FITNESS AND GAME BASED ASSESSMENT OF U-18 GAELIC FOOTBALL PLAYERS

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Declaration

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Abstract

Cullen, Bryan D. Fitness and Game Based Assessment of U-18 Gaelic Football Players

Fitness profiling is a descriptive process that involves benchmarking the fitness characteristics of elite athletes. Three studies were undertaken to evaluate the physical and fitness characteristics, movement patterns and physiological demands during match play in U-18 Gaelic football players.

Study 1 established normative centile scores for selected fitness parameters, and compared the physical and fitness characteristics relative to playing position. Midfield players and goalkeepers were taller and heavier than defenders and forwards. Goalkeepers had the highest sum of 3 skinfolds and covered less distance in the YYIRT1 than all other positions. There was no significant positional difference in the performance scores in the S&R test, CMJ, SLJ and 5 m and 20 m running speed. The results indicate that there are minimal differences in fitness characteristics between outfield playing positions.

Studies 2 and 3 analysed the movement patterns and physiological demands during match play in county and club level players. County players covered a greater distance and performed a higher number of maximal sprint efforts (≥ 20 $Km \cdot h^{-1}$) per game. County players also exercised at a significantly higher %HRmax and spent a greater percentage of playing time between 91-100%HRmax than club players. There was a significant reduction in the total distance covered, frequency of high intensity activity, %HRmax and percentage of playing time between 91-100%HRmax in both club level and county level players. County level games involve a higher physical and physiological demand than club games. A greater technical ability and tactical understanding of the game is the major difference between county and club U-18 Gaelic football players.

Publication of norm-referenced percentile scores will enable conditioning coaches to benchmark elite performance and design training programmes. The development of training strategies will be enhanced with an understanding of movement patterns and physiological demands of Gaelic football match play.

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Glossary of Terms

Anthropometry	Measurement of the human body
Biological age	Development level of maturity
Centile	The value below which a given percentage of observations in a group of observations fall
Chronological age	Age in years based on an individual's date of birth
Club level	Organised competition between teams representing their local community
County level	A selection of the finest club level players representing their county in provincial and national competition
Debutant	A person making their first appearance in a team
Maturation	The timing of specific maturational events and the rate at which maturation progresses towards the mature biological state
Norm-referenced	An estimate of the position of a tested individual in a pre-defined population, with respect to the trait being measured
Motion analysis	Analysis of human movement
Peak height velocity	Age of maximum rate of growth in height during adolescence
Quintile	Five equal groups in to which a population can be divided according to the distribution of values of a particular variable
Solo running	The act of kicking the ball from foot to hand while moving
Starters	The players selected in the starting line-up of a sports team
Tackle	An effort to dispossess an opponent of the ball

List of Abbreviations

AFL	Australian Football League
ATP	Adenosine Triphosphate
CMJ	Counter-movement jump
CMJw	Countermovement jump with arm swing
CO_2	Carbon Dioxide
CV	Co-efficient of Variation
DCU	Dublin City University
DGPS	Differential Global Positioning System
FI	Fatigue Index
GAA	Gaelic Athletic Association
GPS	Global Positioning System
HR	Heart Rate
HRmax	Maximal heart rate
ICC	Intra-class correlation coefficient
MP	Mean Power
N_2	Nitrogen
NAD^+	Oxidised form of NADH
NADH	Nicotinamide adenine dinucleotide
NDGPS	Non-Differential Global Positioning System
NFL	National Football League
O_2	Oxygen

P	Power Output
PCO_2	Partial Pressure Carbon Dioxide
PCr	Phosphocreatine
PO_2	Partial Pressure Oxygen
PP	Peak Power
RAE	Relative Age Effect
RPE	Rate of Perceived Exertion
S&R	Sit and Reach Test
SD	Standard Deviation
SLJ	Standing Long Jump
$\dot{V}O_2$	Oxygen uptake
$\dot{V}O_2max$	Maximal aerobic capacity
YYIRT1	Yo-Yo Intermittent Recovery Test Level 1

List of Publications

Cullen, B.D; Cregg, C.J; Kelly, D.T; Hughes, S.M; Daly, P.G & Moyna, N.M. Fitness profiling of elite level adolescent Gaelic football players. *The Journal of Strength & Conditioning Research*. 2013; 27(8):2096-2103.

CHAPTER I

INTRODUCTION

Gaelic football is the most popular team sport in Ireland, and is one of five games organized and promoted by the Gaelic Athletic Association (GAA). Gaelic football can best be described as a hybrid of soccer, rugby, basketball and Australian Rules football. It is a fast, physical contact game played between two teams of 15 players on a rectangular grass surface approximately 145 m long and 90 m wide. A typical formation includes a goalkeeper, six defenders, two midfielders and six ‘forward’ players; however the exact positioning of each player varies depends on the tactics employed by each team. A forward player is responsible for creating and converting scoring opportunities during match play. The ball which is similar in size but slightly heavier than that used in soccer can be played over any distance by foot or hand, and can be carried using the accepted solo running technique (1). This involves kicking the ball from foot to hand while moving.

The primary objective of the team in possession is to create and exploit space in order to score. Goalposts with a crossbar are located on both end-lines. A team is awarded a point when the ball is kicked or hand-passed between the posts and over the crossbar. A goal is awarded when the ball crosses the end-line between the goal posts and under the crossbar. Three points are awarded for a goal. When the opposition has possession, the primary aim is to decrease the space available in order to prevent them from scoring and to regain possession of the ball. There is no clear definition of the ‘tackle’ in Gaelic football, however players are entitled to strike the ball with an open palm from their opponents grasp in order to retrieve possession. Shoulder to shoulder contact is also permitted.

The physiological demands of any sport are determined largely by the activity patterns of the game. Similar to soccer and Australian Rules football, Gaelic football involves repeated short duration, high intensity bouts of anaerobic exercise interspersed with sustained light to moderate aerobic activity. The duration of these high intensity activities, are largely unpredictable, due to the fact that they are imposed by the pattern of play, and can vary greatly from player to player, and from one game to another. On average, senior players perform 96 bursts of high intensity activity lasting 6 sec followed by an average recovery of 37 sec (2). Players typically work at 80% of their maximum heart rate (HRmax) and cover an average distance of 8.5 km during competitive games (3, 4). Superimposed on the physiological demands of match play are key technical activities such as winning possession of the ball, evading opponents and breaking tackles which involve high running velocities, agility, strength and power.

Profiling is a descriptive process that allows sport scientists to identify and benchmark the physical fitness characteristics of elite athletes. Coaches at an elite level use this information to identify the discrete physical fitness characteristics that may predispose an athlete towards a successful career in sport. Physical fitness scores can also play an important role in team selection, formulating training goals and monitoring athletic development (5-7). Optimal performance in Gaelic football requires that players develop the appropriate fitness attributes that allow them to cope with the physical demands of the game while maintaining technique and skill levels.

Observing athletes during competition can provide useful information regarding the movement patterns and physiological demands during match play. Originally developed as a military tool, global positioning software (GPS) has become increasingly popular among sport scientists as a method of tracking movement patterns in many field based sports. Modern GPS devices are portable, robust and lightweight making them particularly suited to field based sports. They are typically worn between the shoulder blades in a purpose made vest (figure 1.1), offering a non-invasive method of gathering valuable information on player movement patterns. Heart rate (HR) collected simultaneously using telemetry provides sport scientists and coaches with supplementary physiological data (figure 1.2).

Figure 1.1   GPS Device

Figure 1.2   Heart Rate Monitor

1.1 Statement of the Problem

Despite the popularity of Gaelic football, there is a clear lack evidenced based research to assist coaches in the preparation of teams, particularly at underage level. A small number of studies have described the anthropometric and physical fitness characteristics of club, collegiate and county level adult male Gaelic football players, the majority of which are dated and may not accurately reflect the profile of current players (8-14). There is currently no published data describing the anthropometric and physical fitness characteristics of Gaelic football players ≤ 18 years.

Surprisingly few studies have been published on the physiological demand and activity profile of Gaelic football, and none have involved players ≤ 18 years. A decade has passed since the most recent study in this area, which given the changes in playing style and increased adoption of sport science support may not reflect the demands of the modern game. There is a lack of knowledge concerning the activity profile and physiological demands of modern Gaelic football. Information regarding the activity profile and physiological demands of match play may aid coaches in the design and implementation of Gaelic football specific training programmes.

1.2 Study Aim

The following series of studies will develop norm-referenced percentile scores for selected anthropometric and fitness indices relative to each playing position, and describe the activity profile and physiological demands of Gaelic football match play across playing position in U-18 males.

1.2.1 Specific Objectives

1. To evaluate the anthropometric characteristics and fitness levels of elite U-18 Gaelic football players and compare the physical and fitness characteristics relative to each playing position

2. To examine the relationship between anthropometric and physical fitness measures in elite U-18 Gaelic football players

3. To evaluate the total distance covered during match play relative to playing position during U-18 county and club level Gaelic football matches

4. To examine the activity profile of U-18 county and club level Gaelic football players during match play relative to playing position

5. To compare the activity profile during Gaelic football match play in U-18 county and club level games between the first and second 30 min periods of play

6. To describe the physiological demands during U-18 county and club level match play and compare the aerobic demand and cardiovascular response relative to playing position and competition level

7. To compare the physiological demands of Gaelic football match play in U-18 county and club level games between the first and second 30 min periods of play

1.2.2 Hypotheses

1. Players in the midfield position will be taller, have the highest endurance capacity and score best in tests of muscular power compared with other outfield positions
2. Forward players will record the fastest sprint times
3. There will be a strong relationship between body composition and tests of power and speed respectively
4. County level players will cover a greater distance than club level players during match play
5. Players in the midfield position will cover a greater distance than defenders and forward players regardless of playing level
6. County players will perform more high intensity running and sprinting than club players
7. The frequency and duration of high intensity activity performed at club and county level will be position dependant
8. There will be a reduction in the physical demands of match play between the first and second half during county and club level games
9. The relative heart rate and estimated $\dot{V}O_2$ during match play will be significantly higher in county players than club level players

10. The physiological demands during match play will be greatest in the midfield position regardless of playing level

11. There will be a significant difference in the physiological demands of match play between the first and second half of match play

1.3 Summary

The majority of studies in Gaelic football are dated and have focused primarily on adult level players. Although these studies provide an insight in to the characteristics of players and the demands of the game at this level, there is little or no information available concerning underage Gaelic football players. Three studies were undertaken to evaluate the physical and fitness characteristics, movement patterns and physiological demands during match play in U-18 Gaelic football players.

CHAPTER II

REVIEW OF LITERATURE

2. Introduction

Gaelic football is one of the most popular sports in Ireland. It is a 15-a-side invasive field-based team sport played on a rectangular field measuring 145 m x 90 m. Gaelic football and hurling are the national sports of Ireland and together with handball and camogie fall under the umbrella of Gaelic games. Gaelic games are organised and governed by the Gaelic Athletic Association (GAA), which was established in 1884 (15). The GAA quickly became an integral part of Irish society with local clubs establishing themselves as the focal point of their communities. Today, Gaelic football has the highest participatory rate in Irish sport (1), and is also played in several other countries with significant Irish communities. The thirty-two counties of Ireland as well as London and New York compete annually for the All-Ireland Championship in both football and hurling. The inter-county championship finals in both hurling and football are major events in Irish society attracting attendances of up to 82,000 to Croke Park, home of the GAA (15).

Despite its popularity, Gaelic football has largely escaped the attention of sports scientists. Existing research has focused on a small number of elite inter-county and collegiate teams. There is a complete absence of knowledge concerning the physical characteristics and fitness levels of young Gaelic football players. Studies in other field based sports such as soccer, Australian Rules football and rugby provide an insight into the role of fitness profiling in assisting coaches to identify requisites for elite competition

(14, 16, 17). This information may also be used to highlight inherent fitness deficiencies, formulate training goals and monitor progress over time. Anthropometrics, flexibility, muscular power, speed and aerobic capacity are the primary fitness components reported in the literature.

Motion analysis provides information on the activity patterns and physiological load imposed on players according to their position during match play and provides a framework for coaches to devise appropriate conditioning strategies specific to the needs of the game (18). A small number of studies have examined the movement characteristics and/or physiological demands in adult Gaelic football players (2, 3, 19). There is currently no information available describing the movement patterns and physiological demands of Gaelic football at underage level.

2.1 Talent Identification

Talent identification programmes aim to identify talented youths for a career in sport and are widely implemented by national sporting bodies and professional organisations. However, the factors that predispose children and adolescents towards a successful career in sport are multifactorial, and when coupled with inter-individual variations in growth and maturity highlight the difficulty in predicting future performance. Athletes with similar physical and physiological characteristics during initial testing may, however respond at different rates to similar training stimuli accounting for large discrepancies in performance and career progression (20). The factors that discriminate between performers become more complex as young players mature and are exposed to greater volumes of systematic training (17).

2.1.1 Growth and Maturation in Children and Adolescents

Growth is defined as an increase in total body size or the size attained by different parts of the body at a given moment in time (21). Maturation refers to process of becoming biologically mature and fully functional (22). Growth and maturation are measured at one or more points in time with the point of reference being a child's chronological age (21). Biological age refers to the developmental level of maturity and is largely responsible for the functional and performance capabilities of an individual (23). Assessment of skeletal age and sexual maturation are commonly used approaches to determine biological age. Maturation does not necessarily coincide with chronological age. Indeed children of the same chronological age can differ by several years in their level of biological maturity (22). These inter-individual differences in somatic growth and maturation results from the complex interplay between nutritional, genetic and hormonal factors (24). For example, adolescence, the transitional period between childhood and adulthood is associated with sexual maturation, completion of skeletal growth, increase in stature and changes in body composition (figure 2.1) (8). The biological changes that take place during adolescence make the prediction of future performance increasingly difficult (20).

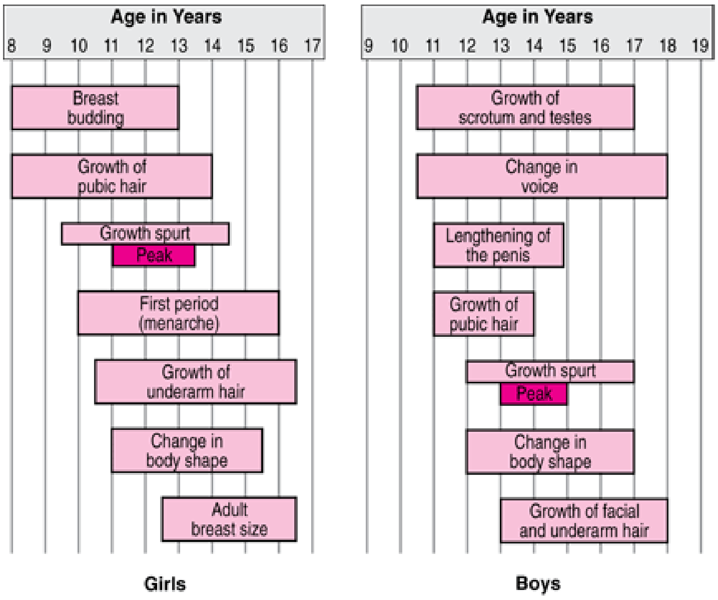

Figure 2.1 Milestones in sexual maturation (25)

2.1.2 Skeletal Development

Skeletal development refers to the changes in length, diameter, and mass of the human skeletal system from the early days of pregnancy until the bones have reached full development in late puberty (26). Bone forming osteoblasts are present in red bone marrow, and a substantial amount of these cells are present in children's bones compared to adult bones. Bone length increases are due to the replacement of cartilage with bone at the epiphyseal growth plate, through the process of ossification (26). Increases in bone diameter involve the deposition and entrapment of bone matrices in cavities by osteoblasts. These eventually form mature bone cells called osteocytes that are responsible for the regulation of bone mineral formation (26).

Skeletal growth in the fetus and infant is rapid, but most childhood bone acquisition is slow until puberty, when it again becomes very rapid. By the age of 12 years, the mean height velocity is 5.0 cm per year in boys, and reaches a maximum of 9.5 cm per year by the age of 14 (27). Mean height velocity is close to zero by the age of 17, and approximately 85–90% of final adult bone mass is acquired by age 20 (27, 28). The growth spurt during adolescence contributes about 15% to adult height, and about 37% to the total body bone mineral (28).

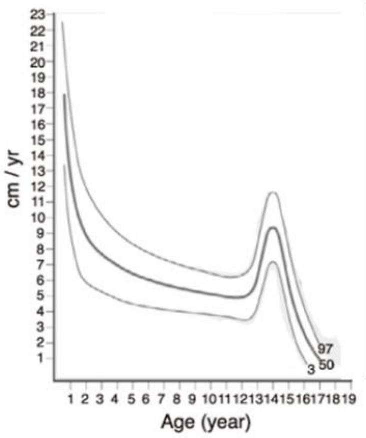

Figure 2.2 Height velocity chart for boys constructed from longitudinal observations of British children. The 97th, 50th, and 3rd percentile curves define the general pattern of growth during puberty (29)

Peak bone mass (PBM) is the amount of bony tissue present at the end of the skeletal maturation (30). More than 90% of peak adult skeletal mass is accrued by the age of 17 years. Gains in bone mass are most rapid during adolescence, with 25% of the peak bone mass acquired during the two-year period surrounding peak height velocity (31), and approximately 40-45% attained during a 3-4 year period in adolescents (32). Bone maturity can be assessed by way of a bone scan, determining which bones have undergone epiphyseal closure (33).

2.1.3 Stature

Statural growth is a complex process that is determined by the interaction of genetics, nutrition, and socioeconomic factors (34). Most healthy infants and children grow in a predictable fashion, following a typical pattern of progression in weight, length, and head circumference. The circumference of a newborn's head is normally 2 cm larger than the chest. After six months both measurements are equal. At two years the chest size becomes larger than the head (figure 2.3) (35)

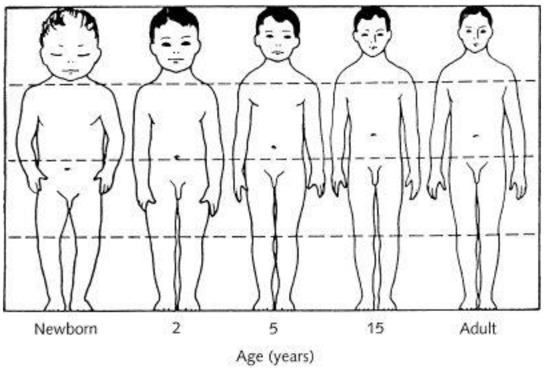

Figure 2.3 Changing proportions of the growing body (36)

Normal human growth is pulsatile, with periods of rapid growth separated by periods of no measurable growth (figure 2.4). Peak growth velocity occurs during the fourth month of intrauterine life, reaching 2.5 cm/week, followed by a slowing until birth. In the first year of life, linear growth remains rapid and a further 25.0 cm is gained. The rate of growth declines and the average gain is 12.5 cm per year between the first and the second year, 7 cm per year between ages two and four, 6.0 cm per year between ages four and six, and then 5.5 cm per year until puberty (35).

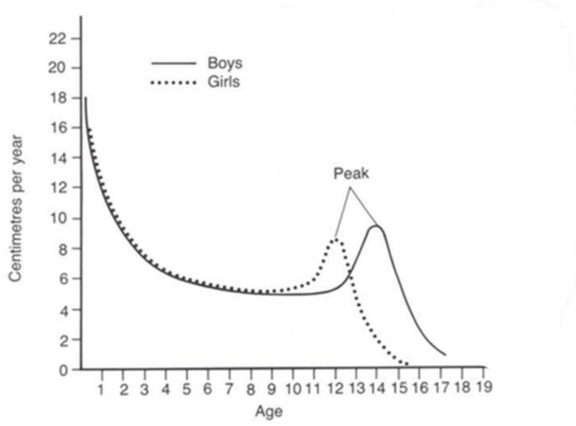

Figure 2.4 Typical human growth velocity curves for boys and girls (37)

The second acceleration in height velocity takes place at puberty (figure 2.4). Increases in height during puberty are primarily attributable to increases in bone length of the legs and vertebral column (38). Peak height velocity (PHV) is the age of maximum rate of growth in height during puberty, and is the most commonly used indicator of physical development. The mean peak height velocity in boys is approximately 9.5 cm per year on average (range 7.1-11.9 cm) and occurs during mid-puberty. Boys that mature early grow 10.3 cm per year (range 7.9-12.5 cm). In contrast, boys that mature late grow on average 8.5 cm per year (range 6.3-10.7 cm) (39). After the pubertal growth spurt, growth velocity diminishes toward zero as the epiphyses of the long bones fuse due to hormonal influences (40).

2.1.4 Body Composition

Increases in weight during the adolescent growth spurt are mainly attributable to an increase in bone and skeletal muscle mass. Boys typically gain 20 kg in weight during adolescence (41). Fat mass and fat free mass (FFM) both change during growth. Fat free mass relates to the non-fat parts of the human body and includes skeletal muscle, bone and water. The contribution of water to FFM declines during childhood and the relative contribution of protein increases. Muscle mass in boys increases steadily from approximately 25% of body weight at birth to a peak of 40% of body weight between 18-25 years (41). During the first two to three years of life estimates of fat mass increase with little change through childhood. Relative fatness increases gradually in boys until just before the adolescent growth spurt and then remains relatively constant in individuals who remain physically active (21).

2.1.5 Strength

An increase in muscle mass throughout adolescence is associated with an increase in muscle strength (22). The increase in strength in boys and girls between the age of 8 and 17 years tend to be proportional to body size (42). Boys reach peak rate of strength development approximately 1.2 years after PHV, (43). However, the increase in strength associated with PHV appears to be greater in boys than predicted by growth in body size. Performance related differences between young males at different levels of maturity are most evident between the age of 13 and 16 years (21).

2.2 Relative Age

Grouping underage players according to chronological age can result in an age gap of up to 12 months between the oldest and the youngest player. The relative age effect (RAE) refers to the overall difference in age between individuals within each age group (44). The subsequent anthropometric and physiological differences between individuals born early and late in the selection have been shown to impact selection for team sports (44-46). There is evidence that coaches in Australian Rules football preferentially select physically mature youth players (47, 48), which may limit the playing time and overall development of late maturing players.

Youth ice hockey players born in the first six months of the selection year are more likely to play for top tier teams than players who are born in the second six months of the selection year (45). Helsen *et al*., (2005) examined the birth date distribution of players representing professional club teams in international youth tournaments and found that the majority of players were born in the first quarter of the selection year (44). Consistent with this finding, Gravina *et al*., (2008) observed that the majority of elite youth soccer players (10 – 14 years) were born in the first half of the selection year (46).

