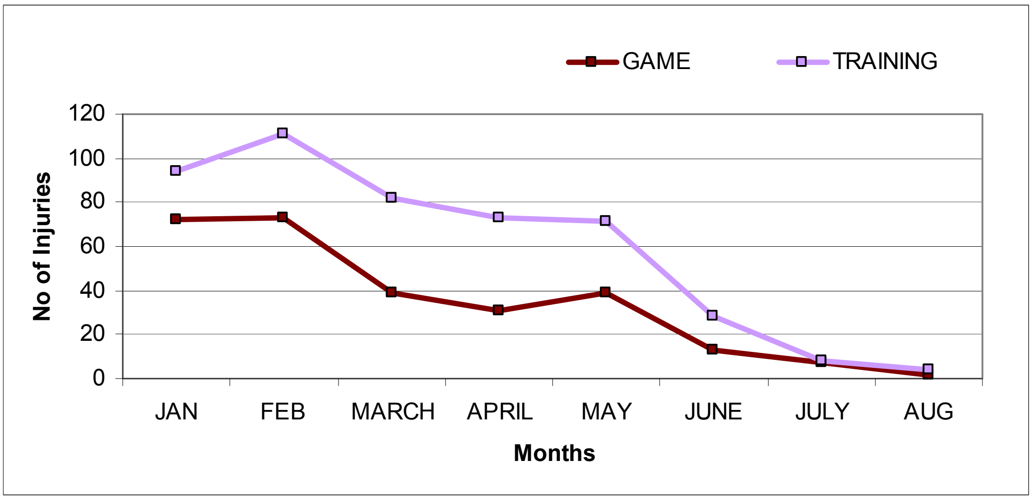


Figure 1.13 Monthly Profile of Training and Game Injuries

The monthly profile pattern of injuries is similar for both games and training. The highest number of injuries was sustained during the pre-season months (January and February).

Table 1.14 *Top Five Injuries Recorded Each Month*

	Jan	Feb	March	April	May	June	July
1	Hams	Hams	Hams	Hams	Hams	Hams	Hams
2	Knee	Knee	Ankle	Knee	Knee	Quads	Knee
3	Ankle	Groin	Knee	Groin	Ankle	Knee	Quad
4	Back	Ankle	Quads	Shoulder	Quads	Calf	Thigh
5	Shoulder	Quads	Back	Ankle	Finger	Ankle	Ankle

1.406 Age and Injury

Injured players were grouped according to their age. The mean (SD) age of injured players was 24 years (3.5). The breakdown for each age group was as follows, 18-20 years (13% of total players), 21-23 years (37%), 24-26 years (27%), 27-29 years (16%), 30-32 years (3%), and 33 years and over (4%). Players in the 21 to 23 age group sustained the highest proportion of injuries and 75% of all injuries recorded were sustained by players between the ages of 18 and 26 years (Figure 1.14).

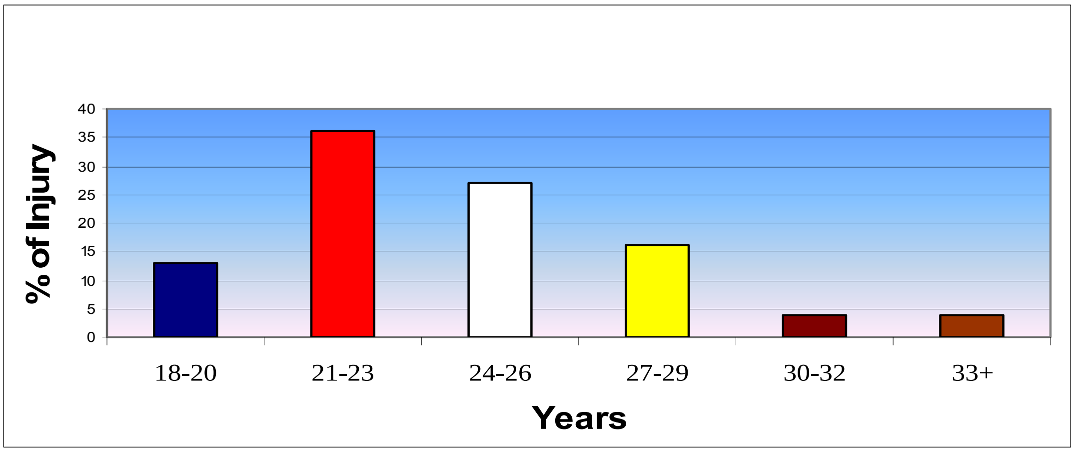


Figure 1.14 Ages of Players and Injury

The highest number of injuries was sustained by players aged between 21 and 23 years respectively.

1.407 Player's Age and Types of Injury

The players in the (30 to 32), and (33+) age groups had the highest percentage of abdominal, arm, back, calf, and facial injuries; younger players particularly the (18-20) and (21-23) age groups reported a higher proportion of Achilles tendon, shoulder and rib injuries (Figure 1.15). The percentage of knee, groin, and hamstrings injuries were similar for all age groups.

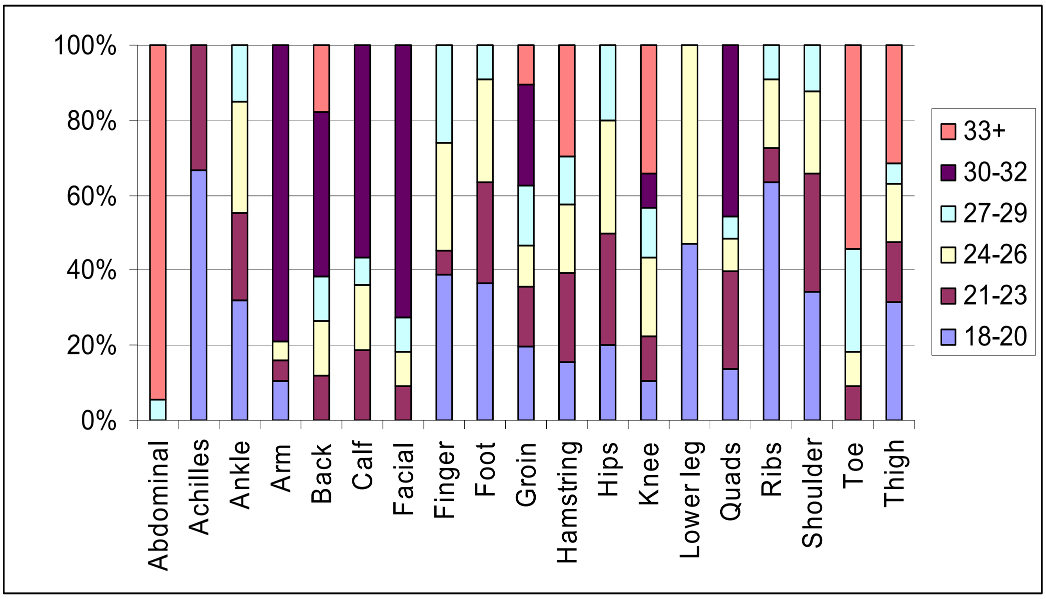


Figure 1.15 Injury Type and Players Age

Older players tended to incur more abdominal injuries than younger players who sustained high proportion of rib injuries

1.408 Playing Position and Injury

In a typical game of Gaelic Football there are six defenders (backs), two midfielders, six attackers (forwards), and a goalkeeper on each team. After adjusting for goalkeepers and the lower numbers of midfield players compared to attackers and defenders there was a uniform pattern of injury (Figure 1.16). The results indicate that there is no evidence of a significant association (p=0.92) between injury and playing position when activity (i.e. training/game) is considered.

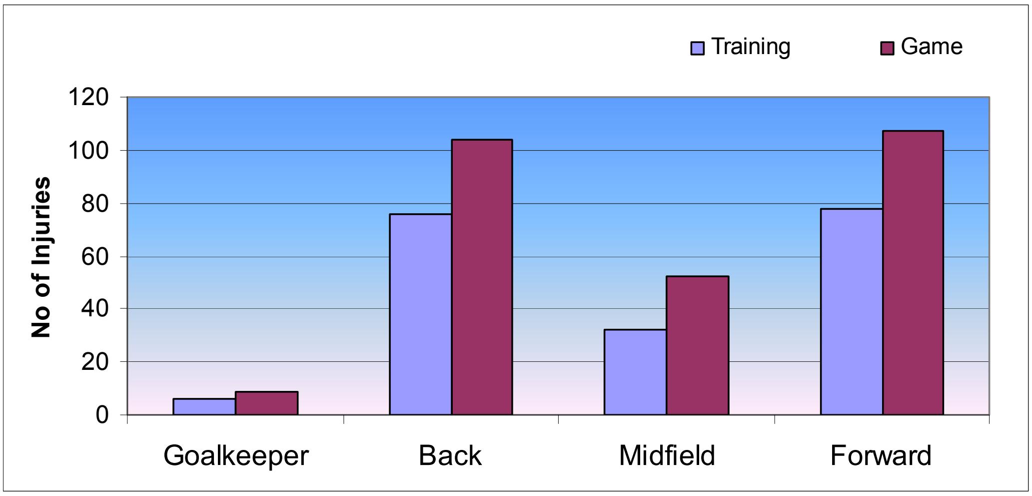


Figure 1.16 Injuries and Playing Position

There was a uniform pattern of injury across the different playing positions with no significant association between playing position and injury (p=0.92).

1.409 Time of Injury

The time of injury is similar for training and games (Figure 1.17). The percentage of injury increased steadily over time with a pronounced increase in the final quarter for both training and games. Fifty five percent of all training injuries occurred in the final quarter of training. There is strong evidence of an association ($p=0.003$) between time of injury and activity (i.e. training/game). There were significantly more injuries in the fourth quarter in training compared to what would be expected if time of injury and activity were unrelated. Also there were significantly more injuries in the second half of games compared to the first half ($p<0.001$).

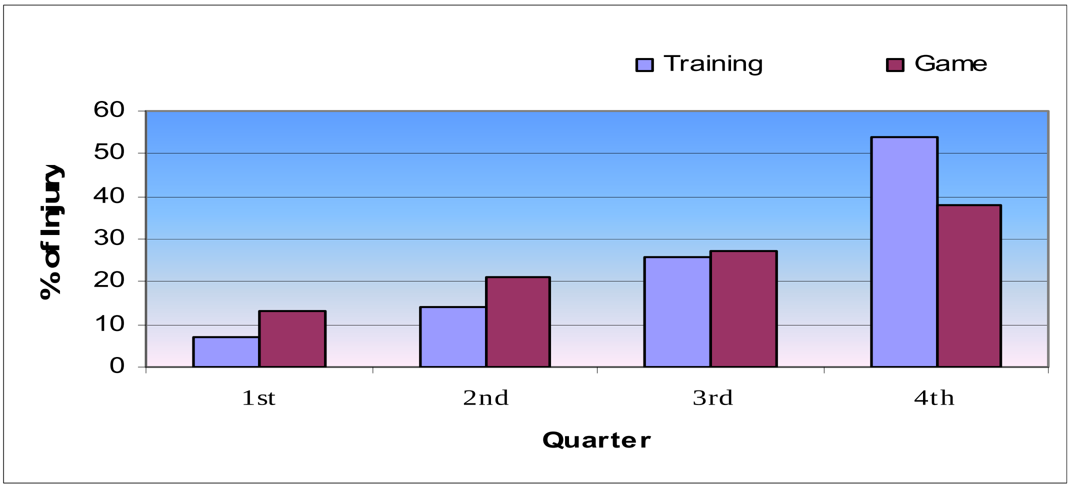


Figure 1.17 Time of Injury

There is strong evidence of an association (p=0.003) between time of injury and activity. Significantly more injuries occurred in the second half of games compared to the first half (p<0.001). Similarly more injuries occurred in the fourth quarter in training compared to what would be expected if time of injury and activity were unrelated.

1.410 Playing Surface

The majority of all training sessions took place on grass; occasionally teams trained on artificial training surfaces especially during the pre-season period. Of the injuries recorded, 97% were sustained on grass with the remainder occurring in the gym or on astro turf. The playing surface conditions at the time of injury were considered under five different categories. Of the injuries sustained, 51% were on dry hard surfaces, 28% on wet surfaces, and 14% on muddy surfaces (Figure 1.18). There was an association between injury and playing surface with significantly more injuries occurring on dry/hard surfaces ($p<0.001$).

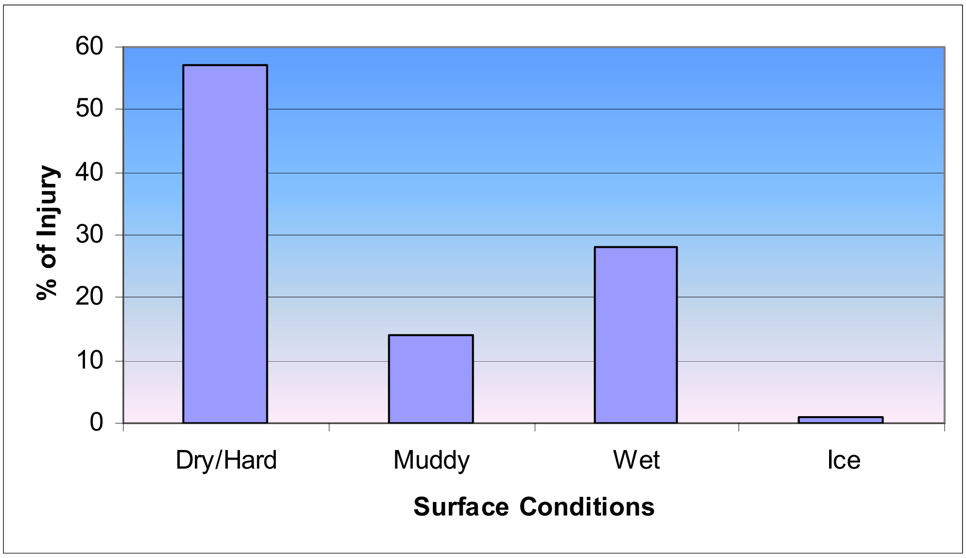


Figure 1.18 Ground Conditions and Injury

There was an association between injury and playing surface with significantly more injuries occurring on dry/hard surfaces (p<0.001).

1.411 Footwear and Injury

Typically players chose between four types of footwear: traditional Football boots with removable studs or cleats, Football boots with moulded rubber studs, Football boots with a blades type sole, and running shoes (mainly used on astro-turf and synthetic surfaces). The type of footwear worn usually depends on the weather and surface conditions. Football boots with moulded studs accounted for the highest proportion of reported injuries (53%), followed by boots with a blades type sole (23%) and traditional Football boots with removable studs or cleats (22%) (Figure 1.19). A more detailed breakdown of the location of injury and the footwear worn when injury was sustained is shown in Figure 1.20.

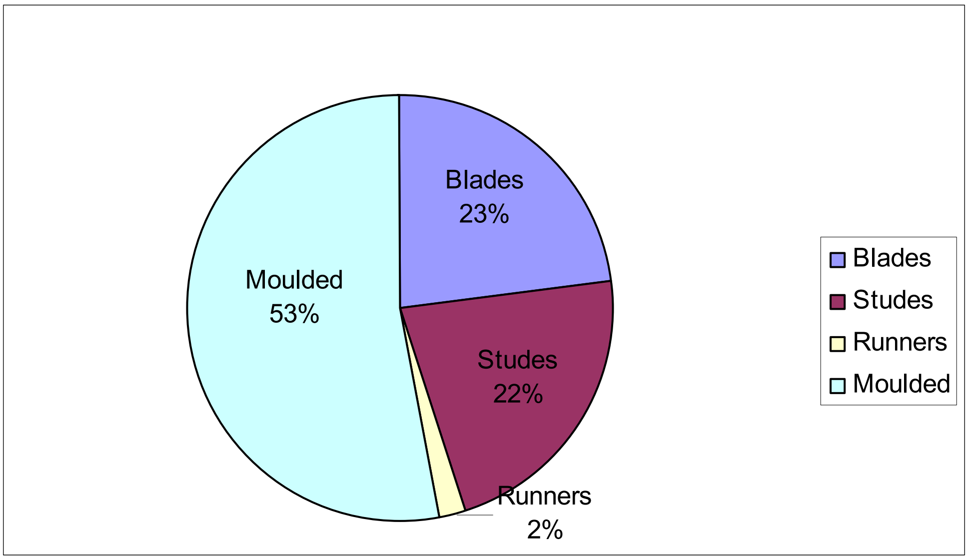


Figure 1.19 Injuries and Footwear

Football boots with moulded studs accounted for the highest proportion of reported injuries (53%), followed by boots with a blades type sole (23%) and traditional Football boots with removable studs or cleats (22%)

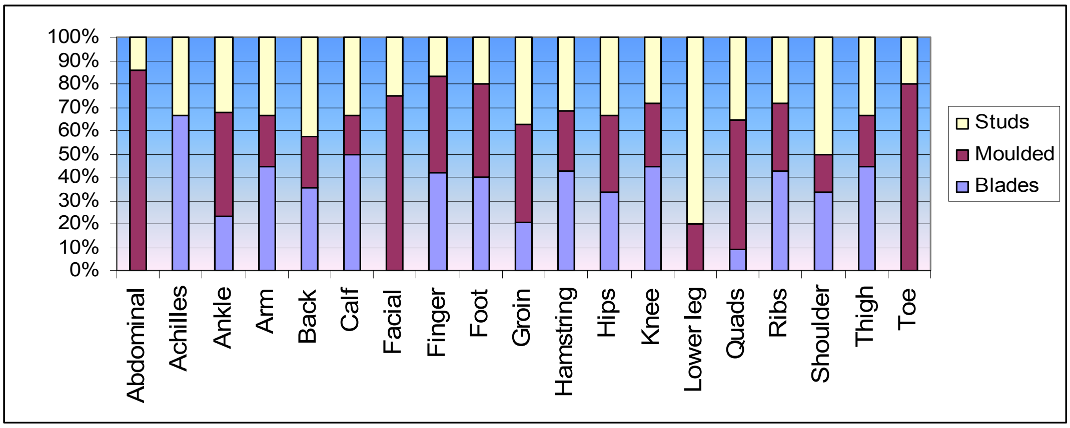


Figure 1.20 Profiles of Footwear and Injury

Pattern of injury and the type of footwear worn by players indicates a higher incidence of lower leg injury when wearing regular studs (80%) as opposed to moulded shorter studs (20%). Players wearing moulded studs had a higher incidence of abdominal injury (85%) as opposed to players wearing regular studs (15%).

1.412 Body Region Injured

There is strong evidence that the proportion of injuries at each body site (Figure 1.21) was different ($p<0.001$). Injuries to the lower limb accounted for over 70% of all injuries recorded. Percentages for each site injury were: hamstrings (22%), knee (13%), ankle (11%), and groin (9%). Injuries to the upper and lower arm including the hand accounted for 5% of all injuries; the back (6%) and shoulder (7%) were the main sites of injury in the upper body. The injury pattern for body site in games and training is strikingly similar although more hamstrings and groin injuries occurred in training than in games. The incidence of knee and ankle injury was higher in games (15% and 15% respectively) than in training (11% and 7% respectively).

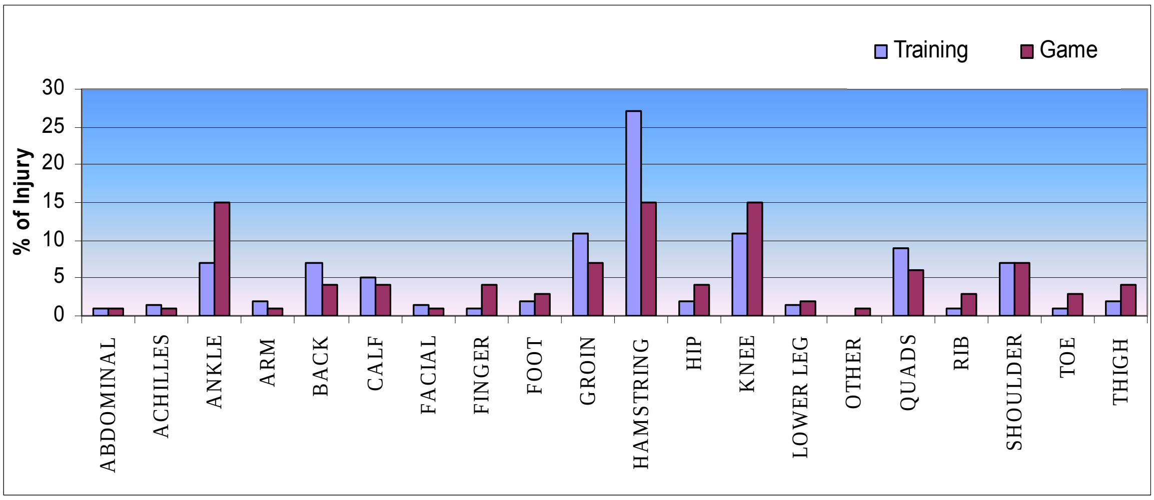


Figure 1.21 Body Region Injured

The proportion of injuries at each body site was different (p<0.001). Injuries to the lower limb accounted for over 70% of all injuries recorded.

1.413 Body Region Injured and Playing Time

The time periods during games and training (1^{st}, 2^{nd}, 3^{rd}, and 4^{th} quarters) that particular injuries occurred is shown below (Figure 1.22). The majority of injuries occurred in the third and fourth quarters for both games and training. Injuries to the Achilles tendon, calf, hamstrings, quadriceps, knees, shoulders, and thighs were more frequent in the second half of games than in the first half; while the opposite is true for injuries to the back which occurred more frequently in the first half of games. The pattern of ankle, and groin injuries is similar for both training and games, with the highest proportion occurring in the final quarter of activity. 90% of all hamstrings injuries and 80% of quadriceps injuries occurred in the 3^{rd} and 4^{th} quarters of training.

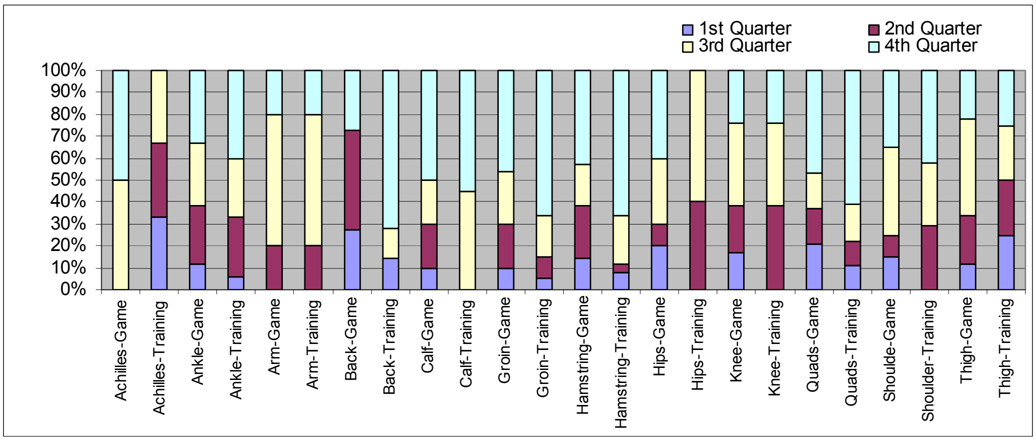


Figure 1.22 Body Region Injured and Timing

The majority of injuries occurred in the third and fourth quarters for both games and training.

1.414 Body Region Injured and Playing Position

Injuries to the hamstrings, knee, ankle, and groin were the four most common injuries recorded for each of the different playing positions i.e. backs, midfield, and forwards (Table 1.15). In total these injuries accounted for over 50% of total injuries in each playing position with the exception of goalkeepers who had a high percentage of abdominal injuries (Figure 1.23).

Table 1.15 *Top Five Injuries According to Playing Position*

Position	**Rank**	**Injury**		**Position**	**Rank**	**Injury**
Goalkeeper	1	Knee		Back	1	Hamstrings
	2	Abdominal			2	Knee
	3	Groin			3	Ankle
	4	Quads			4	Groin
	5	Finger			5	Back
Position	**Rank**	**Injury**		**Position**	**Rank**	**Injury**
Midfield	1	Ankle		Forward	1	Hamstrings
	2	Hamstrings			2	Knee
	3	Knee			3	Ankle
	4	Groin			4	Quads
	5	Shoulder			5	Groin

A comparison of backs, forwards, and midfield players, shows that the proportion of hamstrings, knee, and ankle injuries were very similar for backs and forwards, however midfield players had a greater range of injuries and a lower proportion of hamstrings injuries (13% as opposed to 21% for backs and 24% for forwards) and a higher proportion of ankle injuries (15% as opposed to 12% and 11% respectively) and shoulder injuries (11% as opposed to 6% and 7% respectively).

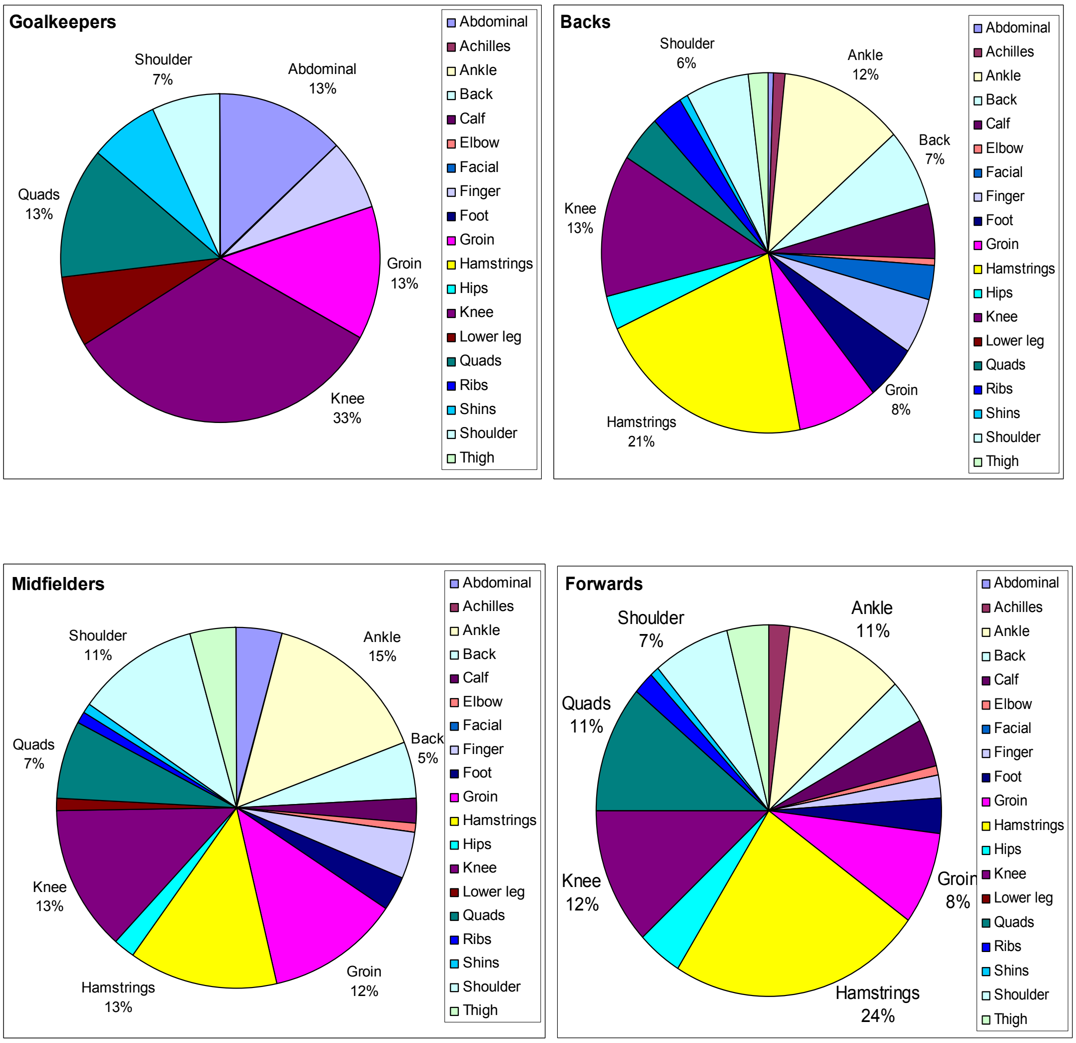


Figure 1.23 Playing Position and Type of Injury

Injuries to the hamstrings, knee, ankle, and groin were the four most common injuries recorded for each of the different playing positions and account for over 50 of all injuries sustained.

The percentages of quadriceps injuries were highest in goalkeepers (13%) and forwards (11%). Goalkeepers also reported the highest percentage of groin injuries (13%), followed by midfielders (12%), with backs and forwards each reporting 8%. There was however no significant relationship (p=0.211) between playing position and injury particularly, with regard to the main injuries recorded, i.e. hamstrings, ankle, knee, groin, shoulder, and quadriceps.

1.415 Injury and Body Side

For every injury recorded reference was made to the body side where injury occurred and whether this was the player's dominant (preferred kicking/passing side) or non-dominant side where appropriate. Of all the injuries reported, there was a significantly higher proportion (52%) of injuries in the dominant side (P=0.001) compared to the non-dominant side (Figure 1.24).

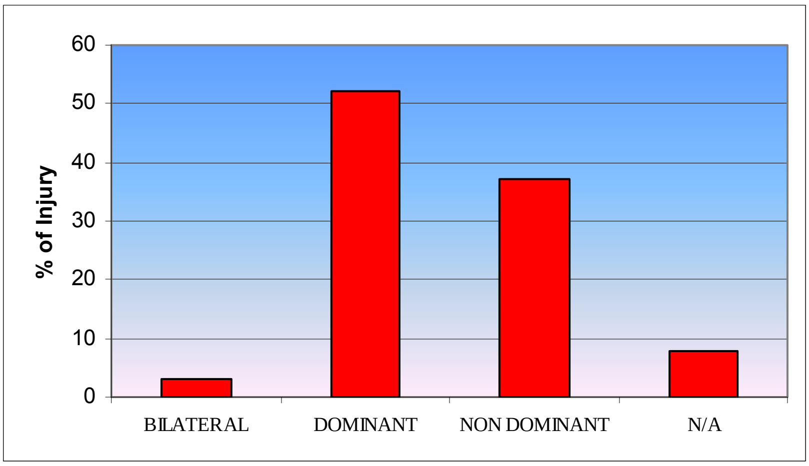


Figure 1.24 Injuries and Body Site

A higher proportion of injuries were sustained to a player's dominant side compared to their non-dominant side (P=0.001).

1.416 Nature of Injury

The majority of total injuries (Figure 1.25) were classified as sprains (stretch or tear of a ligament) (26%), strains (stretch or tear of a muscle or tendon) (42%), and bruises/contusions (damaged or broken blood vessels as a result of a blow to the skin) (17%). The incidence of sprain injuries was significantly higher in games than in training ($p<0.001$) with players approximately three times more likely to sustain a sprain injury in games as opposed to training. There was no significant difference ($p=0.610$) between the incidence of strain injuries in training and games. The incidence of bruising/contusion was higher ($p=0.01$) in games (22%) than in training (11%); similarly significantly more fractures ($p<0.001$) occurred in games (5%) than in training (2%). The majority of fractures were to the hand particularly the fingers and thumbs.

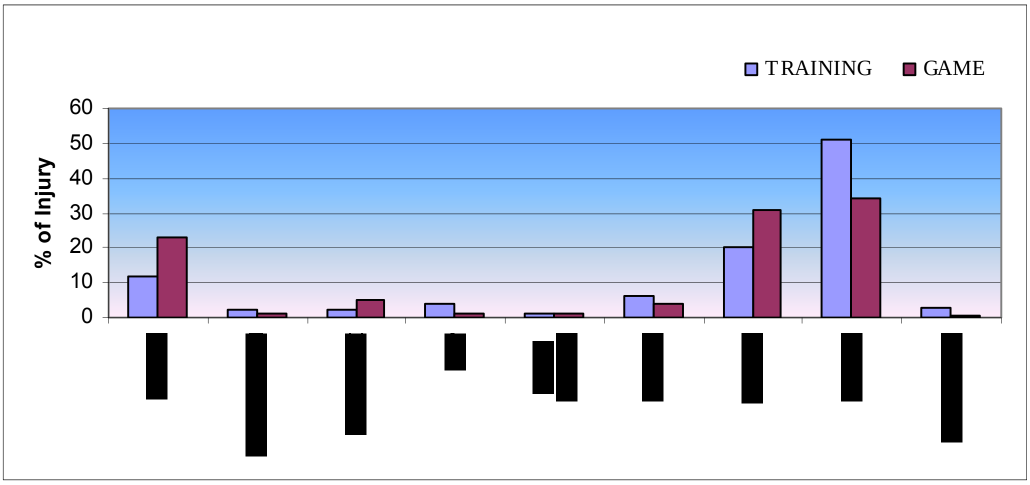


Figure 1.25 Nature of Injury

Significantly more sprain injuries occurred in games than in training ($p<0.001$), while there was no significant difference ($p=0.610$) between the incidence of strain injuries in training and games. The incidence of bruising/contusion was higher in games than in training ($p=0.01$).

1.417 Nature of Injury and Occurrence in Training and Games

The nature of injury and in particular the timing of bruising, fractures, sprains, and strains in training and games is shown in Figure 1.26. The pattern of bruising is similar for both training and games, although no bruising occurred in the first quarter of training. Only one fracture was sustained in training during the entire study period. The percentage of fractures in games was shared equally between the first, third and fourth quarters respectively.

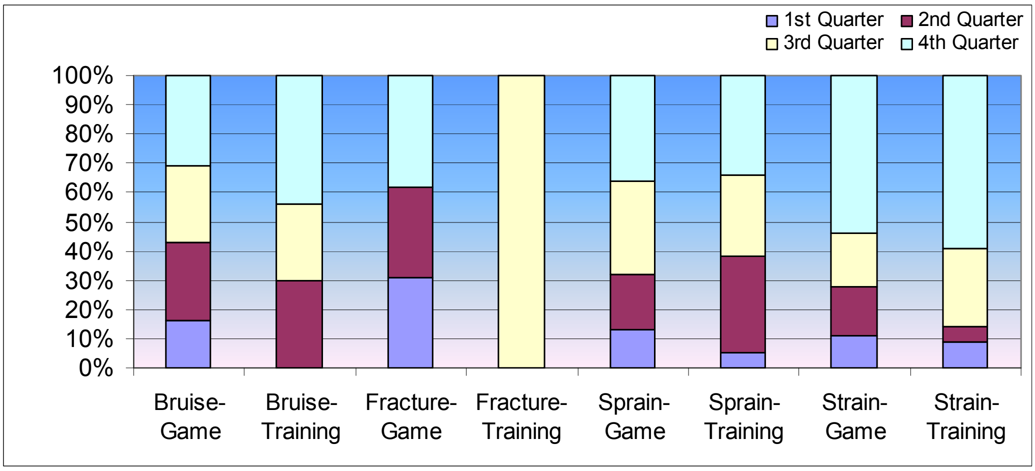


Figure 1.26 Nature of Injury and Occurrence in Training and Games

More sprain and strain injuries occur in the third and fourth quarter of training than during any other period (p<0.001).

There were more sprain (65%) and strain injuries (79%) in the second half (2nd and 3rd quarters) than in the first half (1st and 2nd quarters) of training and games. The pattern of sprain and strain injuries in games indicates that there is borderline association ($p=0.054$) between injury and occurrence, with players more likely to sustain sprain and strain injury in the fourth quarter. With regard to training, significantly more sprain and strain injuries occur in the third and fourth quarter than during any other period ($p<0.001$).

1.418 Cause of Injury

Despite the high intensity and physical contact nature of Gaelic Football, there was a significantly higher proportion of non-contact injuries (p<0.001). 60% of injuries resulted from non-contact and 40% as a result of contact (Figure 1.27).

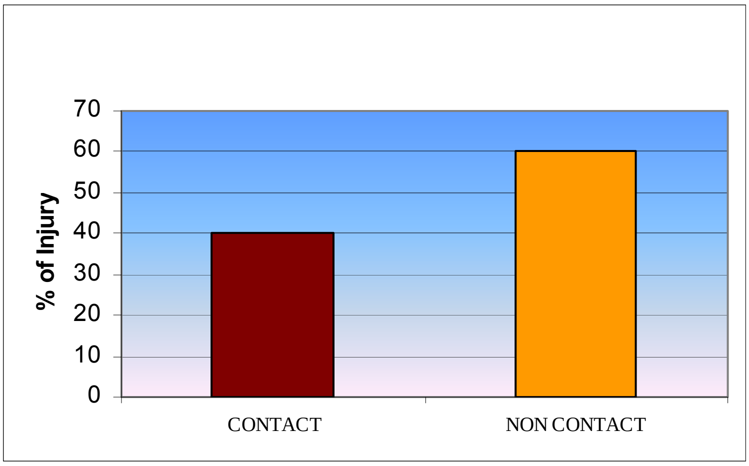


Figure 1.27 Cause of Injury

There was a significantly higher proportion of non-contact injuries (p<0.001) compared to contact injuries.

The main non-contact injuries were muscular strain injuries particularly to the hamstrings (31%) and groin (14%), caused mainly by running, twisting, accelerating, and decelerating (Figure 1.28).

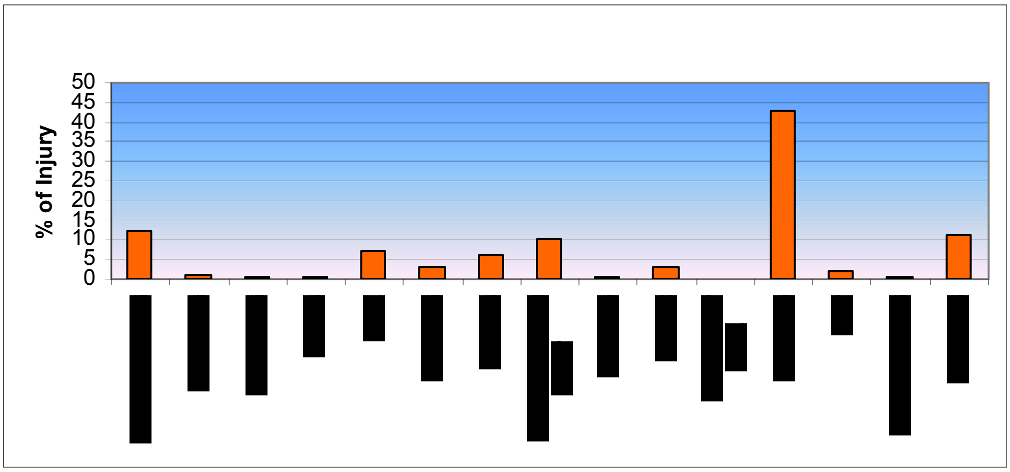


Figure 1.28 Cause of Non-Contact Injury

Muscle strains were the main cause of non-contact injuries

Contact injuries particularly the shoulder (15%), knee (15%), and ankle (9%) resulted predominantly from collisions with other players, tackled, or struck by another player (Figure 1.29).

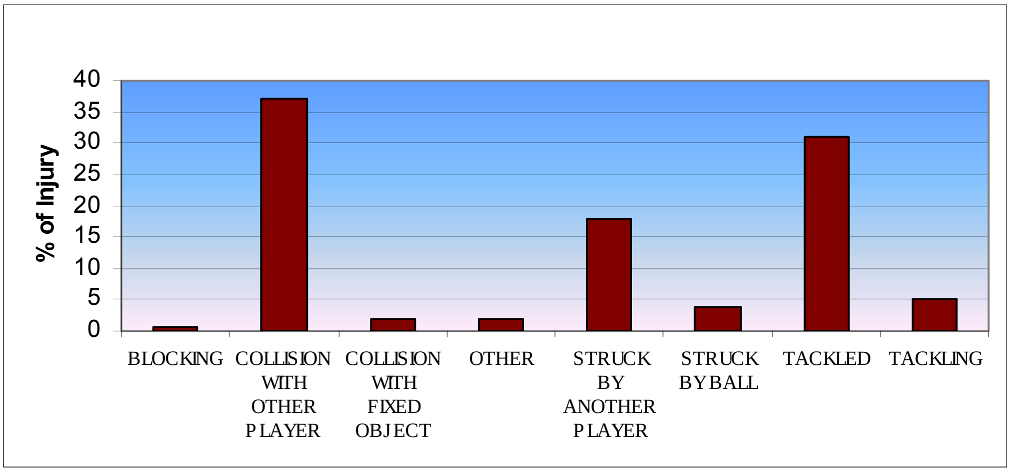


Figure 1.29 Cause of Contact Injury

Collisions with other players were the main cause of contact injuries.

1.419 Impact of Injury on Participation

The effect of injury on a player's participation was considered under three categories (Figure 1.30). There is strong evidence that the proportion of injuries with respect to impact on participation was different ($p<0.001$). The majority of injured players did not complete training or games. 44% of injuries resulted in cessation of activity immediately, 19% at a later stage during training or game, while 37% of players completed their game or training session.

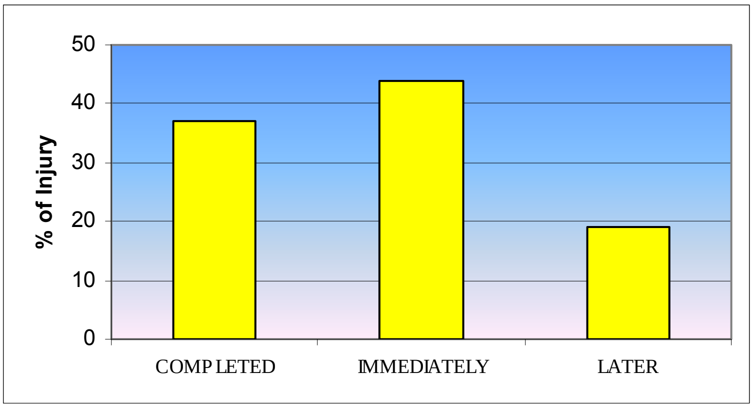


Figure 1.30 Impact of Injury on participation

The proportion of injuries with respect to impact on participation was different (p<0.001). The majority of injured players did not complete training or games.

1.420 Severity of Injury

Injuries were classified into three categories according to the length of absence from training sessions and games: minor (<1 week), moderate (1-3 weeks), and severe (>3 weeks). 10% of all injuries were classified as minor, 56% were moderate, and 34% were severe (Figure 1.31). Of the severe injuries, 12% resulted in the player being unable to participate fully for a period of over six weeks and 3% were serious enough for the player to miss playing for the rest of the season.

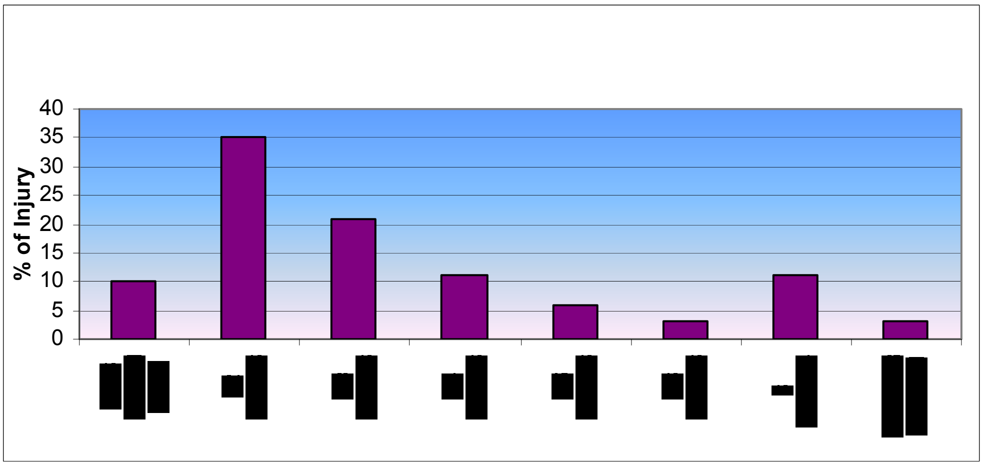


Figure 1.31 Severity of Injury

The majority (56%) of injuries were classified as moderate, resulting in players being absent from training for one to three weeks.

1.421 Summary of Main Results

- Five hundred and eleven players participated in this study.

- Teams from all four divisions participated and provided a reliable and representative sample of the elite Gaelic Football population.

- The incidence of injury was 64 ($\pm$26.5) per 1000 player game hours, and 5.5 ($\pm$2.62) per 1000 player training hours.

- The relative risk of injury is 11 times more likely in games than in training;

- There was a 3:2 ratio of injuries in games versus training.

- The timing of injury is consistent across all teams especially in training.

- More injuries occur in the final quarter of training (55%) and games (38%) than during any other period.

- Hamstrings injuries (22%) are the most common injury.

- Non-contact injuries (60%) are more frequent than contact injuries (40%).

- The older a player is, the less the likelihood of shoulder injury.

- There was an association between injury and playing surface with significantly more injuries occurring on dry/hard surfaces.

- Further investigation is warranted to explore a potential link between the wearing of ‘blades’ type footwear and knee injury.

1.5 Discussion

1.51 Incidence of Injury

The incidence rate of injuries per player per year (1.46) is lower in the present study compared with the figure of 1.78 reported by Cromwell *et al.,* (2000) who retrospectively recorded injuries reported by 107 elite Gaelic Football players over a season**.** The incidence rate of injury per 1000 player hours for training (5.5) is similar to the 5.9 reported by Arnason *et al.,* (1996) in a study involving 84 Swedish Soccer players, and (3.4) reported by Hawkins *et al.,* (2001) in their audit of English professional Footballers. A notable finding of this study is that the incidence rate of injury per 1000 player hours for games in Gaelic Football (64) is much higher than the figures reported for Soccer (34.8 and 25.9) (Arnason *et al., 1996;* Hawkins *et al.,* 2001).

In common with other injury investigations, the overall incidence of injury in this study was much higher in games than in training. The intensity level in games tends to be higher than in training and may be attributable to the higher incidence of injury in games. However when looking at teams individually, five of the sixteen teams reported a higher number of injuries in training than in games respectively. To some observers this may be a disturbing finding that a number of teams participating in this study had a higher proportion of injuries in training than in games. This finding raises two interesting points; firstly, although more time was spent in training activities than playing games, one might expect a lower injury risk in training as a result of managerial supervision, a more controlled setting and a normally less hectic competitive environment compared with actual games. Alternatively, the teams that sustained more injuries in training than in games may have managed to successfully replicate typical game intensities in their training sessions; the training methods employed may have increased the risk of injury in training but they had the advantage of helping to reduce the risk of injury in games. In fact, the relative risk of injury in games compared to training was lowest amongst these five teams (teams 2,8,14,15, and 16), with players less likely to be injured in games compared to other teams. It may be worthwhile investigating the type of training methods used by this particular group of teams, to observe if specific injury prevention exercises that target potential sites of injury, such as knees and hamstrings, were incorporated into training sessions thereby helping to reduce the risk of injury in games.

1.52 The Temporal Profile of Injury

The temporal profile of injury is consistent across all teams especially while training. More injures occur in the final quarter of training (55%) and games (38%) than during any other period. Wilson *et al.,* (2006) reported a similar rise in the number of injuries as the game ran its course, 29% of total injuries occurred in the final quarter and 57% of all injuries occurred in the second half. Other codes similar to Gaelic Football have reported higher levels of injury in the second half than the first half (Arnason *et al., 1996;* Hawkins *et al.,* 2001). The high proportion of last quarter injuries may be due to local muscle fatigue and central brain fatigue (Davis 1996). Electomechanical delay and anterior tibiofemoral displacement have been suggested as potential factors for increased risk of injury particular in the latter stages of activity (Gleeson *et al.,* 1998). Muscle strength deficiency, a reduction in the capacity to absorb energy and a corresponding decrease in muscle force as a result of fatigue can increase the potential for injury (Garrett 1990). Mair *et al.*, (1996) reported that eccentric contractions of fatigued muscles are more susceptible to stretch injury, while Rahnama *et al.*, (2002) and Small *et al.*, (2008) reported an increase disposition to muscle strain injury, particularly to the hamstrings, in the latter stages of Soccer activity due to time dependent decrease in eccentric knee flexor strength and subsequently in the functional eccentric hamstrings to concentric quadriceps ratio.

Traditionally, final periods of training activity in Gaelic Football involve speed work in the form of repetitive sprint exercises which may put added pressure on hamstrings. The timing of this type of activity may well contribute to the higher occurrence of injury in the latter stages of training. High intensity hamstrings activities carried out by fatigued players are likely to increase susceptibility to injury (Muckle, 2004). Further investigation is needed to re-assess the content of training and in particularly the activities conducted during the latter stages of training sessions.

Recognising the high injury rates in the latter stages of games, the timing of substitutions may be important for injury prevention. Five substitutions are permitted during the course of the game. The prudent use of the substitutes before the last quarter of the game may help reduce injury rates. In some instances, tired players or players slightly injured at an early stage in the game may continue to play on thereby increasing their risk of injury. Consideration should be given to the timely removal of tired or injured players who may wish to continue playing.

1.53 Injury Site

The majority of injuries (70%) were soft tissue injuries particularly in the lower limb, a finding similar to the work of Cromwell *et al.,* (2000) and Wilson *et al.,* (2006) who found that lower body injuries predominated (77% and 71% respectively of all injuries). Previous Gaelic Football studies indicated that injuries to the ankle were the most common injury (Watson, 1996; Watson, 1999; Cromwell *et al.,* 2000; Wilson *et al.,* 2006). Although ankle injuries were very prevalent in this study (11%) and the most frequently occurring injury in games (15%), the higher incidence of hamstrings injury reported in this study (as compared to other Gaelic Football injury studies) is probably due to a number of reasons, a greater study population (16 elite teams), the participation of elite players only (rather than club players), the involvement of team physiotherapists (rather than player recall) to record the data, injuries recorded for a full season (rather than a proportion of the season) and nearly six times the amount of exposure time especially in training (39,786 hours v 6,678 hours) recorded than in previously published studies. The high incidence hamstrings injuries in this study is similar to results published for Australian Rules Football and Soccer where hamstrings strain topped the injury list (Seward *et al.,* 1993, Hawkins *et al.,* 2001).

Hamstrings injuries are primarily caused by sprinting and the stretch shortening cycle activities. Video analyses of hamstrings injury, particularly the phases leading up to the injury indicated that the injury was most likely to occur when players were running at high speed and when the body was leaning forward during the late swing phase of the cycle (eccentrically decelerating the forward motion) in preparation for foot contact (Lieber 1988, Orchard 2002, Verrall *et al.*, 2005). However the underlying aetiology of hamstrings injuries is unclear and many factors have been suggested, including poor flexibility, hamstrings-quadriceps muscle imbalance, muscle weakness, improper technique, inadequate warm-up, poor neuromuscular control, and fatigue (Orchard, 2001; Verrall *et al.*, 2001). There is evidence to suggest that hamstrings strains are associated with eccentric contractions, where the contracting muscle is lengthened (Garrett, 1996 and Kujala *et al.*, 1997). This theory has been developed further by Brockett *et al.*, (2004) and Proske *et al.*, (2004) by analysing mechanical changes in the hamstrings muscles as a precursor event to hamstrings strain, in particular microscopic damage of muscle fibres from eccentric contractions. In a three-year study in conjunction with a leading professional Australian Football League team, a new training programme was introduced that focussed on reducing the muscle's susceptibility for eccentric damage. Emphasis was placed on the activities that cause eccentric hamstrings contractions such as sprinting, kicking the ball, and picking up the ball (skills very similar to Gaelic Football), and a series of training exercises including 'straight-legged dead lifts', and the performing of 'knee-curls' on a gluteus-hamstrings-gastrocemius machine (GHG), (similar to a pommel horse apparatus in gymnastics, the individual stretches towards the ground from a kneeling position with his legs strapped to the apparatus, before returning to the start position, thus completing a knee-curl movement). Following the implementation of the training programme the number of reported hamstrings strain injury decreased from 16 to 5 after the first year, with only two incidences of hamstrings injury reported in the second year.

As Gaelic Football is a similar code to Australian Rules Football, it may be very beneficial to teams to monitor the success of eccentric exercise programmes currently in operation in Australia and introduce a similar programme to Gaelic Football. The idea of incorporating additional eccentric training during pre-season as an aid to reducing the incidence of hamstrings strain injuries, is an exciting prospect that warrants further investigation

1.54 Cause of Injury

The objective of the report form was to gather details of the cause of injury; consequently the category ‘overuse injury’ was deliberately omitted from the ‘cause of injury’ as it is a vague term and open to interpretation. Although Gaelic Football is a contact field game, injuries not involving player-to-player contact were more frequent than direct contact injuries, contrary to other Gaelic Football injury studies, where tackling and collisions accounted for the majority of injuries sustained (Watson, 1996; Cromwell *et al.*, 2000; Wilson *et al.*, 2006) The main causes of non-contact injury included running, jumping, sprinting and twisting. It may be possible for trainers and coaches to monitor the frequency of running exercises in training sessions and allow adequate time for recovery in order to reduce the incidence of non-contact injuries.

Collisions with another player and tackles accounted for 66% of contact injuries. Younger players (<23 years) sustained the highest proportion of shoulder injuries and this may be due to differences in physical strength and experience at playing at elite level compared to their older counterparts. The use of shoulder protection equipment (as used by Rugby Union players) may help reduce the number of shoulder injuries in Gaelic Football; younger players in particular should be encouraged to wear shoulder protection. However there are no clear guidelines in the rules of Gaelic Football regarding the use of shoulder protection. Similarly, improved tackling techniques may help reduce the risk of injury associated with player-to-player contact, consequently it may be worthwhile investigating the different tackling methods used by players particularly the types of tackle that resulted in injury.

1.55 Ground Conditions

Although playing position was not a factor in terms of injury, ground conditions were however related to injury. Significantly more injuries occurred when underfoot conditions were dry and hard compared when they were wet or muddy. Studies conducted in Australian Rules Football which monitored ground conditions particularly the hardness of the ground (measured by a Penetrometer) prior to games to assess the risk of injury, reported a significant positive relationship between the incidence of acromioclavicular joint sprains and ground hardness (Orchard, 2001). Similarly in the UK, injury rates in Rugby League increased when the season changed from winter to summer suggesting harder grounds may be a universal risk factor for sports injuries (Hodgson *et al*, 2000). It may be very worthwhile to conduct a similar study on the incidence of injury and ground hardness in Gaelic Football; Due to the size of the geographical county that each elite Gaelic Football team represents it is not unusual for teams to train in different venues during the season; although some teams have dedicated training centres the majority of teams train in different locations. For example teams may alternate training sessions between the north and the south of the county. Conducting training in different venues may be predisposing players to injury due to subtle variances in ground hardness. One of the physiotherapists that participated in this study was adamant that the playing surface was a strong contributing factor to the high incidence of knee injuries due to very hard underfoot conditions. Similarly teams play games in different venues throughout the season and subtle changes in ground conditions may increase the potential risk of injury. A recent study by Orchard *et al.*, (2005) investigated an association between Football boot interactions and underfoot grass type and concluded that rye grass offers more protection against non-contact anterior cruciate ligament injuries compared with Bermuda grass.

1.56 Footwear

Nearly a quarter of players in this study wore blades-type Football boots and there is a suggestion of a potential relationship between the wearing of blades and knee injury. Recent media reports have questioned the design of lightweight Football boots, particularly with regard to the frequency of meta tarsal injuries amongst high profile Soccer players (Hall, 2004; Sawdon-Smith, 2004). Some professional Soccer clubs have even outlawed the wearing of blades by members of their academy. While boot selection amongst other factors may have an influence on injury rates, the interaction between ground conditions and boot traction may be more relevant with regard to the risk of injury (Orchard, 2002) particularly as a large number of injuries are ligamentous involving the ankle or knee. Testing the traction of various boots on different underfoot surfaces is an area that should be investigated, particularly as Gaelic Football is played in all seasons. A study by Chan *et al.,* (1993) indicated a direct correlation between footwear and both performance and rates of injury. Brizeula *et al.,* (1998) investigating the biomechanical design of Football boots and effect of studs on performance and injury prevention, reported that boots with a greater number of studs were associated with poorer performance compared with boots with fewer studs primarily because of inferior traction with the ground. Similarly, players should consider the benefits of wearing customised Football boots, i.e. Football boots with insoles devices designed specifically for the wearer, as a combination of poor running technique and inappropriate footwear may have the potential of increasing the risk of injury (Misevich and Cavanagh, 1984; Cavanagh 1985; Nigg, 1986).

1.57 Consequences of Injury

The majority of players in this study (65%) were unable to participate in Gaelic Football activity for between one and three weeks as a result of injury. Although the majority of the injuries did not require hospitalisation, they did require medical treatment and rehabilitation, and as well the direct costs involved, the injury may have immediate serious financial implications, particularly for players who are self-employed.

There is also the possibly that repeated injury and inadequate rehabilitation may potentially predispose players to re-injury and future medical problems such as early development of osteoarthritis and joint damage in later years (Drawer and Fuller, 2001). Football injury studies by Ekstrand and Gillquist (1983) and

Nielsen and Yde (1989) reported that 17% and 25% respectively of injuries reported were re-injuries attributed to inadequate rehabilitation or the player not having recovered completely from a previous injury. Lysens (1988) and Hawkins and Fuller (1999) have reported re-injury rates of 30% for muscle strains and ligamentous sprains, and Ekstrand (1983) and Hawkins *et al.*, (2001) reported that major injuries were preceded by minor injuries in the same locality, highlighted the case for controlled rehabilitation programme. The risks and costs of participation in Gaelic Football should be investigated further and in particularly the incidence of Gaelic Football related medical conditions amongst ex elite Gaelic Football Players.

1.58 Summary of Main Findings

Reduction in the occurrence of injury is the goal of injury surveillance research. The present study has identified the incidence and severity of injury in Gaelic Football over one full season in accordance with the model set out by Van Mechelen (1992) (Figure 1.1). The sixteen teams that participated in the present study provide a representative sample of the elite Gaelic Football population, as teams from the top, middle and lower leagues were included. The participation of all teams would facilitate a more comprehensive study; consequently team participation should be mandatory for all future Gaelic Football Injury research.

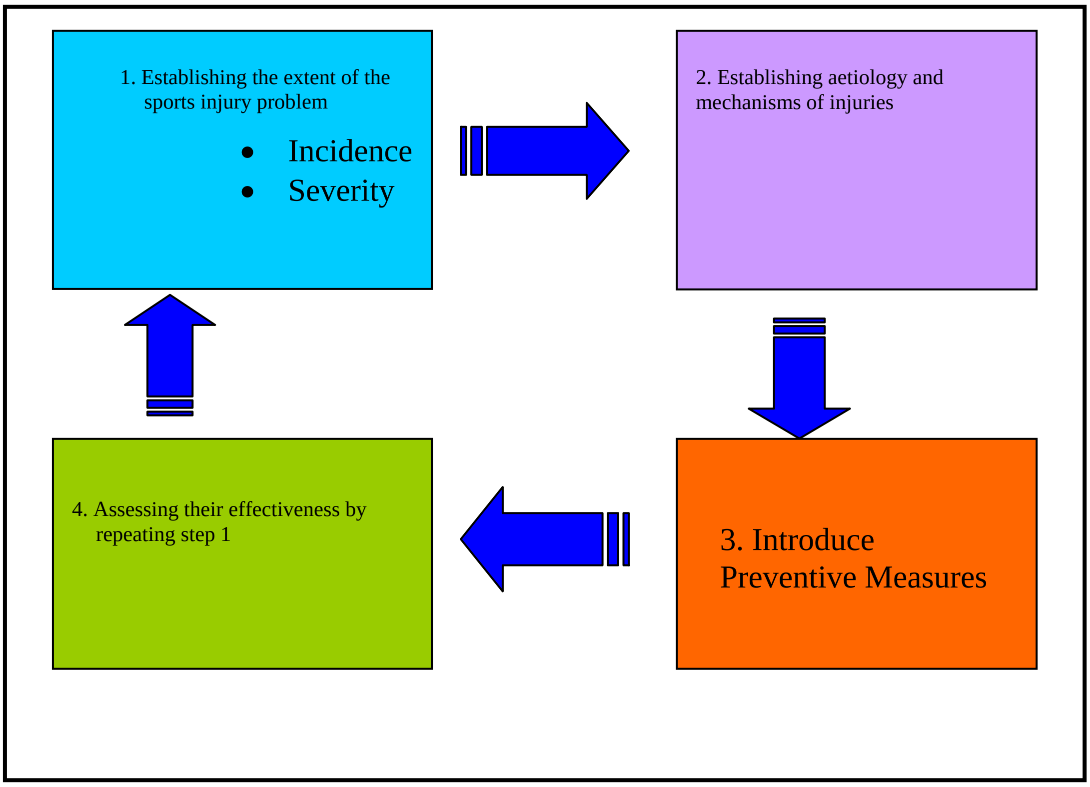


Figure 1.1 The 'sequence of prevention' of sport injuries

(Van Mechelen *et al.*, 1992)

Accordingly, the next step requires further analysis of the injury statistics and in particular a detailed inquiry of the underlying aetiology of injury. For example the results indicate that the pattern of injury is similar throughout the different teams and there is little variation between the teams with regard to timing, site, and types of injury. However, further investigation is warranted in order to explain the striking pattern of hamstrings injuries, particularly in the latter stages of training. The Gaelic Athletic Association should emulate the work carried out by the governing bodies of Australian Rules Football and Soccer; in particular the continuous injury audits published annually and the results of specific injury surveillance research projects. Comparisons with injury data from previous seasons have resulted in the successful implementation of changes in training techniques and facility regulations in accordance with the steps outlined in Van Mechelen's 'sequence of prevention' of sport injuries.

From a player education point of view, the information generated by injury studies is extremely beneficial and should be distributed to players at all levels of the game. While the focus is normally on players participating at elite level, the movement characteristics of the game are the same at all levels, and recommendations with regard to injury prevention will then be valuable to all players not just Gaelic Footballers.

Chapter 2

Study 2:

Are pre-season leg muscle strength ratios a predictor of hamstrings injury in elite Gaelic Football players?

2.1 Introduction

As a follow-up to the initial injury surveillance study (Newell *et al.,* 2006), and in accordance with the phases outlined in Van Mechelen's model (1992), the next phase of research focussed on the aetiology of hamstrings injuries. In particular to investigate if hamstrings muscle strength or functional hamstrings/quadriceps ratio (H:Q ratio) is a predictor of hamstrings injury in Gaelic Football.

Gaelic Football is a high intensity game that requires repetitive bouts running, turning, sprinting, jumping and kicking, and the physical and contact nature of the game inevitably lead to a degree of risk which associated with a certain number of unavoidable injuries (Doran, 1984). The fact that 22% of all injuries sustained during a single season were hamstrings injuries classified mainly as a non-contact injury, with little variation between the teams with regard to the timing of injury, is a worrying trend that warrants further investigation (Newell *et al.,* 2006).

As emphasised by Van Mechelen's injury audit cycle (1992), understanding the mechanism of injury is integral to injury prevention. A greater challenge lies in identifying the underlying aetiology of hamstrings injury, prescribing effective preventive methods, and facilitating rehabilitation (Worrell, 1994, Mason *et al.,* 2007). With contrasting results, follow up studies to initial injury surveillance reports have explored suggested risk factors for hamstrings injury, such as low level of fitness, inadequate warm up, body position, poor flexibility, increased muscle stiffness, poor lumbar posture, muscle fatigue and strength imbalance of reciprocal muscle groups of the thigh (Burkett 1970; Rochcongar *et al.,* 1988; Yamamoto 1993; Orchard *et al.,* 1997;Bennell *et al.,* 1998; Gur *et al.,* 1999; Ahmed *et al.,* 2000; Cometti *et al.,* 2000; Orchard 2001; Proske and Morgan 2001; Verrall *et al.,* 2001; Askling *et al.,* 2003; Cameron *et al.,* 2003; Mjolsnes *et al.,* 2004).

Follow-up studies to initial injury surveillance reports in Australian Rules Football have suggested inequalities in the Hamstrings/Quadriceps strength ratio as possible risk factors for hamstrings injury, with significant correlation between hamstrings muscle strength and risk of hamstrings injury (Burkett, 1970; Yamamoto, 1993; Orchard *et al.,* 1997; and Cameron *et al.,* 2003).

Prospective studies by Burkett (1970), Yamamoto (1993), Orchard *et al.,* (1997) and Cameron *et al.,* (2003) have found a significant correlation between hamstrings muscle strength and risk of hamstrings injury. Orchard *et al.,* (1997) examined the possibility of pre-season hamstrings muscle weakness associated with hamstrings muscle injury. Thirty-seven professional Footballers had pre-season measurements of hamstrings and quadriceps muscles strength. Players were studied prospectively throughout the season and six players (16%) sustained hamstrings muscle injuries. They concluded that muscle strength testing could determine if Australian Rules Football players were at risk of hamstrings injury.

Bennell *et al.,* (1998) assessed the maximum voluntary concentric and eccentric torque of hamstrings and quadriceps muscles in both legs of 102 Australian

Rules Football players at the start of the season. They observed the players throughout the season and twelve players (12%) sustained hamstrings injuries. However, their results found that isokinetic strength testing was not a predictor of hamstrings injury. While their study did not support an association between pre-season muscle weakness or imbalance and subsequent occurrence of hamstrings muscle strain, they did not however exclude muscle weakness or imbalance as playing a role. The contrasting results reflect the multifactorial and heterogeneous nature of hamstrings injury.

Up to now no study has examined hamstrings muscle strength or functional H:Q ratio as a predictor of hamstrings injury in Gaelic Football. Studies involving Australian Rules players have recruited between 21 and 102 subjects. Based on these studies it is considered that 75 subjects will be adequate for the study. Previous research (Newell *et al., 2006*) has shown an incidence of 22% hamstrings injury in Gaelic Footballers over the course of a season and the expected number of hamstrings injuries is 15. Thus, it will be possible to compare the characteristics of those subjects with and without hamstrings injury. The aim of this observational study was to help determine the relationship between isokinetic strength variables and hamstrings injury, and if muscle weakness and muscle imbalance have an impact on injuries in Gaelic Football.

2.2 Literature Review

2.21 Hamstrings Injury: Anatomy and Function

Hamstrings injuries are frustrating, the bane of athletes, coaches, and medical staff, because the symptoms are persistent, healing is slow, and the rate of recurrence is high (Orchard, 2002) Although there is a wealth of scientific information about the incidence, nature, and severity of injury, and numerous risk factors have been suggested, the underlying aetiology, effective preventive methods, and rehabilitation is a challenging complex issue (Worrell, 1994, Mason *et al.,* 2007).

The hamstrings are biarticulate muscles comprising of three separate muscles, the Semitendinosus, the Semimembranosus, and the Biceps Femoris. These muscles make up the bulk in the back of the thigh and originate form the ischial tuberosity just below the Gluteus Maximus on the pelvic bone and run down the back of the thigh crossing the knee joint to connect with each side of the tibia (Figure 3.1). The hamstrings function by pulling the leg backward and by propelling the body forward while walking or running. As well as contributing to propulsion primarily through hip extension, the primary function of the hamstrings is to decelerate and stabilise the hip and knee joints in preparation for ground contact (Mann *et al.,* 1996).

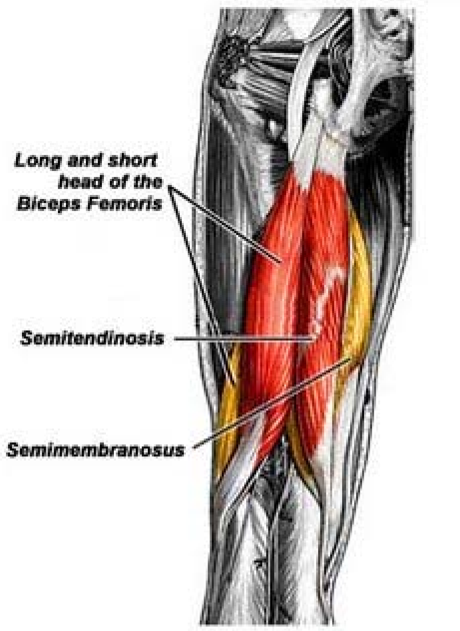


Figure 2.1 The anatomy of the Hamstrings Muscles (www.sprintingpower.com)

Biomechanical research of sprinting mechanics indicates that the hamstrings attain peak length just prior to ground contact (terminal swing phase). At this stage the rate of knee extension is controlled by the lengthening of the active muscles (negative or eccentric muscle action), to maintain balance in preparation for ground contact before a rapid change to concentric muscle action (positive or shortening of the active muscle) to assist propulsion by extending the hip at foot contact. It is proposed that at this phase, the period of maximal eccentric contraction in the running cycle, when the muscle is both lengthening and contracting at the same time that most hamstrings injuries occur (Heiderscheit *et al.*, 2005).

Hamstrings injuries are stretch induced injuries rather than resulting from direct trauma. Muscle strains in the semimembranosus, the semitendinosus, or the biceps femoris injuries tend to occur at the musculotendinous complex (area where muscles and tendons join) during maximum sprinting as the hamstrings muscles work closest to their injury threshold (Safan *et al.,* 1988; Garrett, 1996). It is suggested that hamstrings strains are associated with sports that involve stretch shortening cycle activities such as sprinting, high intensity running, stopping and starting, and often occur due to over-striding when at fast speed (Brooks *et al.,* 2006). In order to maintain or achieve extra speed the body may be leaning forward and consequently the foot lands too far in front of the centre of mass stretching the hamstrings (Orchard, 2002, Verrall *et al.,* 2005). Sports that involve kicking actions also predispose hamstrings muscles to injury as greater forces are required to propel hip flexion and control eccentric breaking during the kicking motion (Carlson, 2008).

Muscle strain results in damage to individual muscle fibres, the human body has a natural ability to repair and protect the damage by producing enzymes and other chemicals at the site of injury to help rebuild muscle tissue. These chemicals produce the symptoms of localised swelling and pain. If blood vessels are damaged as can occur with severe injury, the muscle takes more time to heal. In some instances surgery may be required if an injury causes the muscle and tendons to detach from the bone (avulsions) particularly at the ischial tuberosity.

2.22 Risk Factors of Hamstrings Injury

Sports that require repetitive high intensity bouts of sprinting such as Gaelic Football, Australian Rules Football, Rugby Union, and Soccer have observed a high incidence of hamstrings injury (Heiser *et al.,* 1984; Orchard 2001; Woods *et al.,* 2004; Sherry and Best 2004; Brooks *et al.,* 2005) Hamstrings strain injuries have been the subject of many epidemiological and injury surveillance studies across different sports, Australian Rules Football (12-23% of all reported injuries) and Soccer (12% of all reported injuries) (Seward *et al.,* 1993; Orchard *et al.,* 1997; Bennell *et al.,* 1998; Hawkins *et al.,* 2001; Verrall *et al.,* 2001; Arnason *et al.,* 2004, Woods 2004), and Rugby Union (6-15% of all reported injuries) (Seward *et al.,* 1993; Brooks *et al.,* 2005). The results have raised concerns about the high incidence of hamstrings injury and the associated medical and financial costs

Evidence based information on the risk factors of hamstrings injury remains a challenge (Orchard, 2001; Crosier, 2004), as the evidence is often limited, inconclusive or contradictory particularly with so many variables interacting to produce an injury (Orchard, 2002; Murphy *et al.*, 2003). Risk factors are divided into two main categories, internal (intrinsic) athletic related factors including age, gender, body composition, physical fitness, health, and external (extrinsic) factors such as environment, equipment worn, and opponents. Bahr and Holme (2003) suggest that it would be more relevant to use the distinction between modifiable factors such as hamstrings to quadriceps muscular strength imbalance, muscle fatigue, tightness of the hamstrings, insufficient warm up and previous injury, and non-modifiable factors such as older age and black or aboriginal ethnic origin (Verrall *et al.,* 2001; Woods *et al.,* 2004; Barr and Holme, 2003).

Some of the internal risk factors identified in the literature include low level of fitness, inadequate and improper warm up, poor muscle strength imbalance in leg muscle strength body position, poor flexibility, increased muscle stiffness, poor lumbar posture, and muscle fatigue, neuromeningeal tightness, age, and previous injury (Burkett, 1970; Liemohn, 1978; Ekstrand and Gillquist 1983; Safran *et al.*, 1988; Worrell *et al.*, 1991; Yamamoto, 1993; Heiser *et al.*, 1994; Jonhagen *et al.*, 1994; Mair *et al.*, 1996,; Orchard *et al.*, 1997; Clark 2001; Croisier *et al.*, 2002; Wilk *et al.,* 2003; Croisier, 2004).

Orchard (2001) reported that previous injury was the most significant risk factor for hamstrings injury in Australian Rules Football. Witvrouw *et al.,* (2003) observed a strong correlation between pre-season hamstrings tightness and subsequent hamstrings injury in Soccer players. Jonhagen *et al.,* (1994) examined the role of concentric and eccentric muscle strength and flexibility in sprinters and concluded that sprinters with a history of hamstrings injury tended to have tighter hamstrings than sprinters with no history of previous hamstrings injury. Among the external risk factors identified included inferior playing surfaces and inappropriate footwear (Rochcongar *et al.,* 1988; Gur *et al.*, 1999; Ahmed *et al.,* 2000; Cometti *et al.,* 2000; Verrall *et al.,* 2001; Orchard 2001).

2.23 Strength Imbalance Ratios

Inequalities in the strength of the hamstrings muscles have been proposed as possible risk factors for injury. Burkett (1970) and Christenson and Wiseman (1972) first documented the importance of hamstrings strength. Using cable tensiometers they observed the interaction between the ability of the quadriceps to generate speed and the ability of the hamstrings to resist the resultant forces.

Hamstrings strength was expressed relative to quadriceps strength and was calculated by dividing the maximal knee flexor (hamstrings) moment by the maximal knee extensor (quadriceps) moment measured at identical angular velocity and contraction mode. This measurement is known as the conventional hamstrings to quadriceps ratio (H:Q ratio). Conventional H:Q strength ratios vary from 31% to 80% with the recommended optimum HQ ratio between 50% and 80% through the full range of knee motion (Stafford and Grana 1984; Oberg *et al.*, 1986; Kannus, 1988; Aagaard *et al.,* 1995; Li *et at.,* 1996; Rosene *et al.,* 2001; Silva *et al.,* 2003).

Kannus (1988) measured the H:Q strength ratio in patients with anterior cruciate ligament insufficient knees as a predictor of patient's long-term prognoses. Quadriceps and hamstrings strengths of both legs were measured at 60^0/sec and 180^0/sec respectively. Results indicated that there was high inter subject variability among the 41 subjects, the injured knee had a higher HQ (46-95%) ratio than the non injured knee (42%-85%). Oberg *et al.,* (1986) measured concentric peak torques of hamstrings and quadriceps muscles in Soccer players and observed that higher level players had greater strength. Zakas *et al.,* (1995) reported that there was no significant difference in the H:Q ratio amongst four divisions of Greek Soccer players. Rosene *et al*., (2001) compared the differences in the concentric hamstrings: quadriceps ratio among collegiate athletes participating in different sports (Table 2.1). Mean peak torque at 180^0/sec was significant higher than 120^0/sec and 60^0/sec respectively. There was no significant difference for H:Q ratio scores, side of body, or sport.

Table 2.1 *H:Q ratio of right and left legs for mean peak torque by sport and velocity (^{0}/sec) in collegiate athletes (adapted from Rosene et al., 2001).*

	PT Hcon/Qcon Ratio						
	Right Side				Left Side		
Angular velocity (^{0}/sec)	60	120	180		60	120	180
Soccer athletes	50.82	60.87	60.77		50.18	56.34	58.31
Volleyball athletes	50.94	50.02	57.71		47.09	51.3	57.56

Using the conventional H:Q ratio measurement suggests that concentric or eccentric contraction would take place for the knee extensors and flexors at the same time. In reality this is not the case as true knee movement only allows eccentric hamstrings muscle contraction to be combined with concentric quadriceps muscle contraction during extension or vice versa during knee flexion. It is now suggested that the agonist-antagonist strength relationship for knee extension and flexion is better described by a functional H:Q ratio of eccentric hamstrings to concentric quadriceps muscle strength (Hecc:Qcon representative of knee extension) or concentric hamstrings to eccentric quads muscle strength (Hcon:Qecc representative of knee flexion) (Aagaard *et al.*, 1998).

An H:Q ratio of 1 would indicate equal strength in both muscle groups, with the hamstrings having an increased functional capacity for providing stability of the knee. An overall trend can be observed as velocity increases so does the H:Q ratio in accordance with the force-velocity relationship (eccentric hamstrings torque remains relatively constant while quadriceps torque decreases as angular velocity increases).

Cometti *et al.*, (2001) measured isokinetic leg strength of elite, subelite, and amateur French Soccer players. There was significant difference in the functional Hecc/Qcon ratio among the three groups. The elite players had higher knee flexor torque and a higher hamstrings/quadriceps ratio than the amateurs at all velocities except 300^0/sec. Mean values were reported for both conventional H:Q ratio (range from 0.56 to 0.82) and functional H:Q ratios (range from 0.68 to 1.0) at different angular velocities (Table 2.2).

Table 2.2 Mean *Conventional H:Q ratio and Functional H:Q ratio for elite, sub elite, and amateur French Soccer players (adapted from Cometti et al., 2001).*

H:Q Ratio	Conventional: Hcon/Qcon					Functional: Hecc/Qcon	
Angular velocity (^{0}/sec)	60	120	180	240	300	60	120
Elite	0.68	0.74	0.76	0.82	0.80	0.82	0.98
Sub elite	0.66	0.71	0.72	0.74	0.75	0.8	1.0
Amateur	0.56	0.68	0.73	0.73	0.81	0.68	0.8

Kong and de Heer (2008) measured the strength characteristics of Kenyan distance runners and reported a higher functional H:Q ratio than athletes in other sports (1.03 ± 0.51 at 60^0/sec, 1.44 ± 0.46 at 120^0/sec, and 1.59 ± 0.66 at 180^0/sec). The increased functional H:Q ratio at increasing angular velocity was not significant, nor was there any significant difference in strength values between the two legs. An interesting observation from this study was the fact that none of the athletes participated in strength training, and although their leg strength was relatively low compared to other runners they had a higher H:Q ratio compared to athletes in other sports. The authors attributed the high scores to the athletes running routine and possible genetic or cultural influences. Similarly it was unclear whether the athletes' high H:Q ratio positively contributed to the athletes' lack of injury.

As well as H:Q ratios, bilateral strength asymmetry ratios of both hamstrings and quadriceps are used to quantify functional deficit as a result of injury or surgery as a means to allowing an athlete return to full competition (Impellizzeri *et al.*, 2008). Inequalities in the strength of the hamstrings muscles may be unilateral (same limb) or bilateral, (i) such as between the dominant and non dominant, (ii) injured and non-injured, and (iii) right and left. However values depend on the angular velocity at which isokinetic strength was determined, the selected subjects, and the physical fitness of subjects.

Farrel and Richards (1986); Harding *et al.*,(1988); Tredinnick and Duncan (1988); Wilhite *et al.,* (1992); Mayhew *et al.,* (1994); Kellis *et al.,* (2001); Sole *et al.,* (2007) established the reliability of using an isokinetic dynamometer to measure strength imbalance ratios and absolute isokinetic muscle strength at different angular velocities. Reliability was expressed as interclass correlation coefficient and was found to be highest for strength imbalance rations with eccentric hamstrings to concentric quadriceps ratio as compared with the conventional H:Q ratio.

Holcomb *et al.,* (2007) used functional H:Q ratios to evaluate the effect of a 6 week strength training programme in female collegiate Soccer players. Following a series of strength exercises that included two hamstrings specific exercises, the H:Q ratio increased significantly from 0.96±0.09 in pre-test to 1.08±0.11 in post-test.

2.24 Hamstrings Muscle Strength as a Predictor of Hamstrings Injury

Research studies investigating the potential role of inequalities in hamstrings muscle strength as a predictor of hamstrings injury have reported conflicting results. Early studies by Burkett (1970) and Christensen and Wiseman (1972), considered that a bilateral deficit of 10% in isometric hamstrings strength was predictive of hamstrings injury. Prospective studies by Burkett (1970), Yamamoto (1993), Orchard *et al.*, (1997) and Cameron *et al.*, (2003) have found a significant correlation between hamstrings muscle strength and risk of hamstrings injury. Whereas studies by Paton *et al.,* (1989), Worrell *et al.*, (1991), Bennell *et al.*, (1998), Crosier and Crielaard (2000), and Brockett *et al.*, (2004) suggested that the Hamstrings to Quadriceps ratio was not a risk factor for hamstrings injury. Orchard *et al.,* (1997) associated hamstrings injury with significantly lower concentric isokinetic hamstrings to quadriceps muscle peak torque ratio and a lower hamstrings side to side peak torque at 60 degrees/sec (Bennell *et al.*, 1998).

Studies of track and field athletes with hamstrings injury did not find any differences in isometric hamstrings/quadriceps ratios between injured and non injured groups (Liemohn, 1978), or between hamstrings-injured and control athletes in hamstrings strength indices of eccentric and concentric peak torques (Paton *et al.,* 1989; Worrell *et al.,* 1991). The contrasting results reflect the multifactorial and heterogeneous nature of hamstrings injury as well as difficulties in methodology.

Studies involving Australian Rules Footballers have found diverging results. Orchard *et al.,* (1997) examined the possibility of pre-season hamstrings muscle weakness associated with hamstrings muscle injury. Thirty-seven professional Footballers participated in the study. Measurements of pre-season hamstrings and quadriceps muscles strength were recorded. Players were observed prospectively throughout the season, and six players (16%) sustained hamstrings muscle injuries. The injured hamstrings muscles were all weaker than in the opposite leg in absolute values and hamstrings-to-quadriceps muscle ratios. Their results indicate that pre-season isokinetic testing of professional Australian Rules Footballers can identify players at risk of developing hamstrings muscle strains.

In a larger study, Bennell *et al.,* (1998) assessed the maximum voluntary concentric and eccentric torque of hamstrings and quadriceps muscles in both legs of 102 Australian Football rules players at the start of the season. They observed the players throughout the season and twelve players (12%) sustained hamstrings injuries. However their results found that isokinetic strength testing was not a predictor of hamstrings injury. While their study did not support an association between pre-season muscle weakness or imbalance and subsequent occurrence of hamstrings muscle strain, however they did not exclude muscle weakness or imbalance as playing a role.

2.25 Likely Mechanisms of Fatigue and Gaelic Football

Fatigue is a complex multifactorial phenomenon whose mechanisms are influenced by the characteristics of the task being performed (Boyas and Guevel, 2011). According to Miller (2006) there are at least four different ways of describing the symptoms of fatigue, (i) asthenia, a generalised lack of energy, (ii) mental exhaustion, (iii) reduced muscular endurance, and (iv) a delayed recovery following exercise. From a sports science prospective, fatigue is defined as "failure to maintain the required or expected power output" (Edwards 1983) that is associated with sustained exercise (Reilly 1994). Power refers to the intensity of exercise that can be sustained while work is concerned with the amount of exercise that can be performed (Asmussen, 1979). Fatigue is a normal consequence of continuous high intensity exercise for prolonged periods of time and has been conceptualised as 'being driven by changes occurring anywhere in the chain between the brain and the muscle fibre' (Weir *et al.*, 2006). The cause of fatigue is complex phenomenon influenced by events occurring in the brain, spinal cord and central nervous system (central fatigue) and within the motor unit (periphery fatigue) and depends on the individual, the environment and the specific task (Meeusen *et al.*, 2006; Nimmo and Ekblom, 2007).

Central fatigue refers to inadequate excitation and activation within the central nervous system due to a decrease in performance of the action potentials in motor neurons resulting from a decrease in outflow signals (motor impulses) to the muscles arising from the central nervous system. Central fatigue is often attributed to a lack of motivation, a lack of effort, inattention, and pain (Miller, 2006). It seems to occur particularly during submaximal, low-intensity muscle contractions (Boyas and Guevel, 2011). Peripheral fatigue refers to a site of breakdown within the peripheral nerve, the neuromuscular junction, or within the muscle itself. Peripheral fatigue is due to altered local muscle function resulting from repeated muscle contractions and is attributable to different physiological mechanisms including a decrease in phosphocreatine and glycogen stores, failure of ATP resynthesis (the universal energy molecule), low blood glucose level, increased muscle acidity and accumulation of ADP and inorganic phosphate ions, changes in muscle temperature (especially after half time interval), dehydration, and changes in core temperature (Saltin 1973, Newsholme *et al.*, 1992, Mohr *et al.,* 2005). Peripheral or central fatigue may appear separately or combined depending on the specific situation. The sites and mechanisms potentially affected by neuromuscular fatigue are shown in the table 2.1.

Table 2.1 Sites and mechanisms potentially affected by neuromuscular fatigue (Modified from Ament and Verkerke (2009) in Boyes and Guevel (2011))

Central Fatigue	Peripheral Fatigue
1. Propagation of axonal action potentials may be blocked at the axonal branching sites, inducing a loss of activation of the muscle fibre. The significance of this factor remains to de determined. 2. Motor neuron command may be influenced by reflex activities induced by muscle afferents. Hence, central fatigue could be compensated for by reflexes due to mechanoreceptors (neuromuscular spindles and Golgi tendon organs). 3. The stimulation of type III and IV nerves (chemoceptive and nociceptive afferents may induce a drop in motor neuron discharge rate and an inhibition of motor cortex command. 4. The excitability of the cells within the motor cortex may vary during a sustained motor task. 5. The synaptic effects of serotoninergic neurons could argument and thus induce an increase in the sensation of fatigue. This could occur after an increase in the brain's uptake of serotonin precursor trytophan. During prolonged exercise, this type of increase could be related to the drop in the plasma concentration of branched chain amino acids. 6. The exercise could lead to the release of cytokines such as interleukin-6, which is associated with the sensation of fatigue.	1. Changes in the intracellular environment. Accumulation of lactate and hydrogen ions. Accumulation of ammonia. Accumulation of heat which includes greater sweat secretion. The water loss associated with this phenomenon could lead to dehydration 2. Changes within the muscle fibres Accumulation of inorganic phosphate in the sacroplasma, inducing a drop in the contractile force due to inhibition of the cross-bridge's interactions. Accumulation of hydrogen ions in the sacroplasma, inducing a drop in the contractile force due to inhibition of the cross-bridge's interactions. Moreover this accumulation could trigger impaired reuptake of calcium by the sacroplasmic reticulum (SR). This could be the main cause of the extended relaxation period after a fatiguing contraction. Accumulation of magnesium in the sacroplasma. The magnesium ions may limit calcium release by the SR. Inhibition of the calcium release by the SR, due to accumulation of inorganic phosphate. Calcium release is inhibited by (i) precipitation of calcium phosphate and (ii) phosphorylation of the calcium channels. A decrease in glycogen reserves and (in extreme cases) a drop in blood glucose. The depletion of glycogen reserves leads to fatigue through mechanism that is not well understood. A drop in blood glucose-even a temporary one- could strongly perturb the operation of the central nervous system. Drop in the nerve action potentials speed of propagation along the sacrolemma, probably as a result of biochemical changes inside and around the muscle fibres. The fall in propagation speed is illustrated by a change in the frequency content of EMG signal but has no known immediate effect on force generation. Increase in the efflux of potassium ions from the muscle fibres. The increase in potassium in the lumen of the transverse tubules could block action potentials at this point and hence diminish the force generated due to impaired excitation-contraction coupling.

System failure is the consequence of the peripheral model (when demand overwhelms the capacity of peripheral tissues) and can only be avoided by a reduction in workload or cessation of exercise. Fatigue is also considered as a mechanism for limiting the harmful effects of exhausting muscle exercise (Boyas and Guevel, 2011). An alternative model the central governor model (CGM) has been proposed as a general model to explain the phenomenon of fatigue (Weir *et al.*, 2006). According to this model power output is regulated by the subconscious brain which predetermines the pacing strategy undertaken by the body to allow completion of the task in the most efficient way, preserve homoeostasis and prevent catastrophic failure (Noakes *et al.*, 2004). According to the advocates of the CGM model, ADP depletion does not occur during high intensity exercise and homoeostasis is maintained by active neural processes that act as afferent signallers (teleoanticipation) to prevent the development of absolute fatigue by programming in advance the power output and pacing strategies of the planned exercise activity (Ulmer 1996). Exercise activity is planned and controlled at a subconscious level (incorporating knowledge from previous exercise bouts) of what is required to complete the exercise activity within the biomechanical and metabolic constraints of the body (Hampson *et al.*, 2003).

To summarise, as pointed out by Hornery *et al.*, (2007) fatigue during exercise activity is often as a direct result of an athlete reaching one or a combination of the following states: the accumulation of metabolic by-products, dehydration, hypoglycaemia and/or central disruption.

Successful Gaelic Football performance cannot be defined by a single predominating physical attribute as the game requires a complex interaction of agility, speed, power, and muscular and aerobic endurance. Players must repeatedly perform energy-demanding activities such as intermittent short and quick movements including sprinting, sudden acceleration or deceleration, turning, catching, kicking and jumping, as well as display supreme anticipatory and decision making capacities in pressure situations and varying environmental conditions. Work rates are determined by individual exercise intensity as well as the prevailing demands of competition on the entire team as a group (Reilly *et al*., 2008). The cumulative effects of high intensity efforts may disrupt the physiological, cognitive, and psychological processes and impose limitations on performance (Hornery *et al.,* 2007).

While there is a paucity of scientific papers investigating fatigue and performance in Gaelic Football, there is a large amount of published research investigating the role of fatigue in soccer performance. As there are many similarities between the two codes particularly with regard to the physiological characteristics of players, the intensity level, and work rates, it may be useful to imply the experimental observations in soccer to Gaelic Football.

Several studies investigating fatigue and soccer have found a decline in work-rates of players during a game especially in the second half of games with regard to the amount of distance covered by players and a decrease in amount of sprinting and high intensity running (Reilly and Thomas, 1976; Bangsbo *et al.*, 1991; Bangsbo 1994) and particularly in the last fifteen minutes of a game (Mohr *et al*., 2003). University players in Belgium covered on average 444m more in the first half than in the second half of the game (Van Gool *et al.,* 1988). Elite Italian players covered 160m more in the first half than in the second half respectively (Mohr *et al*., 2003). Ekblom (1986) reported that elite level Swedish soccer players competing in a top professional league tended to have higher core temperatures and covered a greater distance than players competing at a lower level.

At elite level, Gaelic Football players will typically perform circa 100 sprints per game each lasting between 2 and 5 seconds and recovery time tends to be minimal. An important conditioning element is therefore the ability to perform and recover from repeated sprints. Research in soccer has found that the ability to perform repeated sprints varies between before the start of a game and after the end of a game (Robelo *et al.,* 1998; Mohr *et al.,* 2004; Krustrup 2006) with most players experiencing fatigue towards the end of the game. Substitutes who joined the game in the second half sprinted and ran at a higher intensity as opposed to players who had played the full game (Mohr *et al*., 2003). According to Krustrup (2006) in practical terms this reduced sprinting performance equates to players covering a 30 metre distance about 8% slowly than at the start of the game, equating to a concession of 2 meters as a result of fatigue. A big advantage particularly if an attacker and defender are sprinting for the same ball and the defender is starting to fatigue.

In Gaelic Football the ball is played predominantly in the air and players are required to perform repeated intermittent short and quick movements prior to take-off and again on landing from jumps. The ability to perform these energy-demanding activities has been observed to be lower after versus before a soccer game (Rebelo 1999; Mohr *et al.,* 2004). Jump performance has been observed to be accompanied by reductions in EMG activity particularly after prolonged continuous running (Avela and Komi 1998, Oliver *et al.,* 2008).

Saltin (1973) demonstrated that a reduction in glycogen stores is associated with fatigue during prolonged intermittent exercise. Using muscle biopsies from the vastus lateralis to measure muscle glycogen stores pre-game, at half-time, and post-game, it was found that prior to the game players who had rested the day before had more than double the values for muscle glycogen stores than players who trained the day before the game. A similar pattern was reported at half time. Although there was no significant difference in the distance covered by the two groups of players in the first half, there was however a marked difference in the amount of distance covered in the second half. Players low pre-match muscle glycogen spent more time walking and less time sprinting than their counterparts who had higher muscle glycogen content.

According to Bangsbo (1994) the underlying mechanism for the reduced exercise performance particularly at the latter stages of game is unclear and may be a consequence of a number of physiological factors including changes within the CNS, the elevated production of lactate in the muscle and its associated impact on the pH of muscle fibres and the status of the muscle's high energy phosphates (Bangso *et al.,* 2006). Krustrup *et al.,* (2006) monitored muscle and blood metabolite responses during games and attempted to relate these changes to sprint performance. They found that 30 metres sprint performance was reduced both temporarily during the game and immediately post game. They concluded that the impairment in sprint performance at the end of the game was due to low glycogen levels in individual muscle fibres. According to Mohr *et al.,* (2005) temporary fatigue during an intense soccer match could be linked to an accumulation of potassium in the muscle interstitium.

Rahnama *et al.,* (2003) reported a fall in the muscle force of leg extensors and flexors at half-time and the end of a period of 90 minutes exercise activity designed to replicate the exercise intensities of a typical soccer game. Muscle force had declined both concentrically and eccentrically as well as a decreased ability to stabilize the knee joint. In a separate study Rahnama *et al.,* (2002) identified deterioration in muscle performance as a contributor to the increased risk of injury in the final 15 minutes of a soccer match.

Apriantono *et al.,* (2006) induced fatigue using repeated loaded extension and flexion motions to investigate its impact on kinetics and kinematics of instep kicking motion. Impairments in coordination between limb segments during kicking action were evident during the final phase of kicking motion and the reported disturbances in the interactions between limb segments could affect other technical and skills performance aspects such as tackling and evading tackles, as well as increase a player’s susceptibility to injury. Lees and Davis (1988) also identified impairment in coordination between upper and lower limbs prior to the assessment of kicking following a step-up protocol to induce transient muscle fatigue. This impairment affected the energy transfer between upper and lower leg segments adversely affected the timing which in turn resulted in poor impact positioning of the foot on the ball in a fatigued state.

Dehydration and hyperthermia are also contributory factors to the development of fatigue. An increased susceptibility to heat stress, hyperthermia and exercise-induced exhaustion are caused by a failure of homeostatic regulation. Net fluid loss (2% of body weight) by insufficient fluid intake and replacement can impair bodily temperature control systems and cardiovascular function. The failure to maintain fluid balance during repeated and prolonged exercise activity may result in decreased availability of blood flow to both the working muscles and the skin for heat dissipation, as well as an increase in stress on the cardiovascular system. Fitts (1994) reported that rising body core temperatures may cause fatigue in the central nervous system as well as in contracting muscles. Ekblom (1986) reported that changes in ambient temperatures from 20^0C to 30^0C was reflected in a reduction in the distance covered by players in high-intensity running from 900metres to 500 metres respectively during soccer matches.

It is generally accepted that the human body can tolerate dehydration levels of between 1 and 2% body weight particularly in endurance activities in ambient temperatures of 20-21^{o}C lasting less than 60 minutes without decrement in performance. However, dehydration of more than 2% body weight in events lasting longer than 60 minutes in warmer temperatures 31-32^{o}C may increase the risk of fatigue including loss of performance, increased risk of injury and other neuromotor problems (Coyle 2004; Casa *et al.*, 2000; Mohr, Krustrup, & Bangsbo, 2005). Magal *et al.*, (2003) observed an increase in both 5 and ten metres sprint times as a result of hypohydration of 2.7% body mass. McGregor *et al.,* (1997) reported impairment in a soccer specific skill at levels equivalent to body weight decrease of 2.4% dehydration, while Devlin *et al.,* (2001) found that dehydration of 2.8% of body weight loss had an adverse effect on bowling accuracy. All of which have direct implications on Gaelic Football.

If matched for similar technical and tactical ability, the margin between winning and losing at elite level Gaelic Football is very small and the result of the game may depend on players' ability to help sustain physiological performance in different environmental conditions. Particularly during the months of May to September when the physiological demands increase as teams are playing at a faster pace, ground conditions tend to be firmer and the step up in intensity may increase the risk of fatigue.

The evidence that fatigue occurs during competitive games is comprehensive. The corresponding decline in work rates in the latter stages of activity can be attributed to local muscular and central factors and may increase the susceptibility to injury (Reilly *et al.*, 2008).

2.26 Muscle Strength, Hamstrings Injury and Gaelic Football

A recently published study investigating the relationship between previous hamstrings injury and concentric isokinetic muscle strength amongst university Gaelic Footballers reported some evidence of hamstrings muscle weakness and muscle imbalance after previous injury (O'Sullivan *et al.*, 2008). Subjects who had previously injured limbs had a significantly lower conventional H:Q strength ratio and hamstrings to opposite hamstrings (H:oppH) than all other non-injured limbs. Dominant limb hamstrings were stronger than non-dominant hamstrings which the authors attribute to the kicking action of the dominant leg. Investigations of leg dominance and hamstrings injury in other Football codes similar to Gaelic Football, most notably Australian Rules Football have found no significant correlation between leg dominance and hamstrings injury Orchard *et al.*, (1997) and Cameron *et al.*, (2003).

To date no study has examined hamstrings muscle strength or functional H:Q ratio as a predictor of hamstrings injury in Gaelic Football.

2.3 Methods

Studies involving Australian Rules Football players have recruited between 21 and 102 subjects. Based on these studies it was considered that 75 subjects would be adequate for this study. Senior Inter-County (elite) male Gaelic Footballers from five different teams, were invited to participate in this study. The five teams selected were from different geographical locations in Ireland namely Galway, Limerick, Kildare, Cork, and Antrim, and represented the population of players competing at each of the four league divisions in Gaelic Football. The chosen locations had isokinetic dynamometers.

Each subject was given an information sheet to read and a consent form to sign prior to participation. Measurements for each participant were in two categories, player characteristics and muscle strength profiling. Players who were deemed to have any adverse medical condition were not recruited. Ethics approval for the study was obtained from the ethics committees of Glasgow University and the National University of Ireland Galway.