Skeletal maturity has been linked with progression to an elite level in youth sport, which may explain why older players are more likely to be identified as talented. Malina *et al*., (2000) reported that among a squad of 29 elite 13-14 year old youth soccer players only 2 were late in skeletal maturation (49). Similarly, among a squad of 43 elite 15-16 year old elite soccer players only 1 was late in skeletal maturation (49). A similar study of youth soccer players reported that the majority of 11-12 year old and 13-14 year old players were either on time or advanced in skeletal maturity (50). Reporting on the characteristics of youth soccer players, Figueiredo *et al*., (2009) found that the majority of elite 13-14 year old soccer players were significantly older in both chronological and skeletal age than club level players (51). Elite players tended to be born in the first half of the year and on time in relation to maturity status.

There is considerable variation in growth and maturity between individuals of the same chronological age (52). Youth players advanced in sexual and skeletal maturity generally outperform those who are later in maturity in tests of strength, power and speed (53, 54). Maturity has also been shown to positively influence linear speed, isometric strength and rate of force development among young male soccer players (55). Steady increases in jumping ability are evident between the ages of 6 and 17 years (56, 57). Agility and aerobic endurance may also be positively influenced by maturity (51). Finally, power and co-ordination have been shown to gradually increase with advancing age among young elite soccer players (58).

In a study of over 2,000 high school American football players, Dupler *et al*., (2010) highlighted age related differences in physical status and physiological capabilities. As expected, players in the 11^{th} and 12^{th} grades were significantly taller and heavier compared to 9^{th} grade players (59). Players in the 12^{th} grade were significantly heavier compared to 10^{th} and 11^{th} grade players. In terms of physiological performance, 11^{th} and 12^{th} grade players recorded significantly superior results in a 40 yard sprint test, agility run and vertical jump test than 9^{th} and 10^{th} grade players.

Wong *et al.,* (2009) found a significant relation between body mass, 30 m sprint time and ball shooting speed from a distance of 4 m at a 1.0 m^2 target in youth soccer players (60). They also found that height was moderately related to performance in the vertical jump test, 10 m and 30 m sprint times, distance covered during an intermittent endurance run and running time during a $\dot{V}O_2$ max test.

Table 2.1 adapted from Pearson et al., (2006) outlines the effect of puberty on physical and physiological parameters commonly assessed in talent identification programs (20). The effect of maturation on physiological testing makes the prediction of adult performance from adolescent data difficult. Older and early maturing players in a given age grade are at an advantage in terms of physiological testing and therefore more likely to be identified as talented. However, the transient nature of the performance advantages related to early maturity cease to be of significance when all children reach maturity (53). Late maturing children will eventually catch up on their early maturing peers in terms of physiological development, which has important implications for the process of identifying and retaining talented youth players. In terms of talent identification, the importance of performance measures where growth related variables are confounding factors should be minimised (20).

Table 2.1 The effect of puberty on physical and physiological parameters

Characteristic	Effect of puberty	Change during puberty	Age at greatest increase	Trainability	Hormone Mediated
Height	Increase	↑ 17 - 18%	13.5	No	Yes
Weight	Increase in total body mass	↑ 40%	13.5	Yes	Yes
Muscular development	Increase	↑20%	13.5	Yes	Yes
Body fat	Increase (small decrease in % body fat from 14-16 years)	↑ 50%	Steady ↑	Yes	Yes
$\dot{V}O_2$ peak (L min^{-1})	Steady increase throughout adolescence	↑ 70 %	12 – 13	Yes	Yes
$\dot{V}O_2$ peak (mL kg^{-1} min^{-1})	Minor decrease during early adolescence, remaining later during later adolescence	Steady	N/A	Yes	No
Anaerobic power	Small increase during childhood. Rapid increase during puberty	↑ 50%	14 – 16	Yes	Mostly
Anaerobic capacity	Steady increase	↑ 200%	Unknown	Yes	Yes
Strength	Significant increase associated with body size	↑ 150%	14 – 16	Yes	Yes
Skill	Increases are related to practice	Dependant on skill type	Unknown	Yes	Partially
Agility	Possible increase	↑ 20%	Unknown	Probably	Partially

(Adapted from Pearson et al., 2006; pg. 282 (20))

2.2.1 Summary

Anthropometric and physiological tests generally form the basis of talent identification programmes and provide an insight in to the physical capabilities of a young player at a point in time. It is well documented that children mature at varying rates yet sporting organisations continue to categorise children according to chronological age. Existing talent identification models are biased toward early developers who are generally advanced in terms of height, weight, strength, speed and power. Comparing the anthropometric and physiological profiles of children relative to biological maturity rather the chronological age may reduce the likelihood of overlooking late developers. A more suitable model should control for maturity and also assess multidimensional aspects of performance such as game intelligence, psychosocial attributes and technical ability (20).

2.3 Anthropometry

Anthropometry is the science of measurement applied to the human body and generally includes measurements of height and weight (22). Skin-fold measurements are utilised to estimate body composition based on the distribution of subcutaneous adipose tissue (61). Studies examining the anthropometric and body composition profiles of adult Gaelic football players are summarized in table 2.2. There are currently no published studies on the anthropometric characteristics of adolescent Gaelic football players.

Keane *et al.,* (1997) found that inter-county senior football players were significantly taller and heavier than their club counterparts (8). A more recent study by Reeves and Collins (2003) also found a significant difference in height between inter-county and club level Gaelic football players (10). Inter-county players tended to be heavier and have a lower percentage body fat than club level players. It has been suggested that taller and heavier players are more likely to be selected on elite teams in order to cope with the physical demands of the game (8).

Starters were found to be significantly taller than non-starters in elite junior Australian Rules football and rugby league players respectively (47, 48). International level, youth soccer players were also found to be significantly taller than their non-international peers (17). Elite and sub-elite youth soccer players have also significantly less adiposity than non- elite players (56). Gabbett *et al.,* (2009) found that elite junior rugby league starters were significantly heavier than non-starters (48). In contrast, a comprehensive study of 485 junior Australian Rules players, failed to find any difference in height or weight between elite and sub-elite players (62).

Table 2.2 Height, weight and % body fat among Gaelic football players

Source	**Level**	**n**	**Height (cm)**	**Weight (kg)**	**Body Fat (%)**
McIntyre (13)	County	30	179 ± 6	81.0 ± 9.0	13.4 ± 3.0
Brick & O'Donoghue (12)	County	25	-	86.5 ± 8.6	12.0 ± 4.3
McIntyre & Hall (14)	Collegiate†	12	179 ± 5	78.4 ± 7.7	15.0 ± 3.1
McIntyre & Hall (14)	Collegiate‡	12	181 ± 4	82.3 ± 4.2	14.5 ± 3.1
McIntyre & Hall (14)	Collegiate*	4	186 ± 1	87.5 ± 1.2	14.2 ± 3.0
Doran et al.,(9)	County	33	179 ± 1	79.2 ± 8.2	12.3 ± 2.9
Reeves & Collins (10)	County	12	182 ± 4	83.0 ± 2.8	11.3 ± 1.0
Reeves & Collins (10)	Club	13	181 ± 3	80.9 ± 4.0	18.3 ± 3.0
Keane et al., (8)	County	37	181 ± 4	82.6 ± 4.8	-
Keane et al., (8)	Club	40	175 ± 6	76.5 ± 6.7	-
Watson (11)	County	32	181.4 ± 8	81.9 ± 6.9	15.0 ± 4.2
Florida - James & Reilly (19)	Club	11	176 ± 6	70.7 ± 7.7	12.2 ± 2.1

Values are mean ± SD. †defenders; ‡forwards; *midfield players

In terms of match performance, shorter, lighter junior Australian Rules players have more possessions per game than heavier, taller players on the same team. Heavier players had a significantly higher number of marks during a game than other players (62). The difference in performance may be explained by the fact that taller players are positioned closer to goal, where they can use their physical attribute to compete for 'marks', which are rewarded in Australian Rules football with a free kick.

Certain physical and physiological attributes may be a prerequisite for optimal performance in certain playing positions. For example, height is an important physical attribute in competing for aerial possession, and there is a perception among Gaelic football coaches that it is a prerequisite to play at midfield. A study of elite collegiate Gaelic football players did not find any significant positional differences in terms of height. However, defenders were significantly heavier than midfield and forward players (14).

In one of the first studies to characterize the physical attributes of inter county Gaelic football players, Watson (1995) found that goalkeepers had a higher percentage body fat than the other team positions (11). In a more recent study McIntyre & Hall (2005) did not find any positional difference in percentage body fat among elite collegiate Gaelic football players (14). Studies involving soccer players have consistently found goalkeepers to be the tallest, have the highest percentage body fat and to be among the heaviest players on the team (63, 64).

Positional differences in physical characteristics are also evident in rugby league. Youth rugby league prop forwards are taller and heavier and have a higher sum of skin-folds than any of the other playing positions (65). Gabbett *et al*., (2009) also found that youth rugby league players assigned to forward positions were heavier and had a higher sum of skin-folds than players assigned to play in back positions (48). At the professional level, prop forwards are heavier than players in the other positions and have a greater sum of skin folds than half backs, centres and wing players (66). These findings are not surprising considering that forwards, and particularly prop forwards, spend much of their time in physical collisions such as rucks, mauls and scrums. Amateur rugby league forwards are also heavier than backs. In contrast, there are no positional differences in height, sum of skin-folds or estimated body fat at amateur level (67).

The physical and physiological attributes of Gaelic football players have been compared with athletes from other field sports that require similar technical and physiological capabilities. The most common comparisons are with soccer, rugby and Australian Rules football. These sports are team based, involve the fundamental skills of catching, kicking and are largely aerobic in nature interspersed with brief high intensity bouts of anaerobic activity.

Florida-James *et al*., (1995) failed to find any significant difference between the physical characteristics of collegiate level soccer and Gaelic football players (19). In contrast, Watson (1995) found that elite inter-county Gaelic football players were taller and heavier than top level soccer players (11). Other studies have also found that elite level Gaelic football players are taller than semi-professional soccer players (10). More recent studies found no difference in height, weight or percentage body fat between elite Gaelic football players and soccer players (12, 13). Rugby union forwards were significantly heavier and had a higher sum of skin folds than Gaelic football players (12).

2.3.1 Summary

To date, no studies have described the anthropometric profile of adolescent Gaelic football players. Studies on elite youth players in other field sports suggest that elite players are generally taller, heavier and leaner than non-elite players. Adult Gaelic football players have been reported to display anthropometric profiles similar to those of soccer players. Only one study has compared the anthropometric profiles of Gaelic football players across playing groups and found that collegiate level defenders were significantly lighter than midfield and forward players. Percentage body fat values are generally greatest in the goalkeeper position.

2.4 Flexibility

Flexibility can be defined as the ability to move a joint through its complete range of motion (68). The sit and reach test (S&R) is a simple test used to measure hamstring flexibility. The test requires participants to sit on a flat surface with their shoes removed, legs fully extended, heels placed against the edge of a sit and reach box with toes pointed upward. Participants then flex their trunk and reach forward with their arms fully extended while keeping their fingertips in contact with the sit and reach box (figure 2.5).

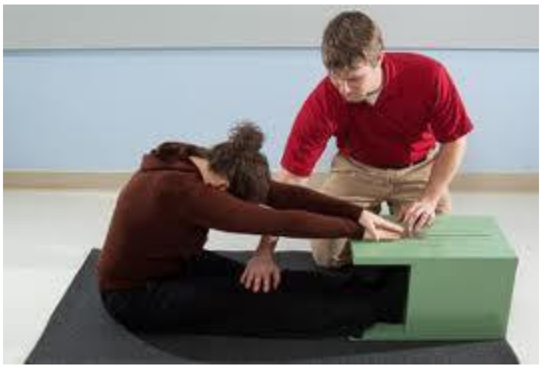

Figure 2.5 The sit and reach test

The S&R is a commonly used test in the measure of hamstring flexibility and has previously been measured in adult Gaelic football players at collegiate and county level (12-14). No positional differences have been found in the sit and reach performance scores among elite collegiate level Gaelic football players (14). In contrast, significantly higher sit and reach test scores have been found in youth midfield soccer players than forward players (69). McIntyre (2005) found no significant difference in the sit and reach performance scores between elite Gaelic football players and soccer players. Soccer players, however, performed significantly better than hurlers in the sit and reach test (13). Similarly, Brick &

O'Donoghue (2005) found no significant difference in S&R test scores between Gaelic football, hurling, soccer and rugby union players (12). A summary of studies investigating the sit and reach performance of Gaelic football players is outlined in table 2.3.

Table 2.3 Selected studies that evaluated sit and reach performance in Gaelic football players

Source	**Level**	**n**	**Distance (cm)**
Brick & O'Donoghue (12)	County	25	29.8 ± 4.1
McIntyre (13)	County	30	25.0 ± 6.0
McIntyre & Hall (14)	Collegiate[†]	12	21.0 ± 9.1
McIntyre & Hall (14)	Collegiate[‡]	12	21.8 ± 7.8
McIntyre & Hall (14)	Collegiate[*]	4	21.6 ± 5.8

Values are mean ± SD. [†]defender, [‡]forward, [*]midfield

The association between hamstring flexibility and performance in intermittent sports has received little attention. A study involving a professional Australian football team found no difference in hamstring flexibility between starters and non-starters (5). Although of limited application to team sports, Trehearn & Buresh (2009) found a significant inverse relation between sit and reach scores and running economy at a given absolute running velocity (70). These findings have been confirmed in other studies (71). It is thought that less flexible runner's exhibit greater running economy as lower limb inflexibility allows for greater elastic energy storage during the stretch shortening cycle (70).

Table 2.4 outlines age and gender specific normative data for the standard sit and reach test (Adapted from Heyward) (72).

Table 2.4 Age-gender norms for the sit and reach test (cm)

	Gender											
	Male						**Female**					
Age (yr)	**15-19**	**20-29**	**30-39**	**40-49**	**50-59**	**60-69**	**15-19**	**20-29**	**30-39**	**40-49**	**50-59**	**60-69**
Excellent	≥ 39	≥ 40	≥ 38	≥ 35	≥ 35	≥ 33	≥ 43	≥ 41	≥ 41	≥ 38	≥ 39	≥ 35
Very Good	34-38	34-39	33-37	29-34	28-34	25-32	38-42	37-40	36-40	34-37	33-38	31-34
Good	29-33	30-33	28-32	24-28	24-27	20-24	34-37	33-36	32-35	30-33	30-32	27-30
Fair	24-28	25-29	23-27	18-23	26-23	15-19	29-33	28-32	27-31	25-29	25-29	23-26
Needs Improvement	≤ 23	≤ 24	≤ 22	≤ 17	≤ 15	≤ 14	≤ 28	≤ 27	≤ 26	≤ 24	≤ 24	≤ 22

2.5 Muscular Power

Power is defined as the work performed per unit time and is the product of force x distance (22). Many of the important activities in Gaelic football such as competing for possession, breaking a tackle, jumping to catch a kick-out, and accelerating from a stationary position require muscular power. The Margaria-Kalamen test and the Wingate test are commonly used laboratory based tests to assess muscular power in the lower body The Margaria-Kalamen test measures maximal power output during stair climbing. The subject stands 2 m from a staircase and then sprints at top speed up the staircase, taking three steps at a time. Pressure pads act as switches recording time taken to run between the pads. A clock starts when the foot strikes the third step and stops when the foot strikes the ninth step (figure. 2.6).

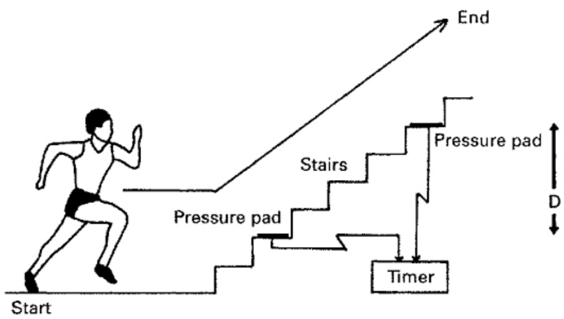

Figure 2.6 Margaria-Kalamen test

The power output (P) is calculated using the formula; $P = (W \times 9.8 \times D)/t$, where W is the body weight of the subject in kilograms: 9.8 is the normal acceleration due to gravity in ms−2; D is the vertical height in metres between the eighth and twelfth steps: and t is the time taken from the first pressure pad to the second pad.

The Wingate test is typically performed on a cycle ergometer. The test protocol is normally 30 sec in duration although multiple shorter bouts are also used. Peak power, average power and fatigue rate are the most common measured indices (73). Peak power (PP) defined as the maximum power exerted during a 5 sec period is calculated using the formula; PP ($kgm^{\cdot}5\ sec^{-1}$) = rev (max) in 5 sec x $D^{\cdot}rev^{-1}$ sec x F, where D is the distance travelled by the flywheel in 1 revolution (6 m), and F is the force setting in kg. Mean power (MP), the average power exerted during the 30 sec work bout is calculated using the formula; MP (kg 30 sec^{-1}) = rev (total) in 30 sec x $D^{\cdot}rev^{-1}$ sec x F, where D is the distance travelled by the flywheel in 1 revolution (6 m), and F is the force setting in kg. The fatigue index (FI) measures the percentage of peak power drop off during the 30 sec test and is calculated using the formula; FI (%) = [1 - (lowest power kgm kg 5 sec^{-1}/ lowest power kgm kg 5 sec^{-1})] x 100 (74).

Laboratory based assessments such as the Wingate and Margaria-Kalamen tests are considered gold standard measures of muscular power. Their lack of specificity and the need for specialised equipment and trained personnel has impeded their widespread use in sport (73). A number of simple jump tests have been developed to assess lower limb muscular power in athletes. Each of the jump tests are performed from a stationary position and involve the complex interaction of several factors, including the maximal force developed, the rate at which force can be developed, and the neuromuscular coordination of the upper and lower-body segments. The stretch shortening cycle, trunk extension and head movements are initiated prior to each jump to develop maximum elastic and contractile energy in the muscles. Upper body and abdominal strength are used to create good posture and act to conduct forces between the upper and lower body.

The counter-movement jump (CMJ) is used to measure vertical displacement. The test is performed with hands placed on the hips throughout the duration of the jump (Figure 11A). A counter-movement jump with arm swing (CMJw), commonly described in the literature as a vertical jump, permits a co-ordinated arm back swing to aid vertical displacement (Figure 11B).

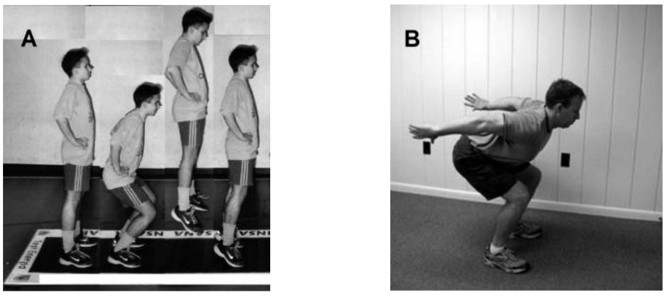

Figure 2.7 (A) Standard counter-movement jump (B) Modified counter movement jump

The assessment of horizontal distance following a standing long jump (SLJ) is another is another commonly used field test (figure 2.7).

Figure 2.8. Standing long jump

Hoffman *et al*., (2000) found a positive relationship between CMJ performance, peak power and mean power assessed during a 30 sec Wingate anaerobic power test among 17 year old basketball players (73). Using a standard linear regression model, Davis *et al*., (2003) found a strong relation between performance in the Margaria - Kalamen test and vertical jump performance (75). These studies suggest that the vertical jump test may be a suitable alternative to the Wingate test and Margaria – Kalamen test.

Reliability refers to the consistency or repeatability of test scores (22). A test is reliable if it produces consistent results when administered under standardised conditions. The test-retest method is a commonly used measure of reliability and measures the variation in measurements taken by a single person on the same item (22). This includes intra-rater reliability and is expressed as the intra-class correlation (range 0.00-1.00) of test scores from two administrations of a given test. In contrast, inter-rater variability describes the degree to which different testers can obtain the same score on the same subjects (22).

Markovic *et al*., (2004) had 93 college age men perform 3 CMJ tests with 1 min recovery between trials and reported an intra-class correlation co-efficient of 0.98 (76). Slinde *et al.,* (2008) examined the test re-test reliability of the vertical jump test with and without arm swing (77). Men and women between the age of 18 and 25 years completed three non-consecutive CMJw and CMJ tests on two separate occasions separated by 7 days. The highest score in each test was selected. High and statistically significant intra-class correlation coefficients were found for the CMJw (r=0.93) and the CMJ (r=0.93) tests.

Moir *et al.,* (2008) investigated the test re-test reliability for the CMJ test among college age men and women (78). Study participants completed three CMJ tests during four testing sessions separated by one week. Peak jump height and the average height achieved in three jumps from each session were recorded. Correlation coefficients ranging from 0.87

– 0.96 were reported based on a single jump and the average of three jumps. Averaging jump height across multiple trails did not greatly improve the reliability of the CMJ jump test.

The National Football League (NFL) is the highest level of competition in American football, and potential collegiate level players are invited to the annual NFL Combine where coaches and scouts get the opportunity to assess physiological capabilities of individual players. Although the SLJ is one of the fitness tests used in the NFL draft, there is anecdotal evidence that it is less popular than the vertical jump test (79). Among children between the age of 6 and 17 years there is a strong relation between performance in the SLJ and the CMJ (r^2=0.83) and the SLJ and the CMJw (r^2=0.86) (57). Performance in the SLJ also showed a stronger association with upper body muscular strength tests than the CMJ or CMJw. In young children, the SLJ test may therefore be a better test of overall muscular strength than CMJw or CMJ tests.

Arm swing may contribute to performance in the vertical jump test. Studies in men and women found that the height attained in the CMJw test was higher than the CMJ test (77, 80). It is possible that the increased height and velocity of the centre of mass at take-off may contribute to the superior jump height in the CMJw. Elevation of the arms in the CMJw raises the centre of mass, while increased velocity at take-off is due to a series of events in which the arms build-up energy early in the jump and the transfer to the energy to the rest of the body (80).

Vertical jump height has been found to range from 50 - 65 cm in Gaelic football players (table 2.5). Among elite collegiate level Gaelic football players, midfielders produce greater power during the vertical jump as well as greater vertical displacement than all other positions (14). Although the relatively small number of subjects (n=28) in this study may not be representative of collegiate players nationwide, this particular finding is not surprising considering that midfield players are required to compete for aerial possession more frequently than players in any of the other positions. Performance in the CMJw test is similar in collegiate level defenders and forwards and elite county players (11, 14). Table 2.5 outlines studies that have evaluated the CMJw test in Gaelic football players.