2.31 Pilot Study

A pilot study took place two months prior to the main study. Six male players from a local Gaelic Football club agreed to participate in the study. The nature of the study was explained to the subjects beforehand and all players consented to participation. The purpose of the pilot study was to perform a trial run of the protocol designed for the main study. The original study protocol consisted of concentric and eccentric isokinetic strength measurements of the hamstrings and quadriceps muscles of the left and right legs at three angular velocities (60^0/sec,

120^0/sec, and 180^0/sec). Three separate measurements would be performed for each leg at each of the angular velocities. In total there would be 36 individual measurements for each player. Access to the elite Gaelic Footballers participating in the main study would be limited to one full day. As testing in the pilot study progressed it became clear that it would not be feasible to perform all the measurements set out in the original protocol for each of the players due to the time constraints. As a result, a revised protocol was designed in order to maximise the testing time available to each player. The new revised protocol consisted of three individual measurements of concentric and eccentric peak torque at 60^0/sec and 180^0/sec.

2.32 Player characteristics

The body mass of each player was determined using a calibrated precision weighing scale before testing (Seca 770, Hamburg, Germany). Age, playing position, and preferred kicking leg (dominant and non-dominant) were also recorded.

2.33 Muscle strength profiling

Isokinetic strength of the hamstrings and quadriceps muscles for both dominant and non-dominant legs were measured on an isokinetic dynamometer (KinCom AP, Chattecx Corporation, Chattanooga, Tennessee, USA) which was calibrated before every testing session (Appendix A10). For the purposes of this study it was decided to test the H:Q ratio at 60^0/sec and 180^0/sec through a range of 5-80^0 of knee flexion and extension (Bennell *et al.*, 1998). The majority of H:Q testing documented in the literature recorded isokinetic muscle strengths at speeds of

60^0sec and 180^0sec sec respectively (Rosene *et al.,* 2001; Impellizzeri *et al.,* 2008; Kong and de Heer, 2008).

2.34 Testing protocol

A standardised aerobic warm up was initially performed on a cycle ergometer for 5 minutes at $60rev^{-1}$ per minute before the experimental protocol. The subject was then seated upright so that the leg being assessed was in a straight line, with hip, knee, and ankle all being aligned. The upper body was stabilised with straps across the shoulder, while the hips and thighs were firmly strapped to the seat of the dynamometer. The motor axis of rotation of the machine was visually aligned with the lateral femoral condyle, and the lower leg was attached to the lever arm of the dynamometer at the level of the lateral malleolus.

Once seated subjects were allowed to familiarise themselves with the workings of the machine until they demonstrated proper technique. 5 sub maximal (50%) concentric and eccentric concentrations were performed as a warm up.

Subject performed 3 maximal reciprocal flexion-extension repetitions at 60^0/sec, and 180^0/sec in concentric followed by eccentric mode with a 30 second interval between each mode, and a 3-minute rest prior to testing of the alternate leg. The order of testing for the different angular velocities was standardised from slowest to the highest as recommended by Wilhite *et al.,* (1992). Verbal instructions were given to encourage maximal effort during testing. H:Q ratios were calculated separately based on peak torque.

2.35 Injury Reporting

A detailed injury reporting form (Figure 2.4) was specifically designed for this study. The injury form consisted of seven sections and was designed to be user friendly and aimed at gaining data with the minimum of time required for completion. The study only included injuries sustained while playing or training, and does not include home accidents or illness, e.g. influenza. It was requested that as much information relating to the injury sustained should be entered onto the Injury Report Form as soon as is practical following the injury. All injuries were recorded as separate injuries. All completed Injury Report Forms (white copy) were returned on a monthly basis (end of each month) in the pre-paid envelope provided. The carbonised copy (coloured) was retained by the physiotherapist for reference.

Section 1. Injury Information:

This section included background details on the injury including:

- The time of day that injury occurred
- The playing surface
- Whether a player was injured in training or in a game
- The time period in the training session or game when injury happened
- The underfoot playing conditions
- The type of footwear worn by the player at the time of injury
- Details of any protective equipment worn by the player

Section 2. Body Region Injured

The physiotherapist completing this section of the form was asked to name the hamstrings region injured and highlight it on the picture provided; as well as indicating if the injured area was the player's dominant side (predominant kicking) or non dominant side.

Section 3.Effect on Participation

This section was designed to record the effects of injury on a player's participation in training or games. It was considered under three categories:

(1) Players who stopped participation immediately,

(2) Players who stopped later, and

(3) Players who completed training/games.

Section 4. Cause of Injury

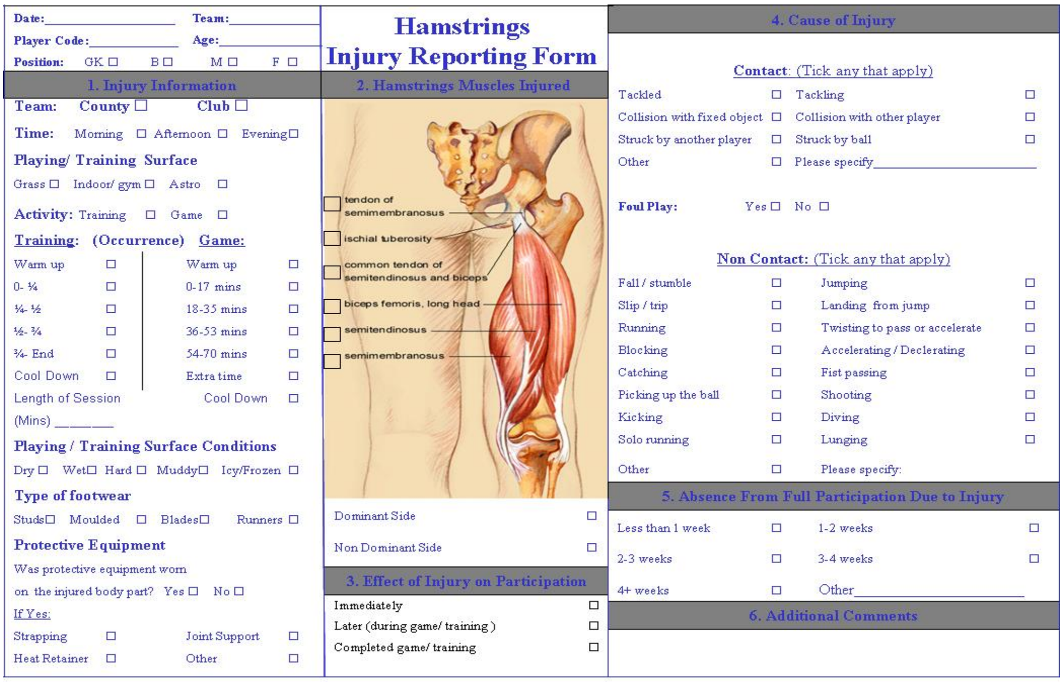
Individuals completing this section of the form were asked to indicate if the cause of injury was as a result of contact, or non-contact, and if foul play was involved. Possible contact and non-contact causes were detailed and reporters were asked to tick any boxes that applied.

Section 5. Absence from Full Participation due to Injury

The duration that a player was able to participate fully in training or games was recoded. Only then could the injury reporting form be submitted.

Section 6. Additional Comments

There was a comments section at the bottom of the form to allow for any other relevant information concerning the player's injury. If the injury was a recurrent injury, it was noted in this section.



Date:______________ Team:__________
Player Code:__________ Age:__________
Position: GK ☐ B ☐ M ☐ F ☐

Hamstrings Injury Reporting Form

1. Injury Information

Team: County ☐ Club ☐

Time: Morning ☐ Afternoon ☐ Evening ☐

Playing/ Training Surface

Grass ☐ Indoor/ gym ☐ Astro ☐

Activity: Training ☐ Game ☐

Training: (Occurrence) Game:

Training		Game	
Warm up	☐	Warm up	☐
0- ¼	☐	0-17 mins	☐
¼- ½	☐	18-35 mins	☐
½- ¾	☐	36-53 mins	☐
¾- End	☐	54-70 mins	☐
Cool Down	☐	Extra time	☐
Length of Session (Mins) ______		Cool Down	☐

Playing / Training Surface Conditions

Dry ☐ Wet ☐ Hard ☐ Muddy ☐ Icy/Frozen ☐

Type of footwear

Studs ☐ Moulded ☐ Blades ☐ Runners ☐

Protective Equipment

Was protective equipment worn on the injured body part? Yes ☐ No ☐

If Yes:

Strapping ☐ Joint Support ☐
Heat Retainer ☐ Other ☐

2. Hamstrings Muscles Injured

Dominant Side ☐
Non Dominant Side ☐

3. Effect of Injury on Participation

Immediately ☐
Later (during game/ training) ☐
Completed game/ training ☐

4. Cause of Injury

Contact: (Tick any that apply)

Tackled	☐	Tackling	☐
Collision with fixed object	☐	Collision with other player	☐
Struck by another player	☐	Struck by ball	☐
Other	☐	Please specify__________	

Foul Play: Yes ☐ No ☐

Non Contact: (Tick any that apply)

Fall / stumble	☐	Jumping	☐
Slip / trip	☐	Landing from jump	☐
Running	☐	Twisting to pass or accelerate	☐
Blocking	☐	Accelerating / Declerating	☐
Catching	☐	Fist passing	☐
Picking up the ball	☐	Shooting	☐
Kicking	☐	Diving	☐
Solo running	☐	Lunging	☐
Other	☐	Please specify:	

5. Absence From Full Participation Due to Injury

Less than 1 week	☐	1-2 weeks	☐
2-3 weeks	☐	3-4 weeks	☐
4+ weeks	☐	Other__________	

6. Additional Comments

Figure 2.4 Hamstrings Injury Reporting Form

2.36 Statistical Analysis

Paired t-tests were used to compare the mean difference in H:Q ratios between the left and right legs (using a significance level of 0.05). A model was fitted to the data to investigate the likelihood of hamstrings injury occurring as a function of isokinetic strength imbalance based on the functional Hecc:Qcon strength ratio. The adequacy of the model was checked using suitable residual plots.

2.4 Results

Four of the original five teams withdrew from the study, however the subjects (n=17) that did participate in this study were members of a Senior Inter-County (Elite) Gaelic Football team. The team was representative of the population of players competing at the highest level of Gaelic Football, whose training intensity and match schedule were typical of elite teams competing at this level (Table 2.3).

Table 2.3. Physical Characteristics for Elite Gaelic Football Players

Physical Characteristics for Elite Gaelic Football Players		
Age 23 ± 4.5	Height (m) 1.84 ± 0.06	Body Mass (kg) 82.1 ± 7.4

Maximal eccentric strength was greater than maximal concentric strength for both the quadriceps and the hamstrings muscles ($p>0.01$). The mean (SD) of H:Q muscle strength ratios, for both conventional (Hcon:Qcon) and functional (Hecc:Qcon) at 60^0/sec and 180^0/sec for left and right legs respectively are shown in Table 2.4. The mean conventional H:Q ratios were 0.5 ± 0.1 at 60^0/sec, and 0.6 ± 0.1 at 180^0/sec respectively. The mean values for functional H:Q ratios were 0.8 ± 0.1 at 60^0/sec 1.2 ± 0.3 at 180^0/sec respectively. While there was great inter-subject variability in leg muscle strength, results of paired t-tests show no significance between the left and right legs for any of the variables ($p>0.05$).

Table 2.4. *Mean (SD) of H:Q muscle strength ratios, for both conventional H:Q and functional H:Q*

H:Q Ratio	Left Leg		Right Leg		
Conventional H:Q	Mean (SD)	Range	Mean (SD)	Range	P value
Ham Con/Quad Con 60^0	0.5 (0.1)	0.42-0.64	0.5 (0.1)	0.33-0.68	0.22
Ham Con/Quad Con 180^0	0.6 (0.1)	0.49-0.69	0.6 (0.1)	0.31-0.82	0.48
Functional H:Q					
HamEcc/QuadCon 60^0	0.8 (0.1)	0.52-1.0	0.8 (0.1)	0.65-0.91	0.102
HamEcc/QuadCon 180^0	1.1 (0.2)	0.67-1.42	1.2 (0.3)	0.74-1.79	0.22

2.41 Injury occurrence

During the 8 month study period three players (players 5, 9, and 14) sustained hamstrings injuries. Two of the injuries occurred in training, and one during a competitive game. All three injuries were non contact injuries and occurred during running and sprinting activity. One of the players had a recurrence of a previous hamstrings injury; the other two were new injuries. All injuries were sustained in the dominant kicking leg.

2.42 Injury Prediction model

A simple linear regression model was fitted to the data to identify players with an isokinetic strength imbalance based on their functional Hecc:Qcon strength ratio relationship. If a linear relationship is a plausible assumption, potential hamstrings injury candidates could be identified based on their residuals (i.e. the difference between the actual value and that predicted by model –outliers).

2.43 Functional H:Q ratio at 60^0/sec

Leg strength ratios for both right and left legs at 60^0/sec are shown in the scatter plot below (Figure 2.4). According to the regression equation player 5 is identified as an outlier. This individual's H:Q strength ratio was substantially lower (0.62) than the team average (0.8). The same player also sustained a hamstrings injury during the playing season.

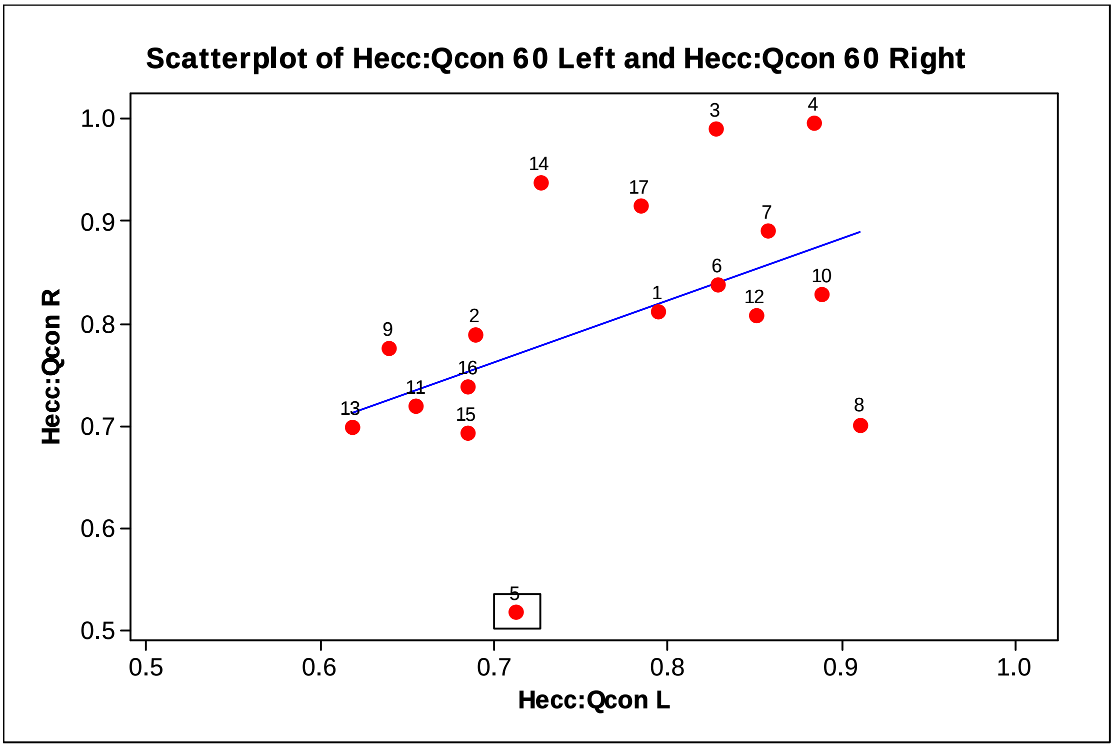


Figure 2.4 Scatterplot and line of best fit for functional isokinetic H:Q strength ratio for left and right legs at 60^0/sec

The regression equation is
Hecc:Qcon 60^0_R = 0.341 + 0.602 Hecc:Qcon 60^0_L

Predictor	Coef	SE Coef	T	P
Constant	0.3413	0.2226	1.53	0.146
Hecc:Qcon 60^0_L	0.6024	0.2883	2.09	0.054

S = 0.111096   R-Sq = 22.6%   R-Sq(adj) = 17.4%

Unusual Observations

Obs	11_L	11_R	Fit	SE Fit	Residual	St Resid
5	0.712	0.5189	0.7703	0.0312	-0.2514	-2.36R

2.44 Functional H:Q ratio at 180^0/sec

Leg strength ratios for both right and left legs at 180^0/sec are shown in the scatter plot below (Figure 2.5). According to the regression equation players 4 and 5 are identified as being an unusual observation or outliers. Leg strength ratios were substantially lower (0.76) for player 5, and higher for player 4 (1.33) than the team average (1.15).

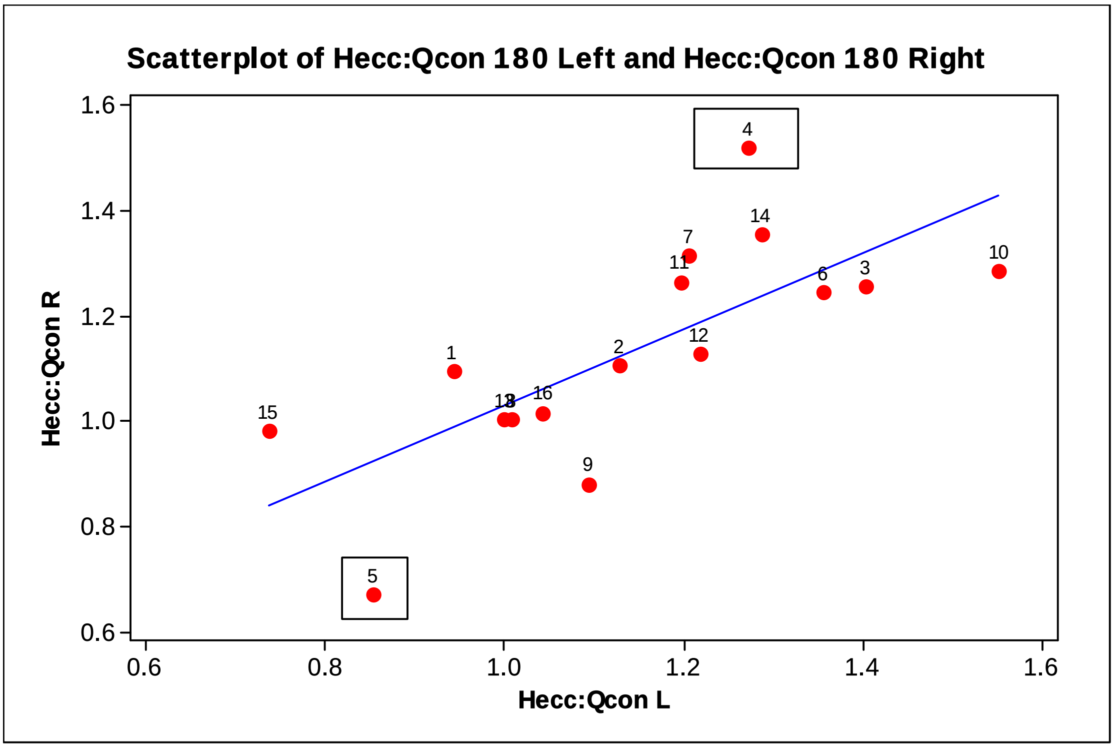


Figure 2.5 Scatterplot and line of best fit for functional isokinetic H:Q strength ratio for left and right legs at 180^0/sec

The regression equation is
Hecc:Qcon 180^0_R = 0.417 + 0.620 Hecc:Qcon 180^0_L

Predictor	Coef	SE Coef	T	P
Constant	0.4169	0.1718	2.43	0.028
Hecc:Qcon 180^0_L	0.6199	0.1423	4.35	0.001

S = 0.146525 R-Sq = 55.8% R-Sq(adj) = 52.9%
Analysis of Variance

Unusual Observations

Obs	12_L	12_R	Fit	SE Fit	Residual	St Resid
4	1.27	1.5196	1.2057	0.0379	0.3139	2.22R
5	0.85	0.6688	0.9453	0.0587	-0.2765	-2.06R

2.45 Summary of main results

- A wide range in the values recorded for individual strength ratios for both conventional and functional H:Q.

- The mean values for functional H:Q ratios were 0.8 ± 0.1 at 60^0/sec and 1.2 ± 0.3 at 180^0/sec.

- The mean conventional H:Q ratios were 0.5 ± 0.1 at 60^0/sec, and 0.6 ± 0.1 at 180^0/sec respectively.

- There was no significant difference between the left and right legs for any of the variables ($p>0.05$). Linear regression model identified two players as potential hamstrings injury candidates.

- One of the two players identified by the model sustained a hamstrings injury during the playing season. This player had a substantially lower H:Q ratio than the team average.

2.5 Discussion

Hamstrings strains are complex injuries with several potential predisposing factors (Askling *et al.,* 2003). The aim of his study was to measure the H:Q strength ratios in elite male Gaelic Football players in order to identify if strength discrepancies could be a predictor of subsequent hamstrings injury. Concentric and eccentric muscle strength of the quadriceps and hamstrings were assessed using isokinetic dynamometry.

One panel of players agreed to participate in this study. The managers of the other teams were reluctant to allow players to participate, as the combination of a short playing season and a tight training schedule, limited the opportunity for player availability for isokinetic testing. However the subjects (n=17) that did participate in this study were members of a Senior Inter-County (Elite) Gaelic Football team. The team was representative of the population of players competing at the highest level of Gaelic Football, whose training intensity and match schedule were typical of elite teams performing at this level. This particular panel also sustained the highest number of hamstrings injury of all the participating teams in the injury study (Newell *et al.,* 2006). For this reason they were specifically targeted to participate in this study.

<u>Strength ratios</u>

The patterns of the mean conventional H:Q ratio (0.5 ±0.1 at 60^0/sec and 0.6±0.1 at 180^0/sec) are in accordance with the recommended optimum H:Q ratio of between 50% and 80% (Aagaard *et al.,* 1995). The mean functional H:Q ratios (0.8±0.1 at 60^0/sec and 1.2±0.1 at 180^0/sec) are similar to results published for professional Australian Rules players and Soccer players (0.8 at 60^0/sec to 0.9 at 180^0/sec respectively), (Bennell *et al.,* 1998; Cometti *et al.*, 2001). The wide variation in the values recorded for individual strength ratios for both conventional and functional H:Q suggests that some players would benefit from additional strength training programmes.

Injury prediction model

The linear regression model fitted to the functional H:Q data identified two players as potential hamstrings injury candidates based on the difference between their individual Hecc:Qcon strength ratio relationship and that predicted by the model. Of the two players identified, only one of them sustained a hamstrings injury during the playing season. This player had a substantially lower H:Q ratio (0.62 and 0.76) than the team average (0.8 and 1.2) at both 60^0/sec and 180^0/sec respectively.

A linear regression model was fitted to the data to identify players with an isokinetic strength imbalance based on their functional Hecc:Qcon strength ratio relationship. The question of using a multiple regression model to adjust for other explanatory variables, such as age and previous injury, and not just functional strength ratio to explain why the players identified as potential injury candidates is of course plausible; however as these variables were not recorded such an analysis is not possible.

The use of a simple regression model in this context is appropriate as there is a single explanatory variable (Hecc:Qcon) and all of the underlying assumptions related to the use of a strength relationship model e.g. linearity, independence, normal errors, and constant variance were deemed appropriate by looking at residual plots. However given that this team is a good representation of players in general, as reported in this thesis, and the results are exploratory findings only, it is worth considering for future studies to include all variables that might influence the outcomes as the statistical analysis is only as good as the number of exploratory variables collected.

Injuries recorded

Only three hamstrings injuries were reported. This was a surprising finding, as the previous season the same cohort of players sustained 17 hamstrings injuries, the highest percentage (33%) of hamstrings injuries of all teams that participated in the injury surveillance study (*Newell et al., 2006*). The sharp decline in the incidence of hamstrings injury, according to the team physiotherapist, may be due to alterations made to the training programme from the previous season, including a reduction in plyometric-type activities and the amount of time spent training on astro-turf surfaces. Despite the low number of hamstrings injuries (3 players out of a total of 17), the pattern of hamstrings injuries recorded was similar to published results for Australian Rules Football players, six players out of a total of 37 (Orchard *et al.,* 1997), and 12 players out of a total of 102 (Bennell *et al.,* 1998).

Prevention of hamstrings injuries is an ongoing process and a greater understanding of individual risk factors is paramount to the development of preventive strategies. Many interventions aimed at preventing hamstrings injuries have been used by coaches, trainers, physiotherapists and the athletes themselves, including exercise therapy, biomechanical analysis of running technique and sport specific drills, muscle activation work to improve hip extension motor patterns and running technique, therapeutic massage and mobilisation to increase flexibility (Brosseau *et al.*, 2002; Hoskins and Pollard, 2005; Verrall, 2005). According to Golman and Jones (2010) in their recent Cochrane Review of interventions for preventing hamstrings injuries, there is insufficient evidence to suggest a specific intervention for decreasing the risk of incurring hamstrings injuries based on current research. There is a need for more randomised controlled trials to evaluate the effectiveness of interventions aimed at preventing hamstrings injuries.

Even though one of the two players identified by the model did sustain a hamstrings injury, given the number of subjects and the number of injuries recorded any relationship between the variables that may exist in the population at large is likely to be missed. If a larger number of injuries were available for analysis, statistical methods for classification, such as Logistic Regression, could be used to model the probability of injury occurring as a function of the explanatory variables.

Ultimately, a randomised control trial should be conducted to examine the potential association between strength (concentric and eccentric) and hamstrings muscle strain injuries in Gaelic Football. It is also considered worthwhile to investigate the hamstrings stretching and strengthening exercises, currently used by each of the elite Gaelic Football teams, while simultaneously recording the incidence of hamstrings injury to see if there is a relationship between the type of training activity and the incidence of hamstrings injury. A similar study was conducted by Brooks *et al*., (2006) with professional Rugby Union players. 546 players took part in the study, of which 122 (22%) sustained at least one hamstring injury. The authors reported that players who undertook Nordic hamstring exercises, in addition to conventional stretching and strengthening exercises, had lower incidences and severities of hamstrings injury during training and competition.

2.51 Summary of Main Findings

The results of this study indicate that there is a wide range in individual H:Q ratios. While specific hamstrings training is an integral part of training for many athletes in individual sports, it is not as common in Gaelic Football. The notion of incorporating personalised additional eccentric training during pre-season is an exciting prospect that warrants further investigation.

The systematic use of baseline evaluations of pre-season H:Q ratios and the subsequent tracking of injuries may help to establish the use of H:Q ratio as a possible screening tool for the susceptibility to injury.

The low number of subjects and injuries reported was a constraint on the present study. There is a need for large scale prospective study to establish a cause and effect relationship between H:Q strength ratios and hamstrings injury. It is considered worthwhile to investigate the training activity of elite Gaelic Football teams, in particular hamstrings stretching and strengthening exercises, to examine if there is a relationship between the type of training and the incidence of hamstrings injury. Further research is required to establish a cause and effect relationship between strength ratios and hamstrings injury.

As a natural sequel to the hamstrings injury study, following Van Mechelen's model (1992), the aim of the next phase of research was to design and implement an intervention study aimed at improving the H:Q ratio and to decrease the corresponding incidence of hamstrings injury. Intervention studies in Soccer, Rugby Union, and Australian Rules have focused on reducing the incidence of hamstrings injury by incorporating more specific eccentric hamstrings work into their general training activity (Proske and Morgan 2001; Askling et al., 2003; Mjolsnes et al., 2004; and Brooks *et al*., 2006).

The aim of this study was to implement a similar intervention programme to the one designed for Australian Rules Footballers by Proske and Morgan (2001) to elite Gaelic Football teams. However, it was not possible to carry out this study for a variety of reasons; firstly it was extremely difficult to get managers to participate in this study, as they had concerns about the time required to conduct isokinetic testing; secondly, they were unwilling to allow any interference with the team's training schedule or content, particularly as some of players would act as a control group for the intervention study; thirdly, the imposed winter break with restrictions on group training sessions has resulted in a contracted pre-season affording limited potential for research opportunities.

Continuation of research on hamstrings injury prevention in accordance with the phases outlined by Van Mechelen's model (1992) was not a feasible proposition. Thus an alternate aetiology of injury was explored in order to complete the model.

Chapter 3

Study 3:

Personal Hydration Strategy and Injury Prevention in Elite Gaelic Football

3.1 Introduction

The margin between winning and losing at elite level Gaelic Football is very small, particularly when teams are matched for technical and tactical ability, the result of a game typically depends on players' ability to help sustain high levels of performance in different environmental conditions particularly in the latter stages of activity. A worrying trend for players and coaches is the fact that players are more likely to be injured in the second half of games than the first half; while the frequency of injury, particularly non-contact injuries, increases in the latter stages of activity (Hawkins *et al.*, 2001; Newell *et al.*, 2006; Wilson *et al.*, 2007). From a tactical performance, as well as an injury prevention viewpoint, it seems prudent to investigate the mechanisms of injuries occurring in the later stages of Gaelic Football activity.

According to Meeuwisse (1994) the presence of internal and external risk factors is not usually sufficient to produce injury, rather they 'prepare' the athlete for an injury to occur and it is the final link in the chain, the inciting event, which causes an injury. According to this model the inciting event depends on the 'sum' of the internal and external risk factors and the interaction between them (Figure 3.1). Therefore, studies undertaken to recognise and control risk factors leading up to injury will help to prevent injuries occurring.

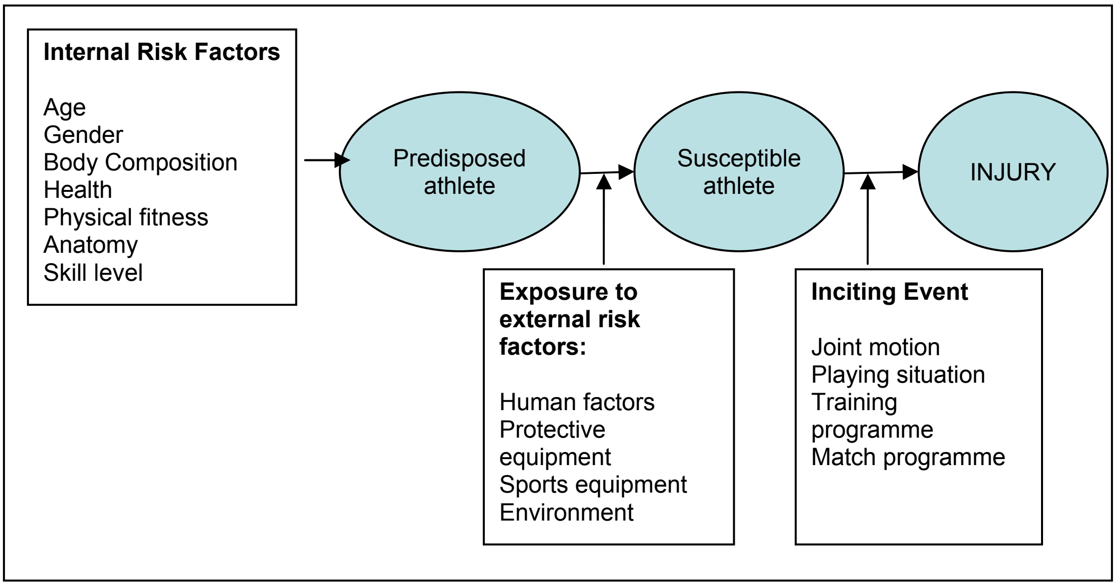


Figure 3.1 A dynamic, multifactorial model of sports injury aetiology-adapted from Meeuwisse (1994) cited in Barr and Holme (2003).

All injuries in sport involve a failure of biological material. Whether injuries are caused by muscle dysfunction, or a decrement in performance due to fatigue, is an open question. Dehydration is a recognised risk factor for injury (Bouchama et al., 1988, Gonzalez-Alonso *et al., 1998;* Hall *et al., 2001;* Hawkins *et al.*, 2001; Bouchama and Knochel 2002; Maughan et al., 2005; Jones *et al.*, 2008; Kovacs 2008). Although the direct evidence linking dehydration and injury has not been established, controlling this 'human factor' could act as a preventive measure against the onset of fatigue and injury due to a decrement in performance. The goal of the next phase of research was to devise personal hydration strategies, including advice on specific post-exercise electrolyte restoration for each player, as a means of controlling the potential impact of dehydration, while simultaneously conducting injury surveillance.

3.1 Literature Review

3.21 Regulation of Body Fluids: Importance of Water

Water is the main component of the human body and is essential in sustaining and facilitating physiological well-being. It provides a medium for biochemical reactions and helps maintain blood flow and cardiovascular performance, while safeguarding internal homeostasis by regulating osmolar equilibrium within and between the cells (Greenleaf and Morimoto, 1996; Kay and Marino, 2000). A 'normal' 70kg male has 42kg of water in the body (Costill and Saltin, 1974), representing approximately 60% of body mass, of which two-thirds is intracellular fluid (inside the cells), with the remaining one third extracellular fluid (between cells, and inside blood vessels) (Sawka and Pandolf, 1990). (Figure 3.1).

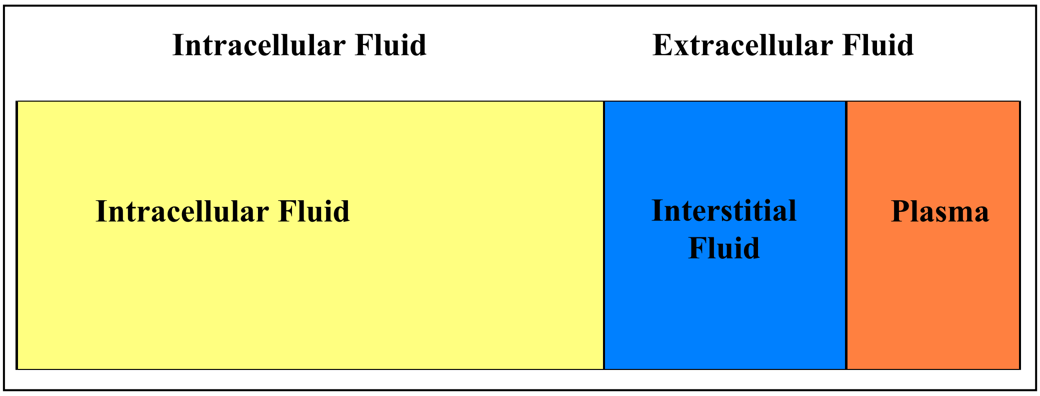


Figure 3.1 Distribution of Total Body Water between ICF and ECF compartments including interstitial fluid and plasma. Water represents approximately 60% of body mass and 72% of lean body mass in a healthy adult.

Under normal conditions the volume of total body fluid (water and dissolved solutes) remains stable with losses and gains in water and electrolytes kept in balance by the regulation of urinary loss (Table 3.1). Fluid balance depends primarily on electrolyte balance (groups of atoms which conduct electrical current) in particular sodium which is the most abundant electrolyte and plays a significant role regulating water movement between the intracellular and extra cellular compartments. Other electrolytes including potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) are found in smaller amounts.

The principle sources of body water are ingested food and water that has been absorbed from the small intestine, and metabolically produced water resulting from the oxidation of organic nutrients (catabolism). There are four sites from which water is lost to the external environment: evaporation from the skin and respiratory passageways (insensible water loss), gastrointestinal tract, and urinary tract. Rarely does the intake of water and electrolytes occur in exactly the same proportions as their presence in body fluids.

Table 3.1 *Summaries of Fluid Intake and Output per Day*

Intake		**Output**	
Ingested Liquids	1200 ml	Kidneys	1500 ml
Ingested foods	1000 ml	Skin	500 ml
Metabolic water	350 ml	Lungs	300 ml
		GI tract	200 ml
		Sweat	50 ml
Total	2550 ml	**Total**	2550 ml

Under normal circumstances, fluid intake equals fluid output thus the body maintains a constant volume (fluid balance). It is suggested that 2.5 litres of water are required each day. Figures quoted are average values normally required each day for a typical sedentary adult male in a normal environment (McArdle *et al.*, 1991; Vander *et al.*, 1994) however these figures are subject to considerable normal variation.

Euhydration is a term used to refer to normal body water or normally hydrated. It can refer to body mass that is relatively stable day to day; or where there is relative stability of total body water, i.e. extracellular body water and intracellular body water. It can also refer to normal blood chemistry, or an adequate fluid intake to sustain normal urinary volume and concentration (Opplinger and Bartok, 2002).

Dehydration refers to water depletion or weight loss and develops when fluid losses outpace fluid gains. This dynamic process of body water loss is usually quantified as a percentage of body mass loss; dehydration that results in a loss of as little as 1-2% body mass (mild dehydration) contributes to a reduction of the subjective perception of alertness and ability to concentrate, an increase of self-reported tiredness, and an increase of headache pain (Armstrong, 2006). The effects of dehydration including decreased flow of saliva, a decreased blood volume, and an increased blood osmotic pressure, become more adverse with increasing levels of percentage body mass loss (Table 3.2).

Table 3.2 *Symptoms by Percentage Body Mass Water Loss*

% Body Water Loss	Symptoms
0%	None, heat regulation, normal exercise performance
1%	Thirst, heat regulation altered, performance begins to decline
2%	Further decrease in heat regulation, increased thirst, performance inhibition, aware of decline
3%	Performance worsens, awareness of decline increases
4%	Performance decreases 20-30%
5%	Headache, irritability, fatigue extreme
6%	Weakness, severe loss of thermoregulation
7%	Collapse unless exercise is stopped
10%	Comatose
11%	Death likely

In response to dehydration the human body tries to redistribute water as required within its fluid compartments in order to minimise the effects of a water deficit. Baroreceptors in the extracellular space detect a reduced flow, triggering a release of anti-diuretic hormones by the hypothalamus stimulating a reuptake of water (that would have been urine) by the kidneys. The sensation of thirst is also triggered (angiotensin is released) and drinking behaviour is stimulated. Fluid consumption results in extracellular hydration and eventually a feeling of satiety.

Similar response mechanisms (the negative-feedback system) are triggered with changes in electrolyte balance. When an individual loses water but retains electrolytes, the osmotic concentration of the extracellular fluid rises. Osmosis then moves water out of the intracellular fluid (ICF) and into the extracellular fluid (ECF) until the two solutions are again isotonic (same number of electrolyte particles) (Figure 3.2). Conversely when sodium loss exceeds gains the volume of the ECF decreases as in the case when an individual sweats heavily but consumes only water, he/she will loose sodium and the corresponding concentration of sodium in the ECF will fall. The osmotic pressure decreases temporarily and fluid leaves the ECF. There is a corresponding decrease in the release of ADH, water losses at the kidneys increase, and ultimately the osmotic concentration returns to normal and homeostasis is restored (Figure 3.2).

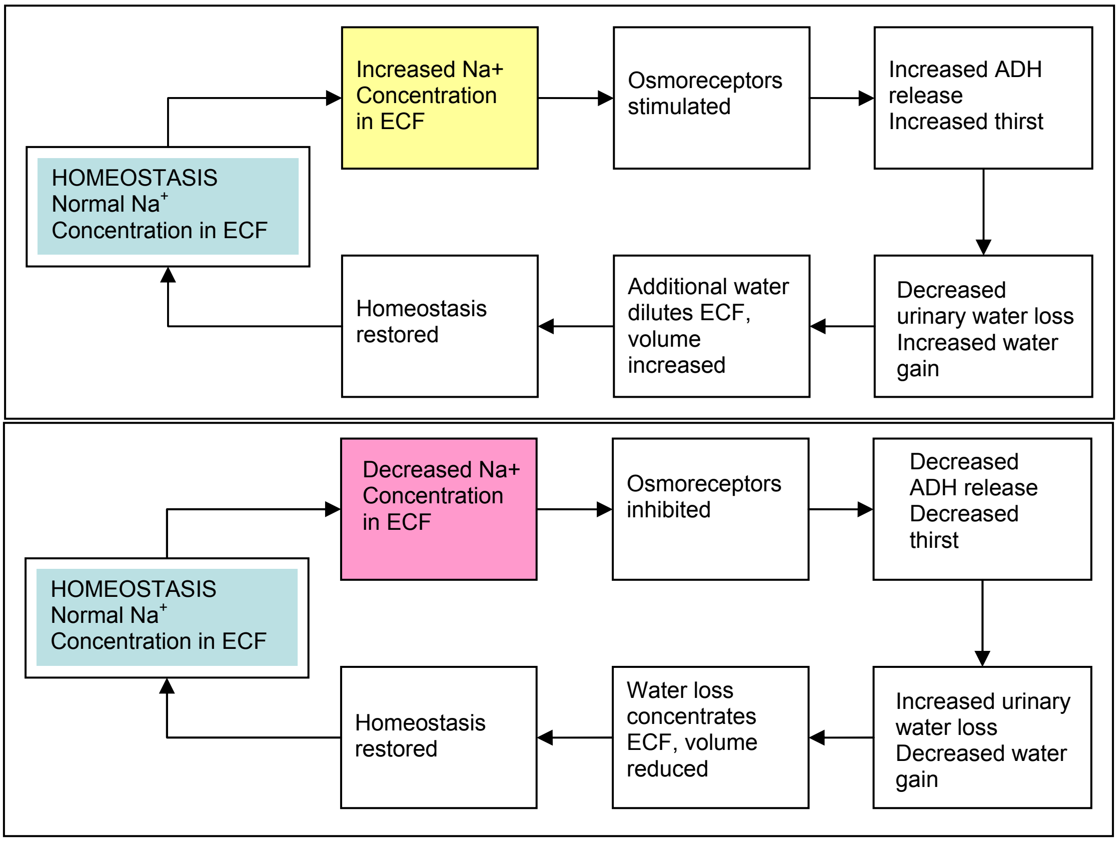


Figure 3.2 Homeostatic Regulation of Normal Sodium Concentrations in Body Fluids (adapted from Martini 2006)

Three conditions commonly alter the distribution of body water and a shift in fluid and electrolyte balance, (1) loss of body water through dehydration, (2) increases in the concentration of plasma sodium, and (3) exercise, leading to a potential state of hypohydration and impaired performance in both occupational and athletic settings (Sawka *et al.*, 2007).

3.22 Regulation of Body Temperature: Thermoregulation

The human body strives to maintain a balance between heat production and heat loss. Average body temperature is 37 ºC with a normal range of 35.5 º-37.7 ºC. Internal heat is produced by metabolism about 1 kcal $kg^{-1}h^{-1}$ (Reilly and Cable, 1996) and from heat released during muscle contraction. External heat input comes from the environment. Heat loss occurs primarily at the shell outer layer (the skin and external parts of the body). If there was no means of heat loss the temperature of the core (comprising of the brain, chest, abdominal areas and some skeletal muscle) would rise by 1ºC per hour in an individual with a body mass of 72kg, death from overheating would follow within 4-6 hours. If the individual was engaged in physical activity, the process would be accelerated, energy expenditure may approach 25 kcal $kg^{-1}h^{-1}$ and the rise in temperature would be 20 ºC in just over an hour.

An increase or decrease in core temperature can result in danger to health and a decrease in endurance performance. If heat gain is greater than heat loss as can happen when exercising vigorously in a warm environment, core temperature rises. A core temperature in excess of 41ºC may lead to convulsions and subsequent death if core temperature reaches 43º. Similarly in the cold, core temperature falls when heat loss exceeds heat production. An individual who has a decrease in core temperature lower than 35ºC is deemed to be hypothermic. Decreases from normal core temperature (which may not reach hypothermic levels) can result in upset to the central nervous system with abnormal behaviour, poor judgement, and impaired coordination possible consequences of a lowering of core temperature. The ability to maintain life depends on the ability to exchange heat with the environment to maintain a core body temperature of ~37°C. (Figure 3.3).

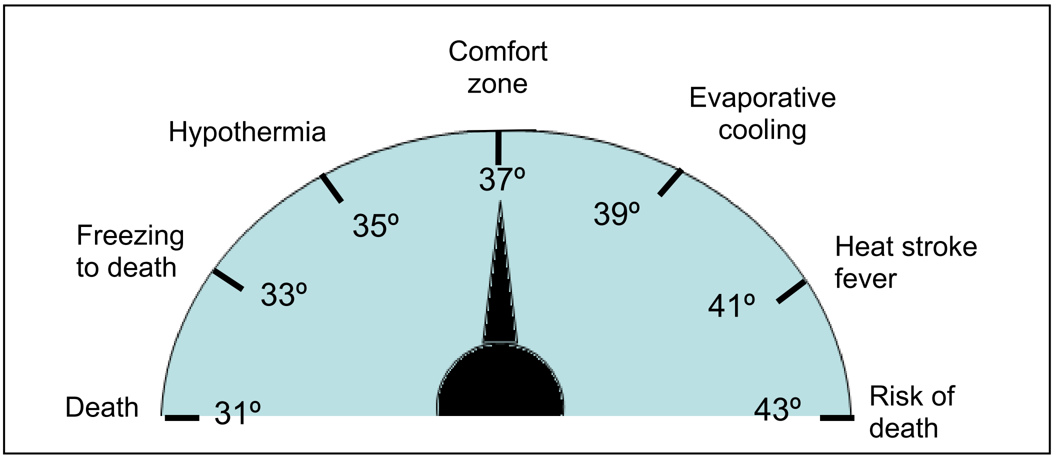


Figure 3.3 The Core Body Temperature Range (Reilly and Cable, 1996) showing the extremes in temperature either side of the comfort zone.

Heat Exchange

In the human body the core temperature is measured by a thermometer receptor organs in the skin peripheral, and central (the hypothalamus, spinal cord and abdominal organs) and compared to a set point of 37°C. If there is a difference from the set-point, the hypothalamic centre reacts by enlisting heating or cooling systems (effectors) to regulate the temperature so that the set point temperature is achieved. The skin receptors provide early information regarding changes in environmental conditions, resulting in regulation of heat flow designed to respond to the prevailing environmental conditions and thus provide stability in core temperature. Excess heat from the core is transported to the skin surface where it can be lost to the surrounding environment, while in a cold environment heat loss is reduced as a result of a decreased skin blood flow caused by constriction of the arterioles supplying blood to the skin (Fox *et al.,* 1989). A reduced core temperature may promote shivering (the forcible contraction of one group of skeletal muscles against their immediate antagonists) to increase metabolic heat production (five times as much heat as resting muscle). Consequently, there is less heat transferred from the body core to the periphery.

Once the metabolic heat is transferred to the skin there are various heat exchange mechanisms through which the human body attempts to prevent major changes in normal core temperature (Figure 3.4). The processes of conduction (transfer of heat between objects that are in contact with each other, e.g. a warm skin surface is cooled when a hand is placed in icy water), radiation (surface of objects emitting heat in the form of electromagnetic waves with no direct contact between surfaces), convection (heat transfer via moving gas or liquid e.g. blood warmed by the working muscles is transported to other cooler parts of the body or a high wind cools the surface of the skin by continually carrying heat from the warm skin surface) and evaporation (heat loss by means of insensible water loss and sweating, e.g. a litre of sweat that vaporises from the skin results in 580 kcals of heat being removed). The body's ability to lose heat by evaporation is directly related to the relative humidity of the air (the ratio of water in ambient air to the total quantity of moisture that can be carried in air at a particular ambient temperature, expressed as a percentage); in dry environments water from sweat on the skin's surface evaporates rapidly, whereas in humid environments evaporative cooling is reduced (the sweat glands continue to secrete, but the sweat remains on the skin or drips off). Air movement across a skin's surface may enhance sweat evaporation particularly in humid environments. The maintenance of a relatively constant core temperature can be expressed as the following heat balance equation (Reilly and Cable, 1996):

Heat Stored = MR- Evaporation ± Radiation ± Convection ± Conduction -Work done

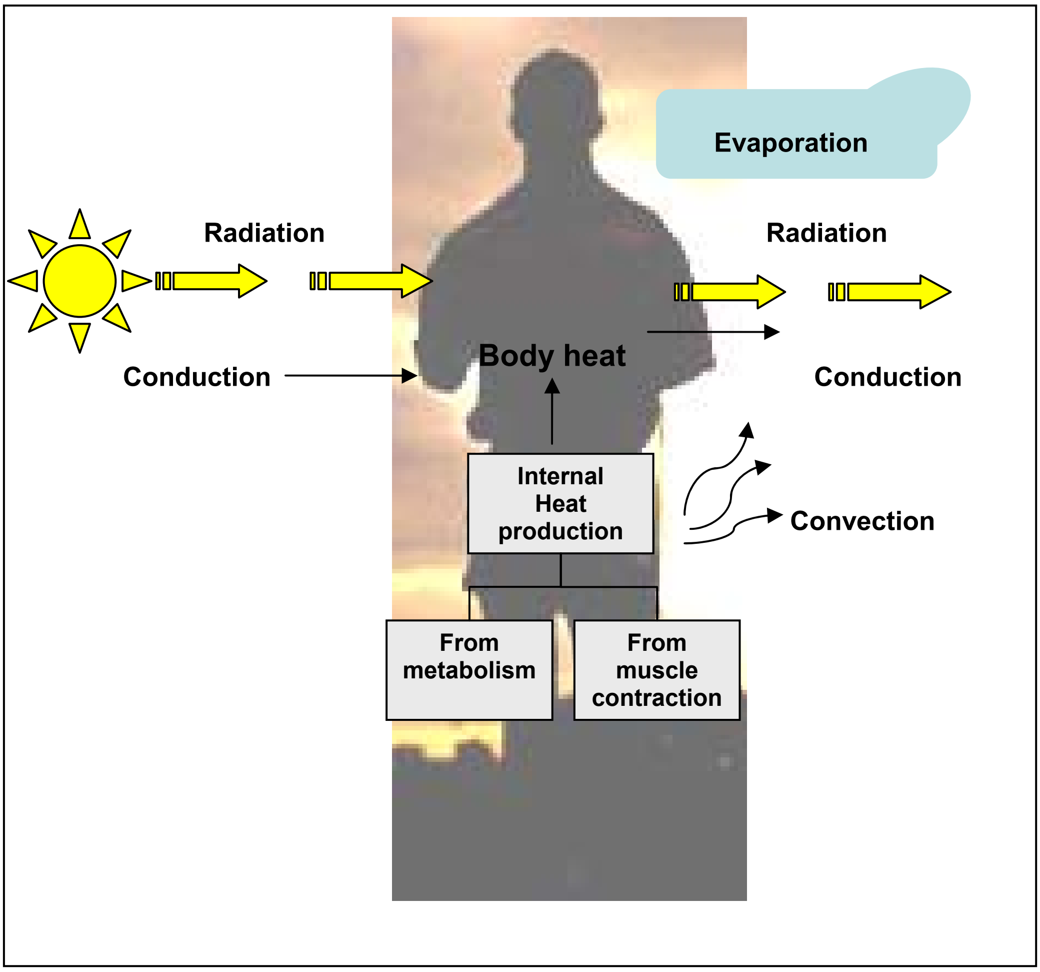


Figure 3.4 Mechanisms of heat loss and heat gain within the working muscles. Under normal environmental conditions, excess body heat will be dissipated to the surrounding environment (Adapted from McArdle *et al.*, 1991).