Table 2.5 Selected studies that evaluated CMJw performance in Gaelic football

	Level	**Position**	**n**	**CMJw (cm)**
McIntyre & Hall (14)	Collegiate	Defender	12	54.0 ± 7.2
McIntyre & Hall (14)	Collegiate	Forward	12	56.0 ± 6.0
McIntyre & Hall (14)	Collegiate	Midfield	4	65.0 ± 4.0
Watson (11)	County	-	32	50.3 ± 5.8
Brick & O'Donoghue (12)	County	-	25	62.2 ± 5.1
Kirgan & Reilly (81)	Club	-	15	48.6 ± 4.7

Values are mean ± SD.

No difference has been found in CMJw or running vertical jump performance between drafted and non-drafted players over a 3 year period at the Australian Football League's (AFL) National Draft Camp (82). However, running vertical jump performance, which involves a 5 metre run-up and take-off from the outside leg was later identified as a distinguishing factor between debutants and non-debutants among drafted players. Data from studies involving an elite adult Australian Rules football team indicate that starters perform better than non-starters in the CMJ test (5). However, there was no difference in CMJw performance between starters and non-starters. Among elite level junior Australian

Rules football players, performance in both the CMJ and CMJw discriminated between starters and non-starters in (47, 83). In contrast, Young & Pryor (2007) found no difference in CMJw performance between starters and non-starters among junior Australian Rules football players (62). Skill players (wide receivers, corner backs, free safeties, strong safeties and running backs) drafted from the NFL Combine, perform better in the CMJw test than non-drafted skill players (84). Performance in the CMJw has also been shown to differentiate between elite and sub-elite rugby league players (48). No positional differences were found in CMJw test performance among junior and amateur rugby league players (65, 67).

Interestingly, elite soccer goalkeepers have been shown to perform better in explosive power tests including the CMJ test than all other positions (64). A review of studies that evaluated vertical jump performance in youth players from a variety of field based sports is provided in tables 2.6 and 2.7. Studies evaluating the SLJ in Gaelic football players are outlined in table 2.8.

Table 2.6 Selected studies that evaluated CMJw performance among young elite field based athletes

Source	**Sport**	**Level**	**n**	**CMJw (cm)**
Veale *et al*., (83)	Australian Rules	Selected	38	60.7 ± 5.8
		Non-selected	16	57.4 ± 5.0
Young & Pryor (62)	Australian Rules	Selected	177 – 200	60.6 ± 5.5
		Non-selected	125 – 154	58.1 ± 6.0
Gabbett *et al*., (48)	Rugby league	Junior elite	28	51.6 ± 7.7
	Rugby league	Junior sub-elite	36	46.9 ± 6.8
le Gall *et al.*, (17)	Soccer	U-14 International	16	43.7 ± 7.25
		U-14 Professional	56	42.6 ± 5.8
		U-15 International	16	47.9 ± 6.1
		U-15 Professional	54	46.3 ± 5.5
		U-16 International	16	50.6 ± 6.4
		U-16 Professional	57	49.4 ± 5.7

Values are mean ± SD.

Table 2.7 Selected studies that evaluated CMJ performance among young Australian Rules and soccer players

Source	**Sport**	**Level**	**n**	**CMJw (cm)**
Keogh (47)	Australian rules -U18	Selected	29	55.2 ± 7.9
		Non-selected	11	50.1 ± 4.6
Wong *et al*., (60)	Soccer-U14	U-14 Goalkeeper	10	52.5 ± 5.7
		U-14 Defender	20	54.3 ± 7.7
		U-14 Midfield	25	53.2 ±12.9
		U-14 Forward	15	53.9 ± 6.1

Values are mean ± SD.

Table 2.8 Selected studies that evaluated standing long jump performance of Gaelic football players

Source	**Level**	**n**	**SLJ (cm)**
Reilly & Doran (1)	County	21	229 ± 16
Keane *et al*., (8)	County	30	244 ± 20
Young & Murphy (85)	County	21	229 ± 16
Keane et al., (8)	Club	40	228 ± 10
Kirgan & Reilly (81)	Club	15	210 ± 8

Values are mean ± SD.

Vertical jump performance is related to muscular force production, jump technique, joint mobility and a number of anthropometric measures (75). Percentage body fat is inversely related to vertical jump performance among recreational adults (75, 77). Sporis *et al*., (2009) also found a strong inverse relation between percentage body fat and performance in a CMJ and squat jump in a group of elite soccer players (64). A squat jump is similar to the CMJ with the exception that a squat position is assumed prior to take off and no counter-movement is permitted. These findings are not surprising considering that excess adipose tissue acts as a dead weight when body mass is repeatedly lifted against gravity (14).

It has been recommended that strength and conditioning professionals should target strength and power training in the hip and knee extensors to maximise vertical jump performance (86). Olympic lifts offer a unique stimulus for developing power. There is evidence that such lifts should be included in a resistance training programme for adolescents requiring quick, powerful movements (87).

2.5.1 Summary

Laboratory based assessments remain the gold standard measure of muscular power. However, the need for expensive equipment and trained personnel has limited the use of these tests outside professional sports teams and research institutions. Vertical jump tests correlate well with laboratory based measures of speed and power and can be used as reliable and practical alternatives. Team based sports are characterised by activities that require a high level of muscular power and elite players will generally possess a greater degree of muscular power than non-elite players. Gaelic football players who play in the midfield position generally perform best in tests of muscular power.

2.6 Speed

Gaelic football is characterised by short periods of high intensity anaerobic efforts interspersed with light to moderate intensity activities. Speed is essential for winning possession of the ball, evading opponents, tackling, and scoring. Time motion analysis studies indicate that collegiate level Gaelic football players perform on average 95 high-intensity bursts per game with an average duration of 6 sec (2). The ability to attack and defend at pace is advantageous in all field sports. Greater speed is also likely to result in the application of greater force during tackles and collisions (48). Maximal sprinting speed although important, is only one aspect of the speed requirements for Gaelic games. Acceleration, the rate of change of velocity as a function of time is also important for optimising performance.

The time required to complete 10 m has been identified as the most significant predictor of 40 m sprint time, highlighting the importance of rapid acceleration to overall sprint performance (88). Brechue *et al.,* (2010) found that maximal acceleration is attained at 9.1 m and maintained through 18.3 m during a 36.6 m sprint in collegiate level American football players. Sprint performance was largely determined by acceleration, a pattern that was consistent across positions (89).

It appears that stronger, leaner athletes have an advantage in terms of sprint performance. Sporis *et al*., (2009) found an inverse relationship between body fat and 5 metre sprint time among elite soccer players (64). Likewise, Brechue *et al*., (2010) found an inverse relation between body mass, acceleration and velocity in sprint tests < 60 m (89) . An inverse relation has also been found between the 3 repetition max (RM) bench press and flying 30 m run time among elite AFL players (5). Measures of lower body strength are also significantly related to acceleration and velocity in collegiate level American football players (89).

Linear running speed over distances ranging from 5 to 40 m has been identified as a characteristic of elite players in Australian Rules football, American football, and junior rugby league (46, 48, 82, 84). Performance in a 40 yard sprint is one of the primary physiological characteristics that discriminate between drafted and non-drafted players across all positional categories in American football (84). Similarly, drafted Australian Rules players have significantly better 5 m, 10 m and 20 m sprint times than non-drafted players (82). In addition, starters in an elite AFL team performed significantly better than non-starters in both standing 10 m and flying 30 m sprint times (5). McIntyre (2005) found no significant difference in 15 m sprint performance between Gaelic footballers, hurlers and soccer players.

Linear speed has also been identified as an important physical attribute among junior level Australian Rules players. The match committee in charge of each junior level Australian Rules football game award points to the best performers during each game. Players participating in the Victorian U-18 football league who received a medium to high number of votes were significantly faster over 5 m and 20 m than players who obtained a low number of votes (62). Elite junior level rugby league players have significantly faster times over 10 m, 20 m and 40 m than their sub-elite counterparts (48).

Sporis *et al.*, (2009) compared positional differences in 5 m, 10 m and 20 m among elite soccer players (48). Soccer goalkeepers had significantly slower times over 10 m and

20 m than other team members. However, goalkeepers compared favourably with other positions in the 5 m sprint times. These findings suggest that acceleration over a very short distance is important for elite goalkeepers. Forwards players were significantly faster over 5 m, 10 m, and 20 m than midfield players. There is no difference in sprint times between forwards and defenders (64). This is unsurprising given that forwards have to consistently try to evade defenders in order to obtain possession while defenders must be able to maintain pace with forwards to prevent them obtaining possession and creating scoring opportunities.

Rugby league players who play in the wing position rely heavily on speed during the course of game. Meir *et al*., (2001) found that ‘wingers’ at the professional level had faster 15 m sprint times than forwards, and with the exception of hookers who were faster over 40 metre than all other forward positions (66). Similarly, elite level junior outside backs are significantly faster over 10 m, 20 m, and 40 m than players in any other position (48). Amateur rugby league backs were also found to faster over 40 m than forwards (67). These results are not surprising given the considerable variation in positional demands in rugby league. A summary of selected studies that evaluated running speed in field based athletes is presented in table 2.9.

Table 2.9 Selected studies that evaluated running speed in field based athletes

Source	**Sport**	**Level**	**n**	**5 metres (sec)**	**10 metres (sec)**	**15 metres (sec)**	**20 metres (sec)**	**40 metres (sec)**
Young & Pryor (62)	Australian Rules	Junior elite	177-200	1.12 ± 0.05			3.13 ± 0.09	
Pyne *et al*., (82)	Australian Rules	Elite	251	1.09 ± 0.06	1.81 ± 0.07		3.04 ± 0.09	
Gabbett *et al*., (48)	Rugby league	Junior elite	28		1.81 ± 0.08		3.11 ± 0.12	5.56 ± 0.22
Young *et al*., (5)	Australian Rules	Professional	17		1.86 ± 0.06			
Sporis *et al*., (64)	Soccer	Professional	270	1.44 ± 0.50	2.27 ± 0.40		3.38 ± 0.70	
Gabbett (67)	Rugby league	Amateur backs	16		2.53			6.79
		Amateur forwards	19		2.62			6.45
Meir *et al*., (66)	Rugby league	Professional backs	28			2.21 ± 0.11		5.27 ± 0.19
		Professional forwards	26			2.32 ± 0.18		5.08 ± 0.20
McIntyre (13)	Soccer	League of Ireland	21			2.48 ± 0.1		
	Hurling	County	29			2.49 ± 0.1		
	Gaelic football	County	30			2.53 ± 0.1		

Values are mean ± SD.

2.6.1 Summary

The ability to complete short bouts of high intensity running is a key requirement of many field based sports and will often determine the outcome of key moments during a game. Although maximal speed is important, the average duration of high intensity bursts in a Gaelic football game is 6 sec, highlighting the importance of acceleration to overall performance. Lean muscle mass and lower body strength is advantageous in this regard. Maximal linear speed is the primary physical fitness measure that consistently differentiates elite players from sub-elite players across a number of team sports. The positive relationship between linear speed and the number of possessions per game underlines the importance of speed to overall performance.

2.7 Intermittent High Intensity Exercise - Bioenergetics

The phosphagen system, aerobic metabolism and anaerobic metabolism are three separate yet closely integrated energy producing systems that operate to satisfy the energy requirements of working muscles during sports that involve repeated bouts of high intensity exercise interspersed with periods of active passive recovery (90). The relative contribution of each energy system is dependent in large part on the intensity and duration of the activity and subsequent recovery intervals (90).

High intensity activities are fuelled primarily by the hydrolysis of intramuscular phosphocreatine (PCr) and the breakdown of carbohydrates during anaerobic glycolysis (91). The intramuscular concentration of PCr, although small is 3 times greater than Adenosine Triphosphate (ATP), and provides a simple and rapid bioenergetic pathway to regenerate ATP (74). The ability to provide an instantaneous source of energy for the synthesis of ATP makes the phosphagen system important for performance in high-intensity, short duration physical activities such as short duration sprints, jumping and accelerating (22).

The breakdown of PCr is catalysed by the enzyme creatine kinase and results in the formation of ATP and free creatine. The bioenergetic pathway of ATP production from the breakdown of PCr is called the ATP-PC system or the phosphagen system (74). Levels of intramuscular PCr decrease significantly during bouts of high intensity activity. A single 30 sec bout of high intensity exercise has been found to decrease PCr levels to 20% of resting values in trained university students (92).

Although the rate of energy release from the phosphagen system is very high, the capacity is very limited. Consequently, the intramuscular PCr stores must be rapidly re-synthesised to allow players undertake repeated bouts of high intensity efforts (93). Following a single 30 sec bout of high intensity exercise, intramuscular PCr levels are restored to 86% of resting values at 6 min of recovery (92). The PCr repletion rate may be dependent of the number and duration of high intensity activity bouts. Dawson *et al*., (1997) compared the effect a single 6 sec maximal sprint on a cycle ergometer and 5 x 6 sec sprints every 30 sec on PCr repletion in trained athletes (94). PCr restoration was 70% complete after 30 sec of recovery following the 6 sec sprint and was fully restored after 3 min. Following the 5 sprints, PCr repletion was slightly < 50% after 30 sec of recovery and was 80% complete after 3 min of recovery.

The resphosphorylation of PCr occurs in the mitochondria and requires the hydrolysis of intramuscular ATP (figure 2.9) (95). The availability of ATP for the restoration of PCr is obviously very limited during high intensity exercise. The ATP required for PCr restoration is largely provided by the aerobic metabolism of carbohydrate and fats during the fast component of the recovery period (74).

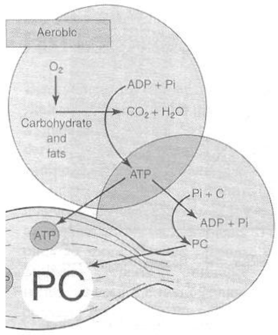

Figure 2.9 Phosphocreatine Repletion (74)

There is a direct relation between PCr depletion during exercise and oxygen required for restoration during the recovery period (74). Under normoxic conditions PCr repletion rate is limited by oxygen availability (96). Haseler *et al.,* (1999) examined the influence of oxygen availability on PCr repletion rate in trained men following 3 bouts of 5 min steady state sub maximal exercise while breathing 3 different oxygen concentrations (96). Each completed exercise bout was followed by a 5 min active recovery period and a 40 min rest period. PCr repletion following sub-maximal exercise slowed with breathing a hypoxic gas mixture and enhanced with breathing a hyperoxic gas compared with normoxia.

Anaerobic glycolysis involves the breakdown of carbohydrates during a series of sequential enzymatically catalysed chemical reactions. Energy released during two of the reactions is directly coupled via two substrate level phosphorylations to the resynthesis of 4 moles of ATP. In addition, the coenzyme nicotinamide adenine dinucleotide (NAD^+) is reduced to NADH during the glyceraldehyde-3-phosphate reaction. When the oxygen supply is available to meet the metabolic demands, the reduced NADH molecules are transported to the mitochondria to produce ATP by oxidative phosphorylation. In contrast, when the oxygen supply is unable to keep up with the metabolic demands, the NADH unloads its hydrogen onto pyruvate resulting in the formation of lactic acid. This enables the continuation of rapid ATP formation by anaerobic substrate level phosphorylation (74). The accumulation of lactic acid during anaerobic glycolysis may ultimately results in the cessation of activity or forced reduction in the work output (90). Anaerobic glycolysis can provide energy to generate ATP at relatively high rates. However, the capacity of the system is limited due to the accumulation of hydrogen ions that result from the accumulation of lactic acid (74).

The aerobic system is the most efficient method for restoring ATP. It involves primarily the breakdown of carbohydrate and fats in the presence of oxygen and is the primary source of ATP production during low intensity activity (90). The capacity of the aerobic system is high but it is limited by the rate of production (74).

2.7.1 Maximal Oxygen Uptake

Maximum oxygen uptake ($\dot{V}O_2$ max) defines the upper limit of the cardiopulmonary system. It is an integrative measure of the ability of the lungs to supply oxygen, the cardiovascular system to pump and transport oxygenated blood to the exercising muscle, and the ability of the working muscles to utilize oxygen (90). According to the Fick equation, $\dot{V}O_2$ max is the product of maximal cardiac output and maximal arteriovenous oxygen across the body. This implies that both oxygen delivery and oxygen extraction factors are important in ensuring that the muscle receives an adequate supply of oxygen (74).

Studies examining the relation between maximal aerobic capacity and performance in soccer have been equivocal. The most successful team in the elite Norwegian soccer league were found to have a significantly higher $\dot{V}O_2$ max than the least successful team. (97) In contrast, others found no relation between $\dot{V}O_2$ max and the final position in the Italian soccer league (98). Aziz *et al*., (2007) examined the relation between aerobic fitness levels and positional ranking among professional soccer teams in Singapore from 2002 – 2004. There was a significant relation between aerobic fitness and positional ranking during the 2003 season, but not during the 2002 or 2004 season (99).

The relation between $\dot{V}O_2$ max and the fitness requirements of intermittent field sports are equally inconclusive. Tomlin & Wenger (2002) examined the relation between $\dot{V}O_2$max, power maintenance and oxygen consumption during intense intermittent exercise among moderate and low fit female recreational soccer players (100). The women performed 10 x 6 sec sprints on a cycle ergometer interspersed with 30 sec of active recovery. Oxygen uptake was measured during exercise and recovery. Peak power output was similar in both groups. The decrement in power over the 10 sprints was smaller in the moderate fitness group than the low fitness group. Oxygen consumption was significantly higher during 9 of the 10 sprints in the moderate fitness group than the low fitness group. There was a significant positive relation between $\dot{V}O_2$max and oxygen consumption ($r = 0.78$) and a significant inverse relation ($r = -0.65$) between $\dot{V}O_2$max and the percentage decrement in power output over the 10 sprints. It appears that a high $\dot{V}O_2$max may be related to an increased aerobic contribution to repeated sprints and enhanced ability to resist fatigue during intermittent activity. Meckel *et al*., (2009) also found a moderate inverse relation between the performance decrement in a 12 x 20 m repeated sprint test and $\dot{V}O_2$ max among elite adolescent soccer players, indicating that the aerobic system may contribute to maintaining the intensity level of short bursts of activity (101). However, Wadley & Rossignol (1998) found no evidence of a relation between aerobic capacity and performance in a repeated sprint assessment consisting of 12 x 20 m sprints among youth Australian Rules football players (102). A recent review of aerobic conditioning in field sports highlighted that $\dot{V}O_2max$ is only moderately related ($r = 0.62 - 0.68$) to repeat sprint ability in field hockey, rugby union and soccer (103).

The measurement of $\dot{V}O_2max$ is typically performed in a laboratory and requires sophisticated equipment and trained personnel. Consequently, laboratory tests are impractical for measuring large groups of individuals. To overcome this problem a number of field based tests have been developed to estimate aerobic capacity. These tests allow large numbers to be tested simultaneously, without the need for expensive equipment and highly trained personnel.

Field based tests consist of walking or running a fixed distance in a given time. The Cooper 12 min test (12 MRT) and the Rockport one mile fitness walk were 2 of the early field based tests developed to estimate $\dot{V}O_2max$ (68). Leger *et al*., (1989) developed a 20 metre shuttle run test (20 MST) to estimate aerobic fitness in adults attending fitness classes and athletes participating in sports characterized by frequent stops and starts (104). The test consists of a number of stages called levels. Each level is one min in duration and is comprised of a number of 20-meter laps called 'shuttles'. Running velocity is controlled by an audio 'bleep' which signals the completion of a stage. Stage 1 begins at a speed of 8.0 $km \cdot hr^{-1}$, stage two starts at 9.0 $km \cdot hr^{-1}$ after which the speed increases by 0.5 $km \cdot hr^{-1}$ at the end of each 1-min stage.

Early validation studies reported correlations ranging from 0.76 to 0.93 have been reported in school children, college level athletes, and adults attending fitness classes (105, 106). The test is easy to administer, requires a relatively small area, allows a large number of individuals to be tested simultaneously, and its progressive multi-stage nature makes it applicable to subjects of all fitness levels. A major limitation of the test is that it does not replicate the intermittent nature of team sports such as Gaelic football, soccer, rugby and Australian Rules football.

The Yo-Yo Intermittent Recovery Test (YYIRT) is a field based test that measures the ability to perform repeated bouts of high intensity intermittent work, and was designed to replicate the physiological strain of intermittent sports (107). The YYIRT has two levels. Level 1 (YYIRT1) is designed for low-level athletes and level 2 (YYIRT2) for elite athletes (108). The YYIRT1 consists of a number of stages or levels. Players perform a series of 20 metre shuttle runs at a pace set by an audio recording. Each series of shuttle is followed by a 10 sec recovery period during which the participants jog or walk 10 m. The time allowed for each shuttle progressively decreases. The YYIRT2 starts and maintains higher running velocities than the YYIRT1, requiring an increased anaerobic contribution in conjunction with a significant aerobic contribution (107).

Krustrup *et al*., (2003) reported a high test re-test reliability (r = 0.98) for the YYIRT1 among a group of elite professional soccer players (109). Similarly, a strong relation has been found between performance in the YYIRT1 and $\dot{V}O_2$max among habitually active males (r = 0.71) (109), recreational team sport athletes (r = 0.87) (108), and elite junior basketball players (r = 0.77) (110), indicating that the YYIRT1 is a good measure of aerobic fitness.

Conversely, Castagna *et al*., (2006) found a relatively moderate relation (r = 0.46) between YYIRT1 performance and $\dot{V}O_2max$ in amateur soccer players (111).

A study by Chaouachi *et al*., (2010) used the YYIRT1 to examine the relation between intermittent endurance and repeated sprint ability in professional soccer players (112). The repeated sprint protocol required players to perform 7 x 30 m maximal sprints with 25 sec recovery between efforts. A moderate inverse relation was found between YYIRT1 performance and repeated sprint ability. The players were then divided into two groups based on whether they achieved a score above or below the median distance. Interestingly, the players who achieved a score above the median value also performed significantly better in the repeated sprint test.

A study of 37 professional soccer players found a relation between performance in the YYIRT1 and several soccer match activities including the amount of high intensity running, the sum of high speed running and sprinting and the total distance covered during a game. A similar pattern was found among elite female soccer players (113). Among youth soccer players, performance in the YYIRT1 has been found to correlate with the frequency of high intensity activities, high intensity running and sprinting, and total distance covered during a game (112, 114).