3.23 Thermoregulatory responses to Gaelic Football

Gaelic Football players are required to perform complex skills and repetitive sprints at a high intensity (~75% of $\dot{V}O_2\max$) with little time for recovery while covering an average distance of 8594 m in a typical 70 minute game (Keane *et al.,* 1993). The diverse intermittent and high-intensity nature of the game coupled with the large body sizes of players places added stress on the body to maintain homeostasis and can lead to heavy sweat losses and dehydration (Burke, 1997). The Gaelic Football season runs from January to September with games played in a variety of environmental conditions. Although players are unlikely to experience extremes in temperature and humidity often associated with hyperthermia, temperatures can rise however to ~26 ^{o}C during the summer months (the peak of the Gaelic Football season) and drop to ~4 ^{o}C occur during the winter months (pre season for Gaelic Football) necessitating appropriate thermoregulatory responses. Sweating rates tend to be lower in a cooler environment as it allows greater dry heat loss (radiation and convection), while conversely in a warmer environment higher sweating rates may be needed to achieve the evaporative cooling requirements (Sawka *et al.,* 2007).

3.231 Sweat Rates and Fluid Intake

Heat loss is greatly accelerated by evaporation of sweat which results from the activation of eccrine sweat glands and subsequent secretion of sweat onto the skin surface. Sweat is a hypotonic solution containing electrolytes particularly sodium, potassium, calcium, and magnesium. Evaporation of the water content of sweat helps promote heat loss (Wendt *et al.,* 2007). There are a number of factors that can influence sweat losses including the intensity and duration of exercise (if exercise task is 20% efficient, then 80% of metabolic energy is converted to heat in the body), the environmental conditions (the dependency for evaporative cooling increases as environmental heat stress increases), the type of clothing or equipment worn (impermeable or heavy clothing can elicit unexpectedly high sweat rates), the characteristics of the individual themselves such as body mass (surface area), genetic predisposition, and heat acclimatization (helps to achieve higher more sustained sweating rates). Some of these factors may be controlled or standardized such as indoor temperature or the type of clothing worn. Other factors will depend on individual exposure, with the result that there is considerable individual variation in sweat rates within activities and between activities and the climatic season. Sweat losses of between 0.2 and 3.4 litres per hour have been observed in various sports both in training and in competition amongst high level athletes (Table 1.23), highlighting the difficulties in providing a single recommendation for all.

To date there has been no published data on sweat rates in Gaelic Football. The nearest comparison is professional Soccer. Sweat losses of between 1.2 ($l \cdot h^{-1}$) and 2.5 ($l \cdot h^{-1}$) have been reported for games played in temperate climates (Ekblom, 1986), with values training range from 0.76 ($l \cdot h^{-1}$) to 2.65 ($l \cdot h^{-1}$) for training (Rehrer and Burke 1996; Shirreffs *et al.,* 2004; Maughan *et al.,* 2005).

The level of sodium lost through sweat depends on the total sweat loss which in turn is influenced by factors including genetic, dietary, environmental, exercise training, sweating rate and heat acclimatization (Verde *et al.,* 1982). Sodium helps regulate the amount of water in the blood, inside cells and outside cells.

Table 3.3 Sweat loses in various sports

Sport	Condition	Sweat rate ($L \cdot h^{-1}$) Mean	Sweat rate ($L \cdot h^{-1}$) Range	Voluntary fluid intake ($L \cdot h^{-1}$) Mean	Voluntary fluid intake ($L \cdot h^{-1}$) Range	Dehydration (% Change in BM) Mean	Dehydration (% Change in BM) Range
Waterpolo	Training (males)	0.29	[0.23-0.35]	0.14	[0.09-0.20]	0.26	[0.19-0.34]
	Competition (males)	0.79	[0.69-0.88]	0.38	[0.30-0.47]	0.35	
Netball	Summer training (females)	0.72	[0.45-0.99]	0.44	[0.25-0.63]	0.7	
	Summer competition (females)	0.98	[0.45-1.49]	0.52	[0.33-0.71]	0.9	
Swimming	Training (males & females)	0.37		0.38		0	
Rowing	Summer training (males)	1.98	[0.99-2.92]	0.96	[0.41-1.49]	1.7	
	Summer training (females)	1.39	[0.74-2.34]	0.78	[0.29-1.39]	1.2	
Basketball	Summer training (males)	1.37	[0.90-1.84]	0.80	[0.35-1.25]	1.0	
	Summer competition (males)	1.6	[1.23-1.97]	1.08	[0.46-1.70]	0.9	
Soccer	Summer training (males)	1.46	[0.99-1.93]	0.65	[0.16-1.15]	1.59	
	Winter training (males)	1.13	[0.71-1.77]	0.28	[0.03-0.63]	1.62	
American Football	Summer training (males)	2.14	[1.10-3.18]	1.42	[0.57-2.54]	1.5	
Tennis	Summer competition (males)	1.6	[0.62-2.58]	1.1		1.3	
	Summer competition (males)		[0.56-1.34]	0.9		0.7	
	Summer competition (cramp-prone males)	2.60	[1.79-3.41]	1.6	[0.80-2.40]		
Squash	Competition (males)	2.37	[1.49-3.25]	0.98		1.28kg	
Half Marathon running	Winter competition (males)	1.49	[0.75-2.23]	0.15	[0.03-0.27]	2.42	
Cross-country running	Summer training (males)	1.77	[0.99-2.55]	0.57	[0.00-1.30]	1.8	
Ironman Triathlon	Temperate competition (males & females)						
	Swim leg					1kg	
	Bike leg	0.81	[0.47-1.08]	0.89	[0.60-1.31]	+0.5kg	
	Run leg	1.02	[0.40-1.80]	0.63	[0.24-1.13]	2kg	
	Total race			0.71	[0.42-0.97]	3.5	

Verde *et al.*, (1982) have observed that a fit-acclimatized runner sweats 1.8 grams sodium per litre sweat loss, a fit but non-acclimatised runner sweats 2.6 grams sodium per litre sweat/hour, and an unacclimatized and unfit person loses 3.5 grams sodium per litre sweat/hour. Acclimatization increases the ability to reabsorb sodium and chloride resulting in lower sweat sodium concentrations for any given sweat rate (Allan and Wilson, 1971, cited in Sawka *et al.*, 2007). However even if the sweat sodium concentration of heat-acclimatized athletes is usually lower compared with the unacclimatized and untrained states, if sweat rates remain high, acclimatized athletes can still lose a large amount of sodium.

Typical mean readings for sweat electrolytes are: sodium (35 $mmol \cdot l^{-1}$), potassium (5 $mmol \cdot l^{-1}$), calcium (1 $mmol \cdot l^{-1}$), and magnesium (0.8 $mmol \cdot l^{-1}$) (Brouns, 1991; Sawka and Montain, 2000; Coyle, 2004). The mean sweat sodium concentration for professional Soccer players was $30 mmol \cdot l^{-1}$ training in cool environment and 35 $mmol \cdot l^{-1}$ training in warm conditions (Shirreffs *et al.*, 2005). In both of these studies the authors drew attention to the fact that the range in values for sweat electrolyte concentration is more relevant than the mean value, especially if the purpose is to identify 'salty sweaters' who may, unbeknown to themselves, be loosing large volumes of sodium and potentially predisposing themselves to problems associated with disturbances to fluid and electrolyte balance.

Performance may begin to suffer with increasing sweat and sodium losses and athletes tend to slow down. It is especially important for athletes to include sodium in fluid replacement (Coyle, 2004). The sodium will enhance fluid absorption and distribution and has the potential to stimulate thirst (as sodium concentration in the blood increases, there's a proportional increase in thirst) and therefore increase fluid intake. However drinking large volumes of low-sodium containing fluid over several hours, combined with losing large amounts of sodium in sweat has the potential to lower blood (plasma) sodium concentration, a condition known as hyponatremia (plasma sodium levels lower than 135mEq/L (Almond *et al.*, 2005). Hyponatremia can progress from general weakness, confusion, and ultimately to death.

3.24 Dehydration and Performance

Dehydration is defined as a dynamic loss of body water or the transition from euhydration to hypohydration, and can be a detrimental factor on performance. For any water deficit there is a similarity in altered physiologic function and performance characteristics. An increased susceptibility to heat stress, hyperthermia and exercise-induced exhaustion are caused by a failure of homeostatic regulation. Net fluid loss (2% of body weight) by insufficient fluid intake and replacement can impair bodily temperature control systems and cardiovascular function. Dehydration increases physiologic strain as measured by core temperature, heart rate, a decrease in stroke volume and serum sodium levels, and perceived exertion responses during exercise-heat stress (Sawka *et al.*, 2007). Dehydration is most commonly seen after exercise in which heavy sweating has occurred (Opplinger & Bartok, 2002). Table 3.4 summarises the physiological responses to dehydration.

Table 3.4 Physiological responses to dehydration (Murray 1996).

Gastric emptying rate	Decreased
Incidence of gastrointestinal distress	Increased
Splanchnic and renal blood flow	Decreased
Plasma volume	Decreased
Plasma osmolality	Increased
Blood viscosity	Increased
Central blood volume	Decreased
Central venous pressure	Decreased
Cardiac filling pressure	Decreased
Heart rate	Increased
Stroke volume	Decreased
Cardiac output	Decreased
Sweat rate at a given core temperature	Decreased
Core temperature at which sweating begins	Increased
Maximal sweat rate	Decreased
Skin blood flow at a given core temperature	Decreased
Core temperature at which skin blood flow increases	Increased
Maximal skin blood flow	Decreased
Core temperature at a given exercise intensity	Increased
Muscle glycogen use	Increased
Endurance performance	Decreased
Endurance capacity	Decreased

The failure to maintain fluid balance during repeated and prolonged exercise activity may result in decreased availability of blood flow to both the working muscles and the skin for heat dissipation, as well as an increase in stress on the cardiovascular system. Dehydration initiates a series of events in which blood volume decreases, resulting in an increase in heart rate, followed by a decrease in stroke volume due to the increased heart rate and decreased filling time of the heart (Casa *et al.,* 2000). As the level of water within the body falls, blood volume decreases leading to thickening of the blood and diversion of blood flow away from 'inactive' organs and towards the contracting muscles. The corresponding decrease in sweating response due to impaired blood flow to the skin causes an increase in core body temperature of an additional 0.15 to 0.20 degrees Celsius for every 1 percent of body weight lost due to sweating during activity. Fitts (1994) reported that rising body core temperatures may cause fatigue in the central nervous system as well as in contracting muscles an increased rate of glycogen degradation, elevated muscle temperature, and increased lactate levels, which if not lowered can result in heat stroke.

It is generally accepted that the human body can tolerate dehydration levels of between 1 and 2% body weight particularly in endurance activities in ambient temperatures of 20-21^{o}C lasting less than 60 minutes. However, dehydration of 2% body weight in events lasting longer than 60 minutes in warmer temperatures 31-32^{o}C may increase the risk of fatigue including loss of performance, increased risk of injury and other neuromotor problems (Coyle 2004; Casa *et al.*, 2000; Mohr, Krustrup, & Bangsbo, 2005).

Dehydration and hyperthermia are considered as contributory factors to the development of fatigue particularly in the latter stages of high intensity physical activities (Rothenberg and Pangos 2008). The random nature of Gaelic Football game play and a lack of scientific papers investigating fatigue make it challenging to measure performance detriments. However research evidence from similar sports codes suggests that performance during a Gaelic Football game could be compromised by even modest losses of body water and that players who become dehydrated are more susceptible to the negative effects of fatigue, including loss of performance, cognitive functioning, increased risk of injury, and impaired sports specific skills (Armstrong *et al.*, 1985; Gopinathan *et al.*, 1988; Sawka 1992; Burge *et al.*, 1993; Cheuvront *et al.*, 2003; McGregor *et al.*, 1997; Cian *et al.*, 2001; Devlin *et al.*, 2001; Baker *et al.*, 2007; and Edwards *et al.*, 2007).

Extensive body water and electrolyte losses from repeated or heavy sweating reduce the capacity of the temperature regulatory and circulatory systems, depleting cells of fluids and electrolytes and can result in a threat to health and performance (Sawka and Montain, 2000). Dehydration results in a reduction in the volume of blood in the body and a strain to the cardiovascular system as it has to work harder to pump the blood and deliver sufficient oxygen to the working muscles. It is estimated that for every one litre of fluid lost, heart rate elevates by eight beats per minute. As dehydration progresses it becomes more challenging for the cardiovascular system to maintain a safe core temperature which rises 0.3°C for every litre of fluid lost during exercise. The research evidence suggests that the physiological factors that contribute to dehydration work in conjunction to degrade aerobic exercise performance (Sawka *et al.*, 2007).

The majority of research studies investigating the impact of dehydration on performance have focussed on exercising in hot and dry conditions and diuretically induced laboratory based controlled environments. Although the results may not be applicable directly to Gaelic Football per se, as similar environmental conditions are unlikely to ever occur in Ireland, they do however give an insight into potential performance detriments associated with increasing levels of body mass loss.

Ladell (1955) found that 75% of subjects participating in a prolonged walk (140mins) in hot conditions (~38^{o}C) suffered from heat exhaustion when subjects received neither water nor salt, compared to 7% incidence of heat exhaustion when subjects received only water. Sawka *et al.,* (1985) had subjects attempt lengthy treadmill walks (~25% VO_{2max} for 140 mins) in a hot-dry environment (49^{o}C, 20% Relative Humidity) when euhydrated and when dehydrated by 3%, 5%, and 7% of their body mass loss. All bar one of the subjects completed the euhydration, 3%, and 5% experiments; however six of the eight subjects discontinued after completing less than half of the treadmill walk when dehydrated to 7% body mass. In a successive experiment that required subjects to walk to exhaustion in a hot-dry environment (49^{o}C, 20% RH), it was shown that dehydration (8% body mass loss) reduced tolerance time from 121 to 55 minutes and also lowered the core temperature a person could tolerate (Sawka *et al.,* 1985).

Gaelic Football players cover an average distance of 8594 m in a typical 70 minute game (Keane *et al.,* 1993). Armstrong, Costill, and Fink, (1985) have reported that middle distance running has also been shown to be decreased with dehydration. In their study 5 and 10 k running times were increased and treadmill endurance time decreased with dehydration of ~2.1% body mass. Burge *et al.,* (1993) investigated the effect of dehydration on rowing performance and found that subjects took on average of 22 seconds longer to complete the task when dehydrated (~2%) than when they were euhydrated. Edwards *et al.*, (2007) found that the denial of fluid over 90 minutes of exercise combining cycling and Soccer significantly impaired post match physiological performance of a sport specific fitness test. Participants also reported a greater sensation of thirst and perceived exertion when access to fluid was denied throughout the 90 minute protocol.

Successful Gaelic Football requires both physical and cognitive skills to perform complex motor skills, Gopinathan *et al.,* (1988) and Cian *et al.*, (2001) showed that cognitive-motor functions, such as short-term memory, working memory, and visual-motor function were adversely affected when dehydration reached 2% body mass loss. Similarly skill levels may be compromised with dehydration of ~2–3% body mass. McGregor *et al.,* (1997) reported impairment in a Soccer specific skill at levels equivalent to body mass decrease of 2.4% dehydration, while Devlin *et al.,* (2001) found that dehydration of 2.8% of body mass loss had an adverse effect on bowling accuracy. Baker *et al.*, (2007) reported an impaired performance in the number of shots made and sprint speed in adult basketball players with 2% dehydration which deteriorated further when dehydration reached 4%.

It is generally accepted that performance is not affected by dehydration levels of between 1 and 2% body mass in endurance activities lasting less than 60 minutes in ambient temperatures of 20-21^{o}C Coyle (2004). However physiological performance is impaired when exercising even in a moderately dehydrated (in excess of 2% loss of body mass) condition (Edwards and Noakes 2009).

There is good evidence to support muscle dysfunction as a cause of injury, particularly in the latter stages of activity, such as changes to the intracellular environment as a result of the depletion of key metabolites or the accumulation of other metabolites. Cumulative microscopic damage to muscle fibres as a result of repetitive over-exertion or after periods of unaccustomed eccentric exercise are attributed to the occurrence of Exercise Associated Cramps (EAMC) and Delayed Onset Muscle Soreness (DOMS), (Byrnes *et al*., 1985; Bergeron, 2003; Rahama *et al.*, 2003; Stofan *et al.*, 2005; Greig, 2008; Horswill *et al*., 2009; Schwellnus 2009).

Simulated protocols of the associated physiological or mechanical demands of match play in Soccer have shown that performance may be inhibited especially in the second half of games with regard to the amount of distance covered by players (5-10% decrease in total distance covered), a decrease in amount of sprinting and high intensity running particularly in the last fifteen minutes of a game, and a decrease in jumping performance accompanied by reductions in EMG activity (Reilly and Thomas, 1976; Van Gool *et al.*, 1988; Bangsbo *et al.*, 1991; Bangsbo 1994; Avela and Komi 1998; Mohr *et al*., 2003; Rahnama *et al.*, 2003; Greig, 2008; and Oliver *et al.*, 2008).

Research evidence from similar sports codes suggests that performance during a Gaelic Football game is probably compromised by even modest losses of body water. Fluid deficits between 1-2% losses of body mass seem typical in competitive Soccer games across the majority of environmental conditions. Such fluid losses are also largely inevitable due to restricted opportunities to drink during a game.

It is considered to be negligent for Gaelic Football coaches and players to neglect the above and not investigate dehydration levels especially prior to the commencement of activity as individuals may start an exercise task dehydrated. Similarly coaches and players should be aware of the increased risk of dehydration as a result of prolonged daily training sessions, or when training takes place twice in one day, especially if players are carrying a fluid deficit from their previous training activity. Controlling dehydration could act as a preventive measure against the onset of fatigue and subsequent risk injury.

3.25 Sodium and Performance

Sodium is the electrolyte most critical to health and human performance. It regulates and helps to maintain body fluid, osmoregulation, and the generation of nerve impulses and proper muscle function. Sodium is important for maintaining heart performance and glucose absorption and even a slight depletion of concentration can cause problems.

Sodium plays an important role in the removal of excess amount of carbon dioxide accumulated in the body and it helps in absorption of glucose by cells for the smooth transportations of nutrients in body cell membranes. Sodium helps to control the reaction of urine in kidneys by altering proportions of acid-base alkali phosphates and plays an important role in balancing the osmotic pressure due to regulation of fluid in body cells. Sodium helps stimulate rapid and complete rehydration (Maughan and Shirreffs 1998). According to Sallis (2008), an athlete needs to be proactive regarding water and electrolyte replacement particularly with multiple training sessions per day. Those who come closest to achieving a balance between fluid and sodium intake and loss give themselves the best chance for optimal performance and avoidance of injury.

Sodium is important as it helps drive the urge to drink therefore maintaining sympathetic output, and transient blood pressure (Stachenfield 2008). The concentration of sodium in sweat is influenced by sweat rate (Shibasakl *et al.*, 2006). An increased fitness promotes conservation of sodium chloride by the sweat glands, and helps to increase plasma sodium volume at rest and maintain higher plasma volume during exercise (Wenger 1988). Correspondingly, athletes tend to have a higher sodium loss than the general population because sodium loss escalates when one sweats. However when sweating is high, sodium losses can be prodigious especially those with high sweating rates or high sweat sodium concentrations. Athletes referred to as ‘salty sweaters’ are prone to sodium deficits, heat cramping, plasma volume concentration, and notably in endurance events hypovolemic hyponatremia (Eichner 2008).

Correct blood volume levels are important as they allow the speedy removal of waste and delivery of nutrients to cells. Blood sodium concentrations are maintained under precise control by various metabolic mechanisms including, the stimulation of thirst, the secretion of aldosterone, the secretion of anti diuretic hormone ADH, and the handling of water and sodium by the kidneys. Measuring sodium levels is important as plasma concentration should remain within the range of 130-160mmol.l^{-1} to keep cells, tissues, and organs functioning with the proper volumes of fluid and thus optimal balance. Research studies suggest that athletes should ingest 450 mg of sodium per hour of exercise when sweating occurs to protect plasma volume and plasma sodium concentration (Baker *et al.,* 2005, Barr *et al.,* 1991, Below *et al.,* 1995, Montain *et al.,* 2006; Twerenbold *et al.,* 2003, Vrijens and Rehrer 1999).

Sodium is needed to transmit electrical impulses in the human body. The transmission of the action potential along the surface membrane of the muscle fibre is influenced by the intracellular and extracellular concentrations of sodium and potassium respectively. The Na^+/K^+ pump located within the muscle fibres membrane, is partly responsible for maintaining this electrical potential by pumping Na+ out of the muscle while simultaneously pumping K^+ back into the muscle cell during repolarisation. According to Deschenes and Kraemer (1989) there must be an electrical potential across the membrane of the muscle fibre in order for a muscle to contract and any alterations in the excitability of the muscle fibres may result in decrement in performance as a result of a reduction in the functional capacity of the Na^+/K^+ pump and other intracellular regulators of the membrane potential and intracellular calcium concentration.

Research suggests that the Na^+/K^+ pump activity can become a limiting factor for muscle endurance especially if the concentration of the Na^+/K^+ pumps is reduced (Nielsen and Clausen 2000) and the performance of working muscles is highly dependent on the ability of the muscle fibres to perform active Na^+/K^+ transport. Alterations in sodium concentration may result in failure of the cells to depolarize and contract and is, therefore, a potential site for a mechanism of muscle fatigue. The function of the Na^+/K^+ pump can, therefore, become limiting factors for contractile endurance (Neilsen and Clausen 2000). According to Fowles *et al.*, (2001) fatigue occurs with an inability of the muscles to respond to an electrical stimulus due to the reduction in the muscle action potential (M-wave). This reduction in M-wave is the result of a decline in ionic transmembrane gradients for Na^+ and K^+ during exercise. Obviously, the balance of both electrolytes are important to the membrane potential (in addition to other electrolytes) but as K^+ is low in the extracellular environment it is less likely to be a significant contributor in the composition of sweat and harder to measure. Thus the contribution of Na^+ loss in sweat production is more appropriate to measure in relation to dehydration through sweat loss.

Sweat sodium concentration normally ranges from a low of 20mmol.l^{-1} to a high of 80 and the consensus holds that independent of sweat genetics, athletes who are more intense in their efforts may lose more sodium than their less intense counterparts, i.e. sweat sodium increases as sweat rate increases (Eichner 2008). Visual clues to identify salty sweaters include sweat that burns the eyes, stings abrasions, or tastes salty when it trickles into the mouth, along with a white residue (salt) visible on clothes or skin (Eichner 2008).

Sweat rates and sodium concentrations in athletes vary widely and are influenced by a number of factors including the type of event, intensity of exertion, the acclimatization of the athlete and environmental conditions, particularly heat and humidity (Sallis 2008). Individual characteristics such as body weight, genetic predisposition, and metabolic efficiency can also influence sweat rates (Sawka *et al.,* 2007).

An athlete who only replaces the lost fluid with water will contribute to a decreased blood sodium concentration. The benefits of ingesting sodium before during and after vigorous physical activity include positive effects on physiological function, exercise performance, and health (Below *et al.,* 1995; Jukendrup 2004). The inclusion of electrolytes in a sports drink provides superior hydration and performance benefits without impairing gastric emptying or intestinal absorption; it helps maintain plasma sodium concentration by improving fluid retention and speeds rehydration because replacement of the electrolytes lost in sweat is just as important as replacing the water lost in sweat (Maughan and Shirreffs, 1998; Ryan *et al.*, 1998).

Thirst is a sensation aroused by a need for water and relief for it is sought by drinking water (Fitzsimons 1998). It is driven by two key physiological changes, a rise in the concentration of sodium level and a drop in blood volume. However relying on thirst alone to stimulate to drink is an inaccurate measure of fluid requirement especially during physical activity. If sweat loss is replaced by water alone, the plasma sodium concentration falls which reduces thirst; thus plain water is a thirst quencher but a poor rehydrator as the thirst mechanism is compromised and the osmotic drive to drink is removed because plasma blood sodium level is quickly lowered below the thirst threshold.

Through education, athletes can learn to recognise the symptoms of salty sweat and learn where appropriate to increase their salt in diet and sports drinks to help avoid performance and clinical consequences of fluid-electrolyte balance by replacing sweat sodium losses (Stachenfeld 2008). Adequate replacement of sodium during exercise can encourage voluntary fluid intake, protect plasma volume, and reduce urine production all responses that promote hydration (Murray 2007). Athletes who come closest to achieving a balance between fluid and sodium intake and loss give themselves the best chance for optimal performance and avoidance of injury (Sallis 2008).

3.26 Measuring Hydration Status

Coaches and medical staff want to ensure that the athlete is adequately hydrated during training and competition so that physiological conditions for physical performance are maximised and the risk of injury minimised. There is a wealth of information and position statements about the benefits of good hydration and the dangers of dehydration (e.g. National Athletic Trainers' Association 2000; and American College of Sports Medicine 1996, and 2007); unfortunately there is very little information with regard to recommendations for hydration testing of athletes. Hydration status can be assessed in a variety of ways, from simple non-invasive tests such as monitoring body mass, to detailed, expensive and invasive, blood tests. The choice of method depends upon many factors including the population being assessed, the resources available, the speed with which results are required, the capacity for collecting samples, and the testing environment.

3.271 Changes in body mass

Body mass, particularly daily change in mass, is a relatively easy and inexpensive method to assess dehydration. A simple and effective method, the use of this technique implies that 1g of lost mass is equivalent to 1ml of lost water, and so long as total body water loss is of interest, failure to account for carbon exchange in metabolism represents the only small error in this assumption (Cheuvront *et al.,* 2002). Steps must be taken to ensure validity and reliability of body mass values. It requires two time points or measurements, such as pre and post activity, and a standardised protocol for measuring body mass. It is recommended that athletes should be weighed in the nude or with minimal clothing and any excess sweat should be towel-dried prior to post activity weighing. The percentage change in body mass can then be compared to published indices of hydration (Table 3.5).

Table 3.5 *Indexes of Hydration Status using different Methods (Casa et al., 2000)*

Hydrated status	% Change in Body Mass	Urine Colour	Urine Specific Gravity	Urine Osmolality
Well hydrated	+1 to -1	1 or 2	<1.010	<300
Minimal dehydration	-1 to -3	3 or 4	1.010-1.020	300 – 600
Significant dehydration	-3 to -5	5 or 6	1.021-1.030	600 – 900
Serious dehydration	>5	>6	>1.030	900 – 1400

Harvey *et al.,* (2008) investigated the validity of body mass changes in professional Soccer players as a reliable measure of dehydration compared to other known methods (urine colour, specific gravity and hematocrit). Pre and post-training activity data were collected for each of the methods; data were then fitted to liner mixed effects models to identify an optimal prediction equation for sweat loss. Body mass change was shown to be an effective, timely, and practical method of monitoring dehydration due to sweat loss. However measuring body mass changes alone provides a conservative (under) estimate in total body fluid loss as it does not account for any fluid intake or excretion. To increase accuracy total fluid intake and excretion should be recorded (Harvey *et al.*, 2008).

According to Maughan *et al*., (2007) using body mass change as a measure of hydration status should also take into account changes in substrate oxidation, metabolic water, and respiratory loss however this method is beyond the scope of this thesis and impractical in field based experiments.

According to the American College of Sports Medicine, Position Statement on Exercise and Fluid Replacement, Sawka *et al.*, (2007),

"Body weight changes can reflect sweat losses during exercise and can be used to calculate individual fluid replacement needs for a specific exercise and environmental conditions. Evidence category A" (recommendation based on consistent and good quality experimental evidence)

3.272 Urine colour

Another practical and simple although slightly invasive method of indicating hydration status is to analysis urine colour. Urine is approximately 95% water, with the remainder consisting of urea, uric acid, hormones, dead blood cells, salts, proteins, minerals and toxins. The yellow colour in urine is due to chemicals called urobilins (which come from degraded bile pigments). If the water in the body is balanced the urine will be a straw colour (normal urine colour), a lighter colour indicates a more diluted urine, while conversely a darker colour (brownish-green) indicates a more concentrated urine (as a result of body water loss exceeding fluid intake and the corresponding need to conserve water by the kidneys).

Using the urine colour method, a urine sample is compared against a urine colour chart (Figure 3.5). A urine colour rating of 1, 2 or 3 is considered to be well-hydrated, a urine colour darker than colour 3 in the chart is an indicator that the individual is dehydrated and a corresponding number in excess of 5 indicates significant dehydration (Armstrong, 2000).

Although a relatively quick and inexpensive method of measuring hydration status especially pre-exercise activity, urine colour does not provide the accuracy or precision of urine specific gravity and it may underestimate the level of hydration (Dolan, 2009). Also the use of urine colour index charts particularly post-exercise has been questioned as urine colour can be affected by factors unrelated to hydration such as food, medication, illness and the ingestion of large volumes of poorly retained fluids such as plain water, and can produce pale coloured urine well before body fluids stabilise (Kovacs *et al*., 1999; Oppliger and Bartok, 2002). Similarly the timing of the urine sampling can also potentially affect the reading, for example if dehydrated persons consume large volumes of hypotonic fluids, they will have copious urine production long before euhydration is re-established (Shirreffs *et al*., 1996). A urine sample taken in this period will be light in colour (indicating good hydration) when in fact the person is dehydrated. If possible it is recommended to use the first morning urine sample or take samples after several hours of stable hydration status. Also collecting urine samples post exercise can be problematic particularly in warm environments. However when precision is not necessary, urine colour provides a valid means of self-assessment of hydration level (Dolan, 2009).

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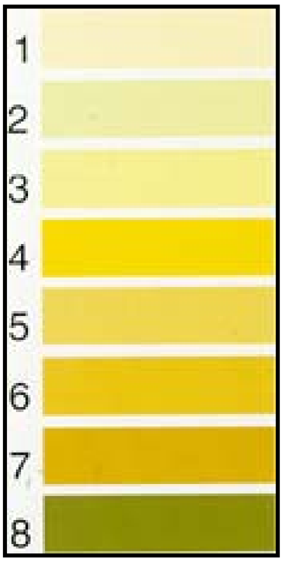

Figure 3.5 Urine colour chart to assess hydration status. The colour of urine sample is matched to a colour on the chart, the lower the number, the better the result (Armstrong *et al.,* 1994).

3.273 Urine Specific Gravity

Hydration status can also be measured by analysing Urine Specific Gravity (the density of urine compared with the density of water). The easiest and least expensive method is to use test strips (Figure 3.6). Reagent strips consist of a plastic strip with small absorbent reagent squares. When a reagent strip is dipped into the sample of urine the a chemical reaction occurs in the small pads that depends on the urine concentration, protons are released in the presence of cations and the strip changes colour according to the Specific Gravity, the strip is then removed from the urine and compared against the corresponding colour chart to give a reading for USG. The range in USG levels are normally between 1.000 and 1.030. According to standardised indices (Table 3.4), a USG reading greater than 1.021 indicates significant dehydration. A potential weakness of using this method is the fact that it requires subjective determination by the technician which may not always be accurate. Also failure to follow a manufacturer's specifications with regard to proper immersion procedure and interpretation of results (particularly as there are a variety of manufacturers of reagent strips) may result in an inaccurate reading (Stuempfle and Drury, 2003; Wilson 2005).

Figure 3.6 Urine Test Strips, (e.g. Bayer Multistix) for testing USG. Strip changes colour according to the specific gravity.

An alternate, more reliable and less subjective method is to use a refractometer (Figure 3.7). This instrument measures urine specific gravity by analyzing the amount of light passing through a drop of urine on a glass plate. This method is a more sensitive indicator of mild hypohydration than blood plasma or hematocrit (Armstrong *et al.*, 1998) and is the preferred method for urine specific gravity measurements. It is also the recommended method of the National Athletic Trainers' Association, according to their position statement on fluid replacement for athletes (Casa *et al.*, 2000).

Figure 3.7 A Refractrometer, used to measure the amount of light beam refracted when passed through a urine sample.

Unlike urine colour, urine specific gravity is quantifiable, however as previously highlighted the timing of the urine sampling can also potentially affect the USG score.

3.274 Other methods of measuring hydration status

Urine osmolality (the amount of dissociated solute particles per kilogram of solution) is another method of measuring hydration status. Urine solutes that dissociate such as NaCl are detected using a freezing point osmometer. This method requires a trained technician and is not practical for clinical use. An alternative to the osmometer, the Sparta 5 conductance meter (Figure 3.8) using a five point scale to provide a measure of urine conductance was validated by Shirreffs and Maughan, (1998).

Measuring blood serum and plasma sodium parameters may provide more accurate information about even the mildest presence of dehydration but this method is time consuming, expensive and requires properly trained phlebotomists. It also is more invasive to the athletes and poses a risk of infection. Although beneficial for laboratory research purposes, it may not be the most practical method for measuring in the field (Oppliger and Bartok, 2002). Although urine tests may lack the precision needed to predict the extent of dehydration compared to blood-bone methods, the use of a cut-off value can help to classify individuals into appropriate categories of euhydrated and dehydrated (Table 3.5).

Figure 3.8 Sparta 5 Conductance Meter designed to provide a marker for urine conductance (Shirreffs and Maughan, 1998).

Table 3.5 *Indexes of Hydration Status using different Methods (Casa et al., 2000)*

Hydrated status	% Change in Body Mass	Urine Colour	Urine Specific Gravity	Urine Osmolality
Well hydrated	+1 to -1	1 or 2	<1.010	<300
Minimal dehydration	-1 to -3	3 or 4	1.010-1.020	300 – 600
Significant dehydration	-3 to -5	5 or 6	1.021-1.030	600 – 900
Serious dehydration	>5	>6	>1.030	900 – 1400

3.275 Summary

Hydration testing is important and there are a number of different methods to choose from (Table 3.6). Although accuracy and precision are paramount, it is also important to consider the cost and practicality of the equipment especially when working with large groups or teams. While plasma osmolality and total body water measurements are considered the best hydration assessment measures for large scale assessment surveys of fluid needs (Sawka *et al.,* 2005), there is no consensus for using any one approach over another (Cheuvront and Sawka, 2005). Body mass change combined with measurement of urine specific gravity is considered to be a safe, precise, and non-invasive option for daily hydration monitoring of athletes as these techniques are easily mastered and amenable to self-monitoring by the athlete (Opplinger and Bartok, 2000). Although urine tests may lack the precision needed to predict the extent of dehydration compared to blood-bone methods, the use of a cut-off value can help to classify individuals into appropriate categories of euhydrated and dehydrated (Table 3.5).

In keeping with the NATA's recommendations for hydration testing (Casa *et al*., 2000), body mass change that accounted for total fluid intake and excretion, and urine specific gravity measurements were the two methods chosen for the experimental studies investigating fluid and electrolyte balance amongst elite Gaelic Football players (*Newell et al.,* 2006).

Table 3.6 *Summaries of Hydration Assessment Techniques (Cheuvront and Sawka 2005)*

Technique	Advantages	Disadvantages
<u>Complex Markers</u>		
Total Body Water (dilution)	Accurate, reliable, (gold standard)	Analytically complex, expensive, requires baseline
Plasma Osmolality	Accurate, reliable, (gold standard)	Analytically complex, expensive, invasive
<u>Simple Markers</u>		
Urine Concentration	Easy, rapid, screening tool	Easily confounded, timing critical, frequency and colour subjective
Body Mass	Easy, rapid, screening tool	Confounded over time by changes in body composition
<u>Other Markers</u>		
Blood: Plasma volume Plasma Sodium Fluid Balance Hormones	No advantages over osmolality (except hyponatremia detection for plasma sodium)	Analytically complex, expensive, invasive, multiple confounders
Bioimpedence	Easy, rapid	Requires baseline, multiple confounders
Saliva	Easy, rapid	Highly variable, immature marker, multiple confounders
Physical Signs	Easy, rapid	Too generalised, subjective
Thirst	Positive symptomology	Develops too late and is quenched too soon

3.27 Measuring Sweat Rates

For athletes in any sport the majority of fluids lost during exercise are as a result of the body's thermoregulatory responses. Exercise produces heat which is dissipated by the evaporation of sweat, with the sweat rate determined primarily by exercise intensity and the ambient temperature and humidity. Every one-kilogram change in body mass there is an approximate equivalent loss of one litre of fluid (Armstrong 1985, Rehrer and Burke, 1996). A practical method to measure sweat rate is to measure the change in body mass, i.e. the difference between pre and post exercise body weight. Added to this is the weight of any fluid consumed during exercise minus any urine output. This total is divided by the duration of exercise to get the sweat rate per hour (Table 3.7).

Table 3.7 *Example of Sweat Rate Calculation*

Variable	Measurement
Pre exercise mass:	75kg
Post exercise mass:	73.5 kg
Decrease in body mass:	1.5kg
Volume of fluid consumed during exercise:	(1litre) 1kg
Urine volume:	0
Total sweat loss (litres):	1.5kg +1 kg = 2.5 kg
Exercise duration:	2 hours
Sweat rate equals (litres/hour):	2.5kg/2 = 1.25l/h
Hydration balance (Fluid deficit): (sweat rate per hour – fluid consumed per hour)	1.25l – 0.5l= 0.75 litres

3.28 Measuring Sweat Electrolyte Concentration

There is considerable debate in the literature regarding the composition of human sweat, the duration of sweating, the rate of sweat secretion and the method of sample collection. Variations in regional sweat composition and the portability and practicality of sweat collecting devices have limited sweat electrolyte research to laboratory based experiments.

Different methods have been used to collect samples of sweat including a whole body wash-down technique (Shirreffs and Maughan, 1997; Baker *et al.,* 2009), placing the forearm in a sealed bag (Chinevere *et al.,* 2008), using a parafilm pouch (Brisson *et al.,* 1991; Patterson *et al.,* 2000; Hayden *et al.,* 2004; Morgan *et al.,* 2004; Montain *et al.,* 2007), and applying absorbent patches or filter paper to body sites (Verde *et al.,* 1982; Shirreffs and Maughan, 1997; Stachenfeld *et al.,* 1999; Maughan *et al.,* 2004; Stofan *et al.,* 2005; Fudge *et al.,* 2008; Laitano *et al.,* 2008; Kilding *et al.,* 2009).

The whole body washdown method is considered the most accurate method of whole body sweat electrolyte loss as all sweat run off is collected and accounted for, and secondly it does not interfere with the normal evaporative processes (Shirreffs and Maughan 1997; Baker *et al.,* 2009). The validity and reliability of using the whole body wash down technique has been demonstrated by Shirreffs and Maughan (1997). However this method requires a controlled laboratory setting and is limited to cycling activity.

Hayden *et al.,* (2004) used a closed-pouch method of collecting sweat samples from cyclists. A parafilm was attached to the skin with a wound dressing. Sweat was then aspirated from the pouch at the end of the trial, and the electrolyte concentrations were determined by flame photometry.

Recent advances in medical wound care technology have facilitated the collection of sweat samples in non-laboratory based settings. Verde *et al.,* (1982) established the validity of using absorbent gauze pads as a method of collecting sweat samples, as it caused minimal contamination of sweat specimens (a problem that tended to occur when filter paper was used), and was readily reproducible. The authors recommended that the patches remain in position for 20 minutes, long enough to gather a sufficient sweat sample without the danger of saturation. The main disadvantage of using gauze pads is that they only represent a small segment of the skin surface and the collection period is limited, however the main advantage of this method is the collection of sweat samples in real time natural athletic environments.

An alternative method using absorbent patches to collect sweat samples was used by Maughan *et al.,* (2005). Spongy absorbent patches (Figure 3.9) were applied directly to the body to collect a sweat sample from the skin surface as the athlete exercises. The pads remained in situ for 20-30 minutes, were later removed from the skin and placed in sealed sterile containers; a known volume of deionised water was added to the containers which were then passed through a vortex. Electrolyte concentrations were finally determined by flame photometry. Maughan *et al.,* (2005) used this method to determine sweat electrolyte concentrations in professional Football players training in cool environments (5 ^{o}C), similarly Shirreffs *et al.,* 2005 using the same method for players training in warm conditions (32 ^{o}C). Most recently, Osterberg *et al.,* (2009) used an adaptation of this method to record sweat electrolyte concentrations of volleyball players.

To date however, there is no consensus in the literature with regard to the number of patches that should be used and their anatomical locations. Some investigators have opted to apply patches to four separate anatomical sites (forearm, back, chest, and thigh) (Maughan *et al*., 2005; Shirreffs *et al.,* 2005) while others have opted for up to ten body sites (Verde *et al.,* 1982), and some have used a single site only (forearm) (Osterberg *et al.,* 2009). Although numerous studies have successfully used sweat patches to estimate sweat electrolyte concentration (Verde *et al.,* 1982; Shirreffs and Maughan, 1997; Stachenfeld *et al.*, 1999; Maughan *et al.,* 2004; Stofan *et al.,* 2005; Fudge *et al.,* 2008; Laitano *et al.,* 2008; Kilding *et al.,* 2009), until recently the validity of using this method as a measure of whole body sweat concentration was limited. This was mainly because of variations in sweat rate and sweat composition across different body regions, and the patches may suppress sweat evaporation in that specific skin region (Baker *et al.*, 2009).

A recent study by Baker *et al.*, (2009) examined the reliability of regional versus whole body sweat electrolyte concentration. They compared the regional patch method (using absorbent patches attached to five body sites, the forearm, back, chest, thigh, and forehead), and the whole body wash down sweat collection method (subjects exercised in a plastic isolation chamber and were washed down immediately after completion of protocol) and concluded that while there is an overestimation of sweat electrolyte concentration associated with the regional sweat patches method, regression equations can be used to accurately and reliably predict whole body wash down sweat electrolyte concentrations from single or multiple site patch collections. According to the authors the chest and thigh locations were the best sites for predicting the whole body wash down method. Other researchers have proposed the forearm location to be highly correlated with whole body sweat sodium when variations in regional sweat composition were investigated Patterson *et al.,* (2000). Similarly the forearm is also the region routinely sampled in clinical tests for cystic fibrosis, a disease characterised by excessive salt loss in sweat (Verde *et al.*, 1982).

Figure 3.9 Sample of Absorbent Sweat Patches as used by Maughan *et al.,* (2005). (Tegaderm +Pad, 3M Healthcare, USA)

The present system of sweat patches used by Maughan *et al.,* (2005) Shirreffs *et al.,* (2005), Baker *et al*., (2009) and Osterberg *et al.,* (2009) was the preferred method chosen for this study for a number of reasons. Primarily, the use of sweat patches facilitates the monitoring of large groups of players in their natural training environment rather than relying on a simulated training session in a laboratory. Secondly the sweat patches are very small, barely noticeable, and can be applied and removed very quickly without disrupting the players' activities.

Conclusion

No study has determined dehydration levels in Gaelic Football, or attempted to control the potential impact of dehydration while investigating the risk factors for injury particularly in the latter stages of activity.

It is considered that assessment (particularly in the summer months) of fluid and electrolyte losses during training and games would provide coaches and players with information on the possible hydration needs during and after exercise.

Accordingly the aims of this study were:

- To investigate fluid and electrolyte losses in elite Gaelic Football players during training and match activities
- To design individual hydration strategies for each player
- To gather evidence-based data investigating the link between dehydration and injury.

3.3 Methods

Three Senior Inter-County (elite) male Gaelic Football teams were invited to participate in this study. The teams were chosen from different geographical locations in Ireland representing the population of players competing at elite level Gaelic Football. All subjects were in good health at the time of testing. Subjects who are deemed to have any adverse medical condition were not recruited. All subjects were given an information sheet and asked to sign a consent form. Physiotherapists and medical staff attached to each team were briefed on the workings of the project. Testing was scheduled to take place at three separate training sessions in varying environmental conditions during the playing season. The injury reporting form devised for the Gaelic Football Injury Study (Newell *et al.,* 2006) was used to record injuries by the team's physiotherapist. Ethics approval for the study was obtained from the ethics committees of Glasgow University and the National University of Ireland Galway. Data on environmental conditions were acquired from the local meteorological office.

3.31 Pilot Studies

In order to learn more about hydration and electrolyte assessment the author visited Prof Ron Maughan's research facility in Loughborough to work alongside his team of researchers investigating fluid and electrolyte balance in elite rugby players and swimmers.

Two pilot studies were conducted with club (recreational) Gaelic Football teams during the month of May 2006, prior to the commencement of the main study in

July of that year. The purpose of the pilot studies was to test the practicality, feasibility and logistical aspects of the fluid and electrolyte balance study. Meetings were arranged with the managers of the two Gaelic Football teams, one based in Scotland, and the other in Ireland. During the meetings the rational for the project was outlined along with a practical demonstration of the equipment to be used during testing. Both managers were in favour of the project and gave their permission to allow for testing to take place during a scheduled training session.

There were two main sections of the pilot study under scrutiny, (i) the data collection stage, and (ii) the laboratory analysis of the sweat samples. The data collection consisted of four elements for each of the players, a pre training urine sample, a measurement of pre-training body mass, the collection of sweat samples from four anatomical regions, and a measurement of post-training body mass. The laboratory analysis consisted of, the storing of samples post collection, their transfer to the laboratory, and the actual testing of the sweat samples.

Pilot Study 1

The first study took place in Scotland on a relatively warm (18 ^{0}C) and humid evening (80% relative humidity). This was the players' first training session of that week. Normally the players train twice a week with a game at weekends. Prior to the start of training the players were briefed on the purpose of the study and were given consent forms to sign. All players in the team participated in the first pilot study (n=18); the players, all male, ranged in age from 19 years to 38 years. The training commenced with a 15 minute warm-up consisting of light jogging and dynamic and static stretching exercises, followed by a series of kicking and catching drills. The latter half of the training included 10 minutes of speed training, a practice game for 20 minutes, concluding with a 10 minute warm down consisting of light jogging and static stretching. The total duration of the training session was 75 minutes.

From a study perspective, the emphasis during this first phase of data collection (i.e. the pre-training phase) was on obtaining a urine sample from each player, recording each player’s body mass, attaching the sweat sampling pads to the relevant anatomical positions, and making sure that each player had two drinks bottle clearly labelled with his study number. The co-ordination of these four steps would be crucial to the successful operation of the main study. It was important to minimize any disruptions to the players’ regular training routine.

The first phase of the pilot study worked well, however a few issues were highlighted. Firstly, amendments would be needed to the logistics regarding urine sampling. In this particular pilot study, the players decided on their own study number and took their relevant universal container (Sarstedt, Wexford, Ireland) from the rack. However there was some congestion with players trying to obtain a blank universal from the rack at the same time as other players were returning their completed sample to the rack. It was decided that in future studies two colour-coded racks would be used. A blue rack to contain the blank universals and a red rack for the completed urine samples. This would hopefully speed up the process and avoid any unnecessary overcrowding. Secondly, players needed to be reminded to have their body mass recorded prior to putting on their training gear as some players had ‘togged out’ fully, causing a slight delay to proceedings. Thirdly, the process of attaching the sweat sampling pads (Tegaderm +Pad, 3M Healthcare, USA) was time consuming and took slightly longer than anticipated, causing a delay to the start of training. For future studies it was decided to start preparations earlier.

During the training session, players were reminded to drink only from their own water bottles (plastic sports drinks bottle containing one litre of water) and all fluid should be swallowed, not spat out or used to rinse their face (as typically occurs during training in warm conditions). This part of the pilot study worked very successfully, however it later transpired that some players would have consumed more fluid if they had access to additional water bottles. It was recommended that in future studies players would be provided with three designated water bottles.

During the training session, some players reported that their sweat collection pads had come loose or in some instances fallen off completely. In order to offset the potential loss of sweat samples (as occurred during the pilot studies), and to prevent saturation of the sweat sample (samples may become dilute if left attached for a prolonged period) it was decided that the pads should be removed from their body locations after twenty minutes (Sherrifs *et al.*, 2005).

Four sterile containers [labelled with the inscriptions, B (Back), C (Chest), T (Thigh) and A (Arm)], were allocated to each player, and the relevant pads were removed using a tweezers and placed in the designated container. There was however an unnecessary delay deciphering through the large amount of grouped containers looking for the relevant study number assigned to each player. In order to speed up the process and minimise interruption, (particularly as it would be taking place during a brief pause in the training session), it was decided to have each group of sterile containers clearly labelled and placed on a table beside the training area. When directed, the players would pick their appropriate group of containers and as they listened to the coach or had a drink break, the tester would be able to move quickly from player to player to remove the sweat pads.

Upon returning to the changing area the players were reminded to towel dry and to weight themselves again (wearing just their shorts) on the same scales as before. Apart from some players forgetting to return their water bottles to the changing area (which necessitated the researcher having to collect them) the post-training weighing of drinks bottles was relatively uncomplicated. A kitchen scales (Soenhle Magnum 802U Digital Food Scale, Switzerland) was used to measure the mass of each bottle, allowing for comparisons with the mass of the bottles at the start of training. It was important to make sure that all bottles were accounted for. In order to offset any potential problems in future tests it was decided to have a designated person in charge of looking after the water bottles. Urine samples were analysed using reagent strips (Combur[10] Test, Roche Diagnostics, Mannheim, Germany), and the results were inserted onto the recording sheet. The urine samples and containers were disposed of appropriately.

Pilot Study 2

The second pilot study took place in Ireland, a week after the first pilot study. The weather conditions were very similar; the ambient temperature was 17 ^{0}C with relative humidity at 82%. For this group of players it was their second training session of that week; the first training session took place 48 hours previously, and their next Gaelic Football game was scheduled to be played two days after the training session. In keeping with the first pilot study, the players were briefed on the purpose of the study and were given consent forms to sign prior to the start of training. All players participated (n=22); the players, all male, ranged in age from 17 years to 32 years. Training lasted 70 minutes and consisted of a 15 minute warm-up consisting of light jogging and static stretching exercises, followed by a series of shooting and defensive drills. The latter half of the training consisted of a practice game for 30 minutes, concluding with a 5 minute warm down consisting of light jogging and static stretching.

<u>Pre-training phase</u>

As outlined in the first pilot study, the players decided on their own study number and took their relevant blank universal from the red coloured rack of universals (Sarstedt, Wexford, Ireland). The players were reminded of their study number and instructed to place their returned urine sample into the empty blue coloured universal rack.

The pre-training body mass for each player was measured using a digital weigh scales (Seca 770, Hamburg, Germany), this information was recorded along with his age, by a member of the management team on specific forms. Once urine samples were returned and body mass recorded, the next step for players was the attachment of sweat pads. In order to speed up the process, the sweat pads (Tegaderm +Pad, 3M Healthcare, USA) were removed from their outside packaging and grouped into bundles of four, this method proved much more efficient (and less messy) than the first pilot study. Finally, players were instructed to take their allocated drinks bottle (plastic sports drinks bottle containing one litre of water) with them out to the training area, and reminded to drink from their own bottle and not to spit out any water. The other two allocated drinks bottles were already positioned in the carry racks, and taken to the pitch by a member of the research team.

Training phase

The crates containing the drinks bottles were positioned around the perimeter of the training area as well as the initial bottles taken by the players from the training area. Players were constantly reminded to drink only from their own bottle. Scheduled breaks were included in the training session (according to normal practice). After twenty minutes the players gathered together and collected their assigned empty universals, the coach used this break to chat to the players, while the researcher promptly removed the sweat patches from each player. Training resumed as normal.

Post-training phase

Once the players had finished their cool down and stretching phase of training, they made their way to the changing area. All drinks bottles were gathered and counted by a member of the research team. The players were instructed to towel dry, and wearing just their shorts to step on to the weigh scales. The results were entered onto the recording sheets as before. A kitchen scales (Soenhle Magnum 802U Digital Food Scale, Switzerland) was used to measure the mass of each drinking bottle, enabling comparisons with the mass of the bottles at the start of training.

As in pilot study 1, the urine samples were analysed using reagent strips (Combur^{10} Test, Roche Diagnostics, Mannheim, Germany), and the results were inserted onto the recording sheet. The urine samples and containers were disposed of appropriately.

Laboratory Analysis of Sweat Samples

A visit to Prof Ron Maughan's laboratory was arranged to view the laboratory techniques that were employed by his team of researchers investigating fluid and electrolyte balance in elite Rugby Union players and swimmers. The collected sweat samples from each of the pilot studies were placed in sterile universal containers (Sarstedt, Wexford, Ireland). These containers were transported in a cool box to the laboratory and stored in the fridge at 4^0C overnight. The samples from both pilot studies were analysed in the lab at the same time. Each universal containing a sweat pad was weighed individually (Precisa, Zurick, Switzerland), the weight of a blank universal was also determined. The volume of sweat collected was calculated by subtracting the mass of a new unused patch and universal from the mass of the universal containing the absorbent patch and sweat sample.

The next step in the process involved the dilution of the sweat samples with deionized water followed by a thorough mixing using a vortex machine, in accordance with methods outlined by Shirreffs *et al.*, (2005). In order to estimate the sodium concentration in each sweat sample, the diluted mixture containing the sweat patch and deionized water was analysed using a flame spectrometer (Corning 410c, Corning Ltd., Essex, UK). Three readings were taken from each sample to give an average reading.

Problems arose when minute particles of the sweat patches started to clog the narrow bore of the tube linking the flame spectrometer to the universal container, resulting in faulty sodium readings. In order to combat this problem, a sample of the solution containing the sweat patch and deionized water was removed after thorough mixing with the vortex. A minute filter was placed on top of the universal (containing the sweat patch and deionized water) and a sample of the liquid was removed using a syringe and placed into a blank universal. This was then analysed for sodium concentration using the flame spectrometer. Thus the problem of clogging in the spectrometer tube was eliminated. Three readings for sodium concentration were taken and the average reading recorded.

3.32 Testing Protocol

Players were initially monitored during a typical training session on a fairly warm and humid evening in June, the air temperature ranged from 16 to 18 ^{o}C, and humidity at 83%. This was the third training session of that particular week and players had a day's rest before the session. Training consisted of a dynamic warm-up (including repetitive sprints and stretching) followed by a variety of intensive game drills (defending and tackling), a series of small-sided conditioned games, culminating in a final cool down. The training session was deemed by the coach to be of typical duration and intensity for the players. The total duration of the training session was 80 minutes and all players followed the same programme.

<u>Before the training session</u>

Each player was assigned a study code (players had already been assigned a squad number for the year and this number was used as their study code) and given three personalised water bottles labelled for each player. Each bottle contained 1litre of tap water. Players were then instructed to provide urine samples (to ascertain pre-training hydration status) and these were assessed for urine specific gravity using a handheld clinical refractrometer (Spartan, Tokyo, Japan). Players were then weighed to nearest 0.1 kg (in dry pants) using calibrated weighing scales (Seca 770, Hamburg, Germany); the weights of the individual drinks bottles were also recorded using scales (Soenhle Magnum 802U Digital Food Scale, Switzerland). Absorbent sweat patches (3M Tegaderm +Pad, 3m Healthcare, MN, USA) were used to measure the electrolyte concentration in sweat. Patches were applied to four different anatomical sites (Table 3.8) on the right hand side of the body, in accordance with the methods described by Maughan *et al.,* (2005) and Shirreffs *et al.,* (2005). Each anatomical site was cleaned with deionized water and dried with a clean electrolyte-free gauze swab prior to the attachment of absorbent patches. The players carried one of their drinks bottle with them as they made their way from the changing area to the training area. The remaining bottles were placed in crates on the ground beside the training area.

The team's physiotherapist had previously received a new book of injury reporting forms (Figure 1.6). The same player study codes were used when recording injuries.

Table 3.8 *Anatomical Reference Points for Sweat Collection patches*

Location	*Anatomical reference*
Back	2cm directly below and in line with the inferior angle of the scapula
Chest	7cm directly below the nipple in the right hypochondriac region along a line running laterally from the distal aspect of the xiphoid process.
Upper Arm	On the anterior surface of the upper arm midway between the lateral aspect of the coracoid process of the scapula and the olecranon process of the ulna
Thigh	25cm from the proximal aspect of the patella on the anterior midline of the thigh

<u>During the training session</u>

The crates containing the drinks bottles were easily accessible to the players and were monitored by the researcher to ensure they drank from the correct bottles. Players were instructed to only drink from their own bottle and not to spit out any water. Any urine voided during the training session was collected and the volume recorded. Sweat patches were removed twenty minutes after the start of the training session (to prevent loss and saturation) and placed in individual sealed sterile universal containers (Sarstedt, Wexford, Ireland).

<u>After the training session</u>

At the end of the exercise session, the drinks bottles were collected. Players were towel dried and their post exercise body mass recorded along with the mass of their individual water bottles. The amount of fluid consumed during training was calculated by subtracting the mass of the drinks bottle at the end of training from the mass of the bottle at the start of training. Total sweat loss was calculated using the formula: Total Sweat Loss = (pre exercise body mass - post exercise body mass + fluid intake – urine volume). This total was divided by the duration of exercise (80 mins) and multiplied by 60 to determine the sweat rate per hour. Similarly, the total amount of fluid consumed during training was used to calculate drink volume consumed per hour. The urine specific gravity readings and percentage change in body mass were compared against published indexes of hydration status (Table 3.9) from the American College of Sports Medicine's Position on Exercise and Fluid Replacement (Casa *et al.*, 2000).

Table 3.9 *Indexes of Hydration Status (Casa et al., 2000)*

Condition	*% Body Mass Change*	*Urine Specific Gravity*
Well hydrated	+1 to -1	<1.010
Minimal dehydration	-1 to -3	<1.010 – 1.020
Significant dehydration	-3 to -5	1.021 – 1.030
Serious dehydration	>5	>1.030

Prior to analysis, the volume of sweat collected in each patch was determined gravimetrically (Precisa, Zurick, Switzerland) by subtracting the mass of a new unused patch and universal from the mass of the universal containing the absorbent patch and sweat. Individual samples were diluted with deionized water and thoroughly mixed using a vortex (Shirreffs *et al*., 2005). The sodium concentration was analysed using a flame spectrometer (Corning 410c, Corning Ltd., Essex, UK).

Statistical Analysis

A Chi-square test was used to compare the proportion of pre-training hydrated and dehydrated players (based on urine specific gravity readings). An Analysis of Covariance model was fitted to the data to compare mean fluid loss across the team while adjusting for initial pre-training hydration status. The adequacy of the model was checked using suitable residual plots while the assumed additive effect of the covariate was tested by including an interaction term to allow for separate slopes. A Bonferroni adjusted one sample-t-test was used to compare the mean fluid balance for the team against a hypothesised value of zero. The adjustment was made in order to maintain a global Type 1 error rate of 0.05 across the two comparisons. The likely mean fluid balance for the population of interest was estimated using (Bonferroni adjusted) 97.5% Confidence Intervals for a mean.

3.4 Results

The results presented are data from one full panel of players. The manager of the team limited the testing of players to only one training session. However, the subjects (n=20) that did participate in this study were members of a Senior Inter-County (Elite) Gaelic Football team. The team was representative of the population of players competing at the highest level of Gaelic Football, whose training intensity and match schedule were typical of elite teams competing at this level (Table 3.10).

Table 3.10. Physical Characteristics for Elite Gaelic Football Players

Physical Characteristics for Elite Gaelic Football Players		
Age 24 ± 4.5	Height (m) 1.82 ±0.08	Body Mass (kg) 81.4± 4.8

No injuries were sustained during the testing period. The environmental conditions were typical of a warm summers evening in Ireland when Gaelic Football training activity would be at a high intensity.

The majority of elite players (n=15) were well hydrated (USG<1.010) prior to exercise activity (Table 3.11 and Figure 3.10), however three players displayed signs of minimal dehydration (USG 1.010 – 1.020) and two players showed significant levels of dehydration (USG 1.021-1.030) (Casa *et al.*, 2000). Mean body mass loss over the duration of the training session was 0.8 kg with values ranging from 0.5 to 2.4 kg. Using percentage body mass loss [(pre-training body mass – post-training body mass)/pre-training body mass*100)] as a measure of post training dehydration, the values recorded ranged from +0.5% to -2.4% (mean 1.1%). The majority (n=12) of elite players were classified as being minimally dehydrated post training (-1 to -3% body mass change). Total sweat losses ranged from 0.85 l to 3.15 l (mean 1.86 l), while the amount of fluid consumed by players (rounded to the nearest 5ml) during training, ranged from 300 ml to 2000 ml with a mean of 1034 ml. Comparing the sweat rate per hour to the amount of fluid consumed per hour, there is a mean fluid balance of $-0.62\ l \cdot h^{-1}$ with values ranging from +0.37 to $-1.5\ l \cdot h^{-1}$. Only 56% of sweat volume was replaced during training with values ranging from 23% to 133%.

Separate analysis was performed to compare the mean fluid deficit only for players classified as being hydrated (USG<1.010) at the start of training. Once again there was significant evidence ($p<0.01$) of fluid deficit across the team, for players classified as being well hydrated at the start of training. Based on the ANCOVA model, there was no evidence to indicate that fluid deficit was simply related to pre-training hydration status ($p= 0.67$).

Table 3.11 *Sweat Loss and Fluid Intake Summary Data (Elite Players)*

	Players (n=20)		
	Mean	*s*	Range
Urine Specific Gravity	1.009	0.006	1.002 –1.027
Pre-Training Body Mass (kg)	81.4	4.8	71 – 87
Post-Training Body Mass (kg)	80.6	4.8	70 – 87.5
%Change in Body Mass	-1.1	0.7	0.5 – -2.4
Fluid Consumed (ml)	1034	457	300 – 2000
Total Sweat Loss (l)	1.86	0.63	0.85 – 3.15
Sweat Rate per Hour ($l \cdot h^{-1}$)	1.39	0.48	0.64 – 2.36
Fluid Consumed per hour ($ml \cdot h^{-1}$)	775	343	225 – 1500
Fluid Balance (ml)	619	504	375 – -1500
%Change in Body Mass if no fluid Consumed	2.2	0.9	0.6 – 3.5

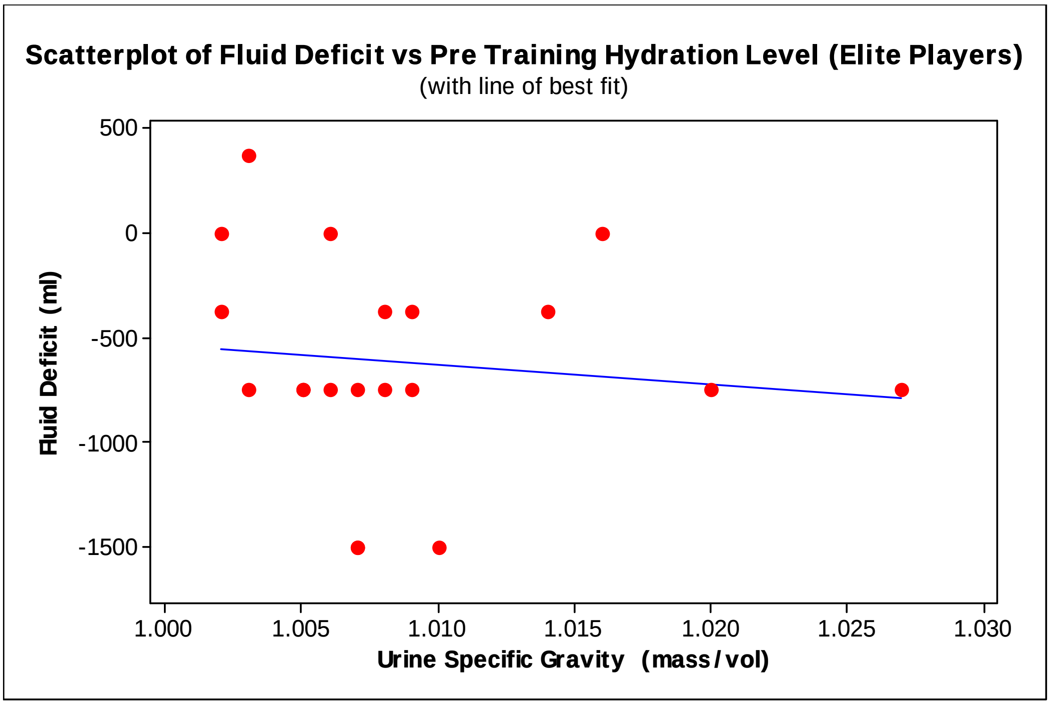

Figure 3.10 Relationship between pre-training hydration level (measured by urine specific gravity) and post-training hydration balance.

Fluid deficit was significant across the team (p<0.01), even for players classified as being well hydrated at the start of training.

With the exception of five players, there was an imbalance between the volume of fluid consumed during exercise and the volume of fluid lost through sweat for all players (Fig. 3.11). Virtually all points lie below the line of equality. There is a suggestion that players tend to lose a greater volume of sweat than the amount of fluid they drink. This was confirmed when comparing the mean fluid deficit to zero (equality) for all players, where the results indicate that there is strong evidence, that the mean fluid deficit is not zero (p<0.001).

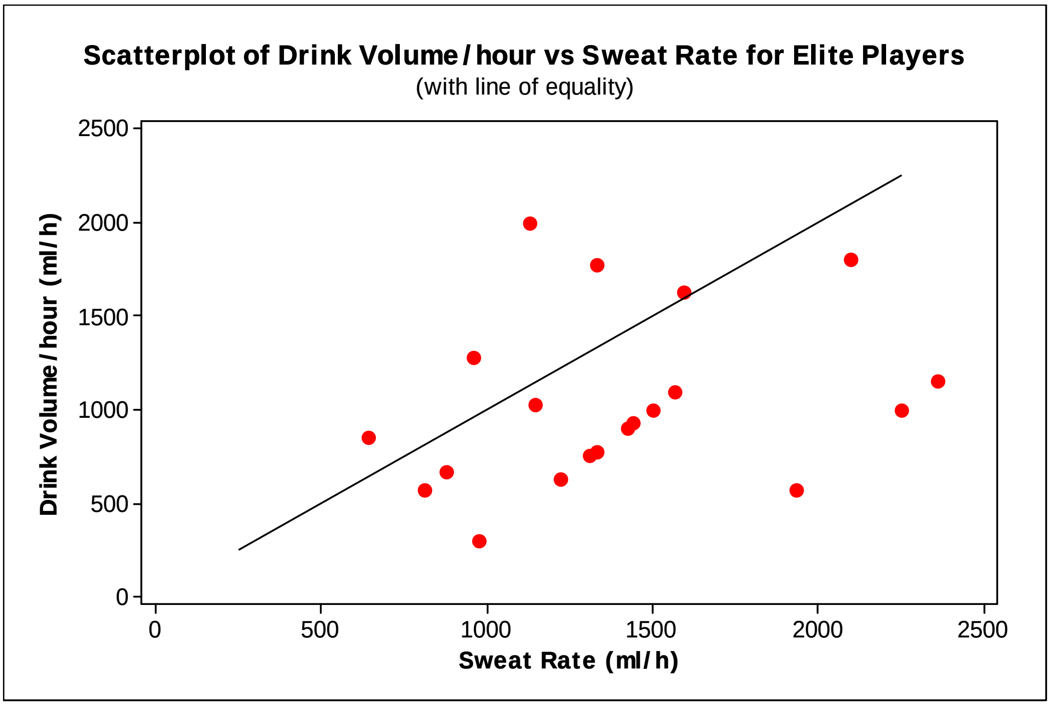

Figure 3.11 Sweat rate and fluid consumption per hour.

With the exception of five players, there was an imbalance between the volume of fluid consumed during exercise and the volume of fluid lost through sweat for all players. There is strong evidence, that the mean fluid deficit is not zero (p<0.001).

Hydration balance ranged from 375ml to -1500ml. A 95% Confidence Interval for the population mean fluid deficit is between 319ml and 881ml. (Figure 3.12).

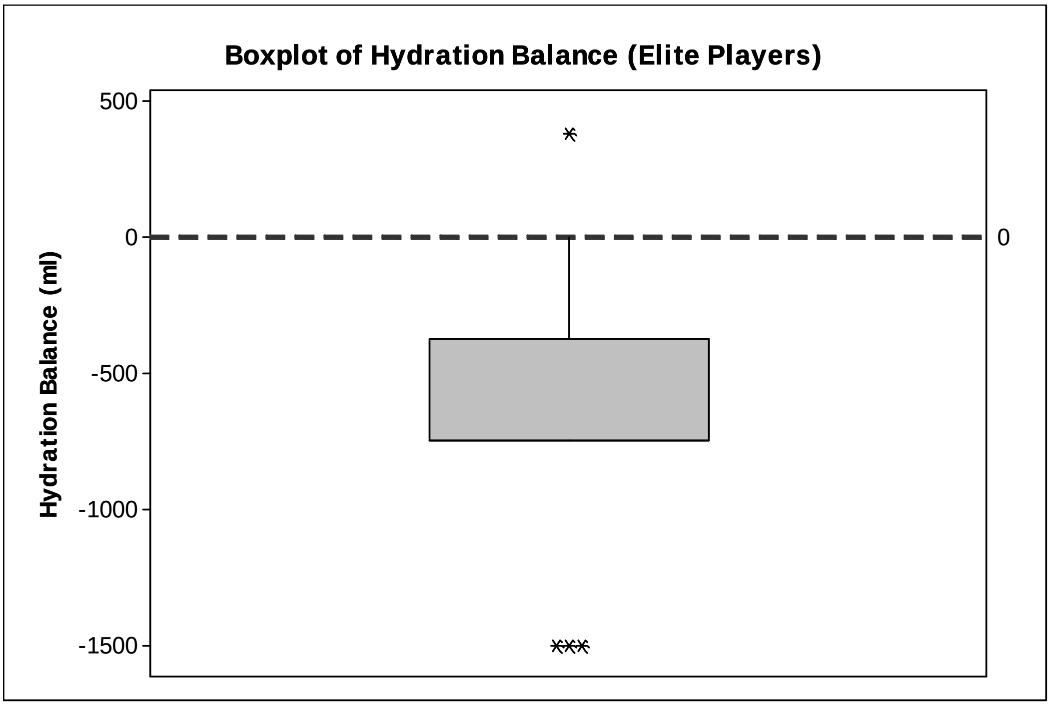

Figure 3.12 Post-training hydration balance (range points indicated by * and **)

A 95% Confidence Interval for the population mean fluid deficit is between 319ml and 881ml.

The mean sweat sodium concentration (based on a four site average) was 35 $mmol \cdot l^{-1}$ (range 19 to 52 $mmol \cdot l^{-1}$). This equates to a total sodium loss (calculated by multiplying mean sweat sodium concentration with mean sweat loss) of 65 mmol (range 35 to 96 mmol) (Table 3.12). There is a suggestion of player-to-player variability with regard to sweat sodium concentration from each of the different collection sites, but no evidence of within player variability ($p=0.811$). The relationship between pre-training body mass and sweat sodium concentration was not significant for all players ($p=0.984$).

Table 3.12. *Sweat sodium concentrations* ($mmol \cdot l^{-1}$).

	Players		
Location	Mean	*s*	Range
Arm	29	11	7 – 48
Back	32	16	11 – 68
Chest	34	14	15 – 61
Thigh	38	17	13 – 71
Four Sites (mean)	35	11	19 – 52
Total Sodium Loss (mmol)	65	33	35 – 96

Summary of Main Results

- Five players were dehydrated prior to the start of exercise, USG readings ranged from 1.002 to 1.027 mass per volume.
- There was individual variability with regard to sweat rate, sweat loss, levels of dehydration, and sodium concentrations
- Dehydration levels ranged from +0.5% to 2.4% body mass loss
- Total sweat loss ranged from 0.85 to 3.15 litres
- Sweat rate ranged from 0.64 to 2.36 $l \cdot h^{-1}$.
- Fluid intake ranged from 300-2000 ml
- Sweat sodium concentration ranged from 19-52 $mmol \cdot l^{-1}$

3.5 Discussion

One full panel of players agreed to participate in this study. The managers of the other teams were reluctant to allow any outside interference in training and team preparation. Secondly, the manager of the participating team restricted testing to a single training session. The subjects (n=20) that did participate in this study were members of a Senior Inter-County (Elite) Gaelic Football team and representative of that population of players competing at the highest level of Gaelic Football. As the majority of the published research on fluid and electrolyte balance research is based on the findings of single training sessions, the data did offer meaningful outcomes and comparisons with other sports. There were no injuries sustained during the testing period. The environmental conditions at the time were typical of mid- summer Ireland, when Gaelic Football teams would be at their peak.

Changes in body mass is used extensively throughout the scientific literature as a method of estimating water losses or gains due to sweating and drinking. The method relies on the assumption that 1ml of water has a mass of 1g (Lentner 1981) and that over a short period of time no other body component will be lost at such a rate (Shirreffs, 2009).

Although the measurement of body mass changes is a simple, non-invasive and valid approach to estimate hydration changes in team sports, it is argued that this method is too simple as it does not take into account the respiratory water loss and water gain as a result of substrate oxidation. These factors should be calculated to correct the sweat loss values (Pagna and Pagna, 1999; Casa et al., 2005; Maughan et al., 2007; Oliver et al., 2008).

The limitation of checking body loss to estimate dehydration is that some players may be hyper-hydrated before the start of exercise and if they lose weight during exercise they may not be strictly dehydrated. It may be more accurate to use a measure of hydration status (e.g. the osmocheck) and use weight to target how much fluid is required for replacing water lost. However as changes in body mass and total body water generally move in the same direction (Bartoli et al., 1993, Bartok et al 2004) and random variation of body water is in the range of ±1% (Cheuvront et al., 2004), it is suggested that a reduction in body mass in excess of this could be used to indicate a state of hypohydration especially in field settings (Casa et al., 2000).

Pre-training hydration

Using USG as the marker of dehydration, the majority of players were well hydrated before the start of training as evidenced by a mean USG reading of 1.009. Surprisingly, despite the fact that players were subjected to regular urine checks, five players were classified as being dehydrated prior to the start of training activity. This finding is of value to the players and coaches. The fact that some players reported for training in a dehydrated state should be highlighted to the players and appropriate strategies put in place to remedy the situation. Possible solutions include better player education. For example, providing players with their own individual results to make them aware of the importance of being suitably hydrated prior to the start of exercise, and equipping players with ‘pee charts’ to enable them compare urine colour with a corresponding colour scale.

Hydration status after training

The mean decrease in body mass at the end of training was 1% with a range of +0.5 % to -2.4%. Coyle (2004) in his review, states that endurance performance in ambient temperatures of <20 ^{0}C is not likely to be impaired, with body mass decrease due to dehydration less than 2%. However, in ambient temperatures greater >20 ^{0}C, Coyle (2004) indicates that endurance performance is reduced. The findings suggest that endurance performance of some of the players may be reduced when they play in hot conditions. Ambient temperatures and relative humidity in this study are considered to be cool conditions and consequently the mean % body mass decrease is unlikely to have a marked effect on endurance performance in these environmental conditions. In hotter conditions the decrease in % body mass may have a greater impact on endurance performance for some players.

Possible Impact on Playing Performance

While it is difficult to directly measure performance detriment in Gaelic Football in response to increasing levels of dehydration, successful performance depends on the ability to perform repetitive intermittent high-intensity exercise and to display excellent cognitive function for decision making, as well as proper execution of complex skills. Although the amount of fluid consumed by players was generally sufficient to maintain a decrease in percentage body mass of less than 2% (mean decrease in % body mass was 1%), nevertheless three players incurred a 2.3% decrease in body mass and a greater susceptibility to the effects of dehydration on performance and possible injury. If no fluid was consumed by players, the mean % decrease in body mass would have doubled to 2.2% BM, with individual extremes of 3.5%. At this level players would be more at risk to the effects of dehydration, such as a definite impairment in physical work capacity and cognitive and physiological function (McArdle *et al*., 1991).

Mean Sweat Rate

Sweat rate is primarily determined by the intensity of exercise and by the ambient temperature and humidity (Maughan and Shirrefs, 1997). The mean sweat rate per hour of 1.39 $l \cdot h^{-1}$ for players in this study is similar to results published for elite players from other codes similar to Gaelic Football. Mean sweat rates for Australian Rules Footballers of 1.4 $l \cdot h^{-1}$ and 1.8 $l \cdot h^{-1}$ have been reported, when they trained in a temperate (12-15^{o}C) and warm (27^{o}C) environments. Published sweat rates for professional Soccer players during training range from 1.2 $l \cdot h^{-1}$ in warm conditions (25 ^{o}C), to 1.46 $l \cdot h^{-1}$ in hot conditions (32 ^{o}C) (Maughan *et al.*, 2005; Shirreffs *et al.*, 2005; Rehrer and Burke, 1996).

Fluid Intake

The mean volume of fluid intake by players (1034ml) is similar to the value published (972ml) for professional Soccer players (Sherriffs *et al.*, 2005) training in temperatures of 32±3 ^{o}C. With the exception of five players, who did not have fluid deficit, the majority of players had a fluid deficit ranging from 375 to 1500ml. Despite unlimited access to drinking water, players replaced 56% of sweat loss on average. These values are in accordance with previous research, which showed that even with unlimited access to plain water, athletes typically only replace around 50% of the water required (Armstrong *et al.*, 1997).

Sweat Sodium

The mean sweat sodium concentration for players was 35 $mmol{\cdot}l^{-1}$. This was in agreement with published values (Sawka and Montain, 2000; Coyle, 2004) for sweat sodium concentration (average 35 $mmol{\cdot}l^{-1}$, range 10-70 $mmol{\cdot}l^{-1}$). The results correspond to published data for professional Soccer players (30.2 ±18.8 $mmol{\cdot}l^{-1}$) training in slightly warmer (32 ^{o}C) conditions (Shirreffs *et al.*, 2005). The highest mean concentration for sweat sodium concentration was found in the thigh (38 $mmol{\cdot}l^{-1}$). This seemed to contradict the published literature, as other studies have reported highest values in the chest and back (Shirreffs *et al.*, 2005; Maughan *et al.*, 2005). However, it was observed in the study that four players wore tight black shorts under their regular Football shorts which may have hindered evaporative cooling. If these players are not included in the pooled data, the highest sodium concentrations are found in the chest and back in accordance with other published studies documenting sweat and electrolyte losses.

Sodium Replacement

The mean volume of total sodium loss was 65 mmol (range from 35 to 96 mmol). If the goal of rehydration is to replace water and electrolyte loss by rates at or near sweat rates, it is suggested that the sodium concentration of the fluid consumed, should be the same as the sodium concentration lost through sweat (Noakes, 2003).

Studies have shown that post-exercise drinks should contain sodium to promote rehydration. Studies that investigated the effect of sodium consumption in post exercise-induced dehydration found that by drinking plain water together with sodium chloride capsules (to give a saline solution with an effective concentration of 77 mmol l^{-1}), voluntary fluid intake was higher, urine output was lower, and plasma volume was completely restored within 20 minutes. As opposed to 60 minutes for plasma restoration and a higher urinary output when drinking plain water together with a placebo (sucrose) capsules (Nose *et al.*, 1988).

The importance of sodium to post exercise recovery drinks was also evaluated by Maughan and Leiper (1995). Subjects exercising in the heat were dehydrated by the equivalent of 2% of body mass. They were given a post-exercise drink with various sodium concentrations (2, 26, 52, or 100 mmol l^{-1}) over a sixty minute period. The results indicated that those who had the highest sodium content in the drink had the smallest urine output and the highest levels of fluid retention.

Most commercially available soft drinks contain virtually no sodium and are considered unsuitable when the need for rehydration is crucial. The majority of commercially available sports drinks have sodium concentrations of 20 mmol·l^{-1}; the fact that sweat concentrations may vary between 20 to 80 mmol·l^{-1} (also reported in this study), makes the selection of the appropriate concentration problematic, unless sodium loss measurements are made. Therefore, it is suggested that players with high sweat sodium loss may benefit from consuming drinks with a higher sodium concentration (40-80 mmol·l^{-1}) post-exercise, especially during intensive periods of training and games, and when there is little recovery time between exercise bouts, as frequently occurs during the busier summer months of the Gaelic Football season.

The results for the group of players have shown that a single hydration strategy based on published guidelines (e.g. ACSM) is unlikely to be suitable for all players, due to variations in individual sweat rates, gastric emptying and intestinal adsorption. In fact, employing a general hydration protocol for all players may cumulatively have the potential to expose players to the associated risks of dehydration as well as the risk of developing hyponatremia (Coyle, 2004; Speedy *et al.,* 2001).

Regarding the measurement of dehydration levels within a team, it is important to emphasise that mean values do not portray the whole picture; the range of values is a better indicator for fluid replacement. This study has highlighted the necessity for each player to be assessed in order to identify individual fluid requirements.

<u>Injuries</u>

The initial aim of the study was to implement a hydration intervention programme as a method of injury prevention. The methods used to assess fluid and electrolyte balance were successful; however, due to the limitations imposed by the managers, there was no supporting injury surveillance data.However, the results particularly the individual variability with regard to sweat rate, sweat loss, levels of dehydration, and sodium concentrations suggests that an enlarged study using a similar research design may provide direct evidence linking dehydration to injury.

3.51 Summary of Main Findings

It is inappropriate to advocate that all players would improve their performance by increasing their fluid intake. Sweat losses for some players, even in relatively cool environments may be considerable and large enough to result in dehydration levels greater than 2% body mass. A single hydration strategy based on published guidelines is unlikely to be suitable for an entire team, due to variations in individual sweat rates. Knowledge of individual hydration requirements and specific advice on post-exercise electrolyte restoration should be considered as a possible contributory factor in performance enhancement during training and games.

It is proposed that Gaelic Football teams should conduct routine urine tests to determine pre and post, training status. Instructing players to be suitably hydrated prior to the start of exercise activity is good advice, however educating the players to take responsibility for recognising their own levels of hydration (such as equipping players with ‘pee charts’ to enable them to compare urine colour with a colour scale) may be a more beneficial solution.

Using weighing scales to measure body mass before and after exercise is an efficient and inexpensive method of estimating sweat rates and dehydration. Similarly, using individually assigned drinks bottles can help quantify individual fluid consumption and subsequent fluid requirements during exercise. Players should be encouraged to check their body mass regularly to make sure they are consuming sufficient fluid and foods to offset losses from repeated bouts of exercise.

Detailed investigation, such as conducting sweat electrolyte testing, should be encouraged to quantify sweat sodium concentration and total sodium loss. Although professional expertise (and relevant financial outlay) is required, the results may be extremely beneficial to players and coaches. Rehydration drinks could be specifically made to meet individual player requirements, thereby helping to maintain fluid and electrolyte balance while simultaneously helping to enhance player performance.

It was intended to conduct fluid and electrolyte balance research in both training and in games particularly as a player was reported to be 11 times more likely to get injured during games compared to training. However, conducting hydration research in games is very difficult (as reflected in the small number of published studies across all team sports) as there are a number of inherent problems including; a lack of scheduled breaks in play, apart from the half-time interval, to consume fluid; the need to have numerous drinks containers clearly labelled close to hand at all times for players; the requirement that all players swallow the fluid and do not spit out the fluid or use it for any other purpose; the requirement that players drink only from their own individual fluid containers and do not offer a team mate or an opponent a drink as is customary in games. Additionally there may be logistical problems when using absorbent sweat patches as it is recommended that the patches should be removed after 20 minutes to avoid saturation or even loss of patches. Of the published studies investigated fluid and electrolyte balance in games, the matches were friendly rather than competitive often with both teams participating and the referee allowing for requested stoppages in play. Consequently the vast majority of publications have focussed on training environments as they tend to be more feasible with fewer logistical issues. To date no published study has managed to investigate fluid and electrolyte balance during playing time;

An attempt was made to conduct a study of fluid and electrolyte balance during a Gaelic Football game. Management agreed to allow its players to participate. Prior to the data collection during the game, testing was conducted at one of their training sessions in order to familiarise players with the procedures and the logistical requirements of the study. The time was spent preparing easily recognisable bottles for each individual player, and inculcating the discipline of non-sharing. When the opposition withdrew from the relevant competition the planned testing did not prove possible. Presented with a bye to the final, the manager deemed it likely that testing during such an important match would be a distraction to the players. This is a prime example of the difficulties encountered when conducting research in Gaelic Football and the researcher's need to suddenly create feasible and imaginative alternatives.

In order to continue with this current line of research enquiry, it was proposed to broaden the study population to include recreational (club) Gaelic Football players. Particularly as the vast majority of Gaelic Football players are classified as club players with an estimated playing population in excess of a quarter of a million people. Research in Gaelic Football tends to focus unduly on elite players many of its recommendations may not seem to be appropriate or indeed available to club level players. Educating all coaches and players, about the importance of hydration and individual fluid requirement will help to improve individual performance.

In accordance with health promotion study design principles (Mittelmark, 2008) an alternative practical and relatively inexpensive method of estimating pre and post training hydration status that could be easily implemented by club teams was piloted. Particularly as the amateur status is an integral component of Gaelic Football and many clubs do not have the financial resources of their elite counterparts.

Chapter 4

Study 4

Fluid and Electrolyte Balance in Club (Recreational) Gaelic Football Players

4.1 Introduction

The results contained in the previous chapter indicated that there were large variations with regard to fluid consumption, hydration balance, and sweat sodium concentrations amongst individual elite players. Current structures within elite Gaelic Football render the sport less conducive to research analysis, particularly repeated time series design and intervention studies. It was not possible to carry out all the desired aspects of the desired study.

If the same study design was applied to club Gaelic Football players it may be possible to gather real-time evidence-based data on dehydration and injury. The potential advantages are a greater population (approximately one quarter of a million club players participate in Gaelic Football on a regular basis), better access to players (fewer managerial sanctions), and an opportunity of conducting health education research aimed specifically at educating club players and managers (rather than applying research findings from elite players).

Although accuracy and precision are paramount it is also important to consider the cost and practicality of the equipment especially when working with large populations (Mittlemark *et al.,* 2008). Body mass change combined with measurement of urine specific gravity is considered to be a safe, precise, and non-invasive option for daily hydration monitoring of athletes as these techniques are easily mastered and amenable to self-monitoring by the athlete (Casa *et al*., 2000; Opplinger and Bartok, 2000). The easiest and least expensive method of estimating hydration status was to use urine test strips (Reagent strips) (Casa *et al*., 2000). The aim of this study was to demonstrate that urine test strips are a practical and relatively inexpensive method of estimating hydration status that could easily be incorporated by all teams into their training regime. Furthermore as most hydration studies are often conducted in warm conditions, an additional aim of this study was to investigate fluid and electrolyte balance during a typical training session in cool conditions.

4.2 Methods

Twenty three players from a senior club level Gaelic Football team participated in this study. The team was selected as a representative population of high level successful senior club players, many of whom go on to play at elite level. All players were male aged between seventeen and thirty five years. Subjects who were deemed to have any adverse medical condition were not recruited. Players were monitored on a cool (10 to 12 ^{O}C) and dry evening (35% relative humidity) in September. This was their second training session of the week prior to their next competitive game three days later. Training consisted of a warm up followed by a series of exercise and skill drills using the Football, small-sided competitive games, interval running, and a cool down. The total duration of the training session was 80 minutes and was deemed by the coach to be of typical duration and intensity for the players.

Before Training

Each player was assigned a study code, and given a blank sterilised universal container to provide a pre-training urine sample. Urine Test Strips (Combur^{10} Test, Roche Diagnostics, Mannheim, Germany) were used to assess urine specific gravity as an indicator of pre-training hydration status. Players were weighed to nearest 0.1 kg (in dry pants) using a calibrated weighing scale (Seca 770, Hamburg, Germany). Absorbent sweat patches (3M Tegaderm +Pad, 3m Healthcare, MN, USA) were applied at four different anatomical sites (Table 4.1) on the right hand side of the body. Each anatomical site was cleaned with deionized water and dried with a clean electrolyte-free gauze swab prior to the attachment of absorbent patches. Players were free to wear their regular training clothing.

Table 4.1 *Anatomical Reference Points for Sweat Collection patches*

Location	*Anatomical reference*
Back	2cm directly below and in line with the inferior angle of the scapula
Chest	7cm directly below the nipple in the right hypochondriac region along a line running laterally from the distal aspect of the xiphoid process.
Upper Arm	On the anterior surface of the upper arm midway between the lateral aspect of the coracoid process of the scapula and the olecranon process of the ulna
Thigh	25cm from the proximal aspect of the patella on the anterior midline of the thigh

During Training

All labelled drinks bottles were placed in crates and situated beside the training area. Bottles were easily accessible to the players and were monitored by the researcher to ensure that players drank from the correct bottles. Players were instructed to only drink from their own bottle and not to spit out any water. Any urine voided during the training session was collected and the volume recorded. Sweat patches were removed after twenty minutes (to prevent saturation) and placed in individual sealed sterile universal containers (Sarstedt, Wexford, Ireland).

Post training

At the end of training all drinks bottles were collected. Players were towel dried and their post exercise body mass recorded along with the mass of their individual water bottles. The amount of fluid consumed during training was calculated by subtracting the mass of the drinks bottle at the end of training from the mass of the bottle at the start of training. Total sweat loss was calculated using the formula: Total Sweat Loss = (pre exercise body mass - post exercise body mass + fluid intake – urine volume). This total was divided by the duration of exercise (80 mins) and multiplied by 60 to determine the sweat rate per hour. Similarly the total amount of fluid consumed during training was used to calculate drink volume consumed per hour.

Prior to analysis the volume of sweat collected in each patch was determined gravimetrically by subtracting the mass of new unused patch and universal from the mass of the universal containing the absorbent patch and sweat. Individual samples were diluted with deionized water and thoroughly mixed using a vortex. The sodium concentration was analysed using a flame spectrometer (Corning 410c, Corning Ltd., Essex, UK) (Shirreffs *et al.,* 2005).

The urine specific gravity readings and percentage change in body mass were compared against published indexes of hydration status (Table 4.2) from the American College of Sports Medicine's Position on Exercise and Fluid Replacement (Casa *et al.,* 2000).

Table 4.2 *Indexes of Hydration Status (Casa et al., 2000)*

Condition	*% Body Mass Change*	*Urine Specific Gravity*
Well hydrated	+1 to -1	<1.010
Minimal dehydration	-1 to -3	<1.010 – 1.020
Significant dehydration	-3 to -5	1.021 – 1.030
Serious dehydration	>5	>1.030

Statistical Analysis

A Chi-square test was used to compare the proportion of pre-training hydrated and dehydrated players (based on urine specific gravity readings). An Analysis of Covariance model was fitted to the data to compare mean fluid loss across the team while adjusting for initial pre-training hydration status. The adequacy of the model was checked using suitable residual plots while the assumed additive effect of the covariate was tested by including an interaction term to allow for separate slopes. A Bonferroni adjusted one sample-t-test was used to compare the mean fluid balance for the team against a hypothesised value of zero. The adjustment was made in order to maintain a global Type 1 error rate of 0.05 across the two comparisons. The likely mean fluid balance for the population of interest was estimated using (Bonferroni adjusted) 97.5% Confidence Intervals for a mean.

4.3 Results

Twenty three players participated in this study. The team was representative of the population of players competing at the highest level of Club Gaelic Football, whose training intensity and match schedule were typical of high level club teams competing at this level (Table 4.3).

Table 4.3. Physical Characteristics for Elite Gaelic Football Players

Physical Characteristics for Elite Gaelic Football Players		
Age	Height (m)	Body Mass (kg)
25 ± 5.5	1.76 ±0.07	73.9 ± 9.1

According to published indexes of hydration status (Table 4.2) from the American College of Sports Medicine's Position on Exercise and Fluid Replacement (Casa *et al.*, 2000), sixteen players were classified as having minimal dehydration (USG 1.010-1.020), five players were classified as being well hydrated (USG <1.010) and the remaining two players showed signs of significant dehydration (USG 1.021 -1.030). A Chi-square test was used to compare the proportion of hydrated and dehydrated players across the team. The results indicate that there was significant evidence (p=0.001) of dehydration amongst the majority of club players prior to the start of training (Figure 4.1).

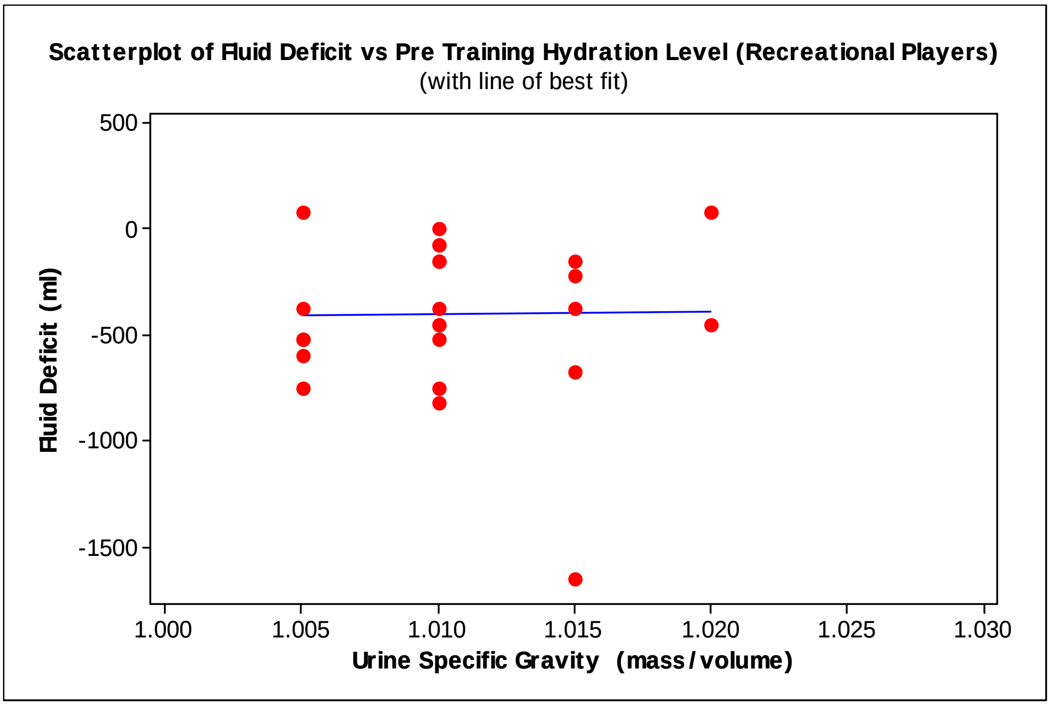

Figure 4.1 Pre Training Hydration Status and Post Training Fluid Deficit

The results indicate that there was significant evidence (p=0.001) of dehydration amongst the majority of club players prior to the start of training

The reason the USG data appears in blocks was as a result of using test strips to measure USG. There were seven different colours corresponding to seven USG readings, i.e. from 1.000 to 1.030. Although two players marginally gained weight during training (+0.1kg), mean weight loss was 0.54 kg, ranging from 0.1kg to 2.2 kg. Post-training dehydration values recorded ranged from +0.1% to -2.9% (mean 0.7%) with the majority (n=20) of club players classified as being well hydrated (+1 to -1% body mass change). Total sweat losses ranging from 0.63 l to 2.48 l (mean 1.29 l) while the amount of fluid consumed ranged from 275 ml to 1060 ml with a mean of 747 ml. The mean sweat rate per hour for club players was 0.97 $l{\cdot}h^{-1}$ with mean fluid consumption of 560 $ml{\cdot}h^{-1}$. There is a mean fluid balance of -405 $ml{\cdot}h^{-1}$ with values ranging from +75 to -1650 $ml{\cdot}h^{-}1$.

Only 64% of sweat volume was replaced during training with values ranging from 11% to 116% (Table 4.4).

Table 4.4 *Sweat Loss and Fluid Intake during Training*

		Players	(n=23)
	Mean	**s**	**Range**
Urine Specific Gravity	1.011	0.005	1.005 – 1.02
Pre-Training Body Mass (kg)	79.3	9	65.8 – 101
Post-Training Body Mass (kg)	78.8	8.9	65.6 – 99.9
%Change in Body Mass	-0.7	0.6	0.1 – -2.9
Fluid Consumed (ml)	747	220	275 – 1060
Total Sweat Loss (l)	1.29	0.423	0.63 – 2.48
Sweat Rate per Hour ($l \cdot h^{-1}$)	0.97	0.32	0.54 – 1.86
Fluid Consumed per hour ($ml \cdot h^{-1}$)	560	165.2	206 – 795
Fluid Balance (ml)	405	369	75 – -1650
%Change in Body Mass if no fluid Consumed	1.6	0.5	0.8 – 3.2

Comparing sweat rate per hour to the amount of fluid consumed per hour (Figure 4.2) there was an imbalance between the volume of fluid consumed during training and the volume of fluid lost through sweat for all players. The majority of points lie below the line of equality. There is a suggestion that players tend to lose a greater volume of sweat than the amount of fluid they drink. This was confirmed when comparing the mean fluid deficit to zero (equality) for all players separately, where the results indicate that there is strong evidence that the mean fluid deficit is not zero ($p<0.001$).