The YYIRT1 has been used in Australian Rules football, rugby league and soccer to differentiate between elite and sub elite players. Elite junior Australian Rules players performed better than sub-elite players in terms of total distance covered and number of runs completed (115). Similarly, professional rugby league players out perform their semiprofessional counterparts in the YYIRT1 (116). Top-level professional soccer players competing in the Italian league and Champions League covered 10.7% greater distance in the YYIRT1 than professionals competing in the lower rated Danish league (117). Table 2.10 summarizes the results of studies that have estimated or measured $\dot{V}O_2$max values in Gaelic football players.

Table 2.10 Studies that have estimated or measured $\dot{V}O2$max values in Gaelic football players

Source	**Level**	**n**	**$\dot{V}O_2$max (ml·kg^{-1}·min^{-1})**
McIntyre (13)	County	30	48.7 ± 7.0*
McIntyre & Hall (14)	Collegiate	28	56.8 ± 5.0
Brick & O'Donoghue (12)	County	25	57.0 ± 3.9*
Keane *et al*., (8)	County	37	54.1 ± 3.2
	Club	35	51.4 ± 5.8
Watson (11)	County	32	58.6 ± 3.8

Values are mean ± SD; *Estimated from progressive 20 m shuttle run test.

2.7.2 Summary

Gaelic football is characterised by short duration high intensity running interspersed with light aerobic walking or jogging. High intensity running is primarily fuelled by the phosphagen system and anaerobic glycolysis. The aerobic system contributes very little to a single sprint but becomes increasingly important during repeated sprint activity. Oxygen consumed during the recovery period and subsequent breakdown of carbohydrates and fat stores provides the ATP required for PCr restoration. Aerobic capacity may be directly related to PCr replenishment allowing individuals with an elevated aerobic capacity recover faster between bouts high intensity running.

$\dot{V}O_2$ max is the standard measure of aerobic capacity and evaluates the ability of the lungs to supply oxygen and the cardiovascular system to transport oxygenated blood to the working muscles, and ability of the muscles to use the oxygen. $\dot{V}O_2$ max is typically measured in a laboratory setting requiring expensive equipment and trained personnel. The YYIRT1 is a field based fitness that was specifically designed to replicate the physiological strain of intermittent sports. Studies have reported satisfactory test re-test reliability values for the YYIRT1. Performance in the YYIRT1 may be related to VO_2 max and repeated sprint ability among team sport athletes. There is also a notable relationship between YYIRT1 performance and several match related activities in soccer.

2.8 Motion Analysis in Team Sports

The complex and irregular nature of field based sports are incompatible with traditional methods of studying exercise in laboratory conditions (118). Furthermore, obtaining physiological data in a competitive environment may be limited by the rules and regulations of competition (119). Video based analysis, computer based tracking (CBT) and global positioning systems (GPS) are now used routinely to analyse movement patterns in team sports (18).

2.8.1 Video Based Analysis

Reilly & Thomas (1976) used video based analysis to investigate player movement patterns in soccer more than 35 years ago. Video footage from a soccer game was captured using a series of individual cameras positioned at various locations around the playing pitch (120). Player movement patterns were later observed and categorised according to speed of locomotion. Independent footage of the same players performing specific activities from walking to sprinting was used for reference purposes. The frequency and duration of each activity was recorded, and the total distance covered was calculated as the sum of the distances covered during each activity. Advances in video based analysis may be attributed to higher quality cameras and improved coding methods. Video based analysis is not without limitation. A major limitation of video based analysis is that filming is limited to one player per camera. In addition, video capture and analysis is time consuming and gait changes during game movements can result in substantial errors (121).

2.8.2 Computer Based Tracking

CBT involves visual and mechanical tracking of player movement in real time (121). This system uses reference markings on the field of play to generate a computerised playing surface that is calibrated so that a given movement of the mouse equates to the distance travelled by the player. Information on distance travelled and mean running velocities are provided in real time, and the entire sequence of player movements may be downloaded at the end of each playing period for analysis (121). CBT requires one recorder per player which may limit the number of players monitored at any one time.

2.8.3 Global Positioning Systems

GPS technology is based on the principle of GPS satellite ranging and was originally developed by the United States (U.S.) Department of Defence.(122). It provides information on time, speed, distance, position, altitude and direction. The integration of GPS and personal devices such as laptops, tablets and mobile phones has generated an unprecedented amount of civilian use particularly in the land transportation, maritime and aviation industries for vehicle tracking (122). In recent years GPS technology has become increasingly popular as a method of tracking movement patterns in many field based sports.

Four orbiting satellites are required to accurately triangulate the location of a GPS receiver (122). Each satellite is equipped with an atomic clock that emits constant radio signals detailing the exact time and its position (123). The orbiting satellites act as a reference point for GPS receivers allowing position and time to be established as a function of its distance from each satellite. Once the GPS receiver establishes its location, changes in distance divided by the time between each logged position is used to determine movement velocity. (124). Doppler shift is a term used to describe the rate of change of radio frequency signals, a technique that may also be used to assess velocity (125).

Accurately triangulating the location of a receiver is dependent on the availability and positioning of satellites relative to each other (126). Dilution of precision (DOP) is the term used to describe the accuracy of triangulation based on satellite arrangements (126). The DOP scale ranges from 1-50. An ideal DOP of 1 means that one satellite is positioned directly overhead and the remainder are equally spaced. Values at the higher end of the scale indicate that satellites are grouped tightly together and the accuracy of triangulation may be reduced (126). The orbiting nature of satellites makes testing conditions impossible to standardise.

2.8.4 Selective Availability

Although GPS technology became fully operational in 1995 there were two distinct levels of service available; a standard and precise service for civil and military uses respectively (122). Intentional degradation of the civilian signal system by the U.S. Department of Defence arose due to growing concern that hostile countries might utilise the civilian GPS signal for precision weapon guidance. During this period of 'selective availability', the use of differential GPS (DGPS) allowed researchers eliminate the majority of error sources. DGPS utilises reference receivers at known locations to compare their fixed position with the position given by the satellites. The reference receiver then sends correctional information via a differential receiver to the mobile receiver to adjust its positional calculations (127). In May, 2000 selective availability was discontinued by order of the president of the U.S. instantly improving the accuracy of commercially available receivers tenfold (122).

Non-differential GPS (NDGPS) receivers have several distinct advantages over DGPS receivers. They are generally cheaper, smaller, and lighter and there is no need for a stationary receiver which makes the process of data collection less complex (124). NDGPS offers a more portable and cost efficient system which may be used in any outdoor venue used for competition (128). GPS units are currently available with a 1, 5, 10 and 15-Hz sample rate, which refers to the speed at which the system may gather movement information (129). They provide information on time, speed, distance, position, altitude and direction. Information on heart rate is also gathered simultaneously with the aid of a heart rate monitor.

2.9 The Validity and Reliability of GPS to Measure Human Locomotion

The validity of a test is the degree to which a test or instrument measures what it purports to measure (22). A measure of validity is obtained by comparing the difference between a standard or 'criterion' measure and the GPS recorded measure. Reliability is an essential component of any measurement and is a simple measure of the consistency or repeatability of a measure (22). The coefficient of variation (CV) is a measure of reliability and may be categorised as good (<5%), moderate (5 – 10%) or poor (>10%) (130). A number of early validation studies investigated the ability of GPS technology to accurately measure movement speed and distance travelled during human locomotion (123-126, 131)

Schutz & Chambaz (1997) used a lightweight navigational tool to assess whether GPS could be used to assess steady state movement at a range of different velocities (123). A healthy male completed 19 and 22 bouts of walking and running respectively at velocities ranging from 2-20 to $km \cdot h^{-1}$ on an athletics track. A portable metronome was used to ensure a consistent speed during each bout of walking and running. There was a very strong correlation between speed of displacement measured by chronometry and that calculated by GPS across all trials (r=0.99). The estimate of error was 1.1 $km \cdot h^{-1}$ for walking and 0.7 $km \cdot h^{-1}$ for running. The overall coefficient of variation was a moderate 5%. This study offered promise regarding the use of GPS to measure velocity.

A similar study by Schutz & Herren (2000) investigated the ability of DGPS with a sample rate of 0.5-Hz to accurately measure speed of movement in humans (125). A 24 year old trained male performed multiple efforts of walking and running distances of 100 m and 200 m respectively, on a straight road. Actual speed was measured using a certified chronometer and ranged from 2.9 to 25.2 $km \cdot h^{-1}$ between the two protocols. Again there was an excellent correlation (r^2=0.99) between actual speed and that measured by DGPS. In comparison with the earlier findings of Schutz and Chambaz (123), the use of DGPS reduced the estimate of error for walking and running by 1 $km \cdot h^{-1}$ and 0.59$km \cdot h^{-1}$ respectively.

The validity of GPS to accurately measure velocity during activities involving non-linear movement patterns was investigated by Witte & Wilson (2004) (126). A cyclist performed multiple laps of a 400 m track, a 16 m and a 30 m diameter roundabout at pre-determined speeds ranging from 10 to 35 $km \cdot h^{-1}$. This was followed by cycling on a straight road while performing rapid accelerations and decelerations. During track cycling, 45% of the speed values determined by the GPS receiver were within 0.2 ms^{-1} of the measured value with a further 19% within 0.4 ms^{-1}. The average error on the small roundabout was 0.75 ms^{-1} compared to 0.49 ms^{-1} on the large roundabout. Only 16% of values determined by the GPS receiver during cycling on the small roundabout were within 0.2 ms^{-1} of the measured value and 28% were within 0.4 ms^{-1} compared with 23% within 0.2 ms^{-1} and 41% within 0.4 ms^{-1} on the larger roundabout. Almost 60% of the speed values determined by the GPS receiver during straight line cycling were within 0.2 ms^{-1} and 82% within 0.4 $ms^{-1}$of the measured value. Overall, the measurements were reasonably accurate with a tendency to underestimate velocity during bend cycling, particularly on circular paths with small radii.

A follow up study from the same laboratory later compared the accuracy of a Wide Angle Augmentation System (WAAS) enabled GPS with previously reported data from NDGPS (131). Originally developed to improve position determination for aircraft guidance during low visibility, WAAS allowed GPS data to be gathered from multiple reference stations known as ‘wide area master stations’ and offered superior accuracy in the determination of both position and speed (131). The initial part of this study compared the positional data provided by a WAAS enabled receiver and a non-WAAS enabled receiver worn simultaneously by a cyclist travelling at a constant speed of 15 $km \cdot h^{-1}$ on a linear path. A median error of 0.11 m and 0.78 m was found for the WAAS enabled and non-WAAS enabled receivers respectively.

The second part of this study trialled the WAAS enabled unit on the same courses and under the same conditions as previously described (126). The speed values determined by WAAS enabled GPS on both the linear and non-linear pathways compared favourably against those previously reported for a NDGPS receiver (126). During cycling on the small circle, 64% of the speed values were within 0.2 ms^{-1} and 87% within 0.4 ms^{-1} of the actual speed values. On the large circle, 65% of the speed values were within 0.2 ms^{-1} and 87% within 0.4 ms^{-1} of the actual speed values. The most accurate values were again collected during the straight line trial with 67% and 88% of values within 0.2 ms^{-1} and 0.4 ms^{-1} respectively. WAAS enabled GPS units may provide improved accuracy of speed determination compared with non-WAAS enabled units. However the tendency to underestimate speed on non-linear paths remains.

Townshend *et al.* (2008) later investigated the effect of curved courses on the accuracy of NDGPS to measure speed and displacement during bouts of walking and running (124). Two active men and one active female between the age of 22 and 28 years performed multiple bouts of walking and running a distance of 100 m and 60 m on linear track, respectively. The final trial involved walking and running the circumference of a 10 m radius circle. Electronic timing gates were used to calculate actual speed during the 60 m linear and circular runs. Compared with the actual distance of 100 m, the average measured GPS distance was 100.46 m. Speed determined by GPS was strongly correlated with actual speed on both the linear and circular courses (r=0.99). The average error on a curved path was 0.06 ms^{-1}. Movement speed was slightly underestimated on a circular path, with increasing error at higher velocities, which is in line with previous research in cycling (126, 131).

These early validation studies found that GPS could provide a valid measure of speed, and distance travelled, highlighting the potential for GPS technology to accurately measure movement patterns in team based sports. However, the fact that GPS tended to underestimate speed over non-linear paths, with increasing error at high velocity is a serious concern, considering that the majority of field based sports are characterised by frequent changes in direction and regular fluctuations in speed.

2.9.1 Validity & Reliability of GPS to Measure Sport Specific Movement Patterns

Increased access coupled with the relatively low cost of GPS technology has led to their widespread adoption in team sports. Several recent studies have assessed the validity of GPS technology to accurately measure movement patterns in field based sports (121, 129, 132-138). These studies typically involve individuals performing repeated bouts of predetermined marked courses while wearing one or more GPS units. Movement intensity is varied and participants follow the course as closely as possible. Information on distance and speed is later downloaded from the GPS receiver for analysis.

Edgecomb and Norton (2006) examined the validity and reliability of the first commercially available GPS device designed for team sports (SPI 10, GPSports Systems, SPI-10) (121). An elite level Australian Rules football player completed multiple trials of two pre-determined marked courses equipped with GPS and set-up to enable CBT. At least three identical trials were recorded using GPS and CBT in order to examine the intra-tester reliability of each system. Although the distance measured by GPS and CBT were both highly correlated with actual distance (r=0.998 – 0.999), there was a modest difference between the distance measured by a calibrated trundle wheel and that recorded by both tracking systems. GPS and CBT overestimated distance covered on the marked course by 4.8% and 5.8% respectively. Intra-tester reliability was 5.5% for GPS and 2.8% for CBT.

Although there is a tendency for both systems to overestimate distance covered by players, the errors are relatively small and therefore may not hinder the use of either system to monitor player movement patterns.

2.9.2 Sport Specific Testing

MacLeod *et al.*, (2009) designed a hockey specific circuit to assess the validity and reliability of a 1 Hz GPS system for analysing player movement patterns (137). Nine hockey players with an average age of 23.3 years completed 14 laps of a measured hockey specific circuit totalling 6818 m. Players were verbally instructed to perform different motions at different stages of the circuit. Time taken to complete four shuttle movements during the circuit was measured using electronic timing gates. Validity was determined by comparing the GPS distance and velocity with the actual distance and velocity at various stages of the circuit. There was a strong correlation (r=0.99) between the mean velocity recorded for the shuttle movements by the timing gates and the GPS. The average velocity and the recorded mean velocity were identical. The mean distance recorded by GPS was marginally overestimated by GPS (+3 m).

Coutts & Duffield (2010) investigated the validity and reliability of three different 1-Hz GPS models to measure the movement demands of field based sports (132). Equipped with 6 portable 1-Hz GPS devices including three different models, two moderately trained men with a mean age of 32 ± 2 years completed six laps of a 128.5 m team sport running circuit. The first 20 m of each lap consisted of a maximal sprint to identify GPS peak speed. Sprint performance was simultaneously measured using electronic timing gates. One min was allowed to complete each lap with a recovery period of 5-15 sec between each lap.

Although the lap distance and total distance were significantly different between the various GPS models, the total distance recorded by all 6 GPS devices were within 5 m of the true distance of the course. In addition, GPS peak velocity was significantly correlated with 20 m sprint time indicating that GPS may provide a valid measure of velocity over distances of at least 20 m. Intra-reliability values exceeded acceptable levels of accuracy during periods of high intensity running. According to these findings, 1-Hz GPS system may estimate total distance and peak speed with reasonable accuracy but may be susceptible to considerable measurement error during periods of high intensity.

Gray *et al.,* (2010) examined the effect of movement intensity and path linearity on the validity of a 1-Hz GPS system to measure distance travelled during walking, jogging running or sprinting and found that high intensity running involving frequent changes in direction may affect the validity of a 1-Hz system to estimate distance covered (133). A 25 year old male triathlete equipped with 8 GPS units (1 Hz) completed trials involving on a linear and non-linear 200 m course at each of the movement intensities outlined. The average total distance was marginally overestimated on the linear course at all intensities with the greatest error found during trials of walking and sprinting. In contrast, distance travelled on the non-linear course was underestimated at all intensities with increasing error from walking to sprinting (1.1 m – 19.6 m). Intra-receiver reliability values were < 5% across all movement categories on both courses. Inter-receiver reliability values were similar except during non-linear sprinting.

The fact that GPS devices with a sample rate of 1-Hz may be incapable of recording brief efforts <1 sec in duration may explain the poor level of reliability during high intensity activity (132, 133). An increased sample rate could potentially improve the data collection process. A number of studies have investigated the validity and reliability of GPS devices sampling at both 1-Hz and 5-Hz (134, 135, 138). These studies involved subjects performing a variety of linear, multidirectional and sports specific activities equipped with two different GPS devices sampling at 1-Hz and 5-Hz respectively.

Portas *et al.,* (2010) compared the efficacy of 1-Hz and 5-Hz GPS devices across several soccer related movement patterns (134). A healthy male participant performed several trials of a linear, multidirectional and soccer specific course. The side-line of a soccer pitch, from the corner flag to the half way line, was used as the linear course. Six different multidirectional courses were mapped out based on the existing line markings on a soccer field. The soccer specific course was based on the typical movement patterns exhibited by elite level players during match play. The linear and multidirectional courses were completed while walking at 6.4 $km\cdot h^{-1}$ and running at 12.9 $km\cdot h^{-1}$. Headphones linked to an audio device that relayed beeps at 1 s intervals to control pace were worn. The required velocity was maintained by passing markers at each audio beep. Sixteen trials were recorded on each course at each velocity. Ten 1 min trials of the soccer specific course involving frequent changes in velocity and direction were performed at maximal effort. There was a strong correlation between actual and measured distance for both the 1-Hz (r=0.99) and 5-Hz (r=0.99) devices on all courses. The margin of error during linear walking and running trials were comparable between the 1 Hz and 5 Hz units. Similar to the findings of Gray *et al.,*(2010), there was a larger measurement error when using the 1-Hz device on the multi-directional courses (133). The 5-Hz device performed slightly better on the same courses. The margin of error when estimating distance on the soccer specific course was modest for both 1–Hz (1.3-3%) and 5–Hz (1.5-2.2%) devices.

The complexity of the course was found to negatively affect the reliability of both GPS systems. The CV for linear motion ranged from 4.4 - 4.5% for 1-Hz and 4.5 - 5.3% for 5-Hz, marginally increasing on the multi-directional course for both 1-Hz (3.1 - 7.7%) and 5-Hz (3.4 - 6.1%) systems. The introduction of 180° turns resulted in the highest CV (1-Hz, 7.7%; 5-Hz, 6.1%) highlighting a threshold where the technology may become unreliable. The CV was comparable for the soccer specific trials, for 1-Hz and 5-Hz. The 5-Hz performed best of the two devices. However the differences between sample rates were trivial. Movement intensity had less of an effect on measurement accuracy that previously reported for a 1-Hz system (132, 133). A possible explanation may be that the peak speed reached in the multi-directional trial was only 12.9 $km \cdot h^{-1}$ and may not have been fast enough to truly test the capabilities of the technology. Furthermore, the duration of the soccer specific trial (1 min) and training status of the subject will have limited the proportion of activity performed at a very high intensity (>20 $km \cdot h^{-1}$).

Jennings *et al.,* (2010) undertook a similar study in 20 elite Australian soccer players (135). Equipped with both 1-Hz and 5-Hz GPS receivers, participants completed two trials of walking, jogging, striding and sprinting at a self-selected pace on both linear and change of direction courses. The linear course was 40 m in length with electronic timing gates at 10 m, 20 m and 40 m. The change of direction courses were both 40 m in length but categorised as either ‘gradual’ or ‘tight’. The gradual course required participants to perform a 90° change of direction every 10 m, compared with a 90°turn every 5 m on the tight course. Ten players completed a team sport running circuit including periods of walking, jogging sprinting, changing direction and decelerating. An inverse relation was found between speed of locomotion and measurement accuracy across all movement categories on both linear and non-linear courses. However, a higher sample rate marginally improved validity regardless of distance and speed on all courses. Nonetheless, 10 m distance on the linear course was substantially underestimated by both 1-Hz and 5-Hz systems. The validity of the devices tended to improve as the distance increased across all movement categories. With the exception of walking, validity decreased as velocity increased on both the gradual and tight change of direction courses. Total distance on the team sport running circuit was underestimated by 5.7% and 3.7% by 1-Hz and 5-Hz devices respectively. Reliability measures over short distances were poor regardless of movement speed or sample rate. Both systems demonstrated good reliability in the team sport circuit. A higher sample rate improved reliability during slower movement speeds regardless of distance, and at higher velocities on the change of direction course.

Peterson et al., (2009) investigated the validity and reliability of 3 commercially available GPS systems to measure distance and different running velocities during match play in cricket (138). Two systems sampled at 5-Hz and the other at 1-Hz. The estimated distance covered in different movement categories by fast bowlers was used to validate each system against the criterion measure of a 400 m track. For the distance trials, a single player covered a total distance of 13 km that involved walking (8800 m), jogging (2400 m), running (1200 m) and striding (600 m). A total of 20 trials were conducted for each unit for each distance. Pacing feedback was provided at 200 m intervals to ensure adherence to the specified locomotion speed. Twenty sprint trials were completed from a standing start over 20 m, 30 m and 40 m and were timed using electronic timing gates. A cricket specific 'run-a-three' test involving multiple runs between the crease lines (17.68 m) with 180° turns was also performed. Electronic timing gates were positioned beside each crease. In cricket, it is common for the batter to touch the crease with his bat therefore running a shorter distance than the length of the crease. To overcome this problem, a camera was placed perpendicular to each crease to identify the exact turning point. Twenty trials of the run-a-three test were performed.

Across all distances, there was a strong correlation between actual distance and the measured distance using the GPS systems (r=0.99). Validity varied as a function of distance and intensity. The measurement error for all GPS models was <4% across the lower intensity categories (walking - striding) and peaked at 23.8% during short sprints over 20 m. The measurement error ranged from 2.6 – 12.7% on the cricket specific course. The reliability of GPS estimation improved over longer distances. The CV was <3% across the lower intensity categories (walking – striding) and peaked at 30% during short sprints over 20 m. Inter-receiver measurement error was also considerably higher during the 20 m sprints. The omission of sprint data for the 1-Hz system used in this study makes it difficult to make comparisons between sample rates. However, the data indicate that there are limitations in the ability of GPS systems to accurately measure short sprint efforts.

Johnston *et al.,* (2010) used a team sport simulated running circuit based on the design by Coutts & Duffield (132) to assess the validity and reliability of a 5-Hz GPS system. Nine well trained men with an average age of 28.9 years each wore 2 GPS units while completing 10 laps of the team sport simulated circuit. Each lap began at 1 min intervals and there was a 5 sec to 15 sec recovery period between bouts. Electronic timing gates were placed at 10 m and 20 m along a straight line sprint at the beginning of the circuit to establish average peak speed. There was no difference between GPS reported total distance, peak speed and the criterion measures. The degree of GPS error was dependant on the intensity of the exercise. The level of error measurement was trivial at lower intensities and increased exponentially (112 - 142%) when running at speeds >25 $km \cdot h^{-1}$. A flying 50 m sprint test was also included to assess peak running speed measured using GPS. Participants performed a 20 m run-in to the starting cone and were encouraged to reach and maintain peak speed over the 50 m run. A researcher stood 2 m away from the finish line with a radar gun that participants were instructed to run towards as fast as possible. Two GPS units were worn simultaneously by each participant to determine inter-reliability. The measurement error between the two units ranged from 45.6 – 59.3% at speeds >25 $km \cdot h^{-1}$, reinforcing the previous studies that found limitations in the ability of a 5-Hz GPS device to accurately measure very high intensity running (135, 138).

There are relatively few studies that have examined the accuracy of a 10-Hz GPS device for measuring human movement (139, 140). In a recent study by Castellano *et al.,* (2011), 9 trained male athletes completed 7 and 6 linear runs of 15 m and 30 m respectively (139). Each repetition was completed in the quickest time possible with 1 min of rest between efforts. Distance was measured using a tape measure and electronic timing gates provided a criterion sprint time. The 10-Hz GPS devices marginally underestimated both 15 m and 30 m sprints distances. The intra-reliability values were modest (CV <4%) across all trials but showed greater stability on the 30 m effort. The inter-reliability between devices measured as CV was 1.3% and 0.7 % for sprints over 15 m and 30 m, respectively. This study suggests that 10-Hz GPS devices provide highly accurate distance data during linear sprints of 15 m and 30 m, and may be used interchangeably.

Varley *et al.,* (2012) also recently investigated the validity and reliability of GPS for measuring velocity during constant motion, acceleration and deceleration (140). Participants wore either two 5-Hz or 10-Hz GPS devices during multiple linear trials. Starting velocity was 1-3 $m \cdot s^{-1}$, 3-5 $m \cdot s^{-1}$ or 5-8 $m \cdot s^{-1}$. Upon entering the desired speed zone for at least 2 sec they were instructed to accelerate maximally for several seconds before decelerating to a complete stop. A mounted tripod laser sampling at 50-Hz was used as the criterion measure of velocity during all trials. The higher sample rate was found to reduce the magnitude of error at all speeds during constant velocity, acceleration and deceleration. Although both devices tended to underestimate distance during the acceleration phase, and overestimate distance during the deceleration phase, lower errors were found in the 10-Hz device. A higher sample rate also improved reliability values during all phases of locomotion.

2.9.3 Summary

GPS technology is a valuable tool that allows sport scientists to analyse player movement patterns during training and competition. The lightweight nature of modern receivers allows the collection of data in a safe and non-invasive manner. An understanding of the physical demands imposed on players during competition allows coaches to create a sport specific training environment. Game simulations may be constructed, conditioning programmes designed according to positional requirements, and recovery protocols adapted according to training load. Despite its widespread adoption in individual and team sports, the use of GPS technology to accurately track player movement patterns is not without its limitations. Total distance may be measured with confidence but receivers with a sample rate of ≤ 5-Hz appear susceptible to considerable error during high intensity activity, particularly activities that involve frequent changes in direction. Recent evidence indicates that this error may be reduced during linear motion with the use of a 10-Hz system (139). However, the validity and reliability of a 10-Hz system to accurately measure velocity and distance covered in a sport specific context warrants further investigation. Compared to other methods such as time motion analysis, GPS technology remains the most accessible and practical method of quantifying player movement patterns during field based sports.

2.10 Exercise Intensity

2.10.1 Oxygen Uptake

Maximal oxygen uptake ($\dot{V}O_2$ max) may be defined as the highest volume of oxygen an individual can consume and utilize to produce chemical energy (ATP) aerobically during exercise (141). It is an integrative measure of the ability of the lungs to supply oxygen, the cardiovascular system to pump and transport oxygenated blood to the exercising muscle, and the ability of the working muscles to utilize oxygen (90). The measurement of $\dot{V}O_2$ max is typically performed in a laboratory setting and describes the functional capacity of the entire cardiovascular system (141). Portable metabolic gas systems with breath by breath analysis offer an alternative method of directly measuring $\dot{V}O_2$ during exercise. However, such equipment is expensive, obstructive and potentially hazardous during collisions between players. Also, the rules of competition do not permit the use of such devices in many field based sports.

2.10.2 Estimating $\dot{V}O_2$ from Heart Rate

Modern GPS devices are compatible with heart rate (HR) monitoring technology facilitating the collection of both physical and physiological data simultaneously. The linear relation between heart rate (HR) and oxygen consumption allows the use of HR data to estimate the aerobic load (%$\dot{V}O_2$) during exercise (142, 143). A direct measurement of $\dot{V}O_2$ in a laboratory setting is required to obtain an individual HR-$\dot{V}O_2$ regression line. This may then be used to estimate the physiological demand associated with a specific HR measured on the field (142). External factors such as stress, dehydration and hyperthermia can affect the cardiovascular response during match play and subsequently the linearity of the HR-$\dot{V}O_2$ relation (144). Many technical aspects of field based sports can have a similar effect on HR, especially at low intensities (142). Furthermore, intermittent activity involving time spent standing still may result in a marginal overestimation of $\dot{V}O_2$ based on HR measurements compared with a continuous workload (145).

Drust *et al.,* (2000) designed a laboratory based soccer specific protocol in order to compare the physiological responses during steady state and intermittent exercise. Seven collegiate level soccer players participated in this study (143). Players were required to visit a performance laboratory on 3 separate occasions exactly 6 days apart. Each participant completed a graded exercise test in order to establish their $\dot{V}O_2$ max. The intermittent and steady state protocols were completed on the second and third visits respectively. The soccer specific intermittent protocol was 46 min and 11 sec in duration consisting of two 22.5 min cycles separated by a static period of 71 sec. Each cycle included 23 bouts of activity at various intensities. The steady state protocol was performed for an identical period at the same average speed as the intermittent protocol (12.0 $km \cdot h^{-1}$). The physiological responses were similar between protocols indicating that HR data obtained during laboratory testing may be used to estimate VO_2 during match play.

Hoff *et al.,* (2002) investigated the validity of heart rate as a measure of intensity during field based soccer specific activities in 6 adult players competing in division 1 of the Norwegian football league (145). $\dot{V}O_2$ max was assessed using an incremental treadmill protocol with open circuit spirometry. Heart rate was measured by short-range radio telemetry system. Players were later equipped with a portable metabolic system and heart rate monitor during a soccer specific dribbling test and a 5-a-side football game, respectively. The soccer specific dribbling test involved two 4 min bouts separated by 3 min of active recovery at 70% of maximal heart rate (MHR). Participants were verbally instructed to increase running intensity to a level that brought them to 90-95% of MHR after 60 sec of each 4 min bout. The 5-a-side game consisted of two 4 min playing periods separated by 3 min of active rest. Intensity was encouraged to be as high as possible. There was a strong relation (r=0.84) between $\dot{V}O_2$ and heart rate measured at several submaximal intensities on the treadmill. There was no significant difference between the HR-$\dot{V}O_2$ relation obtained on the treadmill and that from the soccer specific trials.

Esposito *et al.,* (2004) also examined the relation between the HR-$\dot{V}O_2$ relation in the laboratory and during soccer match play in 7 male soccer players (25.3 ± 1.2 yrs.) (142). Participants undertook an incremental treadmill tests to measure $\dot{V}O_2$ max and performed 3 laps of a soccer specific circuit at moderate, high and maximal intensity. Respiratory gases were measured during both tests using an automated portable gas system. HR measurements were also recorded using a telemetry system. There was no difference between the HR-$\dot{V}O_2$ regression line obtained in the laboratory and during a soccer specific circuit.

Castagna *et al.* (2007) assessed the validity of using HR to estimate $\dot{V}O_2$ during 5-a-side indoor soccer in 16 recreational high school players (16.9 ± 1.8 yr.) (146). Peak physiological values were obtained under laboratory conditions to establish individual HR-$\dot{V}O_2$ relationships. Participants were subsequently fitted with a portable open circuit spirometry and heart rate monitoring system during an indoor 5-a-side soccer game. It was found that 71% of HR variance was explained by VO_2 variations. When the data was averaged across all participants there was no difference between actual and predicted $\dot{V}O_2$ values. However, when the data was evaluated at an individual player level there was considerable estimation error. These findings indicate that $\dot{V}O_2$ during soccer match plays may be estimated from HR data with greater accuracy when assessing large groups.

2.10.3 Summary

Estimating $\dot{V}O_2$ from heart rate data is a non-invasive and valid method of quantifying the aerobic demand of field based sports (142, 145, 146). An estimation of aerobic load should be used in conjunction with GPS data to provide an accurate description of the physical and physiological load associated with training and match play. An understanding of the physiological demand of match play will aid coaches in the physical conditioning of players. The intensity of practice sessions may be predetermined and specifically designed to reflect the demands of match play.

2.11 Physiological Demands of Match Play

The physiological demands of any sport are largely determined by the activity patterns of the game. Exercise intensity may also be influenced by the level of competition, biological maturity of participants, playing position and period of play (147-150). Similar to soccer and Australian Rules football, Gaelic football involves repeated short duration, high intensity bouts of anaerobic exercise interspersed with sustained light to moderate aerobic activity. Only two studies have investigated the physiological demands of Gaelic football (3, 19).

Florida-James & Reilly (1995) investigated the physiological demands of Gaelic football in 11 club level players (19) . The HR response of each player was recorded by way of short range radio telemetry over the course of 6 competitive games. Blood samples were taken at half time and full time to determine blood lactate concentrations. Mean HR values of 157 ± 10 and 158 ± 12 bpm were recorded during the first and second half of play, respectively. This corresponded to 81% HRmax. Blood lactate concentrations were 4.3 and 3.4 $mmol \cdot L^{-1}$ in the first and second half of play, respectively.

The effect of playing level on the physiological demands of Gaelic football was later investigated by Reilly & Keane (2002) (3). Two senior inter-county and 13 senior club level players completed a 20 m progressive shuttle run test to measure individual maximum heart rate values. The HR of each player was later monitored during a 60 min competitive game. The average HR during match play was 169 ± 9 and 160 ± 6 bpm for club and county level players respectively, which in relative terms equated to 80% HRmax (3). Notwithstanding the small no. of the county level players, HR showed a greater degree of variability in club level players, tending to increase as the game progressed. Conversely, the mean HR for county level players did not vary between the first and second half of play or between the first and last 10 min periods of play.

The similarities between Gaelic football and Australian Rules football are such that an International Rules series exists between the two codes. Despite the professional nature of Australian Rules football only two studies have examined the physiological demands of match play (151, 152). Pyke & Smith (1975) collected HR data on a defender and midfield player during one quarter of an AFL game. The average HR was 160 bpm and 178 bpm for the defender and midfield player, respectively (151). Peak hearts rates of 170-180 bpm which equated to 94% of MHR were recorded for the defender during intense periods of play. The HR of the midfield player was generally maintained at 170-185 bpm throughout the quarter and did not fall below 150 bpm. In contrast, the HR for the defensive player dropped as low as 140 bpm during periods of low intensity. Hahn *et al*., (1979) reported a mean HR of 164 bpm and 159 bpm for two midfield AFL players during a full competitive game (152). It is worth noting that both studies were undertaken in the 1970's and are limited by the small number of subjects monitored over short playing periods.

There is currently no published information regarding the physiological demands of Gaelic football at underage level. In contrast, the physiological responses during soccer match play, a sport that shares many similarities with Gaelic football, has been extensively studied. Table 2.11 summarises selected studies that have investigated the physiological demand of match play in terms of HR response in soccer players at youth and elite level.

Table 2.11 Selected studies examining HR response in soccer players

Source	**n**	**Level**	**Games**	**HR (bpm)**	**HRmax (%)**
Aslan *et al*. (153)	36	Elite adolescent / Turkey	4	164	86
Billows *et al*. (154)	20	Academy / United Kingdom	5	174	86
Eniseler (155)	10	Professional / Turkey	1	157	77
Florida-James & Reilly (19)	12	Collegiate / United Kingdom	5	161	84
Helgerud *et al*. (156)	19	Elite youth / Norway	2	-	83
Mohr *et al*. (157)	25	Danish fourth division	1	161	86
Ogushi *et al*. (158)	2	Professional / Japan	1	161	82
Stroyer *et al*. (148)	9	Elite - Early puberty / Danish	1	175	87
Stroyer *et al*. (148)	7	Elite - Post puberty / Danish	1	176	87

Aslan *et al*., (2012) recently investigated the physiological demands of match play in 36 young soccer players with an average age of 17.6 ± 0.6 yr (153). Physiological measurements including HR and circulating blood lactate levels were obtained over the course of 4 friendly matches. The mean HR was 166.9 ± 9.2 bpm during the first half of play and 161.7 ± 8.3 during the second half of play, and equated to 87% and 84% of HRmax, respectively (figure 2.10). The mean HR was significantly different between the first and second half of play. Players spent considerably more time at a HR > 180 bpm during the first than the second half of play (figure 2.9). Blood lactate concentrations were also significantly higher in the first half than the second half of play (4.52 ± 1.88 vs. 3.38 ± 1.15 $mmol \cdot L^{-1}$).

Billows *et al*., (2005) also investigated the physiological response during match play in elite youth soccer players (154). Participants (n= 20, 15.5 ± 0.6 yr) performed a graded exercise test to determine HRmax values. Heart rate responses were later monitored during 5 competitive games. The mean HR during the first half and second half of play equated to 88% and 85% of HRmax, respectively. In agreement with Aslan *et al*., (2012) mean HR values were significantly lower during the second than the first half of play (153).

Capranica *et al*., (2001) compared the physiological load imposed on prepubescent soccer players during 7-a-side and 11-a-side games (159). Six players participated in an official 11-a-side game on a regulation pitch (100 x 65 m) and a 7-a-side game on a modified playing area measuring 60 x 40 m. Heart rate was continuously recorded every 5 sec using a telemetry system (159). Blood samples were taken 1.0-1.5 min after the warm up, and at the same time after the first half and second half of each game. Heart rate exceeded 170 bpm for 88% of the first half and 80% of the second half during the 11-a-side game. Blood lactate measurements taken ranged from 3.1-8.1 $mmol \cdot L^{-1}$. There was no difference in HR distribution or blood lactate concentrations between halves or between games.

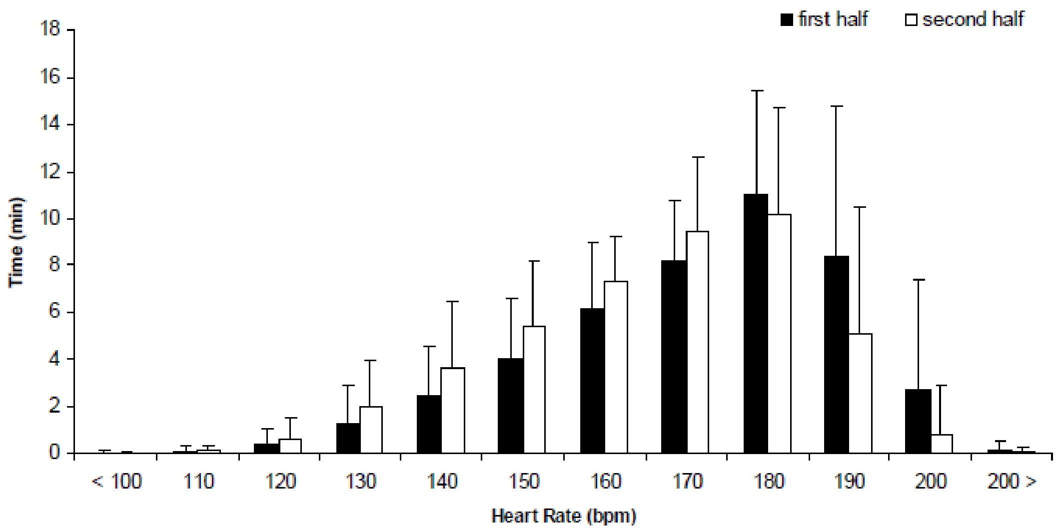

Figure 2.10 Heart rate distribution during elite youth soccer matches (159)

Mendez-Villanueva *et al*., (2013) evaluated the HR distribution in young soccer players (U-14 – U-18) during match play. HR data were classified based on the percentage of total playing time in each of the following intensities: i) < 60% HR max, ii) 61-70% HR max, iii) 71-80% HR max, iv) 81-90% HR max and v) 91-100% HR max (160). This study found that young soccer players spent the majority of playing time exercising at HR intensities >81% HRmax. For the most part there was a reduction in the percentage of playing time exercising in the higher HR zones in the second half across all age groups. Buchheit *et al.*, (2008) also found that young soccer players spent significantly less time exercising at an intensity between 86-95% HRmax during the second half of play (161).

Only one study has directly measured $\dot{V}O_2$ during actual match play in soccer. Ogushi *et al.*, (1993) used Douglas bags to measure oxygen uptake in 2 collegiate level soccer players (158). The equipment weighed 1.2 kg and was worn by each player for a period of 2-3 min over the course of a 90 min friendly match. HR was continuously monitored with short range radio telemetry. Average $\dot{V}O_2$ for each player was 35 and 38 $ml \cdot kg^{-1} \cdot min^{-1}$ druing the first half and 29 and 30 $ml \cdot kg^{-1} \cdot min^{-1}$ during the the second half of play. These values corresponded to 56-61% and 47-49% of $\dot{V}O_2max$ respectively. Oxygen uptake values estimated by HR-VO_2 regression line were up to 25% greater than the measured values. However, the distance covered over the 5 min period was considerably less which may explain the lower values observed.

Stroyer *et al.*, (2004) estimated oxygen uptake from HR measurements obtained during match play in young soccer players (148). Twenty six players were divided in to 1 of 3 groups based on playing standard and biological maturity. The breakdown consisted of 10 non-elite and 9 elite players at the beginning of puberty, and 7 older elite players at the end of puberty. Individual linear regression equations between $\dot{V}O_2$ and HR were calculated for each player based on submaximal and maximal values obtained during teadmill running in a laboratory. Heart rate was collected during competitive matches. Game intensity ranged from 70-80% $\dot{V}O_2$max. Compared with non-elite players at the same stage of puberty, elite players exercised at a significantly higher %$\dot{V}O_2$max in both the first and second half of match play (figure 2.11).

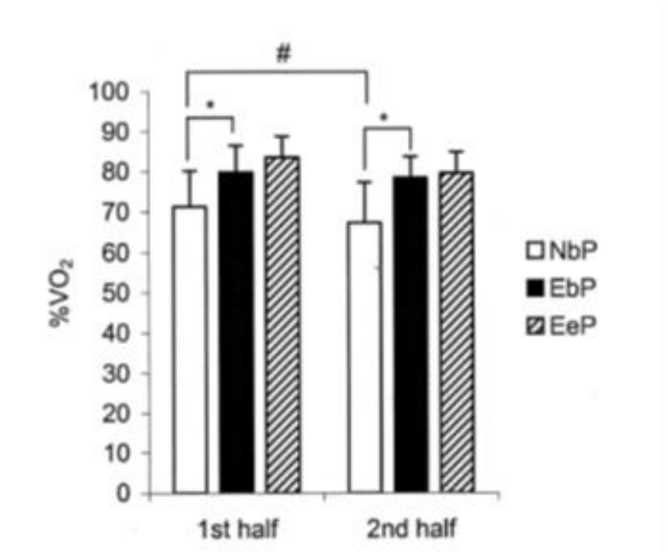

Figure 2.11 Relative $\dot{V}O_2$ during match play in youth soccer players (NbP = Non-elite before puberty; EbP = Elite before puberty; Eep = Elite late puberty) (148)

2.11.1 Summary

The mean HR responses during match play are similar at 80% HRmax in Gaelic football and soccer. The measured $\dot{V}O_2$ in elite soccer players is 70% $\dot{V}O_2max$ is similar to the estimated value using the HR-$\dot{V}O_2$ regression line in collegiate and youth level soccer players. Mean HR and circulating blood lactate blood lactate values tend to be lower during the second half than the first half of play in youth soccer players. Blood lactate measurements obtained during field based sports highlight the important contribution of anaerobic metabolism during periods of high intensity, which constitute up to 7 min of total playing time in elite soccer players (162). No previous studies have investigated the physiological response during match play in U-18 Gaelic football players.

2.12 Activity Pattern during Match Play

To date, no published studies have evaluated the activity pattern of U-18 Gaelic football players during competitive games. A small number of studies have investigated the activity profile of elite male and female Gaelic football players (2, 4, 163). Time motion analysis of 16 inter-county standard players monitored over 8 competitive games found that players cover an average distance of 8.5 km per game (4). Low intensity aerobic activity (35% walking, 32% jogging) accounted for over two thirds of the total distance covered during matches. Backward or sideways movements (17%), striding (12%) and sprinting (4%) accounted for the remaining percentage of total distance covered. There was no significant difference in the total distance covered between playing position or between the first and second half of play.

Elite soccer players cover an average distance of 10-11 km during a 90 min game (117, 149, 150, 164, 165) the majority of which is covered during the first half of play (150, 165, 166). Compared with Gaelic football players, soccer players cover a greater absolute distance during a game. However, the duration of a soccer game is 20 min longer than Gaelic football. When the distance is expressed per min, soccer players cover an average distance of 111-122 $m \cdot min^{-1}$ and elite Gaelic football players 121 $m \cdot min^{-1}$ (4). Soccer players in the midfield position are widely reported to cover significantly more distance per game than all other positional groups (149, 165, 166). The majority of total playing time in an elite soccer match involves low intensity activity, primarily walking 59.4 % and 26.4% jogging (150) indicating that like Gaelic football, much of the energy required during match play is provided via aerobic pathways.

The total distance covered or the average running velocity are limited measures of the physical demands imposed on players during field based invasion sports such as soccer, Australian Rules football and Gaelic football (167). High intensity running is typically described in the literature as velocities ranging from 19 to 23/25 $km \cdot h^{-1}$ (149, 165, 166, 168). Although activities involving high intensity running account for only a small proportion of game time they normally involve key phases of offensive and defensive play that are critical to the outcome of games. There is a strong relation between the volume of high intensity running undertaken during match play and physical fitness in soccer players (109, 113). The distance covered at high intensity velocities may be a more valid measure of physical performance than the total distance covered or the average running velocity in field based sports. It is currently unclear to what extent physical fitness and/or positional roles influence a players running activity during match play (169).