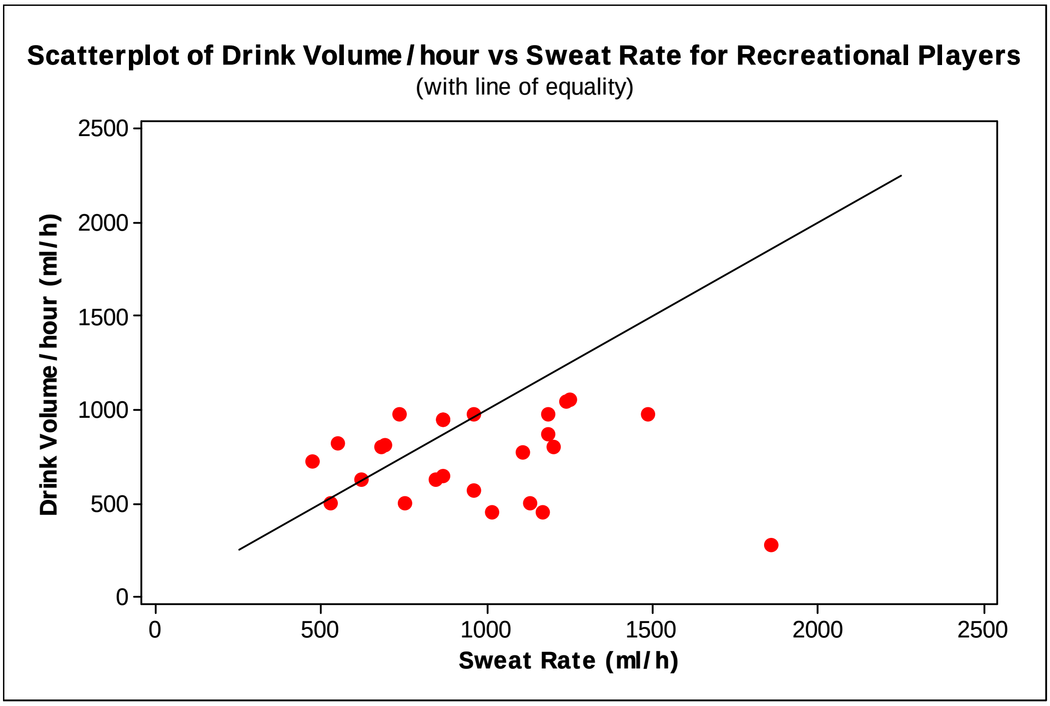

Figure 4.2 Sweat rate and fluid consumption per hour

A 95% Confidence Interval for the population mean fluid deficit for the Senior Club ‘population’ is between 151ml and 785ml (Figure 4.3).

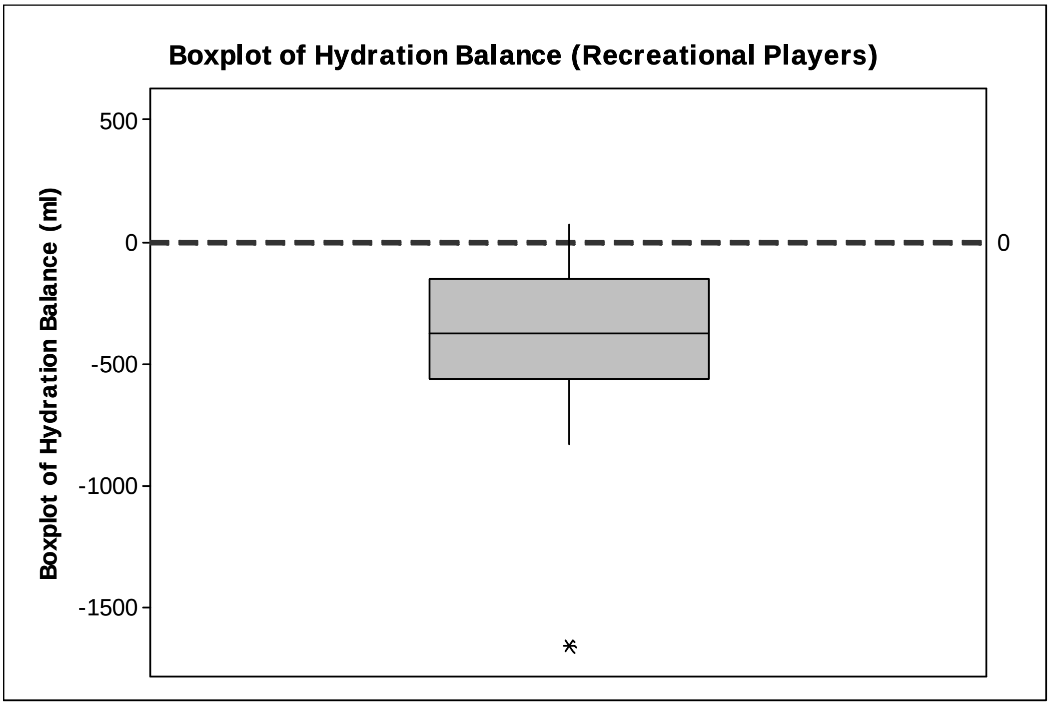

Figure 4.3 Post-training hydration balance

The mean sodium concentration for club players was 28 mmol·l^{-1} (range 13 mmol·l^{-1} to 44 mmol·l^{-1}), with the highest concentration found in the upper arm (Table 4.5). This equates to a total sodium loss of 36 mmol (range 17-57).

Table 4.5 *Sweat sodium concentrations (*mmol·l^{-1})

	Players (n=23)		
Location	**Mean**	**s**	**Range**
Arm	31	10	14 - 45
Back	25	12	9 - 44
Chest	28	9	14 - 44
Thigh	26	9	11 - 44
Four Site (mean)	28	9	13 - 44
Total Sodium loss (mmol)	36	20	17-57

There is a suggestion of player to player variability with regard to sweat sodium concentration from each of the different collection sites (Figure 4.4) but no evidence of within player variability (p=0.459). The relationship between pre-training body mass and sweat sodium concentration across the four sites was not significant for all players (p=0.984).

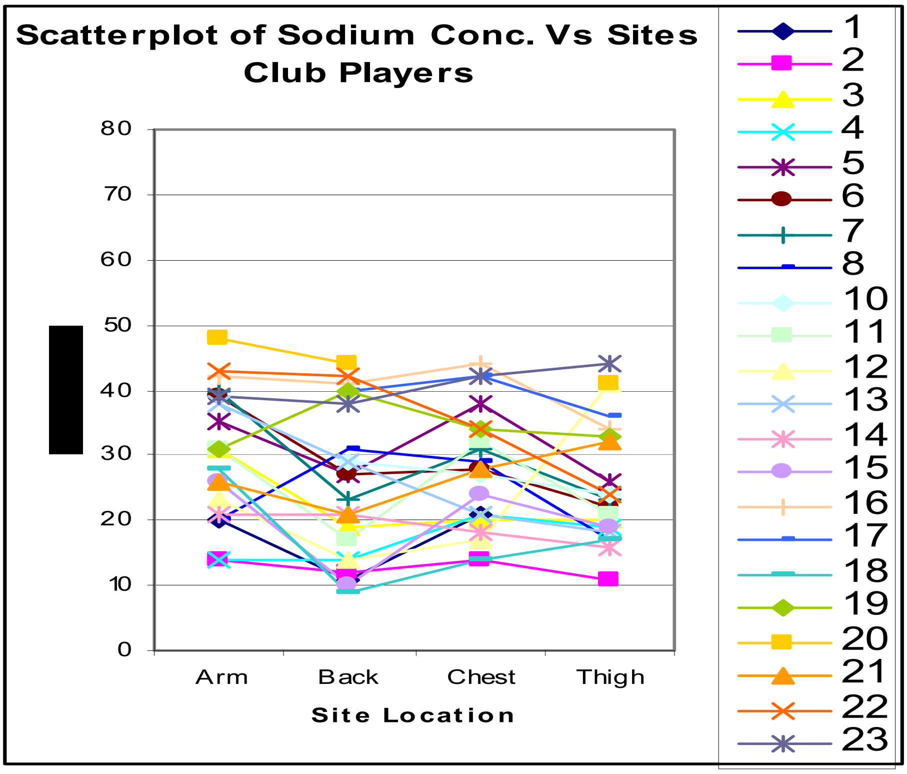

Figure 4.4 Individual Sweat Sodium Concentration at each collection point

Summary of Main Results

- Reagent strips are a practical and relatively inexpensive method of estimating hydration status
- The majority of players were dehydrated prior to the start of exercise
- There was individual variability with regard to sweat rate, sweat loss, levels of dehydration, and sodium concentrations
- Dehydration levels ranged from +0.1% to 2.9% body mass loss
- Total sweat loss ranged from 0.63 to 2.48 litres
- Sweat rate ranged from 0.54 to 1.86 $l \cdot h^{-1}$
- Fluid intake ranged from 265-1060 ml
- Sweat sodium concentration ranged from 13-44 $mmol \cdot l^{-1}$

4.4 Discussion

This study piloted the use of Reagent Sticks as an alternative practical and relatively inexpensive method of estimating pre training hydration status for club level Gaelic Football players, while investigating fluid and electrolyte balance during a typical training session in cool conditions. So long as the manufactures specifications with regard to proper immersion procedure and interpretation of results are adhered to, reagent sticks and the use of a cut-off value (Casa et al., 2000) can help to classify individuals into appropriate categories of euhydrated and dehydrated pre training status. Body mass change combined with measurement of urine specific gravity is considered to be a safe, precise, and non-invasive option for regular hydration monitoring of athletes (Opplinger and Bartok, 2000).

<u>Pre-training hydration</u>

Five players out of the total group of twenty three players were considered to be suitably hydrated prior to start of training. The majority of players were classified as having minimal dehydration (mean USG 1.011), although two players showed signs of significant dehydration (USG 1.021 -1.030). In contrast to the previous study investigating hydration status of elite Gaelic Football players, club players had no previous urine tests as part of their regular training regime and were not given specific advice on hydration. Players were inadvertently predisposing themselves to potential adverse affects of dehydration. This fact should be highlighted to players and coaches and proper strategies put in place to remedy the situation. Simple steps such as educating players on the importance of drinking fluid at regular intervals during the day and not relying solely on thirst mechanisms, and showing players how to recognise their own levels of dehydration using ‘pee charts’ to compare urine colour against standard colour charts. Other strategies may include displaying dehydration information on posters in the training area, conducting regular urine testing and placing the onus on players to make sure they avoid starting exercise in a dehydrated state.

Hydration status post training

The results on post-training dehydration of players indicate that the mean % decrease in body mass (0.68%) is within the recommended levels of tolerable dehydration, although one player had a loss of 2.9% body mass. Sweating rates tend to be lower in cold environments and the effect of dehydration on exercise performance is less marked (Coyle, 2004). Consequently, there may be no good reason to advise these players to increase fluid intake during training as dehydration of 1-2% decrease in pre-exercise body mass may be tolerable in temperate environments and losses in excess of 2% may be tolerable in cold environments (Coyle, 2004).

These recommendations assume that the individual is in a well hydrated state prior to the start of exercise. Therefore it is important to recognise that a loss of 1-2% of pre-exercise body mass may not be very well tolerated by an athlete who commences exercise in a dehydrated state (Maughan *et al.*, 2005). The majority of players in this study were not well hydrated prior to the start of the study, consequently in this instance, there is good reason to advise these players to increase fluid intake in the hours before training and games particularly in hot ambient conditions.

If the players in this study were to exercise at the same intensity in the heat, the decrease in % body mass may have been higher, placing players at a greater risk to performance including impaired cognitive and physiological functioning and an increased risk of developing heat illness. While the fluid strategies employed were generally successful in reducing the potential adverse effects of sweat loss, (the mean % body mass loss of club players would have been 1.64%, although some players would have had % body mass losses in the region of 3.2% if no fluid was consumed). More needs to be done to educate players on the importance of hydration, particularly the importance of being well hydrated prior to exercise.

Sweat rates and fluid intake

The sweat rate for the recreational players ($0.97\ l{\cdot}h^{-1}$), although lower than that reported for elite Gaelic Football players training in warmer conditions (Study 2), is similar to the value reported ($1.13\ l{\cdot}h^{-1}$) for professional Soccer players who trained in a cool environment (5 ^{o}C). The mean volume of fluid intake for players in this study (747ml), while considerably lower than the values (1034 ml) reported for elite Gaelic Football players (*Newell et al., 2006*), is much higher than that published for professional Soccer players (423ml) training in similar ambient temperatures (Maughan *et al.,* 2005). The higher fluid intake by recreational players may be attributable to the fact that the players were mildly dehydrated prior to the start of training (if pre-training urine specific gravity is accepted as a marker of hydration status) and therefore are likely to consume higher volumes of fluid to compensate. With the exception of three players, who did not have fluid deficit, the majority of players in this study had a fluid deficit ranging from -75 ml to 1650 ml respectively. The fact that players only replaced 58% of sweat loss on average is in accordance with previous research (Armstrong *et al.,* 1987).

Poor post-training rehydration strategies should be investigated, as inadequate fluid replacement may have been a contributory factor to the pre-training dehydration levels reported by players in this study. Cool and flavoured fluid (to improve palatability to enhance fluid intake) containing sodium should be readily available in the changing area and in the post-exercise social area to ensure that fluid losses are suitably replaced post exercise. Good hydration habits should be encouraged especially as the Gaelic Football season extends for at least nine months of the year, with training and games taking place in a variety of conditions including hot environmental conditions. Hydration recommendations should be individually focussed rather than collectively based, as highlighted by the individual differences in sweat rate and fluid consumption by players in this study.

<u>Sweat sodium and replacement</u>

The mean sweat sodium concentration for club players was 28 $mmol \cdot l^{-1}$ (range 13-44) is also in accordance with published values for sweat sodium concentration (Sawka and Montain, 2000; Coyle, 2004). However, the values are somewhat lower than those of elite Gaelic Football players (*Newell et al., 2006*) and professional Soccer players (42.5 ±13 mmol·l^{-1}) training in the same ambient temperatures (Shirreffs *et al.*, 2005; Maughan *et al.*, 2005). The highest sodium concentrations were found in the chest, with the lowest sodium concentrations in the thigh location, in accordance with other published studies documenting sweat and electrolyte losses (Maughan *et al.*, 2005; Shirreffs *et al.*, 2005).

Provided a sufficient volume of water is consumed, sodium replacement is the most important factor in achieving effective restoration of fluid balance (Maughan and Leiper, 1995). Drinking large volumes of fluid too quickly immediately following exercise activity increases urine production and blood plasma and may result in a reduction in plasma sodium concentration. Hyponatremia (meaning too little sodium) is associated with excessive water ingestion, leading to water retention and bloating. Conversely, if sufficient sodium and water are consumed, some of the sodium remains in the vascular space and plasma osmolality and sodium concentration do not markedly decline. This may occur if plain water is ingested. As the range of total sodium loss by players in this study was 15 mmol to 87 mmol, players with high sweat sodium loss, may benefit from consuming drinks with a higher sodium concentration (40-80 mmol·l^{-1}) post-exercise. This is especially true during intensive periods of training and games, and when there is little recovery time between exercise bouts, as frequently occurs during the busier summer months of the Gaelic Football season.

I accept that teams will compete at different levels and the physiological demands of the game are different at elite levels. However I believe it is important to individualise the strategy for each player as a single hydration strategy based on published guidelines is unlikely to be suitable for an entire team, due to variations in individual sweat rates. Knowledge of individual hydration requirements and specific advice on post-exercise electrolyte restoration should be considered as a possible contributory factor in performance enhancement during training and games.

Prescribing a general fluid hydration strategy for the entire team, such as the guidelines recommended by the American College of Sports Medicine’s Position Stand on Exercise and Fluid Replacement (1996) or the National Athletic Trainers Association Statement: fluid replacement for athletes, (2000) may not be universally beneficial, as some players may be consuming more fluids than they need and it may be counter-productive to physiological functioning. Instead recommendations should be should be targeted to players on an individual basis as recommended in *Newell et al.*,(*2006*) due to wide range of values.

4.41 Summary of Main Findings

Players in the present study did not consume sufficient fluid during training to match their sweat losses. While the % body mass loss based on pre-training body mass was unlikely to affect performance of players per se, this measurement did not take into account the fact that the majority of players showed signs of dehydration (based on USG markings) prior to the start of exercise and therefore the detrimental risk to performance may be much greater than previously suggested. As there is variability in both sweating rate and composition in individual players, any recommendations on the amount and electrolyte concentration of fluid ingested before, during, and after exercise should target players on an individual basis.

In this study players were free to wear their regular training clothing. As sweat rate is influenced by the amount and type of clothing worn, the intensity of exercise, the state of fitness and heat acclimation (Maughan *et al.*, 2005), it may be worthwhile to conduct similar research in order to examine the possible effects of different types of clothing on individual sweat rates.

Chapter 5

Conclusions and Recommendations

Conclusions and Recommendations

If maximizing physical performance is the ultimate goal of Gaelic Football training, the aim of any training programme should be Gaelic Football specific, designed and delivered in a systematic and efficient manner to prepare the athletes for strenuous exertion with minimal risk of injury, while simultaneously allowing for health and recuperation requirements (Bangsbo, 2003; Reilly, 1996; Burke, 1977; Smith, 2003; Scriber, 1978). Furthermore, any attempts to enhance the performance of players through physiological intervention and changes to playing rules and equipment should be based on solid evidence supported by a dedicated sports science and sports medicine research group.

The valuable information generated by injury studies should be distributed to all domains; coaches, managers, and players of Gaelic Football. Teams need to be aware of the common types and causes of injury, for example hamstrings injury, and use this information to implement a structured progressive conditioning programme that focuses on injury prevention as well as individual player development. Regrettably, the current structure in Gaelic Football makes it very difficult to replicate the best practice research models used by Soccer, Australian Rules, and Rugby Union. The main obstacles are: restricted access to players, an over dependence manager permission to allow player participation, a prolonged winter break, and lack of national directives to insure full cooperation in research studies.

The initial prospective epidemiological study of injuries sustained by Gaelic Football players during a single competitive season (Newell et al., 2006) was based on Van Mechelen's (1992) model of 'sequence of prevention of sports injuries' (Figure 1.1). The results of the study highlight that there is an urgent need for a national system of epidemiological injury data collection in Gaelic Football and the establishment of a national injury database to help predict, reduce, and prevent injury at all grades of the game. Unless the Gaelic Athletic Association is prepared to implement dedicated all-inclusive epidemiological studies, the factors that contribute to the high proportion of injuries in Gaelic Football will remain.

The second phase of this research investigated the aetiology and mechanism of hamstrings injuries, (the most frequently occurring injury reported in the injury surveillance study) particularly to determine whether poor muscle strength in terms of a low H:Q ratio was a predisposing factor for hamstrings injury in Gaelic Football. This study was successful in identifying players who may be susceptible to hamstrings injury based on their H:Q strength ratio. However, if H:Q strength ratio is to be used as a possible screening tool for susceptibility to injury, a larger prospective study that includes a baseline evaluation of the H:Q ratio and a subsequent tracking of injuries in the lower extremities is necessary to establish a cause and effect relationship between H:Q strength ratios and hamstrings injury.

A linear regression model was fitted to the data to identify players with an isokinetic strength imbalance based on their functional Hecc:Qcon strength ratio relationship. The question of using a multiple regression model to adjust for other explanatory variables, such as age and previous injury, and not just functional strength ratio to explain why the players identified as potential injury candidates is of course plausible; however as these variables were not recorded such an analysis is not possible.

The use of a simple regression model in this context is appropriate as there is a single explanatory variable (Hecc:Qcon) and all of the underlying assumptions related to the use of a strength relationship model e.g. linearity, independence, normal errors, and constant variance were deemed appropriate by looking at residual plots. However given that this team is a good representation of players in general, as reported in this thesis, and the results are exploratory findings only, it is worth considering for future studies to include all variables that might influence the outcomes as the statistical analysis is only as good as the number of exploratory variables collected.

The natural sequel to the hamstrings injury study would have been an intervention study aimed at improving the H:Q ratio and decreasing the corresponding incidence of hamstrings injury. However current research support structures within Gaelic Football makes it very difficult to conduct intervention studies with elite Gaelic Football teams. Continuation of research on hamstrings injury prevention in accordance with the phases outlined by Van Mechelen's model (1992) was not a feasible proposition. Thus an alternate aetiology of injury was explored in order to complete the model.

All injuries in sport involve a failure of biological material. Whether injuries are caused by muscle dysfunction, or a decrement in performance due to fatigue, is an open question. Although the direct evidence linking dehydration and injury has not been established, by designing individualised hydration programmes for players it may be possible to control the effect of dehydration while simultaneously investigating the incidence of injury.

Through data collected from single training sessions, the two hydration studies (conducted in warm and cool conditions) have shown that changes to pre and post training body mass (using weigh scales), assessing pre-training hydration status (using a refractrometer and reagent strips), and monitoring of the amount of fluids consumed during training (individualised drinks bottles) can help determine individual hydration requirements.

The results of both studies indicate: a wide variation in sweat rates and fluid and electrolyte balance, evidence of pre and post dehydration, and that a single hydration strategy, based on published guidelines, is unlikely to be suitable for an entire team. Conducting regular testing during varying environmental conditions will help to establish a routine for fluid intake for all situations.

Teams should also consider the merits of assessing sweat electrolyte status, particularly elite teams, as the decision on the amount of fluid to ingest during and after exercise should be based on the individual need to maintain optimal physiological function while playing Gaelic Football.

The evidence that fatigue occurs during competitive games is comprehensive. The corresponding decline in work rates in the latter stages of activity can be attributed to local muscular and central factors and may increase the susceptibility to injury towards the end of a game (Reilly *et al.*, 2008). Research has shown that if an athlete is in a state of fatigue there may be a change in running mechanics, landing mechanics, a decreased ability to maintain joint alignment, control and appropriate muscular activation patterns during potentially risky manoeuvres, and an increase in high risk actions (Gerlach *et al.*, 2005; Kellis and Liassou 2009; Wojtys *et al.*, 1996; Chappell *et al.*, 2005; Rahnama *et al.*, 2002; Hawkins *et al.*, 2001; Newell *et al.*, 2006). Thus a major consideration for injury prevention is delaying the onset of fatigue. Fluid is a primary factor in reducing signs of fatigue.

Dehydration is considered a risk factor for injury as the effects of dehydration largely mimic those of fatigue. Dehydration has been shown to reduce blood flow to the muscles, decreases muscle elasticity or flexibility, and impact negatively on muscle function. It is considered one of the primary precursors to heat-related disorders (Casa et al 2000). Knapik et al., (2001) reported a strong correlation between daily temperature and injury incidence when investigating seasonal variation in injury rates during US army basic training where physical activity was similar at all times of the year. The incidence of injury was higher in the summer and may be attributable to the environmental temperature. Judelson et al., (2007) conducted a literature review on hydration and muscular performance and found that a 3-4% increase in dehydration resulted in a 2% strength reduction, 3% decrease in muscular function and a 10% decrease in muscular endurance. Dehydration is an important factor to consider when attempting to maximise performance and an individual that starts training in a mildly dehydrated state may make him/her more vulnerable to injury.

There are many interactions between dehydration, fatigue, and hyperthermia and links to injury. However individually few studies have isolated the effects and influences of these variables on injury. A possible study would be a prospective study on hydration status and injury audit. It would be possible to make people exercise in a dehydrated state and examine whether it caused more injuries but this isn't very ethical approach. Rather, an audit would be conducted over a period while simultaneously monitoring hydration status to see if dehydration is linked to injury? This would then be followed up with an intervention study to improve individual game and training hydration strategies and repeat the injury audit again. In this way by controlling for hydration it may be possible to see if hydration status per se is the factor, especially in the latter stages of activity. If the pattern of injuries is still the same it may point toward a different factor. The experimental structure would be similar to the steps outlined in Van Mechelens Injury Audit Model (1992). However a study of this magnitude would require the full support of the Gaelic Football Association.

It is clear from this thesis that research aimed at injury prevention, player welfare, and improving performance in Gaelic Football requires the support of a dedicated sports science and sports medicine research group. According to the latest publication from the Gaelic Athletic Association, *The GAA Strategic Vision and Action Plan 2009-2015*, (GAA Publications 2009), the Association will "learn from the latest research and develop best practice" for training teams, injury prevention and recovery, and health and welfare. When the publication is examined in more detail, the research support comes under the remit of games development and the proposed research group “will support and initiate research on games development and other topics”. It is not explicitly stated if sports science and sports medicine are to be included under ‘other topics’. While the move to establish a dedicated research group for Gaelic Games is a welcome initiative, there seems to be an over-emphasis on games development rather than player welfare and a general confusion regarding the exact remit of this group. The sports science and medical support system employed by Australian Rules Football is an excellent example of best practice and a model the GAA should emulate.

Australian Rules Football shares many similarities with the game of Gaelic Football. The two codes are indigenous to their countries, are extremely popular, have a small number of elite teams, a large population of recreational players, and have relatively little international exposure. When one compares the organisational structures, the AFL (Australian Football League) is probably one of the most innovative and professional sporting organisations in the world.

A dedicated research board of the AFL administers the selection of research projects and provides funding to all areas of sports science, sports medicine, injury prevention, coaching and performance, and game evolution in Australian Rules Football. The main objectives are to provide information to upgrade coaching methodology, improve player safety and enhance player performance that is applicable to all levels of the game. For example, the AFL injury survey is the world's longest running publicly-released sports injury surveillance system, data are published annually, the aetiology of injuries are investigated extensively, recommendations based on scientific evidence are brought to the attention of the national governing bodies of sports, and ultimately there has been a significant reduction in the incidence of injury as a result of the introduction of preventive measures. The most recent example is the requirement that all games be played on the same type of surface; this directive came as a result of detailed investigation into the incidence of injury and ground surface conditions. Once detailed injury surveillance systems are in place, it will facilitate more detailed scientific investigation of injury occurrences and causes, as evidenced by the numbers of specific injury studies (e.g. hamstrings injury) published after the initial release of the audit of injuries. A Grand Final Symposium, a foundation for generating research concepts in areas of critical interest to sport is held annually coinciding with the climax of the AFL season. Clubs are encouraged to submit research projects and adopt a more systematic approach to sports science and medical research. Innovative and dynamic research has resulted in the creation of GPS based systems to monitor individual player performance including live television feed of individual player heartbeats. This technology has been exported worldwide.

The current structure in Gaelic Football makes it extremely difficult to replicate the AFL's sports science and sports medicine research model. Gaelic Football players do no have the support of dedicated sports science research programmes, national centres for excellence, or an administration structure that embraces and directs scientific and medical research aimed at injury prevention, player welfare, and improving performance.

The work presented in this thesis highlights the weaknesses with the current structure. All stakeholders, especially players, managers, and coaches should be invited to make a contribution to this proposed new research group and help formulate policy objectives and areas of interest in research activity across all levels of competition and all categories of players.

Appendices

A1. History and Present Day Structure of Gaelic Football

A2. Rules of Gaelic Football

A3. Training Regimes

A4. Gaelic Football Injury Study Information Sheet

A5. Gaelic Football Injury Study Pilot Study Questionnaire

A6. Injury Report Form Guidelines

A7. Activity Report Form Guidelines

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A9. Fluid & Electrolyte Balance Study Information Sheet

A10. Fluid & Electrolyte Balance Study: Results Data

A11. Research Ethics Application Forms

A1. History and Present Day Structure of Gaelic Football in Ireland

The Gaelic Athletic Association (GAA) is Ireland's biggest and best-supported amateur sporting organisation. It was founded in 1884, by Michael Cusack and Maurice Davin to preserve and cultivate the national games of Ireland. Dr. T. W. Croke, (Archbishop of Cashel) became the first patron of the Association, and Croke Park (Figure A1.1) in Dublin (the Association Headquarters) is named in his honour.

Figure A1.1 Croke Park, Dublin, Ireland

There are over two thousand eight hundred clubs in Ireland alone with an estimated Gaelic Football playing population in excess of a quarter of a million people. Clubs are generally based in a specific geographic area, usually a parish, and draw their players from that area. Gaelic Football clubs compete in three amateur grades, Senior, Intermediate, and Junior, often with different divisions for each grade (e.g. Senior A, and Senior B). It is not unusual for clubs to have three adult teams competing in the different divisions. Clubs act as a feeder system for elite (inter county) teams with the best thirty players chosen to represent their county. Accordingly, all elite Gaelic Football players are active members of their local club team as well as their county (elite) team. There are thirty two elite Gaelic Football teams based in Ireland, and one each in New York and London.

The typical Gaelic Football season runs from February to September. All elite teams compete in the National League as well as the All-Ireland Championship. The National League is played between the months of February and May, and the All-Ireland championship is played from May to September. The National league is divided into four divisions and teams play a minimum of seven matches, with the top four in each division qualifying for the knock-out stages of the League competition.

The All-Ireland championship is a knock-out competition; however teams are given two chances to avoid elimination in the early stages of the competition, once eliminated from the All-Ireland Championship teams are entered into a secondary knock-out competition, the Jack Murphy cup. The teams that progress to the All-Ireland championship final compete for the Sam Maguire Cup in September of each year in Croke Park in front of eighty thousand spectators. The typical season for elite Gaelic Football players begins with pre-season in December/January (although some teams can start as early as September), and runs through to September, (although some teams' season may end sooner as a result of being eliminated from the different competitions).

Competitions for club teams are structured in a similar fashion, with an individual county league and championship for each grade. However a recent introduction has made it possible for the winners of each county championship (e.g. Galway county champions) to compete against other county championship winners (e.g. Mayo county champions) in their province (e.g. Connaught), and ultimately competing in the All-Ireland Club finals in March of the following year. Consequently the Gaelic Football season for club players may often start with pre-season in January and run for the entire calendar year and beyond.

A2. Rules of Gaelic Football

The game has similarities with other field sports notably Australian Rules Football (Douge, 1988). It is a contact sport played at a fast pace that places many demands on the technical and the tactical skills of the individual player. It is a field game played by two teams, normally for thirty-five minutes each side. Each team is composed of fifteen players, six defenders, six forwards, two midfielders and a goalkeeper. The pitch is similar to a Rugby Union pitch; the length of the pitch is between 140-160 yards and between 84 and 100 yards wide with 'H' shaped goal posts at either end (Figure A1.2). If the ball goes over the crossbar it is worth one point, whereas the ball ending up in the goal below the crossbar is worth three points.

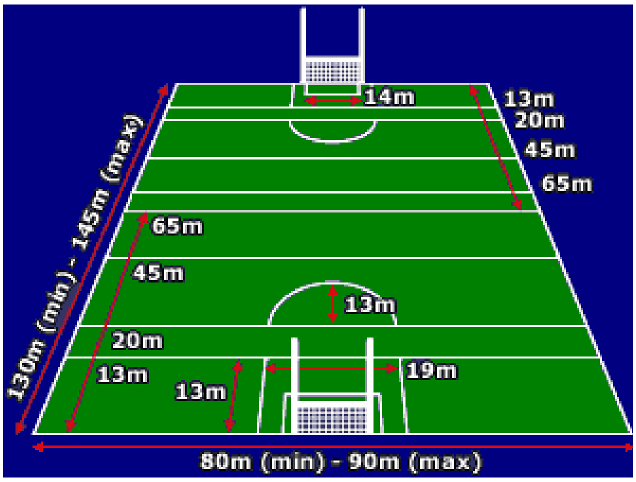

Figure A1.2 Dimensions of a Gaelic Football Pitch

Unlike Soccer, players are allowed to catch the ball and play the ball in the air or along the ground; consequently the majority of the game is played in the air (Figure A1.3). Players can pass the ball to one another by hand or foot. Players are allowed to perform a fist pass, but not permitted to throw the ball. Players may carry the ball for a maximum of four consecutive steps after which they must perform a 'solo' i.e. kick the ball back to themselves and collect it before it hits the ground or bounce the ball once, and once again after each solo (Figure A1.4).

Figure A1.4
Players jumping for possession

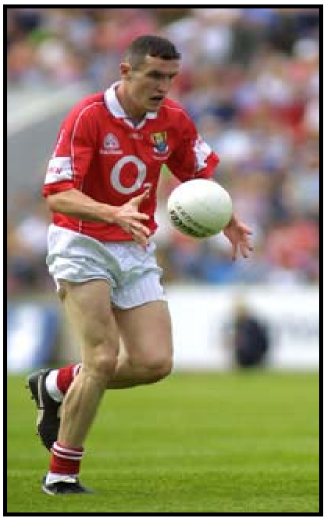

Figure A1.4
Player performing a solo

Tackling a player in order to regain possession is permitted in a number of ways. The ball may be knocked from an opponent's hand(s) by flicking it with the open hand, or by making a side-to-side shoulder charge on an opponent provided that both players have at least one foot on the ground. Alternatively an opponent may block, by using the hands, a players attempted pass or shot at goal. The player in possession of the ball may be shadowed at all times by his opponent in order to reduce any advantage (Figure 1.5). The ball is rarely out of play and players are constantly moving with or without the ball.

Figure A1.5 Players avoiding being tackled

A3. Training Regimes

Modern Gaelic Football is evolving at a fast pace and elite players are training at a level comparable with professional athletes of similar codes such as Soccer, Rugby union, and Australian Rules Football (Reilly *et al.*, 2000). Traditionally, training methods were a combination of customs passed down from former players and coaches together with techniques borrowed and adapted from other sports. The core components of training were endurance bouts and speed sessions. As one ex player famously said of their training sessions, ‘of course we had variety in training, one night we’d run twenty laps, the following session we’d run ten laps twice!’ In more recent seasons, activities focussing on power and speed have been included as games become faster and more physical with less space and time available to players. High intensity interval training incorporating endurance and speed work are incorporated from the very start of the training season. These changes are a result of the result of dedicated scientific research conducted in conjunction with professional sports codes and adapted for Gaelic Football.

A5. Gaelic Football Injury Study Pilot Study Questionnaire

Pilot Study Questionnaire

Please complete and return at the end of the study

Please answer the following questions on a scale of 1 to 5

1: Poor **2**: Fair **3**: Good **4**: Very Good **5**: Excellent

Q.1 How would you rate the clarity of the information given?

Q.2 How would you rate the layout of the information presented?

Q.3 Was any section ambiguous, contradictory or confusing? Yes No

If YES please give details:

Q.4 Did you encounter any problems with the Activity Report Forms? Yes No

If YES please give details:

Q.5 Did you encounter any problems with the Injury Report Forms? Yes No

If YES please give details:

Q.6 For future study, please indicate which method of data entry you would prefer to use?

Electronically via website Pen and Paper Forms No Preference

Q.7 Any further suggestions/comments?

Thank you for your participation

A6. Injury Report Form Guidelines

Gortaithe Peile
Gaelic Football Injury Report Study 2004

Guidance Notes / Comments For Completion of Injury Report Form

1. There are seven sections to complete by "√**".**

2. There is no requirement for laborious manuscript responses.

3. The form is designed to be user friendly, aimed at gaining important research data with the minimum of time required for completion.

4. The study will only include injuries sustained while playing or training, and does not include home accidents or illness, e.g. influenza.

5. For the purpose of this study an injury is defined as "One sustained during training or a game and which prevented the injured player from participating in normal training or games for more than 48 hours, not including the day of the injury".

> **Note 1**: This study purposely deals only with acute injuries and does not include past injury history.
>
> **Note 2**: This should include any rest day where training or playing would not normally take place.
>
> **Note 3**: No audit of medical conditions is required in this study.

6. The study is restricted to Senior inter-county players only.

7. The study will commence in the first week of January and will terminate upon elimination from the Championship.

8. All completed Injury Report Forms (white copy) should be returned on a monthly basis (end of each month) in the pre-paid envelope provided. The carbonised copy (coloured) to be retained for reference

9. It is requested that as much information relating to the injury sustained should be entered onto the Injury Report Form as soon as is practical following the injury.

10. With regard to Section 1, <u>Injury Information</u>:

    - Please indicate if the injury was as a result of a club or county activity.

    - For 'playing/training surface conditions' please tick all that apply.

11. With regard to Section 2, <u>Body Region Injured</u>:

    - 'Dominant side' of a player refers to his predominant kicking/hand passing side.

12. For Section 3, referring to <u>Supplementary Information</u>

- ‘Late fitness test prior to game’ is defined as less than 24 hours prior to the game in which the injury occurred.

13. For Section 4, <u>Nature of Injury</u> it may be that a definitive diagnosis cannot be given immediately. Therefore the box ‘other’ should be used to state ‘no diagnosis identified at this time’. This may be altered at a later date when a diagnosis has been made.

14. For section 5 <u>Mechanism/Cause of Injury</u>

- Please indicate if the injury was as a result of contact, or non contact and tick any boxes that apply

15. At the bottom of the form there is a <u>Comments Section</u> that can be used to provide any information you feel relevant concerning the player’s injury. If there are any doubts or queries concerning the reported injury please utilise this box.

16. **Confidentiality**: Results of this research injury audit will be presented as grouped data only. Each individual physiotherapist or team doctor may have access to data relating specifically to a person or persons under their care at their request.

For the purpose of this study players will not be named. The player will be allocated a research number by the county secretary prior to the commencement of the study and retain the same number through the remainder of the research project.

A7. Activity Report Form Guidelines

Gortaithe Peile
Gaelic Football Injury Report Study 2004

Guidance Notes for Completion of Weekly Activity Report Form

17. All sections to be completed by "√" or digit number response

18. There is no requirement for laborious manuscript responses.

19. The form is designed to be user friendly, aimed at gaining important research data with the minimum of time required for completion.

20. The study is restricted to Senior inter-county players only.

21. The study will commence in the first week of January and will terminate upon elimination from the Championship.

22. All completed Activity Report Forms (white copy) should be returned by the recorder (in the envelope provided), on a weekly basis (Monday) whether or not any activity took place. The carbonised copy (coloured) to be retained for reference.

23. It is requested that as much information relating to the weekly activities should be entered onto the Weekly Activity Report Form as soon as is practical.

24. Before recording takes place, please:

- Allocate a study number to each member of the panel.

> **Note 1**: This number will be the same one used by the physiotherapist when recording injuries.
>
> **Note 2**: Players will retain the allocated number for the entire duration of the study.

- Give the physiotherapist a copy of the study numbers allocated to each player.

25. Entering data on the form:

- Enter the week number, in digit form, beginning with week 1, (Jan 5th ^{to} 11th inclusive).

> **Note 1:** For the purpose of this study, each week will begin on a Monday and end on a Sunday.

- The activity (if any) that took place on each day of the week, according to the codes:
  - T: Training
  - M: Match including challenge games
  - O: Other activity

- The time spent (mins) engaged in the particular activity.

- Leave the section blank if no activity took place.

26. With regard to, Players unable to participate fully

- Please enter an allocated code in the box provided directly opposite the players study number, if they did not participate fully in training or match that particular day.

  - I: Injured
  - PT: Taking part in partial training
  - C: Club related injury
  - SK: Sick / ill
  - W: Working
  - N: No reason given
  - S: Sub (came on)
  - SN: Sub not used

27. **Confidentiality**: Results of this research injury audit will be presented as grouped data only. Each individual recorder or physiotherapist may have access to data relating specifically to a person or persons under their care at their request.

For the purpose of this study players will not be named. Each player will be allocated a study number by the county secretary prior to the commencement of the study and retain the same number through the remainder of the research project.

Example

Enter week no here

Tick Activity, e.g. training on Monday, Wednesday and Friday and a match on Sunday

Week no:	**Gaelic Football Weekly Activity Report**: Please tick one of the following; **T**: Training **M:** Match **O**: Other						
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	T□ M□ O□	**T□ M□ O□**	**T□ M□ O□**	**T□ M□ O□**	**T□ M□ O□**	**T□ M□ O□**	**T□ M□ O□**
Time in Mins	90		110		60		70

Enter the time engaged in training / playing games here, e.g., 90 mins on Monday

	Indicate **ONLY** players who did not participate fully in training or matches by entering one of the following codes:						
Player Code	**I**: Injured **PT**:Taking part in partial training **SK:**Sick/ill **W:**Working **N:**No reason given **S:**Substitute (Came on) **SN:**Substitute not used						
G 01							SN
G 02			W				
G 03	I		I		I		
G 04							SN
G 05							
G 06	I		I		I		
G 07							
G 08	PT		PT		SK		S
G 09							

With regard to training enter only the players who did not participate fully and the reason they were unable to participate.

For matches, indicate the players who were substitutes and if they came on, or substitute not used.

Please return completed forms in the envelopes provided on the Monday at the end of each week. Thank You.

A9. Fluid & Electrolyte Balance Study Information Sheet

Information Sheet

An investigation of fluid and electrolyte balance in elite Gaelic Football players during training and games in different environmental conditions

Introduction

We invite you to participate in an investigation that we believe to be of potential importance. In order to help you to understand what the investigation is about, please read the following information carefully. Be sure you understand it before you formally agree to participate. If there are any points that need further explanation, please ask a member of the research team. It is important that you understand what you are volunteering to do and are completely happy with all the information before you sign this form.

What is the purpose of the study?

Elite Gaelic Footballers train and play in a range of environments from cool conditions in February to hot and sometimes-humid conditions in summer. There is good scientific evidence that athletes who become dehydrated are more susceptible a decrease in endurance performance and an increase in ratings of perceived exertion.

A fluid deficit that is incurred during one training session/game can potentially compromise the next training session or game if adequate fluid replacement does not occur. A detailed Gaelic Football injury study conducted last season found that the majority of injuries are occurring in the last quarter of games and training suggesting a possible link between injury and dehydration. However no single hydration strategy suits all players in all environments. Variation in player characteristics, the intensity of the activity and changing environmental conditions can alter an individual's hydration requirement.

The aim of this study is to investigate the fluid and electrolyte balance of individual elite Gaelic Football players during training and games.

Why have I been chosen?

You have been chosen because you are an elite Inter-County Gaelic Footballer.

Do I have to take part?

It is up to you to decide whether or not to take part. If you decide to take part, you will be given this information sheet to keep and you will be asked to sign a consent form. If you decide to take part, you are still free to withdraw at any time and without giving a reason.

What will happen to me if I take part?

You will be informed of what is required prior to the training/match activity.

Testing will take place at training sessions and games at different times during the season in varying environmental conditions. It is proposed to test players 3/4 times during the season.

You will be weighed prior to the commencement and at the end of the exercise activity and requested to provide a pre-exercise activity urine sample in order to gain an indication of your current hydration status You will also be given your own personal drinks bottle, containing your preferred fluid, e.g. .water/sports drink. This bottle will be weighed before and after the exercise activity. You are requested to drink only from your own drinks bottle and not to spit out any fluid consumed.

Finally, gauze swabs will be applied to different sites on the body prior to the commencement of activity and remain in place for an hour. The purpose of which is to measure the sodium loss in sweat.

What are the side effects of taking part?

There are no perceived side affects associated with this study. You are free to cease participation in the study at any time should you feel uncomfortable with the testing procedure outlined above or feel unwell at any stage during testing.

What are the benefits of taking part?

No study has investigated the magnitude of dehydration levels in Gaelic Football in training or games. Quantification of fluid losses will enable coaches to identify if changes to hydration strategies are necessary for individuals. The findings of this study will identify if the current hydration procedures carried out by elite Gaelic Footballers are adequate and may result in changes in hydration strategies in an attempt to enhance playing performance.

Any improvements that help reduce injury and make the game safer for all participants are a positive step medically, physically, and financially. It may be of benefit to all participants not just of Gaelic Football but all sports within the Gaelic Games.

What if something goes wrong?

If you are harmed by taking part in this research project, there are no compensation arrangements. If you are harmed due to someone's negligence, then you may have grounds for a legal action but you may have to pay for it.

What will happen to the results of the research study?

All data will be coded and any information obtained from the study will be treated confidentially. Test results from this study will not affect team selection. In addition, you must agree to give permission before your results are given to club medical and coaching staff. If you agree, your scores will be given to the club medical and coaching staff so that the need for hydration advice can be assessed. It is our intention to publish results of this study, but not in a way that individuals and their performances can be identified.

If you are worried about any unwanted side effects from any the procedures outlined above you should contact:

Dr Stan Grant
University of Glasgow,
Glasgow G12 8QQ
Phone: 0141 330 6490
Fax: 0141 330 2923
E-mail: S. Grant@bio.gla.ac.uk

Fluid and Electrolyte Balance
in Gaelic Football

Consent Form

**I,...(PRI
NT)**

of...

...

Give my consent to the research procedures that are outlined above, the aim, procedures and possible consequences of which have been outlined to me

By...

Signature (Subject)---Date----------------

Isokinetic strength testing and hamstrings injury
in Gaelic Football

Consent Form

I,...(PRINT)

of...

...

Give my consent to the research procedures that are outlined above, the aim, procedures and possible consequences of which have been outlined to me

By...

Signature (Subject)--Date----------------

UNIVERSITY OF GLASGOW

FACULTY OF BIOMEDICAL AND LIFE SCIENCES

ETHICS COMMITTEE FOR NON CLINICAL RESEARCH INVOLVING HUMAN SUBJECTS

APPLICATION FORM FOR ETHICAL APPROVAL

NOTES:
THIS APPLICATION FORM SHOULD BE TYPED NOT HAND WRITTEN.

ALL QUESTIONS MUST BE ANSWERED. "NOT APPLICABLE" IS A SATISFACTORY ANSWER WHERE APPROPRIATE.

Project No (to be assigned) ________________

Project Title Isokinetic strength testing and hamstring injury in Gaelic Football

Date of submission 21/01/05

Name of all person(s) submitting research proposal Dr. S. Grant; Dr A Henry, Dr J. Newell, Mr M. Newell

Position(s) held Senior Lecturer, IBLS, College Lecturer, Sports Medicine Physician, NUI Galway, Ireland, College Lecturer, Dept of Mathematics, NUI Galway, Ireland, PhD student

Division NABS

Address for correspondence relating to this submission Dr Stan Grant, West Medical Building

Name of Principal Researcher (if different from above e.g., Student's Supervisor) __________

____

____

Position held

____

___

1. Describe the purposes of the research proposed.

Injuries to the hamstrings muscles are the most frequently occurring and reoccurring of all injuries in sports that require bursts of speed or rapid acceleration, particularly in Association Football, Rugby Union and Gaelic Football. Muscle strength deficiency and an imbalance between the hamstrings and quadriceps muscle groups are considered to be some of the risk factors for injury. Some previous research has shown that possible imbalances between muscles, the hamstrings-quadriceps (H:Q) ratio is associated with an increased incidence of hamstrings injury. No study has investigated the relationship between H:Q ratio and hamstrings injury in Gaelic Footballers.

The aim of this study is to measure the strength of the hamstrings and quadriceps muscle groups and compare the strength scores with each player's injury record.

2. Please give a summary of the design and methodology of the project. Please also include in this section details of the proposed sample size, giving indications of the calculations used to determine the required sample size, including any assumptions you may have made. (If in doubt, please obtain statistical advice).

Previous studies have recruited between 21 and 102 subjects. Based on these studies it is considered that 75 subjects will be adequate for the study. Previous research by this group has shown an incidence of 20% hamstrings injury in Gaelic Footballers over the course of a season.

Senior Inter-County (elite) male Gaelic Footballers, from five different teams, will be asked to participate in this study. The five teams will be county sides selected from different geographical locations in Ireland. There are 32 county sides in Ireland. Players (n=75) will be male aged between 18 and 35 years. All subjects will be in good health at the time of testing. They will complete a medical and physical activity questionnaire (attached). Subjects who are deemed to have any adverse medical condition will not be recruited. All subjects will be given an information sheet and asked to sign a consent form (attached).

Player characteristics: age, weight, height, and dominant kicking leg will be recorded. Maximum voluntary torque of hamstrings and quadriceps muscles of both legs will be assessed using an isokinetic dynamometer operated according to standard procedures.

An initial warm up including stretching and gentle cardiovascular exercise will be performed prior to the use of the isokinetic machine. All subjects will have three practice trials at sub-maximal intensities to aid familiarisation with the procedures. Three maximal contractions (concentric and eccentric) will be recorded for each leg at a range of speeds up to 250 degrees. s^{-1}. The subjects will have 1-minute rests between tests at different speeds. A warm down will be undertaken immediately following isokinetic exercise, including stretching and gentle cardiovascular work.

Physiotherapists and medical staff attached to each team will be briefed on the workings of the project. Players will be monitored throughout the season. Team physiotherapists will record any hamstrings injuries incurred by players during training and games on specifically designed injury-reporting forms (attached).

3. Describe the research procedures as they affect the research subject and any other parties involved.

All subjects will complete a medical questionnaire prior to testing which will request details of any condition that may place the subject at risk during testing. Subjects feeling unwell or felt to be even slightly at risk from undertaking the test will not be tested. It is important that the subjects are sufficiently warmed-up before testing to maximise validity of results and minimise risk of muscular injury to the subject.

4. What in your opinion are the ethical considerations involved in this proposal? (You may wish for example to comment on issues to do with consent, confidentiality, risk to subjects, etc.)

It is considered that there is no significant risk to the subjects in this study. Despite the fact that maximal tests will be carried out, the literature indicates that isokinetic testing is safe. Confidentiality will be maintained throughout the study.