O'Donoghue & King (2005) used time motion analysis to investigate the frequency and duration of high intensity activity in 55 collegiate level Gaelic football players. On average, players performed 95.7 bursts of high intensity activity (running, shuffling, game activities) per game (2). The average duration and recovery time of each effort was 5.7 sec and 36.7 sec respectively. The volume of high intensity running varied according to position. The 4 central positions (centre half back, centre half forward and 2 midfield players) performed a significantly greater number of high intensity efforts with less recovery between bouts than the other positional groups.

McErlean *et al.*, (1998) found that the physical demands of elite female Gaelic football players varies according to playing position (163). High intensity activity included jogging, running, sprinting, backward or sideways movement and carrying the ball. The 4 central and wing-half backs and forwards spent a significantly greater percentage of total match time performing high intensity activity than defenders and forward players in the full back and full forward lines respectively. The use of a portable dictation machine to code movement patterns and the vague classification of movement categories are major limitations of this study.

A number of studies have found that playing position has a significant influence on the volume of high intensity undertaken by elite soccer players during match play (149, 166, 168). Di Salvo *et* al., (2009) undertook a comprehensive analysis of high intensity running among 563 English Premier League players over the course of 3 seasons (168). High intensity running values were significaly different between all positional groups with the exception of wide defenders and central midfield players. Wide midfield players performed the highest volume of high intensity running, whereas central defenders perfomed the lowest volume. Analysis of elite soccer players in both the English and Spanish Premier Leagues also found that wide midfield players covered significantly more distance at high intensity than all other positions. This is not surprising considering that midfield players spend a large part of the game transitioning between attack and defence. In contrast, central defenders performed the lowest volume of high intensity running (149, 166). No data is currently available on the volume of high intensity running undetaken by elite level male Gaelic football players.

Few studies have investigated the physical demands of field-based sports in youth players (169-171). Buchheit *et al*., (2010) examined the activity profile of well trained youth soccer players in relation to age, playing position and physical fitness (169). Time motion analysis data on 77 young players across 6 different age groups between 13 and 18 years was colleted over 42 matches against international club teams. Running velocity categories were defined as low intensity (<13 $km \cdot h^{-1}$), high intensity (13.1 – 16 $km \cdot h^{-11}$), very high intensity (16.1 – 19 $km \cdot h^{-1}$) and (≥ 19.1 $km \cdot h^{-1}$). There was a trend for the total distance covered at each movement intensity to increase with age. The U-18 age group covered significantly more distance while sprinting than all other teams. The total distance covered during match play ranged from 7.7 to 8.7 km, depending on position. Midfield players covered the greatest total distance, whereas wide midfield players covered the greatest distance at very high intensity. These findings are consistent with data on elite adult soccer players (149, 165, 166, 168).

2.12.1 Summary

Currently no studies have examined the physical demands during match play in adolescent Gaelic football players. The small number of studies on adult Gaelic footballers indicate that the majority of playing time is spent performing low intensity aerobic activity. The frequency of high intensity activity may be position specific, with the greatest demand placed on players playing in central positions. The results from these studies should be interpreted with caution given the somewhat dated methods used in gathering information on players. There is evidence of a linear relationship between biological age and the volume of high intensity performed during match play in young players involved in field based team sports.

CHAPTER III

RESEARCH STUDY 1

Fitness Profiling of Elite Level U-18 Gaelic Football Players

3. Rationale

Optimal performance in Gaelic football requires that players develop the appropriate fitness attributes that allows them to cope with the physical demands of the game while maintaining technique and skill levels. Many coaches now routinely assess selected fitness indices using a battery of field-based tests. In addition to being valid and reliable, the tests should ideally have accompanying norm-referenced performance standards to assist in the interpretation of scores. There is currently no information available on adolescent Gaelic football players. Information arising from this study will allow coaches at youth level benchmark elite performance and set realistic performance standards.

3.1 Aim

To evaluate the anthropometric characteristics and fitness levels of elite U-18 Gaelic football players.

3.1.1 Specific Objectives

1. To establish norm-referenced percentile scores for selected anthropometric and fitness indices in adolescent Gaelic football players
2. To compare the physical and fitness characteristics relative to each playing position

3.1.2 Hypotheses

1. Midfield players will be taller, have the highest endurance capacity and score best in tests of muscular power compared with other outfield positions

2. Forward players will record the fastest sprint times

3. There will be a significant correlation between body composition and tests of power and speed respectively

3.2 Participants

A total of 265 boys (mean ± SD; 17.0 ± 1 yr.) who were members of secondary school senior (U-18) Gaelic football teams participating in the 'A' level national championship volunteered for the study. Participating schools included the four provincial winners and the national champions. Study participants had a minimum of 5 years playing experience. Teams trained on average 2 days per week and played a game on most weeks during the competitive season.

The sample included 13 goalkeepers, 113 defenders, 30 midfield players and 109 'forward' players. A 'forward' refers to a player positioned in one of the six offensive positions on a Gaelic football team. The experimental procedures were approved by the University Research Ethics Committee. Participants were provided with a plain language statement outlining the nature and demands of the study as well as the inherent risks (Appendix B). Written informed consent was obtained from each of the participants and their parents prior to participation (Appendix B). Participants were advised that they could withdraw from the study at any time.

3.3 Overview of Study Design

A standard battery of field-based tests was selected to establish norm-referenced percentiles for anthropometric and fitness measures. Participants were members of secondary school senior (U-18) Gaelic football teams participating in the 'A' level national championship. The 'A' level championship is the highest standard of schools competition for U-18 Gaelic football players. Players were categorised as goalkeepers, defenders, midfield players, and forwards in order to compare positional differences in anthropometric and fitness levels.

3.4 Methods

Participating schools were contacted in writing to establish their willingness to participate in the study (Appendix B). A team of researchers made a single visit to each participating school within 2 weeks of their elimination from the provincial or national championship. Testing took place over a 2 h period between the hours of 14:00 and 18:00 in a sports hall provided by the school. Participants were requested to abstain from strenuous physical activity for at least 24 h, and fast for 3 h prior to testing. Participants wore loose sports clothing, appropriate footwear, and were permitted to drink water ad libitum during testing. Two weeks following the testing session, 7 participants from the same school repeated all assessments in the same order and under the same conditions.

3.4.1 Anthropometry

Height was measured to the nearest cm using a portable stadiometer (SECA Leicester Height Measure). Body mass was obtained to the nearest 0.1 kg using a calibrated scale (Salter Academy Scale). Footwear was removed prior to both measurements. BMI was calculated as body mass (kg) divided by squared body height in metres. Chest, abdomen and thigh skinfold thickness was measured by an experienced tester using Harpenden skin fold callipers (Baty International Ltd, West Sussex, UK). A minimum of three measurements were taken at each site. The average measurement of each individual site was selected for analysis. Measurements were taken following the guidelines outlined by the International Society for the Advancement of Kinathropometry (172). Lean body mass was calculated using the Jackson and Pollock equation (173). Percentage body fat (% BF) was calculated using the Hume equation (174).

3.4.2 Sit & Reach Test

Participants removed their shoes and sat on the floor with their legs fully extended and feet against a sit and reach box (Eveque Leisure Equipment Ltd, Cheshire, UK). Placing one hand on top of the other and keeping their legs straight, participants reached forward as far as possible while sliding their fingers along the measurement scale on top of the sit and reach box. Participants were asked to hold the final position for 3 sec, and measurements were recorded to the nearest cm. Following a familiarization practice, each participant performed 3 trials with the best score recorded for analysis.

3.4.3 Countermovement Jump

A Takei jump mat (Takei Scientific Instruments, Tokyo, Japan) was used to measure vertical displacement during the CMJ. The Takei jump mat consists of a rubber circular base attached via a retractable cord to a jump belt with a digital read out. Vertical jump height is calculated based on cord displacement. Prior to the CMJ participants stood upright with both feet on the jump mat. Using the cord wheel on the jump belt, the test administrator removed any slack from the cord. With their hands on their hips throughout the test, participants were instructed to flex their lower limbs and then immediately rebound in a maximal vertical jump with no pause between the eccentric and concentric phase, and to land with both feet in contact with the jump mat. No instruction was provided in terms of speed or depth of the countermovement. One practice jump was provided to familiarise participants with the test procedure. Participants performed 3 jumps separated by a 30 sec rest period, and the best score was selected for analysis. Following each jump, the score attained was provided to the participant for motivational purposes.

3.4.4 Standing Long Jump

Participants aligned themselves parallel to a measuring tape that was fixed to the ground with their toes in line with the zero reference point on the tape. When instructed, they performed a counter movement jump with arm swing to propel themselves horizontally forward as far as possible. No instruction was provided in terms of speed or depth of the counter movement. One practice jump was provided to familiarise participants with the test procedure. Participants performed 3 jumps and the distance from the rear heel to the zero reference points was recorded in cm. A 30 sec rest period was provided between jumps and the best score recorded for analysis. Following each jump, the score attained was provided to the participant for motivational purposes.

3.4.5 5 m and 20 m Speed

A 10 min warm up including jogging, striding and dynamic movement patterns was completed prior to the sprint test. Wireless electronic timing gates (Fusion Sport International) were positioned on the starting line and at a distance 5 m and 20 m from the start line. Participants placed their front foot on a marked line, 50 cm behind the first timing gate. Three trials were performed and the times were recorded to the nearest millisecond (ms). Each sprint was separated by a 3 min recovery period.

3.4.6 Yo-Yo Intermittent Recovery Test Level 1 (YYIRT1)

The YYIRT1 was administered according to the procedures outlined by Krustrup *et al.,* (2003) (109). The test involves repeated pairs of 20 m runs at progressively increasing speeds controlled by audio bleeps. The rest interval between runs was 10 sec in duration, during which time participants completed a 10 m (2 x 5 m) walk. Participants were instructed to commence each shuttle from a stationary position. The time required to complete each shuttle run was progressively decreased. Failure to complete a shuttle run in the required time resulted in a verbal warning, and a second offence resulted in termination of the test. The distance covered was recorded and represented the test score.

3.5 Statistical Analysis

Data were analysed using SPSS (v17.0, SPSS Inc., IL). Descriptive statistics were calculated for all data (mean ± SD). One way analysis of variance (ANOVA) was used to determine mean differences between playing positions (goalkeeper, defence, midfield and 'forward'). A Tukey's post-hoc analysis was used to locate significant differences. Pearson correlations were used to determine the relation between selected fitness parameters. A probability of $p \leq 0.05$ was accepted for statistical significance. The reliability of each test was assessed by Cronbach's alpha and intra-class correlation coefficients (ICC's). A reliability coefficient >0.7 was deemed acceptable (175).

3.6 Results

The anthropometric measurements had high reliability values (alpha, ICC's); height (α=0.99, ICC=0.99), weight (α=0.99, ICC=0.99), BMI (α=0.94), %BF (α=0.91, ICC =0.84). All measures of physical fitness used in this study had high reliability values; S&R (α=0.95, ICC=0.90), CMJ (α=0.84, ICC=0.73), SLJ (α=0.96, ICC=0.91), 5 m sprint (α=0.99, ICC=0.96), 20 m sprint (α=0.79, ICC=0.77), YYIRT1 (α=0.87, ICC=0.75).

Table 3.1 details the anthropometric and fitness measures for each positional group. Midfield players were significantly older than forward players ($p<0.05$). The sum of 3 skin folds was significantly higher in goalkeepers than defenders ($p<0.001$), forward ($p<0.001$) and midfield players ($p<0.01$). Percentage body fat was significantly higher ($p<0.01$) in goalkeepers than any other position. Goalkeepers and midfield players were taller and heavier ($p<0.01$) than defenders and forward players. BMI values were higher among goalkeepers than defenders ($p<0.05$) and forwards ($p<0.01$). The total distance covered in the YYIRT1 was significantly lower ($p<0.01$) among goalkeepers than the other positions. There was no significant difference in any other measures of physical fitness between playing positions.

Table 3.1 Anthropometric and physical fitness measures

Variable	Combined	Goalkeeper	Defender	Midfielder	Forward	Range
Age (yr)	16 ± 1	17 ± 1	16 ± 1	17 ± 1[a]	16 ± 1	16 - 18
Height (cm)	178.11 ± 6.27	182.50 ± 3.79	177.08 ± 5.72[cd]	185.63 ± 5.64	176.57 ± 5.50[cd]	163 - 201
Weight (kg)	72.09 ± 8.68	81.62 ± 13.65	71.03 ± 6.85[cd]	80.67 ± 8.84	69.71 ± 7.44[cd]	49 - 111
BMI ($kg \cdot m^2$)	22.69 ± 2.15	24.52 ± 4.10	22.65 ± 1.88[e]	23.37 ± 1.96	22.34 ± 2.00[c]	18 - 33
Sum of 3 SF (mm)	40.56 ± 13.48	57.04 ± 25.73	40.13 ± 12.88[b]	42.26 ± 10.92[c]	38.58 ± 11.24[b]	17 - 119
Body fat (%)	9.48 ± 3.90	14.08 ± 7.00	9.36 ± 3.78[c]	10.06 ± 3.23[c]	8.90 ± 3.34[c]	2 – 30
Sit & Reach (cm)	21.87 ± 6.88	24.00 ± 8.34	22.83 ± 6.62	21.40 ± 7.04	20.75 ± 6.80	2 – 43
CMJ (cm)	43.32 ± 5.08	42.69 ± 5.12	43.51 ± 4.95	43.93 ± 6.31	43.03 ± 4.88	29 - 55
SLJ (cm)	198.23 ± 20.69	193.00 ± 25.21	199.37 ± 22.28	202.47 ± 19.73	196.51 ± 18.55	134 - 265
5 m (sec)	1.13 ± 0.08	1.16 ± 0.67	1.13 ± 0.08	1.14 ± 0.09	1.13 ± 0.07	0.92 – 1.33
20 m (sec)	3.22 ± 0.15	3.30 ± 0.14	3.21 ± 0.15	3.23 ± 0.15	3.21 ± 0.13	2.85 – 3.92
YYIRT1 Distance (m)	1464.75 ± 370.12	1070.77 ± 401.71	1498.41 ± 356.05[c]	1502.67 ± 327.45[c]	1466.42 ± 369.93[c]	440 – 2320

Values are mean ± SD. [a]$p<0.05$ vs. forward; [b]$p<0.001$ vs. goalkeeper; [c]$p<0.01$ vs. goalkeeper; [d]$p<0.01$ vs. midfield; [e]$p<0.05$ vs. goalkeeper

Quintiles scores for anthropometric and performance measures are outlined in tables 3.2 – 3.4.

Table 3.2 Quintile values for anthropometric measurements

	Quintiles			
Variable	**20**	**40**	**60**	**80**
Height (cm)				
Combined	173.00	176.00	180.00	184.00
Goalkeeper	180.40	181.30	183.00	186.40
Defender	171.90	176.00	179.00	182.20
Midfielder	180.00	185.40	187.00	190.80
Forward	172.00	175.00	178.00	180.00
Weight (kg)				
Combined	65.00	70.00	74.00	79.00
Goalkeeper	73.60	74.00	80.40	91.20
Defender	65.00	69.00	73.40	76.20
Midfielder	74.00	77.40	83.60	88.40
Forward	64.00	68.00	72.00	75.00
BMI (kg·m^2)				
Combined	21.01	21.97	22.99	24.50
Goalkeeper	21.39	22.54	24.34	27.46
Defender	21.12	21.87	22.98	24.38
Midfielder	21.76	22.63	23.49	25.40
Forward	20.81	21.60	22.49	24.03
Sum of 3 SF (mm)				
Combined	49.52	41.00	35.33	30.20
Goalkeeper	69.87	62.19	50.72	31.76
Defender	49.41	40.96	35.92	29.67
Midfielder	50.48	43.47	39.40	32.40
Forward	46.43	39.87	34.00	29.73
Body Fat (%)				
Combined	12.23	9.66	8.00	6.35
Goalkeeper	18.02	15.81	12.57	6.77
Defender	12.22	9.60	8.11	6.30
Midfielder	12.51	10.46	9.27	7.10
Forward	11.37	9.33	7.47	6.23

Table 3.3: Quintile values for the sit & reach, countermovement jump and standing long jump assessments

	Quintiles			
Variable	**20**	**40**	**60**	**80**
Sit & Reach (cm)				
Combined	15.20	21.00	24.00	28.00
Goalkeeper	14.00	21.60	25.40	32.20
Defender	17.00	22.00	25.00	28.00
Midfielder	15.00	19.40	22.00	27.40
Forward	14.00	19.00	24.00	27.00
CMJ (cm)				
Combined	39.00	42.00	44.00	48.00
Goalkeeper	35.80	41.60	45.80	47.20
Defender	39.80	42.00	44.00	48.00
Midfielder	37.40	41.40	45.00	48.60
Forward	39.00	41.00	44.00	47.00
SLJ (cm)				
Combined	181.00	195.00	204.00	213.00
Goalkeeper	161.80	196.80	202.00	214.20
Defender	182.00	197.60	206.00	214.00
Midfielder	183.00	197.40	206.60	218.80
Forward	180.00	192.00	202.00	211.00

Table 3.4 Quintile values for 5 m, 20 m speed and Yo-Yo intermittent recovery test

	Quintiles			
Variable	**20**	**40**	**60**	**80**
5 m Speed (sec)				
Combined	1.19	1.15	1.12	1.07
Goalkeeper	1.22	1.17	1.16	1.09
Defender	1.19	1.14	1.12	1.06
Midfielder	1.20	1.16	1.13	1.07
Forward	1.19	1.15	1.11	1.07
20 m Speed (sec)				
Combined	3.33	3.25	3.18	3.10
Goalkeeper	3.43	3.37	3.24	3.15
Defender	3.33	3.25	3.18	3.09
Midfielder	3.36	3.29	3.17	3.09
Forward	3.32	3.26	3.17	3.10
YYIRT1 (m)				
Combined	1120.00	1400.00	1560.00	1800.00
Goalkeeper	552.00	1048.00	1240.00	1416.00
Defender	1240.00	1400.00	1560.00	1800.00
Midfielder	1208.00	1416.00	1584.00	1752.00
Forward	1120.00	1440.00	1600.00	1800.00

There was an inverse relation between %BF and performance in the CMJ ($r=-0.200$, $p<0.01$), SLJ ($r=-0.235$, $p<0.001$) and YYIRT1 ($r=-0.283$, $p<0.001$) respectively. %BF was significantly related to sprint performance in the 5 m ($r=0.148$, $p<0.05$) and 20 m ($r=0.197$, $p<0.01$) tests. Performance in the CMJ was inversely related to 5 m ($r=-0.234$, $p<0.001$) and 20 m ($r=-0.435$, $p<0.001$) sprint times. SLJ performance was inversely related to 5 m ($r=-0.322$, $p<0.001$) and 20 m ($r=-0.456$, $p<0.001$) sprint times.

3.7 Discussion

This is the first study to describe the physical characteristics of adolescent Gaelic football players. The anthropometric profiles of Gaelic football players are broadly similar to soccer players, rugby league backs, and Australian Rules football players at youth level (63, 65, 83). This study described a group of elite U-18 Gaelic football players competing in the premier secondary schools Gaelic football competition. The hypothesis that midfield players would be taller than the other outfield playing positions was accepted. Midfield players in this study were taller and heavier than defenders and forward players.

To date, one previous study has examined the physical characteristics of Gaelic football players relative to playing position. McIntyre & Hall (2005) found that collegiate level midfield players were heavier than defenders, which is broadly in line with the present findings. Midfield players are required to contest kick-outs in a crowded midfield area where height and physical mass may be advantageous in securing possession (14). Unlike Australian Rules football where a free kick or 'mark' is awarded for a clean catch from a kick, midfield players in Gaelic football are required to break tackles and distribute possession upon taking possession of the ball. It seems that height and physical mass may be distinguishing characteristics between midfield players and other outfield positions in U-18 Gaelic football players, irrespective of playing level.

Goalkeepers in this study were taller, heavier and had a greater BMI than defenders and forward players. Goalkeepers also had the highest sum of 3 skin folds and percentage body fat of all playing positions. The 3 site skin fold assessment administered in this study was used as opposed to the more commonly used 7 site protocol given the large number of participants and time constraints during data collection.

Assigning physically larger players to the goalkeeping position is not unique to Gaelic football. Professional and youth soccer goalkeepers are also taller and heavier than other positional groups (6, 63, 64). Above average height provides goalkeepers with an advantage in dealing with aerial threats. However, there are other important characteristics of successful goalkeepers, such as agility and reaction speed, which should be considered in the selection process. The fact that goalkeepers had the highest percentage body fat is consistent with previous studies involving senior county Gaelic football players and soccer players at both professional and youth level (11, 63, 64).

The similar anthropometric characteristics between defenders and forward players within school level players may be due in part to the fact that man-on-man marking is the standard defensive tactic employed by Gaelic football coaches. Defenders are ideally of a similar size and stature to offensive opponents in order to track their movements and contest possession. Collegiate level defenders and forward players have also been found to have similar anthropometric characteristics (14).

This is the first study to evaluate the physical fitness characteristics of U-18 Gaelic football players. The hypothesis that midfield players would have the highest endurance capacity and score best in tests of muscular power, and that forwards would record the fastest sprint times was rejected. The uniform nature of the physical fitness profiles across the different playing positions indicates that muscular power, speed and endurance are important components of fitness regardless of playing position in U-18 Gaelic football players.

The fact that SLJ is not a commonly used test for assessing muscular power in youth players in team based field sports makes it difficult to draw comparisons between Gaelic football players in this study and other sports codes. However, U-18 Gaelic football players compare favourably with youth rugby league and soccer players in tests of 20 m speed and muscular power (CMJ) (63, 65).

Despite the limitations of the S&R test as a measure of hamstring flexibility (176-178), it is easily administered and therefore practical when testing a large number of participants under time constraints. The S&R test has also been administered in previous studies assessing hamstring flexibility as part of an overall battery of fitness tests in adult Gaelic football players (14). Performance in the S&R test is broadly similar between players in the present study and collegiate level Gaelic football players (14). In contrast, S&R scores are up to 8 cm higher among senior county players than collegiate level players (12). Similar to previous studies involving collegiate level players (14), there were no significant positional differences in hamstring flexibility. The fact that the average S&R score in this study compares poorly with age related norms for the test (72) suggests that elite level adolescent Gaelic football players need to develop lower back and hamstring flexibility.

A major role of midfield players is to win primary possession from kick-outs. This requires being able to jump vertically, from a running or stationary position. McIntyre & Hall (2005) found that collegiate level midfield players had greater vertical displacement in a vertical jump test than defenders and forwards (14). In contrast, there were no positional differences in the jump test scores among elite level U-18 Gaelic football players in the present study. The fact that collegiate level competition involves a greater degree of player specialization may help to explain these differences.

Performance in the YYIRT1 between players in the present study was similar to sub-elite Australian Rules football players. The distance covered by elite Australian Rules football players was 472 m greater than their sub-elite counterparts (115). A greater playing surface and increased duration of match play in Australian Rules football may help explain the greater ability of these players to perform a higher level of sustained intermittent activity as measured in the YYIRT1. Among professional soccer players, full backs and midfield players cover significantly greater distances in the YYIRT1 than central defenders and forward players (117). The similar score in the YYIRT1 among all outfield players in the present study indicates that the ability to perform high intensity intermittent exercise is an important fitness attribute for optimal performance in all playing positions. Not surprisingly, goalkeepers covered significantly less distance in the YYIRT1 than each of the other playing positions. At youth soccer level, it is common for physically larger players to be selected for the goalkeeper position largely due to inferior fitness levels rather than superior goalkeeping skills (63). This practice may also be prevalent in the selection of U-18 Gaelic football teams given the anthropometric and fitness profile of goalkeepers found in the present study.

It was hypothesised that there would be a significant relationship between body composition and tests of power and speed respectively, which was partly accepted. The inverse relation between body fat and the vertical and horizontal jump test scores found in this study is not surprising considering that excess body fat acts as dead weight when the body is lifted against gravity. Sporis *et al.*, (2009) also found an inverse relation between body fat and performance in the CMJ test among elite soccer players (64).

Vertical jump height has been shown to be related to running velocity over distance between 5-30 m (179). Although performance scores in the jump tests were significantly related to both 5 m and 20 m sprint times in the present study, they accounted for ≤20% of the variance in sprint performance, suggesting that there are other significant factors affecting sprint performance. Running speed in any sport is relative to the distance run. Sprint performance over a distance of 10 m and 20 m is largely determined by acceleration (89). The strong positive relation between 5 m and 20 m sprint time highlights the importance of acceleration to overall 20 m sprint performance among U-18 Gaelic football players.

Although it has been has been suggested that taller and heavier players are more likely to be selected on elite teams (8), the poor correlation between anthropometric measures and physical fitness test scores found in this study indicate that anthropometric profiles should only be considered from a tactical perspective when selecting players

3.7.1 Practical Application

This is the first study to provide normative data on the anthropometric and fitness profile of elite level adolescent Gaelic football players. The norm-referenced percentile scores will allow coaches compare the anthropometric and fitness profile of secondary school U-18 Gaelic football players participating in the ‘A’ level national championship. Coaches at youth level may use this information to identify strengths and weaknesses within their squads, benchmark elite performance and set realistic performance standards.

3.7.2 Study Limitations

1. Testing took place in different venues nationwide therefore the testing surface was not standardised
2. There was no control over the external commitments of participants in the 24 h before testing
3. Motivation levels among participants may have been diminished upon exiting the schools championship
4. The study design did not control for biological age

CHAPTER IV

RESEARCH STUDY 2

Analysis of Player Movement Patterns in U-18 Gaelic Football Players

4. Rationale

An understanding of the physical demands of a sport is necessary so that optimal training strategies may be devised. There is currently no published research describing the player movement patterns in adolescent Gaelic football players. The lack of information to guide coaches in this area has yielded generic training strategies with little or no consideration for individual positional requirements. This study will provide novel information describing the player movement patterns of county and club level Gaelic football players relative to playing position.

4.1 Aim

To describe the activity profile of minor level (U-18) Gaelic football players relative to competition level and playing position.

4.1.1 Specific Objectives

1. To compare the total distance covered during match play in county and club minor level Gaelic football players during 15-a-side games
2. To compare the total distance covered relative to playing position during match play in county and club minor level Gaelic football players

3. To compare the frequency of high intensity running (>18-20 $km \cdot h^{-1}$) and sprinting ($\geq$20 $km \cdot h^{-1}$) during match play in county and club level Gaelic football players
4. To compare the frequency of high intensity running and sprinting relative to playing position during match play in county and club level Gaelic football players
5. To compare the activity profile between the first and second half of play in county and club level Gaelic football players

4.1.2 Hypotheses

1. County level players will cover a greater distance than club level players during match play
2. Players in the midfield position will cover a greater distance than defenders and forward players regardless of playing level
3. County players will perform more high intensity running and sprinting than club players
4. The frequency and duration of high intensity activity performed at club and county level will be position dependant
5. There will be a reduction in the physical demands of match play between the first and second half during county and club level games

4.2 Participants

A total of 85 players from six U-18 Gaelic football teams (3 county; 3 club level) volunteered to participate in this study. The club level players represented the best U-18 Gaelic football players in their respective communities. All club teams participated in Division 1 of the Dublin minor football league. The county players are a selection of the finest club level players in their respective county. Included in the county teams that participated in this study are the 2012 provincial and All-Ireland football champions. All players trained on average twice per week and played a competitive game most weekends. Each player had a minimum of 2 years playing experience. Participants were provided with a plain language statement outlining the nature and demands of the study as well as the inherent risks (Appendix B). Written informed consent was obtained from each participant and their parents prior to participation (Appendix B). The experimental procedures were approved by the Research Ethics Committee at Dublin City University (DCU).

4.3 Overview of Study Design

A total of 17 official 15-a-side games were analysed in this study (9 county; 8 club level). All games were played on a standard adult pitch and consisted of two 30 min periods with a 10 min interval between periods. Data was collected during their competition phase of the season. A maximum of 10 players per game excluding goalkeepers were purposely selected to wear a portable 10-Hz GPS device (SPI Pro X II, GPSports Systems Pty. Ltd, Canberra, Australia) in the upper thoracic region and a Polar heart rate monitor (Polar Team Pro, Polar Precision Performance SW 3.0, Kempele, Finland) around the chest. The devices were supported in a purpose built harness worn by the player underneath their playing kit. Player selection was rotated in an attempt to capture data representative of different positions and to limit bias from individual responses. No instruction was given to players outside their normal tactical cues.

4.4 Methods

4.4.1 Game Day Procedures

Participants were fitted with a GPS device 30 min prior to the start of each game. The playing number of each participant and unit number of each device were manually recorded for identification purposes. To ensure that data collection was strictly limited to match activities, the GPS system was synced with an electronic mobile device (iPhone 4GS, Apple Inc. San Francisco, CA) that was used to manually record the exact start and end time of each playing half. The exact times of all tactical or injury enforced substitutions of monitored players were also manually recorded. Data were later downloaded from each GPS unit to a personal laptop computer (Intel i7, Intel, Santa Clara, CA) where further analysis was undertaken using a specifically designed computer software analysis programme.

4.4.2 Data Analysis

The initial stage of analysis involved the removal of any obvious outliers and corrupted data caused by hardware error. In the second phase data was transformed to a format suitable for our analytical methods. This involved 3 steps, i) data reduction, ii) data alignment and iii) outlier removal. The GPS receivers used provided up to 20 readings per sec. The average of these readings was taken to reduce the data and generate sensed readings on a per sec basis. The data was then extracted at each 1 sec interval across three categories: player, time and heart rate. Contextual data recorded during each match allowed the programme to align times recorded on the GPS devices with the actual start times for both playing halves, thereby filtering all non-game related data. Outliers were removed using the outlier algorithm previously described by Roantree *et al.*, (2012) (180). Analyses of individual data files were limited to an entire first half and / or second half of play.

4.4.3 Movement Categories

Player movements were categorised as walking (0-6 $km \cdot h^{-1}$), jogging (6-12 $km \cdot h^{-1}$), cruise running (12-14 $km \cdot h^{-1}$), striding (14-18 $km \cdot h^{-1}$), high-intensity running (18-20 $km \cdot h^{-1}$) and sprinting (≥20 $km \cdot h^{-1}$). The speed thresholds for each category are similar to that reported by Cunniffe *et* al., (2009) (181). Entry into a speed zone was recognised and recorded when a player maintained the relevant running speed for ≥2 sec. The frequency, duration and distance covered in each speed zone were evaluated.

4.5 Statistical Analysis

Data were analysed using SPSS (IBM SPSS Statistics v21). Descriptive statistics (mean ± SD) were calculated for all data. An independent samples t-test was used to determine mean differences between competition levels. A paired samples t-test was used to determine the mean differences between playing halves. A two way analysis of variance (ANOVA) was used to determine mean differences between playing positions (defender, midfield and forward at county and club level. A Bonferroni post-hoc analysis was used to locate significant differences. A probability of $p \leq 0.05$ was accepted for statistical significance.

4.6 Results

4.6.1 Distance Covered

Figure 4.1 shows the distance covered during county and club level matches. When the data were combined across both club and county level, U-18 Gaelic football players were found to cover an average distance of 5.7 km during a 60 min game. County players covered a significantly greater distance than club players during the first half ($p<0.001$) and second half of play ($p<0.05$) and over the course of a 60 min game ($p<0.01$). Figure 4.2 outlines the distance covered during county and club games according to 10 min segments. Compared to club players, the total distance covered during the first and last 10 min periods of the first half, and the second 10 min period of the second half was greater in county players ($p<0.05$).

County and club players both covered a significantly greater distance during both the first 10 min of play and during the first half of play than compared to the same corresponding periods during the second half of play ($p<0.05$). Club players also covered a significantly greater distance ($p<0.05$) during the second 10 min segment of the first half than during the second 10 min segment of the second half of play.

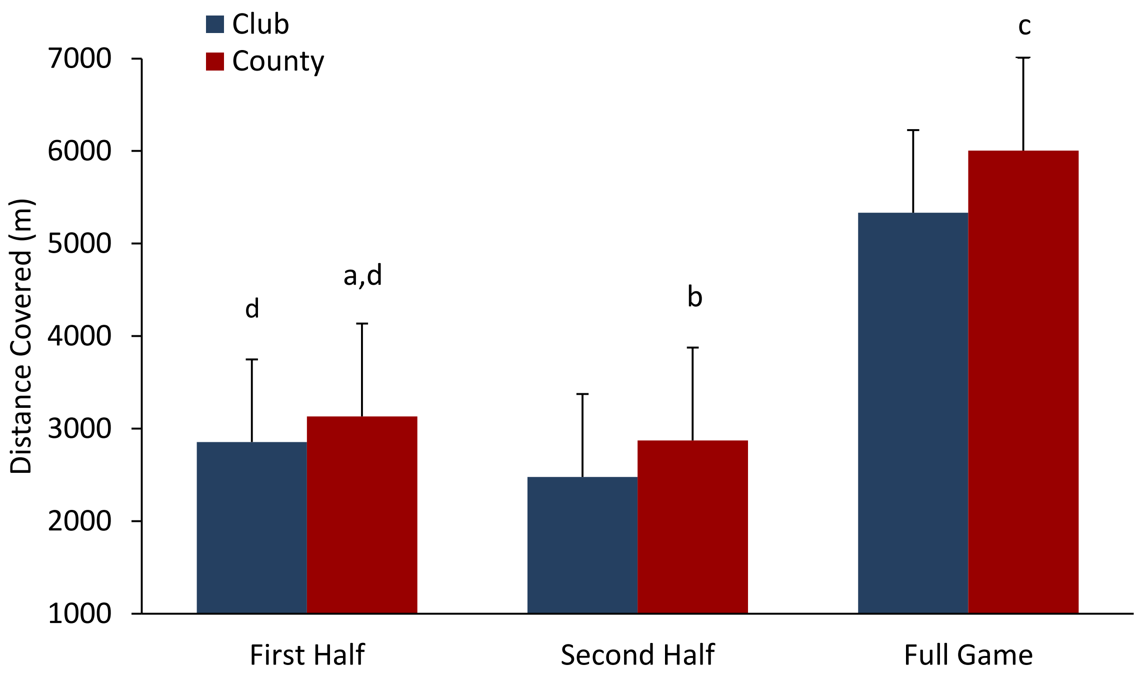

Figure 4.1 Distance (m) covered during match play in club and county games. [a]$p<0.001$ vs. club game; [b]$p<0.05$ vs. club game; [c]$p<0.01$ vs. club game; [d]$p<0.05$ vs. 2^{nd} half

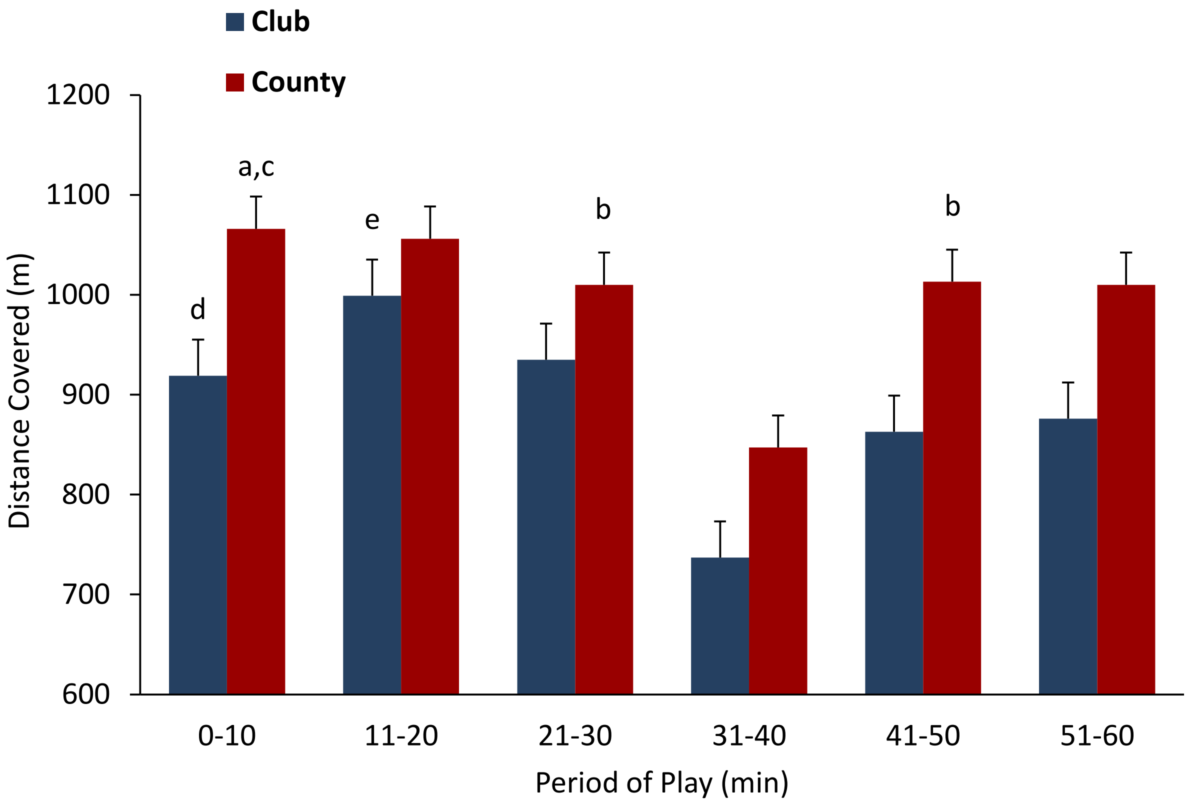

Figure 4.2 Distance (m) covered during 10 min game segments. [a]$p < 0.01$ vs. club game; [b]$p<0.05$ vs. club game; [c]$p< 0.001$ vs. 31-40 min; [d]$p<0.05$ vs. 31-40 min; [e]$p<0.05$ vs. 41-50 min

Table 4.1 shows the distance covered during county and club level games relative to playing position. County midfield players covered a significantly greater distance than county defenders during both the first half of play ($p<0.001$) and over an entire 60 min game ($p<0.05$). This was largely due to the fact that county level midfield players covered greater distance than county level defenders during the second and third 10 min segments of the first half ($p<0.01$). County midfield players also covered a greater distance than county forwards players during the first half of play ($p<0.05$). The total distance covered by county forward players during the first half was significantly greater ($p<0.05$) than for county defenders. Club midfield players covered significantly greater ($p<0.01$) distance than club defenders and forward players during each 10 min segment of the first half, the entire 30 min of the first half and over the course of a the full 60 min game.

County forwards covered a greater distance than club forwards over the course of a 60 min game ($p<0.05$). The distance covered during the first half of play was significantly greater ($p<0.001$) in county forwards than club forwards. This was due to the fact that county forwards covered a significantly greater distance ($p<0.01$) during the first and last 10 min period of the first half of play. County level defenders covered a greater distance ($p<0.05$) than club level defenders during the first 10 min of play.

County defenders, midfield and forward players covered a significantly greater ($p<0.05$) distance during the first 10 min of the first half of play than during the first 10 min of the second half. County midfield and forward players also covered a greater distance during the first half than during the second half of play ($p<0.05$). Club forwards covered a greater distance during the first 10 min of the first half of play than during the first 10 min of the second half ($p<0.05$). Club midfield players covered significantly greater ($p<0.05$) distance during the last 10 min segment of the first half and the entire first half than during the same time periods in the second half of play.

Table 4.1 Distance (m) covered during match play by level and position during different game segments

	Club			County		
	Defender	Midfield	Forward	Defender	Midfield	Forward
First Half						
0-10 min	881.41 ± 115.71	1055.71 ± 56.45[ic]	881.3 ± 106.75[k]	1006.84 ± 105.00[dj]	1122.13 ± 97.87[k]	1097.83 ± 104.30[bk]
11-20 min	964.81 ± 111.48	1218.79 ± 150.57[ic]	943.54 ± 133.74	986.88 ± 110.77	1198.31 ± 130.76[e]	1059.51 ± 94.42
21-30 min	932.11 ± 85.29	1137.07 ± 118.80[icm]	880.7 ± 137.82	940.64 ± 82.94	1129.75 ± 105.99[f]	1044.01 ± 59.20[c]
0-30 min	2778.33 ± 268.32	3411.57 ± 292.90[ibl]	2705.55 ± 316.45	2934.37 ± 212.01	3450.19 ± 201.94[fhl]	3201.35 ± 149.70[bgl]
Second Half						
31-40 min	730.49 ± 219.68	896.07 ± 187.02	725.26 ± 126.60	793.98 ± 91.40	885.57 ± 172.86	792.17 ± 236.61
41-50 min	880.92 ± 277.13	1062.93 ± 112.05	852.14 ± 110.33	973.84 ± 178.51	1127.71 ± 182.38	891.05 ± 240.84
51-60 min	897.29 ± 290.39	1040.36 ± 169.41	892.92 ± 189.00	991.38 ± 186.14	1022.43 ± 171.97	909.49 ± 259.14
31-60 min	2508.7 ± 707.02	2999.36 ± 266.56	2470.33 ± 358.09	2759.2 ± 352.37	3035.71 ± 456.58	2592.71 ± 667.16
Total Game	5287.03 ± 736.99	6410.93 ± 438.31[ic]	5175.87 ± 578.81	5693.57 ± 390.37	6460.79 ± 614.42[g]	5794.06 ± 680.04[a]

Values are mean ± SD. [a]p<0.05 vs. club forward; [b]p<0.001 vs. club forward; [c]p<0.01 vs. club forward; [d]p<0.05 vs. club defender; [e]p<0.01 vs. county defender; [f]p<0.001 vs. county defender; [g]p<0.05 vs. county defender; [h]p<0.05 vs. county forward; [i]p<0.01 vs. club defender; [j]p<0.01 vs. 31-40 min; [k]p<0.05 vs. 31-40 min; [l]p<0.05 vs. 31-60 min; [m]p<0.05 vs. 51-60 min

4.6.2 Movement Categories

Table 4.2 shows the player movement patterns during club and county games. County players performed more sprinting ($p<0.05$) and covered more distance per sprint ($p<0.05$) than club players during the first half of play and over the course of an entire 60 min game. County players performed a greater amount of striding activity than club players during the first half of play ($p<0.05$) and over the course of an entire 60 min game ($p<0.05$).

County players performed a significantly greater ($p<0.05$) amount of sprinting activity during the first half than the second half of play. At both club and county level the average frequency of walking ($p<0.01$) and the average duration of jogging ($p<0.05$) activity was significantly greater during the second half than the first of play.

Table 4.2 Analysis of player movement categories by level of competition and playing period

	Club			County		
	First Half	**Second Half**	**Full Game**	**First Half**	**Second Half**	**Full Game**
Sprinting						
Frequency (n)	8.32 ± 1.18	7.15 ± 3.23	15.48 ± 3.36	10.72 ± 1.56[bc]	8.79 ± 1.85	19.51 ± 2.53[a]
Duration (s)	3.26 ± 0.20	3.23 ± 0.22	3.32 ± 0.29	3.45 ± 0.16	3.38 ± 0.25	3.42 ± 0.17
Distance (m)	20.26 ± 1.30	20.03 ± 1.57	20.05 ± 1.07	21.77 ± 1.08[a]	21.63 ± 2.08	21.7 ± 1.32[a]
High Intensity Running						
Frequency (n)	4.69 ± 0.99	4.24 ± 1.33	8.94 ± 1.33	5.06 ± 0.68	4.64 ± 1.55	9.71 ± 1.69
Duration (s)	2.29 ± 0.06	2.35 ± 0.13	2.32 ± 0.07	2.36 ± 0.90	2.39 ± 0.13	2.38 ± 0.09
Distance (m)	11.95 ± 0.34	12.21 ± 0.79	12.1 ± 0.43	12.32 ± 0.50	12.52 ± 0.70	12.43 ± 0.46
Striding						
Frequency (n)	20.57 ± 1.90	18.47 ± 6.63	39.04 ± 5.92	22.46 ± 1.59[a]	22.6 ± 5.90	45.06 ± 5.37[a]
Duration (s)	2.85 ± 0.17	2.92 ± 0.11	2.88 ± 0.1	2.81 ± 0.11	2.84 ± 0.08	2.83 ± 0.08
Distance (m)	12.49 ± 0.72	12.81 ± 0.51	12.65 ± 0.45	12.32 ± 0.51	12.43 ± 0.36	12.38 ± 0.35
Cruise Running						
Frequency (n)	13.34 ± 1.68	12.35 ± 3.86	25.7 ± 5.02	14.2 ± 1.80	14.64 ± 3.31	28.84 ± 2.84
Duration (s)	2.57 ± 0.08	2.5 ± 0.12	2.54 ± 0.04	2.51 ± 0.11	2.61 ± 0.12	2.56 ± 0.09
Distance (m)	9.36 ± 0.26	9.1 ± 0.47	9.26 ± 0.15	9.15 ± 0.42	9.57 ± 0.50	9.36 ± 0.36
Jogging						
Frequency (n)	63.81 ± 6.23	62.26 ± 17.16	126.07 ± 22.04	71.33 ± 9.68	74.16 ± 16.89	145.49 ± 19.12
Duration (s)	3.62 ± 0.06	3.83 ± 0.24[d]	3.72 ± 0.11	3.71 ± 0.12	3.83 ± 0.16[d]	3.77 ± 0.13
Distance (m)	9.27 ± 0.16	9.77 ± 0.61	9.52 ± 0.29	9.49 ± 0.32	9.69 ± 0.41	9.59 ± 0.32
Walking						
Frequency (n)	100.19 ± 11.24	131.74 ± 27.27[e]	231.93 ± 37.14	95.4 ± 10.36	139.83 ± 24.28[e]	235.23 ± 24.61
Duration (s)	10.14 ± 0.48	9.88 ± 0.67	10 ± 0.46	10.25 ± 0.86	9.83 ± 0.89	10.01 ± 0.73
Distance (m)	11.01 ± 0.61	10.23 ± 1.02	10.58 ± 0.64	11.45 ± 1.11	10.31 ± 1.00	10.78 ± 0.71

Values are mean ± SD. [a]$p<0.05$ vs. club level players; [b]$p<0.01$ vs. club level players; [c]$p<0.05$ vs. 2nd half; [d]$p<0.05$ vs. 1st half; [e]$p<0.01$ vs. 1st half

Tables 4.3-4.5 show the player movement patterns during club and county games relative to playing position, over a full match and during the first and second halves.