Subjects will be free to withdraw from testing should they feel uncomfortable with the testing procedure. No tests results will be used as a basis for subsequent team selection by the coach.

5. Outline the reasons which lead you to be satisfied that the possible benefits to be gained from the project justify any risks or discomforts involved.

A recent study by this group showed that hamstrings injuries are the most common injury in Gaelic Football. However the underlying aetiology of hamstrings injuries is unclear.

Muscle strength deficiencies and an imbalance between the hamstrings and quadriceps muscle groups is one of several risk factors of hamstrings injury. This study will help to ascertain if a hamstrings-quadriceps muscle imbalance is a predictor of hamstrings injury in Gaelic Football.

6. Who are the investigators (including assistants) who will conduct the research and what are their qualifications and experience?

Dr. S. Grant, PhD, MSc, B Ed, DPE, Senior Lecturer, IBLS.
Dr A. Henry, Sports Medicine Physician, MB ChB, NUI, Galway, Ireland

Dr J. Newell, PhD, MSc, College Lecturer, Dept of Mathematics, NUI, Galway, Ireland
Mr. M. Newell, MSc, BA,HDE, PhD Student

The main experimenters have a wide range of experience in research projects.

7. Are arrangements for the provision of clinical facilities to handle emergencies necessary? If so, briefly describe the arrangements made.

Trained users will operate Isokinetic machines according to standard procedures. The risks associated with strength testing are not considered to be great. Clinical emergencies are not anticipated. A first aid box will be available in case of minor accidents that may occur in the laboratory.

8. In cases where subjects will be identified from information held by another party (for example, a doctor or hospital), describe the arrangements you intend to make to gain access to this information including, where appropriate, which Multi Centre Research Ethics Committee or Local Research Ethics Committee will be applied to.

N/A

9. Specify whether subjects will include students or others in a dependent relationship.

There is no dependent relationship.

10. Specify whether the research will include children or people with mental illness, disability or handicap. If so, please explain the necessity of involving these individuals as research subjects.

N/A

11. Will payments or any other incentive, such as a gift or free services, be made to any research subject? If so, please specify and state the level of payment to be made and/or the source of the funds/gift/free service to be used. Please explain the justification for offering payment or other incentive.

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Fluid and Electrolyte Balance in Elite Gaelic Football Players

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Abstract
The aim of this study was to investigate fluid and electrolyte balance in elite Gaelic Football players (n=20) during a typical training session in a warm environment (16 to 18°C, 82-88% humidity). Pre-training urine samples were used to determine hydration status. Sweat sodium concentration was collected from four body site locations using absorbent patches. The mean sweat rate per hour was 1.39 $l{\cdot}h^{-1}$ and mean body mass loss was 1.1%. Mean sweat sodium concentrations were 35 $mmol{\cdot}l^{-1}$ (range 19-52 $mmol{\cdot}l^{-1}$). On average, players did not drink enough fluid to match their sweat rates ($p<0.001$) and this fluid deficit was not related to pre-training hydration status ($p= 0.67$). A single hydration strategy based on published guidelines may not be suitable for an entire team due to variations in individual sweat rates. Maximising player performance could be better achieved by accurate quantification of individual fluid and electrolyte losses.

Introduction

Sweating has an important role in body thermoregulation during exercise and is influenced by the duration and intensity of exercise, fitness levels, environmental conditions, acclimatisation, body mass, and choice of clothing.[1] However, extensive body water and electrolyte losses from prolific and repeated sweating reduce the capacity of the temperature regulatory and circulatory systems, depleting cells of fluids and electrolytes and can result in

Table 1 Sweat Sodium Concentrations and Anatomical Reference Points				
Location	**Mean**	**s**	**Range**	**Anatomical Reference**
Back	32	16	11-68	2cm directly below and in line with the inferior angle of the scapula
Chest	34	14	15-61	7cm directly below the nipple in the right hypochondriac region along a line running laterally from the distal aspect of the xiphoid process
Upper Arm	29	11	7-48	On the anterior surface of the upper arm midway between the lateral aspect of the coracoid process of the scapula and the olecranon process of the ulna
Thigh	38	17	13-71	25cm from the proximal aspect of the patella on the anterior midline of the thigh
Four Site Average	35	11	19-52	
Total Na+ loss (mmol)	65	33	35-96	

a threat to health and performance.[2] It is generally accepted that the human body can tolerate dehydration levels of between 1 and 2% body mass particularly in endurance activities in ambient temperatures of 20-21°C lasting less than 60 minutes. However, dehydration of 2% body mass in events lasting longer than 60 minutes in warmer temperatures 31-32°C may increase the risk of fatigue including loss of performance, increased risk of injury, and other neuromotor problems.[3,4,5]

A recent study of American football players found that players who suffer muscle cramps in training and competition had greater sweat losses and a higher sweat sodium content than players matched for fitness who did not suffer from muscle cramps.[6] Although difficult to link exercise-induced muscle cramps with electrolyte disturbances directly, a recent study on Gaelic Football injuries reported that more injuries occurred in the final quarter of training and games than at any other time, and may suggest a possible link between dehydration and injury.[7] The aim of this study was to investigate fluid and electrolyte losses in a group of elite Gaelic Football players training in a warm environment. Assessment of fluid and electrolyte losses during training would provide coaches and players with information on the possible hydration needs during and after training.

Methods

Gaelic Football players (n=20) were recruited from a Senior Inter-County (elite) team. The elite team was representative of the population of players competing at the highest level of Gaelic Football, whose training intensity and match schedule were typical of elite teams competing at this level.[7] All players were male aged between 18 and 36 years. Subjects, who were deemed to have any adverse medical condition, were not recruited. Ethics approval for the study was obtained from the ethics committees of Glasgow University and the National University of Ireland Galway. Data on environmental conditions were acquired from the local meteorological office.

Players were monitored during a typical training session on a warm and humid evening in June, the air temperature ranged from 16 to 18°C, and humidity ranged from 82 to 88%. This was the third training session of that particular week and players had a day's rest before the session. Training consisted of a dynamic warm-up (including repetitive sprints and stretching) followed by a variety of intensive game drills (defending and tackling), a series of small-sided conditioned games, culminating in a final cool down. The training session was deemed by the coach to be of typical duration and intensity for the players. The total duration of the training session was 80 minutes and all players followed the same programme.

Before the training session
Each player was assigned a study code and given three personalised water bottles. Each bottle contained 1litre of tap water and were placed in crates on the ground beside the training area. Players were then instructed to provide urine samples (to ascertain pre-training hydration status) and these were assessed for urine specific gravity using a handheld clinical refractrometer (Spartan, Tokyo, Japan). Players were then weighed to nearest 0.1 kg (in dry pants) using calibrated weighing scales (Seca 770, Hamburg, Germany); the mass of the individual drinks bottles were also recorded using scales (Soenhle Magnum 802U Digital Food Scale, Switzerland). Absorbent sweat patches (3M Tegaderm +Pad, 3m Healthcare, MN, USA) were used to measure the electrolyte loss in sweat. Patches were applied at four different anatomical sites (Table 1) on the right hand side of the body. Each anatomical site was cleaned with deionized water and dried with a clean electrolyte-free gauze swab prior to the attachment of absorbent patches.[8]

During the training session
Players were instructed to only drink from their own bottle and not to spit out any water. Any urine voided during the training session was collected and the volume recorded. Sweat patches were removed after twenty minutes (to prevent saturation) and placed in individual sealed sterile universal containers (Sarstedt, Wexford, Ireland).

After the training session
At the end of the exercise session, the drinks bottles were collected. Players were towel dried and their post exercise body mass recorded along with the mass of their individual water bottles. The amount of fluid consumed during training was calculated by subtracting the mass of the drinks bottle at the end of training from the mass of the bottle at the start of training. Total sweat loss was calculated using the formula: Total Sweat Loss = (pre exercise body mass – post exercise body mass + fluid intake – urine volume). Similarly the total amount of fluid consumed during training was used to calculate drink volume consumed per hour. The urine specific gravity readings and percentage change in body mass were compared against published indexes of hydration status (Table 2) from the American College of Sports Medicine's Position on Exercise and Fluid Replacement.[4]

Table 2 Indexes of Hydration Status (Casa et al., 2000)[4]		
Condition	% Body Mass Change	Urine Specific Gravity
Well hydrated	+1 to -1	<1.010
Minimal dehydration	-1 to -3	<1.010 – 1.020
Significant dehydration	-3 to -5	1.021 – 1.030
Serious dehydration	>5	>1.030

Prior to analysis, the volume of sweat collected in each patch was determined gravimetrically (Precisa, Zurick, Switzerland) by subtracting the mass of a new unused patch and universal from the weight of the universal containing the absorbent patch and sweat. Individual samples were diluted with deionized water and thoroughly mixed using a vortex.[9] The sodium concentration was analysed using a flame spectrometer (Corning 410c, Corning Ltd., Essex, UK).

Statistical Analysis

A Chi-square test was used to compare the proportion of pre-training hydrated and dehydrated players (based on urine specific gravity readings). An Analysis of Covariance model was fitted to the data to compare mean fluid loss across the team while adjusting for initial pre-training hydration status. The adequacy of the model was checked using suitable residual plots while the assumed additive effect of the covariate was tested by including an interaction term to allow for separate slopes. A Bonferroni adjusted one sample-t-test was used to compare the mean fluid balance for the team against a hypothesised value of zero where each test was performed at the 0.05/2 significance level. The adjustment was made in order to maintain a global Type 1 error rate of 0.05 across the two comparisons. The likely mean fluid balance for the population of interest was estimated using (Bonferroni adjusted) 97.5% Confidence Intervals for a mean.

Results

The majority of elite players (n=15) were well hydrated (usg<1.010) prior to exercise activity (Table 3), however three players displayed signs of minimal dehydration (usg 1.010 – 1.020) and two players showed significant levels of dehydration (usg 1.021-1.030).[4] Mean body mass loss over the duration of the training session was 0.8kg with values ranging from 0.5 to 2kg. Using percentage body mass loss as a measure of post training dehydration, the values recorded ranged from +0.5% to -2.4% (mean 1.1%). The majority (n=12) of elite players were classified as being minimally dehydrated post training (-1 to -3% body mass change). Total sweat losses ranged from 0.85 l to 3.15 l (mean 1.86 l), while the amount of fluid consumed by players (rounded to the nearest 5ml) during training, ranged from 300ml to 2000ml with a mean of 1034ml. Comparing the sweat rate per hour to the amount of fluid consumed per hour, there is a mean fluid balance of -0.62 $l \cdot h^{-1}$ with values ranging from $+0.37$ to -1.5 $l \cdot h^{-1}$. Only 56% of sweat volume was replaced during training with values ranging from 23% to 133%.

Table 3 Sweat Loss and Fluid Intake Summary Data

	Players (n=20)		
	Mean	**s**	**Range**
Urine Specific Gravity	1.009	0.006	1.002-1.027
Pre-Training Body Mass (kg)	81.4	4.8	71-87
Post-training Body Mass (kg)	80.6	4.8	70-87.5
% change in Body Mass	-1.1	0.7	0.5-2.4
Fluid consumed (ml)	1034	457	300-2000
Total Sweat Loss (l)	1.86	0.63	0.85-3.15
Sweat Rate per hour ($l.h^{-1}$)	1.39	0.48	0.64-2.36
Fluid consumed per hour ($ml.h^{-1}$)	775	343	225-1500
Fluid Balance (ml)	619	504	375-1500
% Change in Body Mass if no Fluid consumed	2.2	0.9	0.6-3.5

There was significant evidence (p<0.01) of fluid deficit across the team (Fig. 1). Based on the ANCOVA model, there was no evidence to indicate that fluid deficit was simply related to pre-training hydration status (p= 0.67).

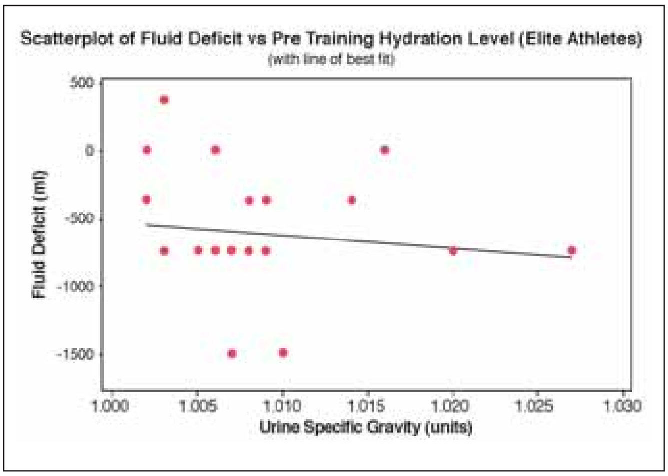

Figure 1 Relationship Between Pre-Training Hydration Level (measured by urine specific gravity) and Post-Training Hydration Balance.

Fluid deficit was significant across the team (p<0.01), even for players classified as being well hydrated at the start of training.

Virtually all points lie below the line of equality and there is strong evidence, that the mean fluid deficit is not zero (p<0.001). An estimate of the likely mean fluid deficit for the Elite 'population' is between 319ml and 881ml.

With the exception of 5 players, all points lie below the line of equality indicating an imbalance between the volume of fluid consumed during exercise and the corresponding volume lost through sweat.

The mean sweat sodium concentration (based on a four site average) was 35 $mmol \cdot l^{-1}$ (range 19 to 52 $mmol \cdot l^{-1}$). This equates to a total sodium loss (calculated by multiplying mean sweat sodium concentration with mean sweat loss) of 65 mmol (range 35 to 96 mmol) (Table 1). There is a suggestion of player-to-player variability with regard to sweat sodium concentration from each of the different collection sites, but no evidence of within player variability (p=0.811). The relationship between pre-training body mass and sweat sodium concentration was not significant for all players (p=0.984).

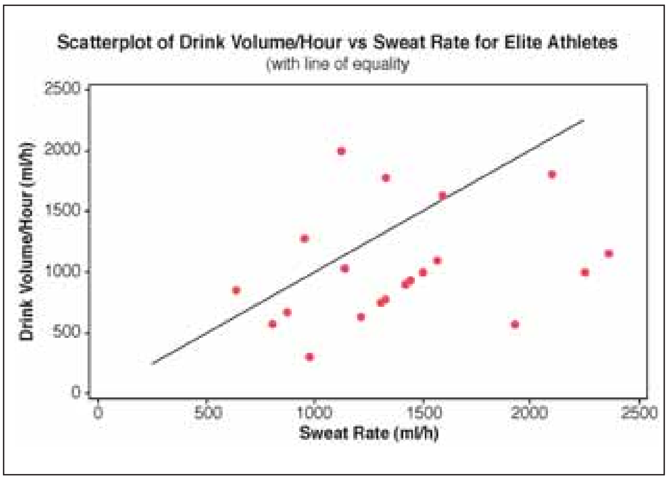

Figure 2 Sweat rate and fluid consumption per hour.

Discussion

The mean sweat rate per hour of 1.39 $l.h^{-1}$ for elite Gaelic Football players is similar to results published for elite players from other codes similar to Gaelic Football. Mean sweat rates for Australian Rules Footballers of 1.4 l h^{-1} and 1.8 l h^{-1} have been reported, when they trained in a temperate (12-15°C) and warm (27°C) environments. Published sweat rates for professional soccer players during training range from 1.13 l h^{-1} in a cool environment (5°C), 1.2 l h^{-1} in warm conditions (25°C), to 1.46 l h^{-1} in hot conditions (32°C).[8,9,10]

The mean volume of fluid intake by elite players (1034ml) is similar to the value published (972ml) for professional soccer players[9] training in temperatures of 32±3°C. With the exception of four players, who did not have fluid deficit, the majority of players had a fluid deficit ranging from 375 to 1500ml. On average, players replaced 56% of sweat loss. These values are in accordance with previous research, which showed that even with unlimited access to plain water, athletes typically only replace around 50% of the water required.[11]

It is suggested that if an athlete begins exercise in a reasonably euhydrated state (usg <1.010) and continues to exercise at moderate levels of intensity for less than an hour in cool (5 to 10°C) or temperate conditions (21-22°C), there is no clear physiological need to consume additional fluid so long as body mass dehydration is within the 2%.[3] The majority of players in this study were suitably hydrated prior to the commencement of training (mean usg 1.009), and although the mean % body mass loss (1.12%) is within the recommended levels of tolerable dehydration (<2%) there is however, wide variety across the team. Three players had measured levels of hypohydration of (2.3%, 2.3%, and 2.4% decrease in body mass). Conversely, assuming that drinking does not influence sweating response, if no fluid had been consumed the mean % body mass loss of players would have been 2.3% although some players would have had % body mass losses in the region of 3.5%, highlighting that the fluid intake strategies in general, were successful in reducing the potential adverse effect of sweat loss.

The mean sweat sodium concentration (35 $mmol{\cdot}l^{-1}$) for players in this study, is in accordance with published values[2,3] for sweat sodium concentration (average 35 $mmol{\cdot}l^{-1}$, range 10-70 $mmol{\cdot}l^{-1}$). The results correspond to published data for professional soccer players10 (30.2 ±18.8 $mmol{\cdot}l^{-1}$) training in slightly warmer (32°C) conditions.

The highest mean concentration for sweat sodium concentration was found in the thigh (38 $mmol{\cdot}l^{-1}$). This contradicts the published literature as other studies have reported highest values in the chest and back.[8,9] However, it was observed in the study that four players wore insulative shorts under their regular shorts and may suggest a possible link between the insulative shorts and a (hypothesised) corresponding localised increase in thigh temperature and subsequent increase in sweat rate. If these players are not included in the pooled data, the highest sodium concentrations are found in the chest and back in accordance with other published studies documenting sweat and electrolyte losses.

The mean volume of total sodium loss was 65 mmol (range from 35 to 96 mmol). It is suggested that players with high sweat sodium loss, may benefit from consuming drinks with a higher sodium concentration (40-80 $mmol{\cdot}l^{-1}$) post-exercise, especially during intensive periods of training and games with little recovery time between exercise bouts as typically occurs during the summer months of the Gaelic Football season. It is inappropriate to advocate that all players would improve their performance by increasing their fluid intake. However, sweat losses for some players, even in relatively cool environments may be considerable and large enough to result in dehydration levels greater than 2% body mass. A single hydration strategy based on published guidelines is unlikely to be suitable for an entire team, due to variations in individual sweat rates. Knowledge of individual hydration requirements and specific advice on post-exercise electrolyte restoration should be considered as a possible contributory factor for performance enhancement during training and games.[4,8,9] It is suggested that Gaelic Football teams should conduct routine urine tests to determine pre and post, training, and match hydration status, and sweat electrolyte assessments to determine sweat sodium concentration.

Acknowledgement

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Incidence of Injury in Elite Gaelic Footballers

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Abstract
The purpose of this study was to undertake a comprehensive prospective epidemiological study of injuries sustained by elite Gaelic Football players over one season.The pattern of injury is strikingly similar across all teams with 47% of all injuries occurring in the final quarter of games and training. Injuries to the lower limb, particularly the hamstrings muscles accounted for the majority of injuries. 65% of players were unable to participate fully in Gaelic Football activity for between one and three weeks as a result of injury. The high incidence of injury especially hamstrings injuries in the latter stages of training and games warrants further investigation.

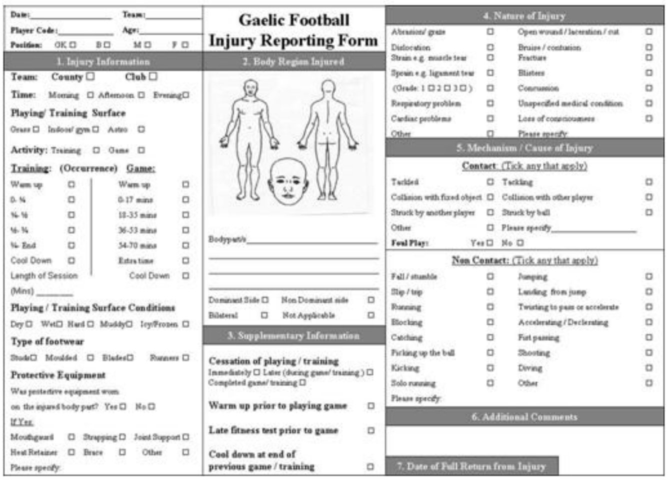
Introduction

Gaelic Football is Ireland's most popular field game. It is a competitive high intensity contact field game played over two thirty-five minute halves, characterised by intermittent short and fast movements such as sprinting and turning, jumping, catching, and kicking[1]. Despite the game's popularity and high participation rates, to date, there have been few detailed prospective studies on injury[2]. Compared with other team games the investigations into injuries in Gaelic Football have been limited to short duration studies carried out on a small number of teams and players[3,4]. Injury rates in other field games including Australian Rules Football, Rugby Union, Soccer, and Rugby League, are well documented in the scientific literature [5,6,7,8,9,10,11]. The lack of injury data in Gaelic Football is an obvious omission that needs to be addressed.

Detailed injury reporting is the first step as an aid to injury prevention[12]. Determination of the incidence of injury as well as the type, location, nature, mechanism, and severity of injuries will provide meaningful information for administrators, coaches, medical staff and players. Identification of the most prevalent injuries and possible causes of injury will assist in the development of procedures to reduce injury in Gaelic Football. The aim of this study was to complete a detailed prospective epidemiological study of injuries in Gaelic Football over an entire season.

Methods

Ethics approval for the study was obtained from the ethics committees of Glasgow University and the National University of Ireland Galway. The team physiotherapist recorded all injuries using a specially designed injury report form (figure 1). The injury report form included details on the body region injured, nature of the injury, the mechanism of injury, and the severity of injury. All injuries were recorded as separate injuries. If an injury was a recurrent injury, it was noted in the comments section of the reporting form. Records were kept for all training sessions and games for each team throughout the season. A separate form was used to record the weekly training and match activity schedules of each player. Data collection began in January 2004 (pre season) and continued throughout the season through to the end of September. Injury and activity forms were submitted monthly by each team's physiotherapist for the duration of their team's season.


Gaelic Football Injury Reporting Form
1. Injury Information
2. Body Region Injured
3. Supplementary Information
4. Nature of Injury
5. Mechanism / Cause of Injury
6. Additional Comments
7. Date of Full Return from Injury

For the purpose of this study a player was considered injured if he was unable to participate fully in training or games for a period of at least forty-eight hours after the injury was sustained[10]. The player was defined injured until the club medical staff cleared him for participation in full training or match play. The severity of injury was defined as minor (<1 week), moderate (1-3 weeks), and severe (>3 weeks)[6]. Physiotherapists and medical staff were briefed on the workings of the project and were given detailed instructions on how to complete the relevant forms. Full statistical analysis of the data was calculated using SPSS (Chicago, Illinois, USA). The resulting descriptive and comparative data are presented. Chi squared tests were used to investigate differences and statistical significance was accepted at $P<0.05$ level.

Results

A total of 16 teams agreed to participate in the study. All subjects (n=511) were male between 18 and 36 years of age and members of Senior Inter County (elite) Gaelic Football teams. Total exposure time for all Gaelic Football activity throughout the season from January to September was 39785.8 hours, 4310.4 hours in games and 35475.4 hours training. The mean (+ s.d.) hours of exposure per player was 67.4 (+33.1) in training and 16.8 (+7.7) in games. A total of 471 injuries were recorded. Significantly more injuries occurred in games (276) than in training (195) ($p<0.001$). This represents 0.38 (+0.27) injuries per player in training, 1.08 (+0.81) injuries per player in games, and 1.46 (0.54) injuries in total, per player per season. The overall incidence of injury was 11.8 (+4.36) per 1000 player hours. The incidence for games was 64 (+26.5) per 1000 player game hours, and 5.5 (+2.62) per 1000 player training hours (table 1).

Table 1 Injury Incidence

Injuries per Player per Season	Mean	SD
Total	1.46	0.54
Training	0.38	0.27
Games	1.08	0.81
Injuries per 1000 hours of Gaelic Football		
Total	11.8	4.36
Training	5.5	2.62
Games	64	26.5

The relative risk of injury in the sample is 10.94 times more likely in games than in training, despite the fact that over eight times the amount of time was spent training than in games. 66% of all players were injured at some stage during the season. Of the injuries sustained 59% occurred in games and 41% in training. For most teams, the percentage of match injuries was higher than the percentage of training injuries, however some teams [2,8,14,15,16] had a higher percentage of training injuries than match injuries (figure 2).

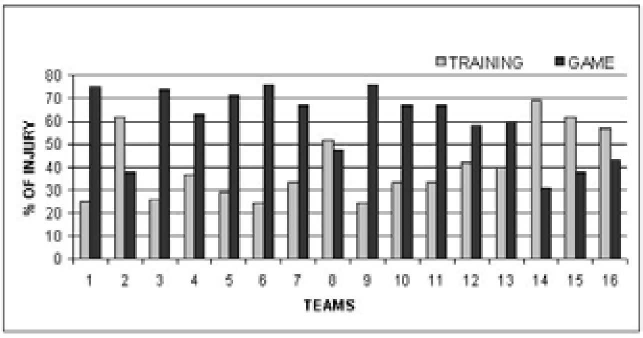


Figure 2. Total Injuries: Training and Games for all Teams

In a typical game of Gaelic Football there are six attackers, six defenders, a goalkeeper, and two midfielders on each team. After adjusting for goalkeepers and the lower numbers of midfield players compared to attackers and defenders there was a uniform pattern of injury. The results indicate that there is no evidence of a significant association (p=0.92) between injury and playing position when considering activity (i.e. training/game).

The time of injury is similar for training and games (figure 3). The percentage of injury increased steadily over time with a pronounced increase in the final quarter. 55% of all training injuries occurred in the final quarter of training. There was strong evidence of an association (p=0.003) between time of injury and activity (i.e. training/game). There were significantly more injuries in the fourth quarter in training compared to what would be expected if time of injury and activity were unrelated.

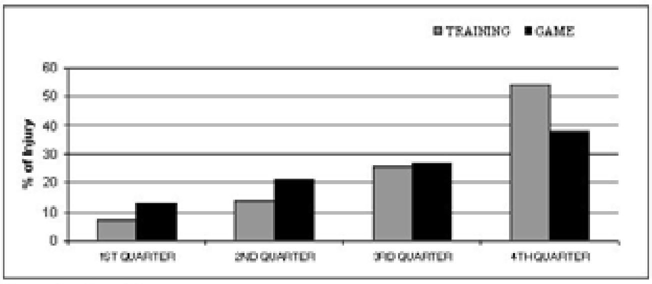


Figure 3 Time of Injury

There was strong evidence that the proportion of injuries at each body site was different (p<0.001). Injuries to the lower limb accounted for over 70% of all injuries recorded. Percentages for each site injury were: hamstrings (22%), knee (13%), ankle (11%), and groin (9%). Injuries to the upper and lower arm including the hand accounted for 5% of all injuries, the back (6%) and shoulder (7%) were the main sites of injury in the upper body. The injury pattern for body site in games and training is strikingly similar although more hamstring and groin injuries occurred in training than in games. The incidence of knee and ankle injury was higher in games (15% and 15% respectively) than in training (11% and 7% respectively). There was a significantly higher proportion (59%) of injuries in the dominant side (preferred kicking side) (P=0.001) compared to the non-dominant side.

The effect of injury on a player's participation was considered under three categories: (1) Players who completed training/games, (2) Players who stopped immediately, and (3) Players who stopped later. There was strong evidence that the proportion of injuries with respect to impact was different (p<0.001). The majority of injured players did not complete training or games. 44% of injuries resulted in cessation of activity immediately, 19% at a later stage during training or game, while 37% of players completed their game or training session.

The majority of total injuries (figure 4) were classified as sprains (stretch or tear of a ligament) (26%), strains (stretch or tear of a muscle or tendon) (42%), and bruises/contusions (damaged or broken blood vessels as a result of a blow to the skin) (17%). The incidence of sprain injuries was significantly higher in games than in training (P<0.001) with players approximately three times more likely to sustain a sprain injury in games as opposed to training. There was no significant difference (p=0.610) between the incidence of strain injuries in training and games. The incidence of bruising/contusion was higher (p=0.01) in games (22%) than in training (11%), similarly significantly more fractures (P<0.001) occurred in games (5%) than in training (2%). The majority of fractures were to the hand particularly the fingers and thumbs.

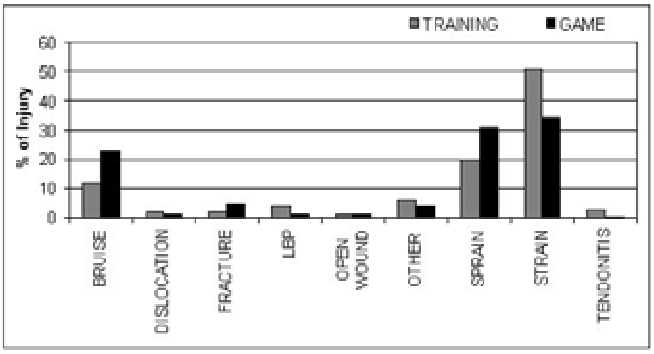


Figure 4. Nature of Injury

Despite the high intensity and physical contact nature of Gaelic Football, there was a significantly higher proportion of non-contact injuries (P<0.001). 60% of injuries resulted from non-contact and 40% from contact. The main non-contact injuries were muscular strain injuries particularly to the hamstrings (31%) and groin (14%), caused mainly by running, twisting, accelerating and decelerating. Contact injuries particularly the shoulder (15%), knee (15%), and ankle (9%) resulted predominantly from collisions with other players, tackled, or struck by another player (figure 5).

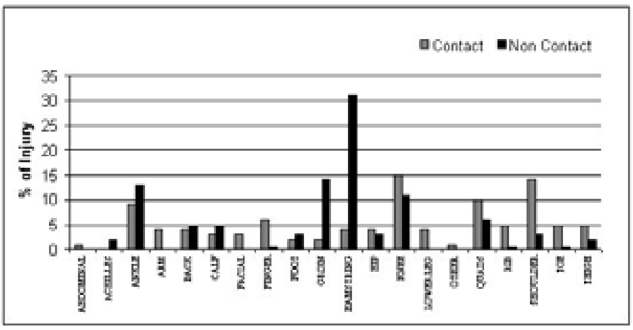


Figure 5 Cause of Injury

Injuries were classified into three categories according to the length of absence from training sessions and games: minor (<1 week), moderate (1-3 weeks), and severe (>3 weeks). 10% of all injuries were classified as minor, 56% were moderate, and 34% severe. Of the severe injuries, 12% resulted in the player being unable to participate fully for a period of over six weeks and 3% were serious enough for the player to miss playing for the rest of the season.

Discussion

This study investigated injury incidence in 511 elite Gaelic Football players in 16 different teams in Ireland. The teams that participated provide a reliable and representative sample of the elite Gaelic Football population as teams as from the top, middle and lower leagues were included.The results indicate that the pattern of injury is similar throughout the different teams and there is little variation between the teams with regard to timing, location, and types of injury.

The incidence rate of injuries per player per year (1.46) is lower in the present study than the figure of 1.78 reported by Cromwell et al[3], who retrospectively recorded injuries reported by 107 elite Gaelic Football players over a season. The incidence rate of injury per 1000 player hours for training (5.5) is similar to the 5.9 reported by Arnason et al[8] in a study involving 84 Soccer players, and (3.4) reported by Hawkins et al[10] in their audit of professional soccer players. A notable finding of this study is that the incidence rate of injury per 1000 player hours for games in Gaelic

Football (64) is much higher than the figures reported for Soccer (34.8 and 25.9)[8,10].

In common with other injury investigations, the incidence of injury in this study was much higher in games than training. Although more time was spent in training activities than playing games, one might expect a lower injury risk in training as a result of managerial supervision, a more controlled setting and a normally less hectic competitive environment compared with actual games. However it is therefore a disturbing finding that a number of teams participating in this study had a higher proportion of injuries in training than in games.

The temporal profile of injury is consistent across all teams especially while training. More injures occur in the final quarter of training (55%) and games (38%) than during any other period. Other codes similar to Gaelic Football have reported higher levels of injury in the second half than in the first half of competitive matches[8,10]. The high proportion of last quarter injuries may be due to fatigue and slower reaction time. Traditionally, final periods of training involve speed work in the form of repetitive sprint exercises. The timing of this type of activity may well contribute to the higher occurrence of injury in the latter stages of training. High intensity power activities carried out by fatigued players are likely to increases susceptibility to injury.

Recognising the high injury rates in the latter stages of games, the timing of substitutions may be important for injury prevention. Five substitutions are permitted during the course of the game. The prudent use of the substitutes before the last quarter of the game may help reduce injury rates. In some instances, tired players or players slightly injured eat an early stage in the game may continue to play on thereby increasing their risk of injury. Consideration should be given to the timely removal of tired or injured players who may wish to continue playing.

The majority of injuries were soft tissue injuries particularly in the lower limb. Hamstrings injuries were the most common, especially in training. However the underlying aetiology of hamstring injuries is unclear and many factors have been suggested including, poor flexibility, hamstring-quadriceps muscle imbalance, muscle weakness, improper technique, inadequate warm-up, poor neuromuscular control, and fatigue[13,14]. Recent studies have highlighted the benefits of incorporating additional eccentric training during pre-season as an aid to reducing the incidence of hamstring strain injuries[15,16]
The objective of the report form was to gather specific details of the cause of injury; consequently the category 'overuse injury' was deliberately omitted from the 'cause of injury' as it is a vague term and open to interpretation. Although Gaelic Football is a contact field game, injuries not involving player-to-player contact were more frequent than direct contact injuries. The main causes of non-contact injury included running, jumping, sprinting and twisting. It may be possible for trainers and coaches to monitor the extent of running exercises in training sessions and allow adequate time for recovery in order to reduce the incidence of non-contact injuries.

The majority of players in this study (65%) were unable to participate fully in Gaelic Football activity for between one and three weeks as a result of injury. This can have serious financial implications particularly for players who are self employed. Previously the only available injury data on Gaelic Football was obtainable from insurance and hospital records[17]. These types of records tend only to list the more serious injury while less serious ones are rarely recorded[18]. While these records reflect the popularity of the game, they reveal little however, about the general risks and cost of participation in Gaelic Football.

The need for more scientific research into the injuries associated with playing Gaelic Football and the importance of detailed injury reports as an aid to injury prevention has been well documented [2,18] . As stated by Walter et al[20]

> *Unless sports and athletic associations are prepared to imple ment epidemiological studies, the factors that could eliminate or reduce both the numbers and severity of injuries received by sports participants will remain undefined. A detailed pro spective study is the first step in approaching injury prevention*

VanMechelen's[12] model sequence for prevention of sports injuries has been successfully employed in Australian Rules Football. Injury surveillance data is published annually and there has been a significant reduction in the incidence of injury as a result of various national directives- such a requirement that all professional games be played on the same type of turf surface.

There is an urgent need for a similar system of epidemiological injury data collection in Gaelic Football and the establishment of a national injury database to help predict, reduce, and prevent injury at all grades of the game. The high incidence of injury in the final quarter of training activity merits further investigation and analysis. A detailed study of the underlying aetiology of hamstrings injuries is warranted.

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Acknowledgement
The Gaelic Athletic Association; Lucozade Sport; The Irish Society of Chartered Physiotherapists, the physiotherapists and medical staff, team liaison officers, and secretaries associated with the Senior Inter County Gaelic Football Teams that participated in this study.

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No incentive will be given to subjects. However it is hoped that sponsorship will be obtained to provide sportswear and medical equipment such as charts and joint models for participating physiotherapists.

12. Please give details of how consent is to be obtained. A copy of the proposed consent form, along with a separate information sheet, written in simple, non-technical language MUST ACCOMPANY THIS PROPOSAL FORM.

The project will be explained to all participating physiotherapists and medical staff and any queries will be answered. Each subject will receive an information sheet outlining the purpose of the study. They will be asked to read the form and their questions will be answered. They will be assured that there is no pressure from their teams to take part in the study.

13. Comment on any cultural, social or gender-based characteristics of the subject which have affected the design of the project or which may affect its conduct.

Only Senior Inter County male Gaelic Footballers have been selected for this study for reasons of homogeneity.

14. Please state who will have access to the data and what measures which will be adopted to maintain the confidentiality of the research subject and to comply with data protection requirements e.g. will the data be anonymised?

The information obtained will be anonymous. Summary data will be given to each participating team and the Gaelic Football administration body, the Gaelic Athletic Association.

15. Will the intended group of research subjects, to your knowledge, be involved in other research? If so, please justify.

No

16. Date on which the project will begin.
Project will start in February 2005.

17. Please state location(s) where the project will be carried out.
The study will be carried out in Ireland and locations will be selected from the following: Galway, Limerick, Kildare, Cork, Armagh, Kerry, Derry, Ireland. These locations have isokinetic dynamometers.

Isokinetic dynamometers will be calibrated before use.

A human calibration will take place using all of the dynamometers used in the study. Five subjects will be tested on all dynamometers and scores will be compared.

18. Please state briefly any precautions being taken to protect the health and safety of researchers and others associated with the project (as distinct from the research subjects) e.g. where blood samples are being taken

It is considered that there is minimal risk to the health and safety of the researchers.

Signed ______________________________ Date ______________

(Proposer of research)

Where the proposal is from a student, the Supervisor is asked to certify the accuracy of the above account.

Signed ______________________________ Date ______________

(Supervisor of student)

Send completed form to

Mr Stuart Morrison
FBLS Research Office
West Medical Building
University of Glasgow
Gilmorehill
Glasgow
G12 8QQ

UNIVERSITY OF GLASGOW

FACULTY OF BIOMEDICAL AND LIFE SCIENCES

ETHICS COMMITTEE FOR NON CLINICAL RESEARCH INVOLVING HUMAN SUBJECTS

APPLICATION FORM FOR ETHICAL APPROVAL

NOTES:
THIS APPLICATION FORM SHOULD BE TYPED NOT HAND WRITTEN.

ALL QUESTIONS MUST BE ANSWERED. "NOT APPLICABLE" IS A SATISFACTORY ANSWER WHERE APPROPRIATE.

Project No (to be assigned) _________________

Project Title An investigation of fluid and electrolyte balance in elite Gaelic Football players during training and games in different environmental conditions

Date of submission 21/01/05

Name of all person(s) submitting research proposal Dr. S. Grant; Dr A Henry, Dr J. Newell, Mr M. Newell

Position(s) held Senior Lecturer, IBLS, College Lecturer, Sports Medicine Physician, NUI Galway, Ireland, College Lecturer, Dept of Mathematics, NUI Galway, Ireland, PhD student

Division NABS

Address for correspondence relating to this submission Dr Stan Grant, West Medical Building

Name of Principal Researcher (if different from above e.g., Student's Supervisor)

____

Position held

____

1. Describe the purposes of the research proposed.

There is good scientific evidence that players who become dehydrated are more susceptible to the negative effects of fatigue including loss of performance and increased risk of injury (Armstrong et al 1985, Sawka 1992, Cheuvront et al 2003). Our recent study on Gaelic Football injuries has been presented at the Royal College of Surgeons in Ireland, Sports and Exercise Medicine Conference in September of last year. The results of the study reported that more injuries to Gaelic Footballers occurred in the final quarter of training and games than at any other time, suggesting a possible link between dehydration and injury.

In theory, fluid should not be ingested at rates in excess of sweating rate and thus body water and weight should not decrease during exercise (Coyle 2004). For a player participating in regular training and games, any fluid deficit that is incurred during one training session/game can potentially compromise the next training session or game if adequate fluid replacement does not occur (Maughan et al 1996). However no single hydration strategy suits all players in all environments. Variation in player characteristics, the intensity of the activity and changing environmental conditions can alter an individual's hydration requirement (Shirreffs et al 2004).

The aim of this study is to investigate the fluid and electrolyte balance of individual elite Gaelic Football players and to design and implement a personal hydration strategy for each player.

References:

Coyle EF. Fluid and fuel intake during exercise. J Sports Sci 2004; 22: 39-55

Armstrong LE, Costill DL, and Fink WJ. Influence of diuretic-induced dehydration on competitive running performance. Medicine and Science in Sports and Exercise 1985; 17: 456-461

Sawka MN. Physiological consequences of hypohydration: exercise performance and thermoregulation. Medicine and Science in Sports and Exercise 1992; 24: 657-670

Cheuvront SN, Carter R III, and Sawka MN. Fluid balance and endurance exercise performance. Current Sports Medicine Reports 2003; 2: 202-208

Maughan RJ, Leiper JB, and Shirreffs, SM. Restoration of fluid balance after exercise-induced dehydration: effects of food and fluid intake. European Journal of Applied Physiology1996; 73: 317-325

Shirreffs SM, Armstrong LE, and Cheuvront SN. Fluid and electrolyte needs for preparation and recovery from training and competition. J Sports Sci 2004; 22: 57-63

2. Please give a summary of the design and methodology of the project. Please also include in this section details of the proposed sample size, giving indications of the calculations used to determine the required sample size, including any assumptions you may have made. (If in doubt, please obtain statistical advice).

Senior Inter-County (elite) male Gaelic Footballers, from three different teams, will be asked to participate in this study. The three teams will be selected from different geographical locations in Ireland. Players (n=75) will be male aged between 18 and 35 years. All subjects will be in good health at the time of testing. Subjects who are deemed to have any adverse medical condition will not be recruited. All subjects will be given an information sheet and asked to sign a consent form. Physiotherapists and medical staff attached to each team will be briefed on the workings of the project

Testing will take place at training sessions and games at different times during the season in varying environmental conditions. It is proposed to test players at 3/4 times during the season.

Each player will be weighted prior to the commencement and at the end of the exercise activity, and administered individual drinks bottle, which will also be weighed before and after the exercise activity (Maughan et al 1996). Players will be asked to provide a pre-exercise activity urine sample in order to get an indication of the player's current hydration status. Gauze swabs applied at different sites will be used to measure the sodium loss in sweat. Prevailing environmental conditions will be recorded on the days of testing (Shirreffs et al 2004).

<u>References:</u>

Maughan RJ, Leiper JB, and Shirreffs, SM. Restoration of fluid balance after exercise-induced dehydration: effects of food and fluid intake. European Journal of Applied Physiology1996; 73: 317-325

Shirreffs SM, Armstrong LE, and Cheuvront SN. Fluid and electrolyte needs for preparation and recovery from training and competition. J Sports Sci 2004; 22: 57-63

3. Describe the research procedures as they affect the research subject and any other parties involved.

Subjects feeling unwell or felt to be even slightly at risk from undertaking the test will not be tested.

4. What in your opinion are the ethical considerations involved in this proposal? (You may wish for example to comment on issues to do with consent, confidentiality, risk to subjects, etc.)

It is considered that there is no significant risk to the subjects in this study. Confidentiality will be maintained throughout the study.

Subjects will be free to withdraw from testing should they feel uncomfortable with the testing procedure. No tests results will be used as a basis for subsequent team selection by the coach.

5. Outline the reasons which lead you to be satisfied that the possible benefits to be gained from the project justify any risks or discomforts involved.

A recent study by this group showed that injuries in Gaelic Football are most commonly occurring in the latter stages of training and games. However the relationship between possible dehydration, fatigue and injuries is unclear.

For a player participating in regular training and games, any fluid deficit that is incurred during one training session/game can potentially compromise the next training session or game if adequate fluid replacement does not occur. Ingesting mixes of carbohydrate, electrolytes, and water can have positive affects on athletic performance through improved performance, and/or reduced physiological stress on an athlete's cardiovascular, central nervous and muscular systems. However no single hydration strategy suits all players in all environments. Variation in player characteristics, the intensity of the activity and changing environmental conditions can alter an individual's hydration requirement.

The findings of the main study may help reduce the incidence of injury in Gaelic Football

6. Who are the investigators (including assistants) who will conduct the research and what are their qualifications and experience?

Dr. S. Grant, PhD, MSc, B Ed, DPE, Senior Lecturer, IBLS.
Dr A. Henry, Sports Medicine Physician, MB ChB, NUI, Galway, Ireland
Dr J. Newell, PhD, MSc, College Lecturer, Dept of Mathematics, NUI, Galway, Ireland
Mr. M. Newell, MSc, BA,HDE, PhD Student

The main experimenters have a wide range of experience in research projects

7. Are arrangements for the provision of clinical facilities to handle emergencies necessary? If so, briefly describe the arrangements made.

The risks associated with hydration testing are not considered to be great. Clinical emergencies are not anticipated. A first aid box will be available in case of minor accidents that may occur.

8. In cases where subjects will be identified from information held by another party (for example, a doctor or hospital), describe the arrangements you intend to make to gain access to this information including, where appropriate, which Multi Centre Research Ethics Committee or Local Research Ethics Committee will be applied to.

N/A

9. Specify whether subjects will include students or others in a dependent relationship.

There is no dependent relationship.

10. Specify whether the research will include children or people with mental illness, disability or handicap. If so, please explain the necessity of involving these individuals as research subjects.

N/A

11. Will payments or any other incentive, such as a gift or free services, be made to any research subject? If so, please specify and state the level of payment to be made and/or the source of the funds/gift/free service to be used. Please explain the justification for offering payment or other incentive.

No incentive will be given to subjects. However it is hoped that sportswear and medical equipment will be given to the physiotherapists in return for prompt collection and submission of data. It is hoped that sponsorship will be obtained to provide sportswear and medical equipment such as charts and joint models for participating physiotherapists.

12. Please give details of how consent is to be obtained. A copy of the proposed consent form, along with a separate information sheet, written in simple, non-technical language MUST ACCOMPANY THIS PROPOSAL FORM.

The project will be explained to all participating physiotherapists and medical staff and any queries will be answered. Each subject will receive an information sheet outlining the purpose of the study.

13. Comment on any cultural, social or gender-based characteristics of the subject which have affected the design of the project or which may affect its conduct.

Only Senior Inter County male Gaelic Footballers have been selected for this study for reasons of homogeneity.

14. Please state who will have access to the data and what measures which will be adopted to maintain the confidentiality of the research subject and to comply with data protection requirements e.g. will the data be anonymised?

The information obtained will be anonymous. Summary data will be given to each participating team and the Gaelic Football administration body, the Gaelic Athletic Association.

15. Will the intended group of research subjects, to your knowledge, be involved in other research? If so, please justify.

No

16. Date on which the project will begin.
Project will start in February 2005.

17. Please state location(s) where the project will be carried out.
Galway, Mayo, Roscommon, Leitrim, Clare, Down, Cavan, Monaghan, Fermanagh, Sligo, Donegal, Limerick, Dublin, Cork, Armagh, Kerry, Derry, Ireland.

18. Please state briefly any precautions being taken to protect the health and safety of researchers and others associated with the project (as distinct from the research subjects) e.g. where blood samples are being taken

It is considered that there is minimal risk to the health and safety of the researchers.

Signed ____ Date _______

(Proposer of research)

Where the proposal is from a student, the Supervisor is asked to certify the accuracy of the above account.

Signed ____ Date ________

(Supervisor of student)

Send completed form to

Mr Stuart Morrison
FBLS Research Office
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G12 8QQ

A10 Kin-Com Calibration.

The Kin-Com is a computer controlled electromechanical dynamometer. The device provides resistance during isokinetic (constant velocity) movement and during isometric muscle contractions. In the isokinetic mode the software allows the investigator to control the velocity at which the lever arm will move. Calibration of the system is necessary to ensure the validity of the test.

The Kin com was calibrated prior to the start of the testing session according the manufactures guidelines using with known weights. The software was provided by the manufacturer. Initial load cell calibration was performed by hanging certified weights (4 x 10 pound) from the Kin-Com lever arm and verifying the accuracy of the recorded torque value using the system software.

The following steps were taken in accordance with recommended guidelines (NHANES Muscle Strength Procedures Manual 2001).

- Set the dynamometer tilt (A) to 0
- Remove the shin pad from the load cell and then attach the load cell to the lever arm
- Move the load cell down so the bottom of the load cell is flush with the end of the lever arm
- Move the load cell to a vertical position. Check the position with the level
- Select 3 for Load Cell at the next Service program menu
- The Load Cell calibration screen will appear. A green box in the center of the screen will display the force.
- The force should read zero
- If the force reading is not zero, adjust Pot 8 on the back of the computer until the force reads zero. Turn the screw clockwise to decrease the force, anticlockwise to increase the force.
- Bring the lever arm to a horizontal position. Use the level to make sure it is horizontal
- Brace the lever arm with the wooden support bar
- Put the calibration weight holder in the attachment hole at the end of the lever arm
- Place the weights on the bar
- Use all four 10 pound weights for the Load Cell calibration
- Remove the weights, the bar, and the wooden brace
- Attach the shin pad to the lever arm
- Move the dynamometer to the initial settings for right side testing
- Press Esc three times to return to the Kin Com Main Menu

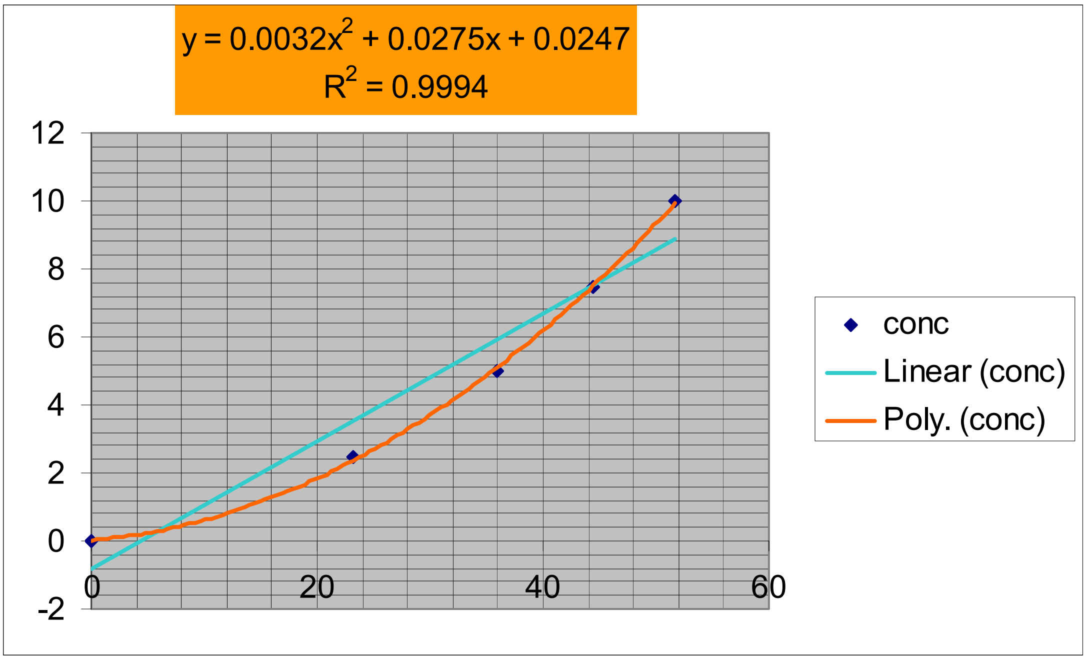
Elite Team Fluid Data

Elite Fluid and Electrolyte Study: Individual Hydration Patterns													
A	B	C	D	E	F	G	H	I	J	K	L	M	N
Player No	Urine Reading	Pre Training Hydration Stat	Pre Weight	Post Weight	Change in weight	% Dehydration	Post Training Hydration Status	Drink Volume	Total Sweat loss	Training Time	Sweat Rate Per hour ml/h	Drink Volum Consumed Per hour	Deficit drink vol ml/hour
1													
2													
3	1.014	minimal dehydr	78	77.5	-0.5	0.64%	well hydrated	1625	2125	80	1593	1218	-375
4	1.007	well hydrated	86.5	84.5	-2	2.30%	minimal dehydrati	1000	3000	80	2250	750	-1500
5	1.007	well hydrated	85	83	-2	2.35	minimal dehydrati	575	2575	80	1931	431	-1500
6	1.003	well hydrated	87	87.5	0.5	0.57	well hydrated	2000	1500	80	1125	1500	375
7													
8	1.006	well hydrated	87	87	0	0	well hydrated	850	850	80	637	637	0
9	1.003	well hydrated	83	82	-1	1.2	minimal dehydrati	1000	2000	80	1500	750	-750
10	1.008	well hydrated	73.5	73	-0.5	0.68	well hydrated	665	1165	80	873	498	-375
11													
12													
13													
14	1.006	well hydrated	78	77	-1	1.28	minimal dehydrati	1090	2090	80	1566	817	-743
15													
16	1.002	well hydrated	81	81	0	0	well hydrated	1275	1275	80	956	956	0
17	1.007	well hydrated	82	81	-1	1.21	minimal dehydrati	625	1625	80	1218	468	-750
18	1.002	well hydrated	86	85.5	-0.5	0.58	well hydrated	1025	1525	80	1143	768	-375
19	1.02	significant dehy	71	70	-1	1.42	minimal dehydrati	300	1300	80	975	225	-750
20													
21	1.005	well hydrated	79	78	-1	1.26	minimal dehydrati	775	1775	80	1331	581	-750
22	1.016	minimal dehydr	80	80	0			1775	1775	80	1331	1330	0
23	1.009	well hydrated	85	84.5	-0.5	0.59	well hydrated	575	1075	80	806	431	-369
24													
25	1.008	well hydrated	76	75	-1	1.31	minimal dehydrati	925	1925	80	1440	693	-747
26	1.01	minimal dehydr	87	85	-2	2.29	minimal dehydrati	1150	3150	80	2362	862	-1490
27	1.027	significant dehy	85	84	-1	1.17	minimal dehydrati	750	1750	80	1310	562	-748
28	1.005	well hydrated	81	80	-1	1.23	minimal dehydrati	1800	2800	80	2100	1350	-750
29													
30	1.009	well hydrated	76.5	75.5	-1	1.31	minimal dehydrati	900	1900	80	1425	675	-745

Club Team Data

Club Fluid and Electrolyte Study: Individual Hydration Patterns													
A	B	C	D	E	F		H	I	J	K	L	M	N
Player No	Urine Reading	Pre Trainin Hydration S	Pre Weight	Post Weight	Change in weight	% Dehydratio	Post Traini Hydration S	Drink Volume	Total Sweat loss	Training Time	Sweat Rate Per hour ml/h	Drink Volur Consumed Per hour	Deficit drink vol ml/hour
1	1.01	Minimal	101	99.9	-1.1	-1.09	Minimal	450	1550	80	1163	338	825
3	1.01	Minimal	84	83.8	-0.2	-0.24	Well Hydr	950	1150	80	863	713	150
4	1.015	Minimal	80.5	80	-0.5	-0.62	Well Hydr	625	1125	80	844	469	375
5	1.01	Minimal	69	68.4	-0.6	-0.87	Well Hydr	975	1575	80	1181	731	450
6	1.01	Minimal	65.8	65.6	-0.2	-0.30	Well Hydr	500	700	80	525	375	150
7	1.005	Well Hydr	68	68.1	0.1	0.15	Well Hydr	825	725	80	544	619	-75
8	1.01	Minimal	79.4	78.4	-1	-1.26	Minimal	975	1975	80	1481	731	750
9	1.005	Well Hydr	83	82.3	-0.7	-0.84	Well Hydr	875	1575	80	1181	656	525
10	1.02	significant	77	77.1	0.1	0.13	Well Hydr	725	625	80	469	544	-75
11	1.015	Minimal	89.7	89.5	-0.2	-0.22	Well Hydr	950	1150	80	863	713	150
12	1.01	Minimal	67.6	67.5	-0.1	-0.15	Well Hydr	800	900	80	675	600	75
13	1.01	Minimal	81.7	81.1	-0.6	-0.73	Well Hydr	1060	1660	80	1245	795	450
14	1.01	Minimal	80.7	80	-0.7	-0.87	Well Hydr	775	1475	80	1106	581	525
15	1.01	Minimal	78.9	78.8	-0.1	-0.13	Well Hydr	815	915	80	686	611	75
16	1.005	Well Hydr	67.5	66.5	-1	-1.48	Minimal	500	1500	80	1125	375	750
17	1.005	Well Hydr	85	84.5	-0.5	-0.59	Well Hydr	650	1150	80	863	488	375
18	1.01	Minimal	78.1	77.9	-0.2	-0.26	Well Hydr	625	825	80	619	469	150
20	1.005	Well Hydr	80.6	79.9	-0.7	-0.87	Well Hydr	575	1275	80	956	431	525
21	1.01	Minimal	69.5	69	-0.5	-0.72	Well Hydr	500	1000	80	750	375	375
32	1.015	Minimal	76.4	74.2	-2.2	-2.88	Minimal	275	2475	80	1856	206	1650
35	1.01	Minimal	85.9	85.9	0	0.00	Well Hydr	975	975	80	731	731	0
36	1.005	Well Hydr	84	83.2	-0.8	-0.95	Well Hydr	800	1600	80	1200	600	600
37	1.015	Minimal	74.3	73.4	-0.9	-1.21	Minimal	450	1350	80	1013	338	675
39	1.015	Minimal	75.7	75.4	-0.3	-0.40	Well Hydr	975	1275	80	956	731	225
40	1.02	significant	99	98.4	-0.6	-0.61	Well Hydr	1050	1650	80	1238	788	450

Sweat Sodium Calculation



Formula for flame Photometry readings:

Y= 0.0032x2 +0.0275x+0.0247

Density of sweat = 1

Dilution factor calculation (vol of sweat+dilution/vol of sweat)

NA Reading: conc x dilution factor

			from graph	measured	addition of 50ml	Na conc *
Elite	Machine R	y =0.0032x2 + 0.0275x ·	NA+ Conc	Sweat weig	dilution calculation	NA+
	15		1.1572	1.23	41.65	48
	9		0.5314	0.86	59.14	31
	13		0.923	1.39	36.97	34
	11		0.7144	1.98	26.25	19
ARM	3		0.136	0.87	58.47	8
	8		0.4495	0.47	107.38	48
	7		0.374	0.7	72.43	27
	14		1.0369	1.38	37.23	39
	11		0.7144	1.46	35.25	25
	9		0.5314	0.71	71.42	38
	17		1.417	1.53	33.68	48
	5		0.2422	0.65	77.92	19
	13		0.923	1.33	38.59	36
	14		1.0369	1.45	35.48	37
	9		0.5314	0.82	61.98	33
	16		1.2839	2.72	19.38	25
	8		0.4495	1.67	30.94	14
BACK	4		0.1859	0.75	67.67	13
	18		1.5565	1.01	50.50	79
	14		1.0369	0.96	53.08	55
	12		0.8155	1.41	36.46	30
	9		0.5314	0.38	132.58	70
	11		0.7144	1.38	37.23	27
	11		0.7144	1.82	28.47	20
	4		0.1859	0.43	117.28	22
	15		1.1572	0.73	69.49	80
	10		0.6197	1.39	36.97	23
	17		1.417	1.71	30.24	43
	12		0.8155	0.96	53.08	43
	11		0.7144	1.09	46.87	33
	7		0.374	1.19	43.02	16
	12		0.8155	2.42	21.66	18
	15		1.1572	1.05	48.62	56
CHEST	10		0.6197	0.64	79.12	49
	13		0.923	1.67	30.94	29
	13		0.923	1.13	45.25	42
	7		0.374	1.17	43.74	16
	11		0.7144	1.27	40.37	29
	8		0.4495	0.34	148.06	67
	8		0.4495	1.03	49.54	22
	9		0.5314	0.83	61.24	33
	9		0.5314	0.92	55.35	29
	7		0.374	0.41	122.95	46
	6		0.3049	0.4	126.00	38
	9		0.5314	2.2	23.73	13
	11		0.7144	0.7	72.43	52
THIGH	8		0.4495	0.32	157.25	71
	7		0.374	0.51	99.04	37
	9		0.5314	0.68	74.53	40
	5		0.2422	0.37	136.14	33
	6		0.3049	0.37	136.14	42
	10		0.6197	0.82	61.98	38
	7		0.374	0.79	64.29	24
	13		0.92	0.99	51.51	48
	9		0.53	0.78	65.10	35
	14		1.04	0.7	72.43	75
	5		0.24	0.35	143.86	35
	15		1.16	0.68	74.53	86
Club	16		1.28	0.68	74.53	96
	23		2.35	1.26	40.68	96
	8		0.45	0.45	112.11	50
	16		1.28	0.86	59.14	76
ARM	14		1.04	0.96	53.08	55
	15		1.16	0.62	81.65	94
	10		0.62	0.61	82.97	51
	8		0.45	0.35	143.86	65
	9		0.53	0.39	129.21	69
	9		0.53	0.35	143.86	76
	14		1.04	0.84	60.52	63
	18		1.56	0.84	60.52	94
	9		0.53	0.98	52.02	28
	8		0.45	0.77	65.94	30
	11		0.71	0.79	64.29	46
	5		0.24	0.36	139.89	34
	13		0.92	0.72	70.44	65
	17		1.42	1.11	46.05	65
	15		1.16	1.08	47.30	55
	10		0.62	0.41	122.95	76
Back	12		0.82	0.56	90.29	74
	18		1.56	1.13	45.25	70
	12		0.82	0.98	52.02	42
	13		0.92	1.4	36.71	34
	16		1.28	0.94	54.19	70
	6		0.30	0.3	167.67	51
	9		0.53	1.1	46.45	25
	22		2.18	1.13	45.25	99
	20		1.85	0.97	52.55	97
	7		0.37	0.84	60.52	23
	14		1.04	1.05	48.62	50
	22		2.18	1.23	41.65	91
	15		1.16	1.16	44.10	51
	10		0.62	0.9	56.56	35
	10		0.62	0.63	80.37	50
	5		0.24	0.23	218.39	53
	20		1.85	1.04	49.08	91
	24		2.53	1.95	26.64	67
	17		1.42	0.97	52.55	74
CHEST	13		0.92	0.66	76.76	71
	21		2.01	1.62	31.86	64
	19		1.70	1.12	45.64	78
	16		1.28	1.67	30.94	40
	12		0.82	0.79	64.29	52
	11		0.71	0.85	59.82	43
	10		0.62	0.54	93.59	58
	7		0.37	0.53	95.34	36
	12		0.82	0.49	103.04	84
	17		1.42	1.06	48.17	68
	16		1.28	0.78	65.10	84
	5		0.24	0.45	112.11	27
THIGH	7		0.37	0.39	129.21	48
	4		0.19	0.2	251.00	47
	9		0.53	0.42	120.05	64
	10		0.62	0.58	87.21	54
	10		0.62	0.56	90.29	56
	4		0.19	0.22	228.27	42
	12		0.82	0.49	103.04	84
	12		0.82	0.71	71.42	58
	9		0.53	0.51	99.04	53
	6		0.30	0.34	148.06	45
	6		0.30	0.39	129.21	39
	6		0.30	0.32	157.25	48
	15		1.16	0.7	72.43	84
	10		0.62	0.35	143.86	89
	2		0.09	0.11	455.55	42
	5		0.24	0.15	334.33	81
	7		0.37	0.24	209.33	78
	9		0.53	0.46	109.70	58
	5		0.24	0.17	295.12	71

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Fluid and Electrolyte Balance in Elite Gaelic Football Players

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Abstract
The aim of this study was to investigate fluid and electrolyte balance in elite Gaelic Football players (n=20) during a typical training session in a warm environment (16 to 18°C, 82-88% humidity). Pre-training urine samples were used to determine hydration status. Sweat sodium concentration was collected from four body site locations using absorbent patches. The mean sweat rate per hour was 1.39 $l \cdot h^{-1}$ and mean body mass loss was 1.1%. Mean sweat sodium concentrations were 35 $mmol \cdot l^{-1}$ (range 19-52 $mmol \cdot l^{-1}$). On average, players did not drink enough fluid to match their sweat rates ($p<0.001$) and this fluid deficit was not related to pre-training hydration status ($p= 0.67$). A single hydration strategy based on published guidelines may not be suitable for an entire team due to variations in individual sweat rates. Maximising player performance could be better achieved by accurate quantification of individual fluid and electrolyte losses.

Introduction

Sweating has an important role in body thermoregulation during exercise and is influenced by the duration and intensity of exercise, fitness levels, environmental conditions, acclimatisation, body mass, and choice of clothing.[1] However, extensive body water and electrolyte losses from prolific and repeated sweating reduce the capacity of the temperature regulatory and circulatory systems, depleting cells of fluids and electrolytes and can result in

Table 1 Sweat Sodium Concentrations and Anatomical Reference Points

Location	Mean	s	Range	Anatomical Reference
Back	32	16	11-68	2cm directly below and in line with the inferior angle of the scapula
Chest	34	14	15-61	7cm directly below the nipple in the right hypochondriac region along a line running laterally from the distal aspect of the xiphoid process
Upper Arm	29	11	7-48	On the anterior surface of the upper arm midway between the lateral aspect of the coracoid process of the scapula and the olecranon process of the ulna
Thigh	38	17	13-71	25cm from the proximal aspect of the patella on the anterior midline of the thigh
Four Site Average	35	11	19-52	
Total Na+ loss (mmol)	65	33	35-96	

a threat to health and performance.[2] It is generally accepted that the human body can tolerate dehydration levels of between 1 and 2% body mass particularly in endurance activities in ambient temperatures of 20-21°C lasting less than 60 minutes. However, dehydration of 2% body mass in events lasting longer than 60 minutes in warmer temperatures 31-32°C may increase the risk of fatigue including loss of performance, increased risk of injury, and other neuromotor problems.[3,4,5]

A recent study of American football players found that players who suffer muscle cramps in training and competition had greater sweat losses and a higher sweat sodium content than players matched for fitness who did not suffer from muscle cramps.[6] Although difficult to link exercise-induced muscle cramps with electrolyte disturbances directly, a recent study on Gaelic Football injuries reported that more injuries occurred in the final quarter of training and games than at any other time, and may suggest a possible link between dehydration and injury.[7] The aim of this study was to investigate fluid and electrolyte losses in a group of elite Gaelic Football players training in a warm environment. Assessment of fluid and electrolyte losses during training would provide coaches and players with information on the possible hydration needs during and after training.

Methods

Gaelic Football players (n=20) were recruited from a Senior Inter-County (elite) team. The elite team was representative of the population of players competing at the highest level of Gaelic Football, whose training intensity and match schedule were typical of elite teams competing at this level.[7] All players were male aged between 18 and 36 years. Subjects, who were deemed to have any adverse medical condition, were not recruited. Ethics approval for the study was obtained from the ethics committees of Glasgow University and the National University of Ireland Galway. Data on environmental conditions were acquired from the local meteorological office.

Players were monitored during a typical training session on a warm and humid evening in June, the air temperature ranged from 16 to 18°C, and humidity ranged from 82 to 88%. This was the third training session of that particular week and players had a day's rest before the session. Training consisted of a dynamic warm-up (including repetitive sprints and stretching) followed by a variety of intensive game drills (defending and tackling), a series of small-sided conditioned games, culminating in a final cool down. The training session was deemed by the coach to be of typical duration and intensity for the players. The total duration of the training session was 80 minutes and all players followed the same programme.

Before the training session

Each player was assigned a study code and given three personalised water bottles. Each bottle contained 1litre of tap water and were placed in crates on the ground beside the training area. Players were then instructed to provide urine samples (to ascertain pre-training hydration status) and these were assessed for urine specific gravity using a handheld clinical refractrometer (Spartan, Tokyo, Japan). Players were then weighed to nearest 0.1 kg (in dry pants) using calibrated weighing scales (Seca 770, Hamburg, Germany); the mass of the individual drinks bottles were also recorded using scales (Soenhle Magnum 802U Digital Food Scale, Switzerland). Absorbent sweat patches (3M Tegaderm +Pad, 3m Healthcare, MN, USA) were used to measure the electrolyte loss in sweat. Patches were applied at four different anatomical sites (Table 1) on the right hand side of the body. Each anatomical site was cleaned with deionized water and dried with a clean electrolyte-free gauze swab prior to the attachment of absorbent patches.[8]

During the training session

Players were instructed to only drink from their own bottle and not to spit out any water. Any urine voided during the training session was collected and the volume recorded. Sweat patches were removed after twenty minutes (to prevent saturation) and placed in individual sealed sterile universal containers (Sarstedt, Wexford, Ireland).

After the training session

At the end of the exercise session, the drinks bottles were collected. Players were towel dried and their post exercise body mass recorded along with the mass of their individual water bottles. The amount of fluid consumed during training was calculated by subtracting the mass of the drinks bottle at the end of training from the mass of the bottle at the start of training. Total sweat loss was calculated using the formula: Total Sweat Loss = (pre exercise body mass – post exercise body mass + fluid intake – urine volume). Similarly the total amount of fluid consumed during training was used to calculate drink volume consumed per hour. The urine specific gravity readings and percentage change in body mass were compared against published indexes of hydration status (Table 2) from the American College of Sports Medicine's Position on Exercise and Fluid Replacement.[4]

Table 2 Indexes of Hydration Status (Casa et al., 2000)[4]

Condition	% Body Mass Change	Urine Specific Gravity
Well hydrated	+1 to -1	<1.010
Minimal dehydration	-1 to -3	<1.010 – 1.020
Significant dehydration	-3 to -5	1.021 – 1.030
Serious dehydration	>5	>1.030

Prior to analysis, the volume of sweat collected in each patch was determined gravimetrically (Precisa, Zurick, Switzerland) by

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subtracting the mass of a new unused patch and universal from the weight of the universal containing the absorbent patch and sweat. Individual samples were diluted with deionized water and thoroughly mixed using a vortex.[9] The sodium concentration was analysed using a flame spectrometer (Corning 410c, Corning Ltd., Essex, UK).

Statistical Analysis
A Chi-square test was used to compare the proportion of pre-training hydrated and dehydrated players (based on urine specific gravity readings). An Analysis of Covariance model was fitted to the data to compare mean fluid loss across the team while adjusting for initial pre-training hydration status. The adequacy of the model was checked using suitable residual plots while the assumed additive effect of the covariate was tested by including an interaction term to allow for separate slopes. A Bonferroni adjusted one sample-t-test was used to compare the mean fluid balance for the team against a hypothesised value of zero where each test was performed at the 0.05/2 significance level. The adjustment was made in order to maintain a global Type 1 error rate of 0.05 across the two comparisons. The likely mean fluid balance for the population of interest was estimated using (Bonferroni adjusted) 97.5% Confidence Intervals for a mean.

Results
The majority of elite players (n=15) were well hydrated (usg<1.010) prior to exercise activity (Table 3), however three players displayed signs of minimal dehydration (usg 1.010 – 1.020) and two players showed significant levels of dehydration (usg 1.021-1.030).[4] Mean body mass loss over the duration of the training session was 0.8kg with values ranging from 0.5 to 2kg. Using percentage body mass loss as a measure of post training dehydration, the values recorded ranged from +0.5% to -2.4% (mean 1.1%). The majority (n=12) of elite players were classified as being minimally dehydrated post training (-1 to -3% body mass change). Total sweat losses ranged from 0.85 l to 3.15 l (mean 1.86 l), while the amount of fluid consumed by players (rounded to the nearest 5ml) during training, ranged from 300ml to 2000ml with a mean of 1034ml. Comparing the sweat rate per hour to the amount of fluid consumed per hour, there is a mean fluid balance of -0.62 $l \cdot h^{-1}$ with values ranging from $+0.37$ to -1.5 $l \cdot h^{-1}$. Only 56% of sweat volume was replaced during training with values ranging from 23% to 133%.

Table 3 Sweat Loss and Fluid Intake Summary Data

Players (n=20)	Mean	s	Range
Urine Specific Gravity	1.009	0.006	1.002-1.027
Pre-Training Body Mass (kg)	81.4	4.8	71-87
Post-training Body Mass (kg)	80.6	4.8	70-87.5
% change in Body Mass	-1.1	0.7	0.5-2.4
Fluid consumed (ml)	1034	457	300-2000
Total Sweat Loss (l)	1.86	0.63	0.85-3.15
Sweat Rate per hour ($l.h^{-1}$)	1.39	0.48	0.64-2.36
Fluid consumed per hour ($ml.h^{-1}$)	775	343	225-1500
Fluid Balance (ml)	619	504	375-1500
% Change in Body Mass if no Fluid consumed	2.2	0.9	0.6-3.5

There was significant evidence ($p<0.01$) of fluid deficit across the team (Fig. 1). Based on the ANCOVA model, there was no evidence to indicate that fluid deficit was simply related to pre-training hydration status (p= 0.67).

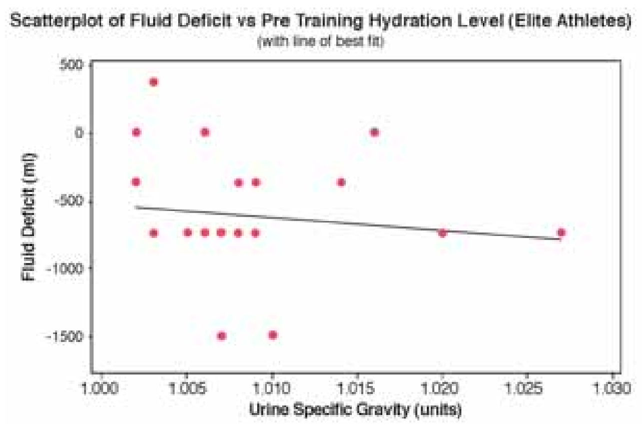

Figure 1 Relationship Between Pre-Training Hydration Level (measured by urine specific gravity) and Post-Training Hydration Balance.

Fluid deficit was significant across the team ($p<0.01$), even for players classified as being well hydrated at the start of training.

Virtually all points lie below the line of equality and there is strong evidence, that the mean fluid deficit is not zero ($p<0.001$). An estimate of the likely mean fluid deficit for the Elite 'population' is between 319ml and 881ml.

With the exception of 5 players, all points lie below the line of equality indicating an imbalance between the volume of fluid consumed during exercise and the corresponding volume lost through sweat.

The mean sweat sodium concentration (based on a four site average) was 35 $mmol \cdot l^{-1}$ (range 19 to 52 $mmol \cdot l^{-1}$). This equates to a total sodium loss (calculated by multiplying mean sweat sodium concentration with mean sweat loss) of 65 mmol (range 35 to 96 mmol) (Table 1). There is a suggestion of player-to-player variability with regard to sweat sodium concentration from each of the different collection sites, but no evidence of within player variability (p=0.811). The relationship between pre-training body mass and sweat sodium concentration was not significant for all players (p=0.984).

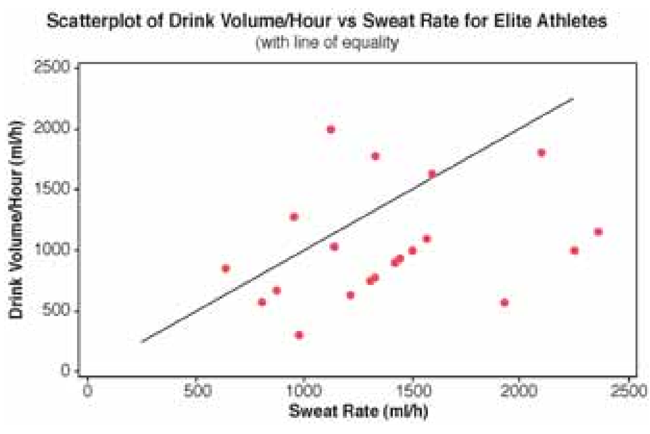

Figure 2 Sweat rate and fluid consumption per hour.

Discussion

The mean sweat rate per hour of 1.39 $l.h^{-1}$ for elite Gaelic Football players is similar to results published for elite players from other codes similar to Gaelic Football. Mean sweat rates for Australian Rules Footballers of 1.4 l h^{-1} and 1.8 l h^{-1} have been reported, when they trained in a temperate (12-15°C) and warm (27°C) environments. Published sweat rates for professional soccer players during training range from 1.13 l h^{-1} in a cool environment (5°C), 1.2 l h^{-1} in warm conditions (25°C), to 1.46 l h^{-1} in hot conditions (32°C).[8,9,10]

The mean volume of fluid intake by elite players (1034ml) is similar to the value published (972ml) for professional soccer players[9] training in temperatures of 32±3°C. With the exception of four players, who did not have fluid deficit, the majority of players had a fluid deficit ranging from 375 to 1500ml. On average, players replaced 56% of sweat loss. These values are in accordance with previous research, which showed that even with unlimited access to plain water, athletes typically only replace around 50% of the water required.[11]

It is suggested that if an athlete begins exercise in a reasonably euhydrated state (usg <1.010) and continues to exercise at moderate levels of intensity for less than an hour in cool (5 to 10°C) or temperate conditions (21-22°C), there is no clear physiological need to consume additional fluid so long as body mass dehydration is within the 2%.[3] The majority of players in this study were suitably hydrated prior to the commencement of training (mean usg 1.009), and although the mean % body mass loss (1.12%) is within the recommended levels of tolerable dehydration (<2%) there is however, wide variety across the team. Three players had measured levels of hypohydration of (2.3%, 2.3%, and 2.4% decrease in body mass). Conversely, assuming that drinking does not influence sweating response, if no fluid had been consumed the mean % body mass loss of players would have been 2.3% although some players would have had % body mass losses in the region of 3.5%, highlighting that the fluid intake strategies in general, were successful in reducing the potential adverse effect of sweat loss.

The mean sweat sodium concentration (35 $mmol{\cdot}l^{-1}$) for players in this study, is in accordance with published values[2,3] for sweat sodium concentration (average 35 $mmol{\cdot}l^{-1}$, range 10-70 $mmol{\cdot}l^{-1}$). The results correspond to published data for professional soccer players10 (30.2 ±18.8 $mmol{\cdot}l^{-1}$) training in slightly warmer (32°C) conditions.

The highest mean concentration for sweat sodium concentration was found in the thigh (38 $mmol{\cdot}l^{-1}$). This contradicts the published literature as other studies have reported highest values in the chest and back.[8,9] However, it was observed in the study that four players wore insulative shorts under their regular shorts and may suggest a possible link between the insulative shorts and a (hypothesised) corresponding localised increase in thigh temperature and subsequent increase in sweat rate. If these players are not included in the pooled data, the highest sodium concentrations are found in the chest and back in accordance with other published studies documenting sweat and electrolyte losses.

The mean volume of total sodium loss was 65 mmol (range from 35 to 96 mmol). It is suggested that players with high sweat sodium loss, may benefit from consuming drinks with a higher sodium concentration (40-80 $mmol{\cdot}l^{-1}$) post-exercise, especially during intensive periods of training and games with little recovery time between exercise bouts as typically occurs during the summer months of the Gaelic Football season. It is inappropriate to advocate that all players would improve their performance by increasing their fluid intake. However, sweat losses for some players, even in relatively cool environments may be considerable and large enough to result in dehydration levels greater than 2% body mass. A single hydration strategy based on published guidelines is unlikely to be suitable for an entire team, due to variations in individual sweat rates. Knowledge of individual hydration requirements and specific advice on post-exercise electrolyte restoration should be considered as a possible contributory factor for performance enhancement during training and games.[4,8,9] It is suggested that Gaelic Football teams should conduct routine urine tests to determine pre and post, training, and match hydration status, and sweat electrolyte assessments to determine sweat sodium concentration.

Acknowledgement

The author wishes to acknowledge the support of the Gaelic Football teams that participated in this study, Prof Ron Maughan, and Dr Susan Shirreffs, (Loughborough Univ) Lucozade Sport and 3M Ireland for their assistance with this study.

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Incidence of Injury in Elite Gaelic Footballers

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Abstract
The purpose of this study was to undertake a comprehensive prospective epidemiological study of injuries sustained by elite Gaelic Football players over one season.The pattern of injury is strikingly similar across all teams with 47% of all injuries occurring in the final quarter of games and training. Injuries to the lower limb, particularly the hamstrings muscles accounted for the majority of injuries. 65% of players were unable to participate fully in Gaelic Football activity for between one and three weeks as a result of injury. The high incidence of injury especially hamstrings injuries in the latter stages of training and games warrants further investigation.

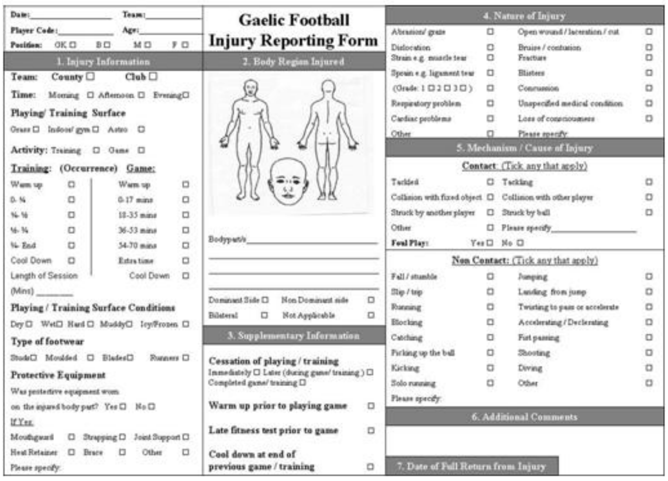
Introduction

Gaelic Football is Ireland's most popular field game. It is a competitive high intensity contact field game played over two thirty-five minute halves, characterised by intermittent short and fast movements such as sprinting and turning, jumping, catching, and kicking[1]. Despite the game's popularity and high participation rates, to date, there have been few detailed prospective studies on injury[2]. Compared with other team games the investigations into injuries in Gaelic Football have been limited to short duration studies carried out on a small number of teams and players[3,4]. Injury rates in other field games including Australian Rules Football, Rugby Union, Soccer, and Rugby League, are well documented in the scientific literature [5,6,7,8,9,10,11]. The lack of injury data in Gaelic Football is an obvious omission that needs to be addressed.

Detailed injury reporting is the first step as an aid to injury prevention[12]. Determination of the incidence of injury as well as the type, location, nature, mechanism, and severity of injuries will provide meaningful information for administrators, coaches, medical staff and players. Identification of the most prevalent injuries and possible causes of injury will assist in the development of procedures to reduce injury in Gaelic Football. The aim of this study was to complete a detailed prospective epidemiological study of injuries in Gaelic Football over an entire season.

Methods

Ethics approval for the study was obtained from the ethics committees of Glasgow University and the National University of Ireland Galway. The team physiotherapist recorded all injuries using a specially designed injury report form (figure 1). The injury report form included details on the body region injured, nature of the injury, the mechanism of injury, and the severity of injury. All injuries were recorded as separate injuries. If an injury was a recurrent injury, it was noted in the comments section of the reporting form. Records were kept for all training sessions and games for each team throughout the season. A separate form was used to record the weekly training and match activity schedules of each player. Data collection began in January 2004 (pre season) and continued throughout the season through to the end of September. Injury and activity forms were submitted monthly by each team's physiotherapist for the duration of their team's season.


Date: Team:
Player Code: Age:
Position: GK ☐ B ☐ M ☐ F ☐

Gaelic Football Injury Reporting Form

1. Injury Information
Team: County ☐ Club ☐
Time: Morning ☐ Afternoon ☐ Evening ☐
Playing/ Training Surface
Grass ☐ Indoor/ gym ☐ Astro ☐
Activity: Training ☐ Game ☐
Training: (Occurrence) Game:
Warm up ☐ | Warm up ☐
0- ¼ ☐ | 0-17 mins ☐
¼- ½ ☐ | 18-35 mins ☐
½- ¾ ☐ | 36-53 mins ☐
¾- End ☐ | 54-70 mins ☐
Cool Down ☐ | Extra time ☐
Length of Session (Mins) | Cool Down ☐
Playing / Training Surface Conditions
Dry ☐ Wet ☐ Hard ☐ Muddy ☐ Icy/Frozen ☐
Type of footwear
Studs ☐ Moulded ☐ Blades ☐ Runners ☐
Protective Equipment
Was protective equipment worn on the injured body part? Yes ☐ No ☐
If Yes
Mouthguard ☐ Strapping ☐ Joint Support ☐
Heat Retainer ☐ Brace ☐ Other ☐
Please specify

2. Body Region Injured
Bodypart/s
Dominant Side ☐ Non Dominant side ☐
Bilateral ☐ Not Applicable ☐

3. Supplementary Information
Cessation of playing / training
Immediately ☐ Later (during game/ training) ☐
Completed game/ training ☐
Warm up prior to playing game ☐
Late fitness test prior to game ☐
Cool down at end of previous game / training ☐

4. Nature of Injury
Abrasion/ graze ☐ | Open wound / laceration / cut ☐
Dislocation ☐ | Bruise / contusion ☐
Strain e.g. muscle tear ☐ | Fracture ☐
Sprain e.g. ligament tear ☐ | Blisters ☐
(Grade: 1 ☐ 2 ☐ 3 ☐) ☐ | Concussion ☐
Respiratory problem ☐ | Unspecified medical condition ☐
Cardiac problems ☐ | Loss of consciousness ☐
Other ☐ | Please specify

5. Mechanism / Cause of Injury
Contact: (Tick any that apply)
Tackled ☐ | Tackling ☐
Collision with fixed object ☐ | Collision with other player ☐
Struck by another player ☐ | Struck by ball ☐
Other ☐ | Please specify
Foul Play: Yes ☐ No ☐
Non Contact: (Tick any that apply)
Fall / stumble ☐ | Jumping ☐
Slip / trip ☐ | Landing from jump ☐
Running ☐ | Twisting to gain or accelerate ☐
Blocking ☐ | Accelerating / Decelerating ☐
Catching ☐ | Fist passing ☐
Picking up the ball ☐ | Shooting ☐
Kicking ☐ | Diving ☐
Solo running ☐ | Other ☐
Please specify

6. Additional Comments

7. Date of Full Return from Injury

For the purpose of this study a player was considered injured if he was unable to participate fully in training or games for a period of at least forty-eight hours after the injury was sustained[10]. The player was defined injured until the club medical staff cleared him for participation in full training or match play. The severity of injury was defined as minor (<1 week), moderate (1-3 weeks), and severe (>3 weeks)[6]. Physiotherapists and medical staff were briefed on the workings of the project and were given detailed instructions on how to complete the relevant forms. Full statistical analysis of the data was calculated using SPSS (Chicago, Illinois, USA). The resulting descriptive and comparative data are presented. Chi squared tests were used to investigate differences and statistical significance was accepted at $P<0.05$ level.

Results

A total of 16 teams agreed to participate in the study. All subjects (n=511) were male between 18 and 36 years of age and members of Senior Inter County (elite) Gaelic Football teams. Total exposure time for all Gaelic Football activity throughout the season from January to September was 39785.8 hours, 4310.4 hours in games and 35475.4 hours training. The mean (+ s.d.) hours of exposure per player was 67.4 (+33.1) in training and 16.8 (+7.7) in games. A total of 471 injuries were recorded. Significantly more injuries occurred in games (276) than in training (195) ($p<0.001$). This represents 0.38 (+0.27) injuries per player in training, 1.08 (+0.81) injuries per player in games, and 1.46 (0.54) injuries in total, per player per season. The overall incidence of injury was 11.8 (+4.36) per 1000 player hours. The incidence for games was 64 (+26.5) per 1000 player game hours, and 5.5 (+2.62) per 1000 player training hours (table 1).

Table 1 Injury Incidence

Injuries per Player per Season	Mean	SD
Total	1.46	0.54
Training	0.38	0.27
Games	1.08	0.81
Injuries per 1000 hours of Gaelic Football		
Total	11.8	4.36
Training	5.5	2.62
Games	64	26.5

The relative risk of injury in the sample is 10.94 times more likely in games than in training, despite the fact that over eight times the amount of time was spent training than in games. 66% of all players were injured at some stage during the season. Of the injuries sustained 59% occurred in games and 41% in training. For most teams, the percentage of match injuries was higher than the percentage of training injuries, however some teams [2,8,14,15,16] had a higher percentage of training injuries than match injuries (figure 2).

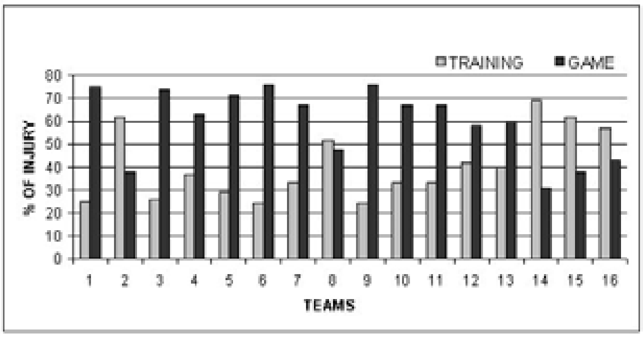


Figure 2. Total Injuries: Training and Games for all Teams

In a typical game of Gaelic Football there are six attackers, six defenders, a goalkeeper, and two midfielders on each team. After adjusting for goalkeepers and the lower numbers of midfield players compared to attackers and defenders there was a uniform pattern of injury. The results indicate that there is no evidence of a significant association (p=0.92) between injury and playing position when considering activity (i.e. training/game).

The time of injury is similar for training and games (figure 3). The percentage of injury increased steadily over time with a pronounced increase in the final quarter. 55% of all training injuries occurred in the final quarter of training. There was strong evidence of an association (p=0.003) between time of injury and activity (i.e. training/game). There were significantly more injuries in the fourth quarter in training compared to what would be expected if time of injury and activity were unrelated.

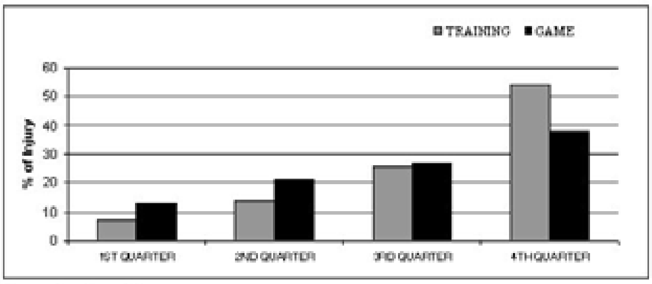


Figure 3 Time of Injury

There was strong evidence that the proportion of injuries at each body site was different (p<0.001). Injuries to the lower limb accounted for over 70% of all injuries recorded. Percentages for each site injury were: hamstrings (22%), knee (13%), ankle (11%), and groin (9%). Injuries to the upper and lower arm including the hand accounted for 5% of all injuries, the back (6%) and shoulder (7%) were the main sites of injury in the upper body. The injury pattern for body site in games and training is strikingly similar although more hamstring and groin injuries occurred in training than in games. The incidence of knee and ankle injury was higher in games (15% and 15% respectively) than in training (11% and 7% respectively). There was a significantly higher proportion (59%) of injuries in the dominant side (preferred kicking side) (P=0.001) compared to the non-dominant side.

The effect of injury on a player's participation was considered under three categories: (1) Players who completed training/games, (2) Players who stopped immediately, and (3) Players who stopped later. There was strong evidence that the proportion of injuries with respect to impact was different (p<0.001). The majority of injured players did not complete training or games. 44% of injuries resulted in cessation of activity immediately, 19% at a later stage during training or game, while 37% of players completed their game or training session.

The majority of total injuries (figure 4) were classified as sprains (stretch or tear of a ligament) (26%), strains (stretch or tear of a muscle or tendon) (42%), and bruises/contusions (damaged or broken blood vessels as a result of a blow to the skin) (17%). The incidence of sprain injuries was significantly higher in games than in training (P<0.001) with players approximately three times more likely to sustain a sprain injury in games as opposed to training. There was no significant difference (p=0.610) between the incidence of strain injuries in training and games. The incidence of bruising/contusion was higher (p=0.01) in games (22%) than in training (11%), similarly significantly more fractures (P<0.001) occurred in games (5%) than in training (2%). The majority of fractures were to the hand particularly the fingers and thumbs.

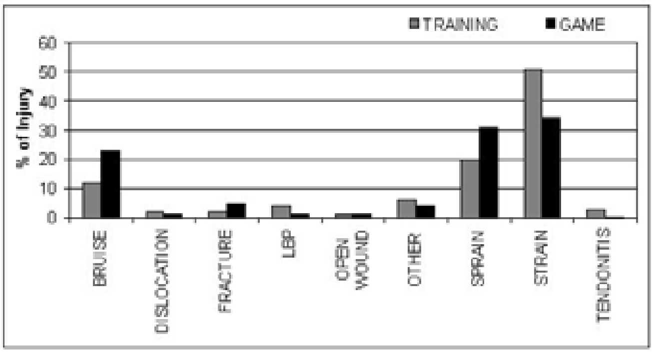


Figure 4. Nature of Injury

Despite the high intensity and physical contact nature of Gaelic Football, there was a significantly higher proportion of non-contact injuries (P<0.001). 60% of injuries resulted from non-contact and 40% from contact. The main non-contact injuries were muscular strain injuries particularly to the hamstrings (31%) and groin (14%), caused mainly by running, twisting, accelerating and decelerating. Contact injuries particularly the shoulder (15%), knee (15%), and ankle (9%) resulted predominantly from collisions with other players, tackled, or struck by another player (figure 5).

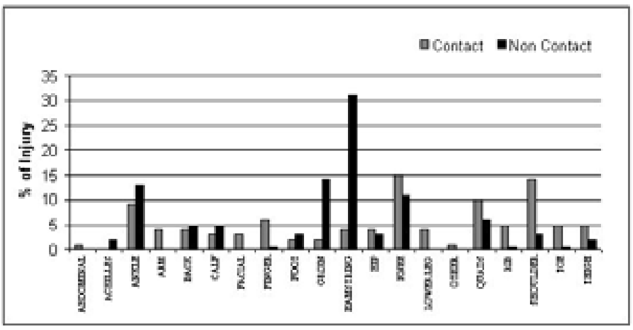


Figure 5 Cause of Injury

Injuries were classified into three categories according to the length of absence from training sessions and games: minor (<1 week), moderate (1-3 weeks), and severe (>3 weeks). 10% of all injuries were classified as minor, 56% were moderate, and 34% severe. Of the severe injuries, 12% resulted in the player being unable to participate fully for a period of over six weeks and 3% were serious enough for the player to miss playing for the rest of the season.

Discussion

This study investigated injury incidence in 511 elite Gaelic Football players in 16 different teams in Ireland. The teams that participated provide a reliable and representative sample of the elite Gaelic Football population as teams as from the top, middle and lower leagues were included.The results indicate that the pattern of injury is similar throughout the different teams and there is little variation between the teams with regard to timing, location, and types of injury.

The incidence rate of injuries per player per year (1.46) is lower in the present study than the figure of 1.78 reported by Cromwell et al[3], who retrospectively recorded injuries reported by 107 elite Gaelic Football players over a season. The incidence rate of injury per 1000 player hours for training (5.5) is similar to the 5.9 reported by Arnason et al[8] in a study involving 84 Soccer players, and (3.4) reported by Hawkins et al[10] in their audit of professional soccer players. A notable finding of this study is that the incidence rate of injury per 1000 player hours for games in Gaelic

Football (64) is much higher than the figures reported for Soccer (34.8 and 25.9)[8,10].

In common with other injury investigations, the incidence of injury in this study was much higher in games than training. Although more time was spent in training activities than playing games, one might expect a lower injury risk in training as a result of managerial supervision, a more controlled setting and a normally less hectic competitive environment compared with actual games. However it is therefore a disturbing finding that a number of teams participating in this study had a higher proportion of injuries in training than in games.

The temporal profile of injury is consistent across all teams especially while training. More injures occur in the final quarter of training (55%) and games (38%) than during any other period. Other codes similar to Gaelic Football have reported higher levels of injury in the second half than in the first half of competitive matches[8,10]. The high proportion of last quarter injuries may be due to fatigue and slower reaction time. Traditionally, final periods of training involve speed work in the form of repetitive sprint exercises. The timing of this type of activity may well contribute to the higher occurrence of injury in the latter stages of training. High intensity power activities carried out by fatigued players are likely to increases susceptibility to injury.

Recognising the high injury rates in the latter stages of games, the timing of substitutions may be important for injury prevention. Five substitutions are permitted during the course of the game. The prudent use of the substitutes before the last quarter of the game may help reduce injury rates. In some instances, tired players or players slightly injured eat an early stage in the game may continue to play on thereby increasing their risk of injury. Consideration should be given to the timely removal of tired or injured players who may wish to continue playing.

The majority of injuries were soft tissue injuries particularly in the lower limb. Hamstrings injuries were the most common, especially in training. However the underlying aetiology of hamstring injuries is unclear and many factors have been suggested including, poor flexibility, hamstring-quadriceps muscle imbalance, muscle weakness, improper technique, inadequate warm-up, poor neuromuscular control, and fatigue[13,14]. Recent studies have highlighted the benefits of incorporating additional eccentric training during pre-season as an aid to reducing the incidence of hamstring strain injuries[15,16]

The objective of the report form was to gather specific details of the cause of injury; consequently the category 'overuse injury' was deliberately omitted from the 'cause of injury' as it is a vague term and open to interpretation. Although Gaelic Football is a contact field game, injuries not involving player-to-player contact were more frequent than direct contact injuries. The main causes of non-contact injury included running, jumping, sprinting and twisting. It may be possible for trainers and coaches to monitor the extent of running exercises in training sessions and allow adequate time for recovery in order to reduce the incidence of non-contact injuries.

The majority of players in this study (65%) were unable to participate fully in Gaelic Football activity for between one and three weeks as a result of injury. This can have serious financial implications particularly for players who are self employed. Previously the only available injury data on Gaelic Football was obtainable from insurance and hospital records[17]. These types of records tend only to list the more serious injury while less serious ones are rarely recorded[18]. While these records reflect the popularity of the game, they reveal little however, about the general risks and cost of participation in Gaelic Football.

The need for more scientific research into the injuries associated with playing Gaelic Football and the importance of detailed injury reports as an aid to injury prevention has been well documented [2,18] . As stated by Walter et al[20]

> *Unless sports and athletic associations are prepared to imple ment epidemiological studies, the factors that could eliminate or reduce both the numbers and severity of injuries received by sports participants will remain undefined. A detailed pro spective study is the first step in approaching injury prevention*

VanMechelen's[12] model sequence for prevention of sports injuries has been successfully employed in Australian Rules Football. Injury surveillance data is published annually and there has been a significant reduction in the incidence of injury as a result of various national directives- such a requirement that all professional games be played on the same type of turf surface.

There is an urgent need for a similar system of epidemiological injury data collection in Gaelic Football and the establishment of a national injury database to help predict, reduce, and prevent injury at all grades of the game. The high incidence of injury in the final quarter of training activity merits further investigation and analysis. A detailed study of the underlying aetiology of hamstrings injuries is warranted.

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