County midfield players performed a greater amount of striding activity than county defensive and forward players during the first half of play ($p<0.01$) and over a full 60 min game ($p<0.05$). County midfield players also performed a greater amount of cruise running than county defenders during both the first and second half of play ($p<0.05$) and over the course of a 60 min game ($p<0.01$). The frequency of cruise running undertaken by county midfield players was also significantly greater ($p<0.05$) than county forward players during the second half of play and over the course of a 60 min game. County midfield players performed a greater amount of jogging than county defensive and forward players during the first half of play and over a full 60 min game ($p<0.05$). County forward players performed significantly less walking than county midfield players during the first half ($p<0.01$) and over the course of a full 60 min game ($p<0.05$). The average duration per bout of walking undertaken by county forward players was significantly longer ($p<0.05$) than the county midfield player during the first half of play. The frequency of walking among forwards was also significantly less ($p<0.05$) than defensive players during the first half of county games.

The average duration per bout of high intensity running was significantly higher ($p<0.05$) in club forwards than club midfield players over the course of a full 60 min game. Club level midfield players performed a significantly ($p<0.05$) greater amount of striding activity than club level defensive and forward players during the first half of play and over a full 60 min game. A significantly greater ($p<0.05$) distance was covered per bout of striding activity by club midfield players than club defenders during the first half of play. Club midfield players performed significantly more cruise running than club defensive and forward players during the first ($p<0.001$) and second half of play ($p<0.05$) and over a full 60 min game ($p<0.001$). The average distance per bout of cruise running undertaken by club midfield players during the first half was also significantly greater ($p<0.05$) than club forward players. Club midfield players undertook significantly more jogging than club level defensive and forward players during the first ($p<0.001$) and second half of play ($p<0.01$) and over the course of a full 60 min game ($p<0.001$). The duration of jogging activity and average distance covered per bout was also significantly greater ($p<0.001$) in club midfield players than club defensive and forward players during the first half of play. When averaged over a 60 min game, the duration and distance covered per bout of jogging activity was significantly greater ($p<0.05$) in club midfield players than club defenders. The average duration per bout of walking was significantly greater ($p<0.05$) in club forwards than club midfield players during the first half of play.

The distance covered during bouts of sprinting and high intensity running during the full 60 min game was significantly greater ($p<0.05$) in county than club defenders. County defenders also performed a greater amount of sprinting activity ($p<0.05$) than club defenders during the first half of play. The distance and duration of striding activity was significantly greater ($p<0.05$) in club than county midfield players during the second half of play and over the course of an entire 60 min game. During the first half of play the frequency of cruise running was greater ($p<0.001$) in club than county midfield players. County forwards jogged for longer periods and covered a greater distance per effort than club forwards during the first half of play ($p<0.05$). The frequency of walking was greater ($p<0.05$) in club than county forwards during the first half of play.

County defenders performed a significantly greater ($p<0.001$) amount of sprinting activity during the first half than the second half of play. The average duration of jogging and the distance covered per effort was significantly greater ($p<0.05$) during the second half than the first half of play in county and club defenders respectively. All positional groups performed a significantly greater ($p<0.05$) amount of walking during the second half of play than the first half of play regardless of playing level. The average distance covered per bout of walking was significantly greater ($p<0.05$) during the first than second half of play in county and club forwards. The average duration per bout of walking was significantly greater ($p<0.05$) during the first than the second half in club forwards.

Table 4.3 Analysis of player movement categories by level and playing position during a full game

	Club			County		
Full Game	**Defender**	**Midfield**	**Forward**	**Defender**	**Midfield**	**Forward**
Sprinting						
Frequency (n)	13.38 ± 5.13	19.43 ± 6.08	15.75 ± 4.13	17.44 ± 6.21	22.5 ± 5.68	19.75 ± 4.56
Duration (s)	3.22 ± 0.28	3.44 ± 0.47	3.37 ± 0.47	3.5 ± 0.21	3.25 ± 0.31	3.34 ± 0.29
Distance (m)	19.94 ± 1.63	21.39 ± 3.22	20.07 ± 1.82	22.34 ± 1.77[a]	20.08 ± 2.04	21.3 ± 2.27
High Intensity Running						
Frequency (n)	8.63 ± 3.29	10.14 ± 2.61	8.38 ± 1.77	8.22 ± 2.33	12.25 ± 5.9	8.87 ± 2.03
Duration (s)	2.29 ± 0.14	2.24 ± 0.08	2.39 ± 0.12[f]	2.42 ± 0.13	2.37 ± 0.20	2.36 ± 0.10
Distance (m)	11.9 ± 0.8	11.71 ± 0.52	12.47 ± 0.72	12.68 ± 0.71[a]	12.36 ± 0.99	12.31 ± 0.59
Striding						
Frequency (n)	37.13 ± 12.87	54.29 ± 11.79[ag]	37.88 ± 6.67	40.44 ± 7.5	61.38 ± 19.46[cd]	43.13 ± 11.13
Duration (s)	2.82 ± 0.16	3.06 ± 0.23[b]	2.84 ± 0.13	2.83 ± 0.10	2.86 ± 0.20	2.83 ± 0.11
Distance (m)	12.38 ± 0.72	13.4 ± 1.01[ba]	12.47 ± 0.55	12.4 ± 0.47	12.44 ± 0.95	12.37 ± 0.44
Cruise Running						
Frequency (n)	20.86 ± 7.10	45.14 ± 15.40[hi]	24.13 ± 4.09	26.44 ± 6.67	39.75 ± 10.28[de]	27.5 ± 6.28
Duration (s)	2.53 ± 0.14	2.67 ± 1.16	2.5 ± 0.09	2.58 ± 0.12	2.55 ± 0.12	2.52 ± 0.16
Distance (m)	9.23 ± 0.49	9.72 ± 0.56	9.1 ± 0.35	9.39 ± 0.52	9.33 ± 0.46	9.22 ± 0.59
Jogging						
Frequency (n)	119.25 ± 37.75	187.43 ± 22.8[hi]	119.25 ± 16.77	137.67 ± 23.29	185.25 ± 29.21[de]	143.5 ± 36.65
Duration (s)	3.65 ± 0.11	3.91 ± 0.24[a]	3.69 ± 0.16	3.71 ± 0.16	3.8 ± 0.35	3.83 ± 0.16
Distance (m)	9.2 ± 0.21	10.08 ± 0.68[j]	9.5 ± 0.41	9.45 ± 0.44	9.68 ± 1.00	9.75 ± 0.36
Walking						
Frequency (n)	224.88 ± 57.38	253.14 ± 27.25	238.63 ± 18.42	254.78 ± 40.75	266.75 ± 39.42[d]	217.75 ± 32.05
Duration (s)	9.81 ± 0.44	9.69 ± 0.61	10.43 ± 1.13	9.99 ± 1.20	9.36 ± 1.13	10.33 ± 0.71
Distance (m)	10.25 ± 0.83	10.96 ± 0.94	11.01 ± 1.37	10.47 ± 1.35	10.6 ± 1.45	11.27 ± 0.77

Values are mean ± SD. [a]p<0.05 vs. club defender; [b]p<0.05 vs. county midfield; [c]p<0.05 vs. county defender; [d]p<0.05 vs. county forward; [e]p<0.01 vs. county defender; [f]p<0.05 vs. club level midfield; [g]p<0.05 vs. club forward; [h]p<0.001 vs club defender; [i]p<0.001 vs. club forward; [j]p<0.01 vs club level defender

Table 4.4 Analysis of player movement categories by level and position during the first half of match play

	Club			County		
First Half	**Defender**	**Midfield**	**Forward**	**Defender**	**Midfield**	**Forward**
Sprinting						
Frequency (n)	7.00 ± 2.56	10.57 ± 3.95	8.75 ± 2.19	10.22 ± 3.23[a]	12.13 ± 3.19	10.38 ± 2.07
Duration (s)	3.25 ± 0.32	3.48 ± 0.57	3.19 ± 0.32	3.51 ± 0.31	3.22 ± 0.32	3.45 ± 0.33
Distance (m)	20.17 ± 2.02	21.51 ± 3.74	19.84 ± 2.18	22.23 ± 2.22	19.83 ± 2.27	21.93 ± 2.43
High Intensity Running						
Frequency (n)	4.38 ± 2.00	5.57 ± 1.81	4.50 ± 1.51	4.33 ± 1.73	5.75 ± 3.33	5.13 ± 0.64
Duration (s)	2.25 ± 0.16	2.27 ± 0.15	2.32 ± 0.14	2.40 ± 0.13	2.31 ± 0.30	2.29 ± 0.14
Distance (m)	11.70 ± 0.90	11.96 ± 0.92	12.09 ± 0.79	12.6 ± 0.68	11.99 ± 1.57	11.93 ± 0.75
Striding						
Frequency (n)	19.13 ± 5.79	27.71 ± 4.99[ad]	20.25 ± 5.85	19.67 ± 4.53	31.88 ± 7.94[fg]	22.38 ± 3.16
Duration (s)	2.79 ± 0.20	2.97 ± 0.38	2.77 ± 0.18	2.79 ± 0.13	2.90 ± 0.27	2.86 ± 0.11
Distance (m)	12.22 ± 0.90	13.07 ± 1.64	12.15 ± 0.8	12.25 ± 0.62	12.69 ± 1.27	12.51 ± 0.44
Cruise Running						
Frequency (n)	11.13 ± 3.52	23 ± 5.66[bjk]	12.25 ± 1.49	12.67 ± 4.21	17.38 ± 3.7[h]	15 ± 2.88
Duration (s)	2.54 ± 0.13	2.74 ± 0.25	2.51 ± 0.14	2.49 ± 0.20	2.60 ± 0.18	2.47 ± 0.17
Distance (m)	9.23 ± 0.44	9.98 ± 0.89[d]	9.12 ± 0.51	9.03 ± 0.71	9.46 ± 0.56	9.02 ± 0.62
Jogging						
Frequency (n)	60.88 ± 16.90	91.86 ± 7.13[jk]	59.88 ± 7.81	67.11 ± 14.74	90.5 ± 14.66[ei]	72.13 ± 11.89
Duration (s)	3.54 ± 0.15	3.89 ± 0.17[jk]	3.52 ± 0.11	3.60 ± 0.13	3.83 ± 0.36	3.80 ± 0.19[c]
Distance (m)	8.92 ± 0.35	10.12 ± 0.39[jk]	9.08 ± 0.36	9.17 ± 0.36	9.88 ± 1.01	9.71 ± 0.45[d]
Walking						
Frequency (n)	98.25 ± 19.82	105.29 ± 7.23	102.75 ± 8.73[e]	103.56 ± 6.15[e]	109.25 ± 14.62[g]	86.13 ± 18.21
Duration (s)	10.04 ± 0.50	9.48 ± 0.40	10.59 ± 1.14[l]	10.30 ± 1.13	9.15 ± 0.83	10.93 ± 1.49[l]
Distance (m)	10.69 ± 0.76	11.02 ± 0.52	11.53 ± 1.44	11.10 ± 1.32	10.79 ± 0.92	12.59 ± 2.03

Values are mean ± SD. [a]p<0.05 vs. club defender; [b]p<0.001 county midfield; [c]p<0.01 vs. club forward; [d]p<0.05 vs. club forward; [e]p<0.05 vs. county forward; [f]p<0.001 vs. county defender; [g]p<0.01 vs. county forward; [h]p<0.05 vs. county defender; [i]p<0.01 vs. county defender; [j]p<0.001 vs. club defender; [k]p<0.001 vs club forward; [l]p<0.05 vs. county midfield

Table 4.5 Analysis of player movement categories by level and position during the second half of match play

	Club			County		
Second Half	**Defender**	**Midfield**	**Forward**	**Defender**	**Midfield**	**Forward**
Sprinting						
Frequency (n)	6.38 ± 3.34	8.86 ± 3.63	7.00 ± 3.96	7.22 ± 3.11[h]	10.38 ± 4.75	9.38 ± 3.96
Duration (s)	3.17 ± 0.32	3.37 ± 0.47	3.53 ± 0.57	3.51 ± 0.28	3.14 ± 0.62	3.21 ± 0.48
Distance (m)	19.58 ± 1.81	21 ± 3.38	20.85 ± 2.33	22.58 ± 3.14	19.29 ± 4.35	20.49 ± 3.76
High Intensity Running						
Frequency (n)	4.25 ± 2.12	4.57 ± 1.40	3.88 ± 1.46	3.89 ± 0.93	6.5 ± 3.38	3.75 ± 2.38
Duration (s)	2.28 ± 0.19	2.21 ± 0.22	2.46 ± 0.21	2.41 ± 0.21	2.36 ± 0.28	2.38 ± 0.25
Distance (m)	11.88 ± 1.07	11.52 ± 1.41	12.83 ± 1.16	12.62 ± 1.10	12.39 ± 1.47	12.46 ± 1.51
Striding						
Frequency (n)	18.00 ± 9.06	26.57 ± 8.42	17.63 ± 5.78	20.78 ± 4.47	29.5 ± 13.64	20.75 ± 9.98
Duration (s)	2.85 ± 0.16	3.15 ± 0.33[a]	2.85 ± 0.24	2.88 ± 0.13	2.77 ± 0.24	2.78 ± 0.17
Distance (m)	12.45 ± 0.70	13.78 ± 1.4[a]	12.57 ± 1.08	12.61 ± 0.57	11.97 ± 1.20	12.21 ± 0.69
Cruise Running						
Frequency (n)	9.75 ± 4.77	22.14 ± 10.75[de]	11.88 ± 3.72	13.78 ± 2.91	22.38 ± 9.12[bc]	12.5 ± 6.5
Duration (s)	2.53 ± 0.24	2.54 ± 0.18	2.48 ± 0.16	2.64 ± 0.21	2.52 ± 0.11	2.28 ± 0.25
Distance (m)	9.27 ± 0.96	9.26 ± 0.66	9.05 ± 0.55	9.68 ± 0.88	9.21 ± 0.54	9.45 ± 0.99
Jogging						
Frequency (n)	58.38 ± 24.11	95.57 ± 20.66[df]	59.38 ± 15.28	70.56 ± 10.76	94.75 ± 24.02	71.38 ± 34.92
Duration (s)	3.77 ± 0.19[g]	3.92 ± 0.44	3.86 ± 0.30	3.83 ± 0.26[g]	3.77 ± 0.40	3.87 ± 0.19
Distance (m)	9.52 ± 0.40[g]	10.03 ± 1.17	9.88 ± 0.74	9.72 ± 0.70[g]	9.48 ± 1.07	9.76 ± 0.50
Walking						
Frequency (n)	126.63 ± 39.49[g]	147.86 ± 24.67[g]	135.88 ± 16.53[g]	151.22 ± 39.03[g]	157.7 ± 37.83[g]	131.63 ± 20.39[g]
Duration (s)	9.63 ± 0.76	9.86 ± 1.00	10.30 ± 1.36[g]	9.82 ± 1.43	9.51 ± 1.56	9.87 ± 0.78
Distance (m)	9.90 ± 1.15	10.94 ± 1.41	10.58 ± 1.75[g]	10.09 ± 1.64	10.45 ± 2.21	10.32 ± 1.02[g]

Values are mean ± SD. [a]p<0.01 vs. county midfield; [b]p<0.05 vs. county defender; [c]p<0.05 vs. county forward; [d]p<0.01 vs club defender; [e]p<0.05 vs. club forward; [f]p 0.01 vs club level forward; [g]p<0.05 vs. 1st half; [h]p<0.001 vs. 1st half

4.7 Discussion

4.7.1 Anthropometrics

Similar to study 1, club midfield players were taller than club defenders and forwards. In addition, county midfield players were taller and heavier than county defenders. County forwards were taller than their club counterparts. The difference in height between county and club players may be due to differences in the tactical positioning of players between club and county level. County forward players were also older and may just simply be more advanced in terms of physical development.

There is no U-17 competition in Gaelic games. In many instances players compete at the U-18 age grade for two consecutive years. The difference in age between club and county players may due to the fact that club teams are limited to their local community in terms of player selection, whereas the catchment area at county level is much greater. There is anecdotal evidence that players in their first year of minor football represent a small percentage of county team squads, highlighted by the large turnover of players between calendar seasons. The fact that county players are advanced in terms of chronological age may help explain the difference in body weight compared to club players.

4.7.2 Distance Covered

This is the first study to evaluate the movement patterns during match play in county and club level U-18 Gaelic football players. Understanding the activity profile according to playing position and competition level is necessary to develop sport specific training strategies. As expected, the mean distance covered by minor level county and club players was much less than that in adult Gaelic football players (4). Recent studies in elite soccer players of a similar age to the participants in this study found that the total distance covered during match play ranged from 7.6-8.8 km (169, 182). The greater distance covered by young soccer players than Gaelic football players may be attributed to the fact that competitive soccer games are up to 90 min in duration compared to 60 min for Gaelic football. However, when expressed relative to the total min of match play, on average young soccer cover a similar distance to Gaelic football players (5.8 km vs. 5.7 km).

As expected, county players covered a greater distance than club players during Gaelic football games. The increased distance covered by county players may be attributed to the increased quality of opposition rather than superior fitness levels given the similarity in $\dot{V}O_2max$ levels between playing levels. Several studies in similar field based sports have found that majority of distance covered during match play occurs during the first half in elite, sub-elite and youth players (147, 150, 165, 166, 183). The hypothesis that there would be a reduction in the physical demands of match play between the first and second half during county and club level games was accepted. Both county and club players covered less distance during the second than the first half of play. A reduction in total distance covered between the first and second half was evident in county midfield and forward players. In contrast, only midfield players at club level covered less distance during the second half than the first half of play. The reduction in distance covered may be attributed to the depletion of muscle glycogen stores and subsequent onset of fatigue.

Based on the fact that previous research found that elite midfield soccer players cover the most distance during match play (149, 164-166, 168) it was hypothesised that county and club midfield Gaelic football players would cover a greater distance than defenders and forwards. This was evident in club players during the entire game and county players only during the first half of play. County midfield players did however cover a greater distance than county defenders during games. Given the vital tactical role in linking defence and attack it is not surprising that midfield players cover a greater distance than other positional groups.

The change in Gaelic football tactics, particularly at county level over the past decade has involved county forwards playing a much greater role in shutting down and tracking opposition players. Furthermore, the quality of coaching that young players receive is generally higher at county level. As a result, county forwards develop a better tactical understanding and awareness of the game and learn to use their movement tactically in order to generate space for themselves and team-mates. Together, this may explain the greater distance covered by county forwards players than their club counterpart over the course of a 60 min game.

4.7.3 Movement Categories

This is the first study to categorise and quantify the activity profile of Gaelic football players. No previous studies have clearly defined locomotor categories in Gaelic football. The allocation of speed zones were based on the work of Cunniffe *et al*., (2009) in rugby union. Although rugby union has very different demands to Gaelic football, the classification of sprinting (≥20 $km{\cdot}h^{-1}$) in this study corresponded with the average peak running speed of 22 $km{\cdot}h^{-1}$ obtained from 20 m linear speed data in U-18 Gaelic football players (Study 1) (184). The speed zones selected were therefore believed to be typical of varying locomotor categories during intermittent team sport. Recognition of entry in to a speed zone was limited to when a player maintained the relevant running speed for ≥2 sec in order to minimise the measurement of marginal movements during match play.

Minor level Gaelic football players perform 465 discrete events from walking to sprinting during a game. When the county and club data were combined low intensity activity represented 92.5% of total playing time, consisting of standing (13.5%), walking (64.9%) and jogging (14.1%). Moderate intensity activity represented 5.2% of playing time, consisting of cruise running (1.9%) and striding activity (3.3%). Only 2.3% of total playing time involved high intensity running (0.6%) and sprinting (1.7%). Using the same speed thresholds, similar results have been found in elite rugby union backs (181). A number of researchers have undertaken similar studies in other field-based sports (117, 147-150, 164-166, 169, 183), the use of different definitions and notation techniques make it difficult to compare findings.

The hypothesis that county players would perform more high intensity running and sprinting than club players was partly accepted. County players performed more sprinting activity and covered more distance per sprint than club level players over the course of a game. Similar findings have been reported in elite and sub-elite adult soccer players (117). Studies in youth soccer and adult Australian Rules football players found no difference in the frequency of sprinting activity between elite and sub-elite players during match play (147, 148). When combined, the average distance covered per sprint was 21 m and the average time per sprint was 3.37 sec. These findings highlight the importance of developing explosive strength and acceleration in young Gaelic football players. The greater amount of cruise running performed by county players suggests that the difference in total distance between playing groups is largely covered at a moderate intensity.

The second half of match play was characterised by a reduction in the frequency of sprinting at county level. The frequency of walking and the duration of jogging was considerably greater during the second half of play in both county and club level players. The increased frequency in walking during the second half of games was similar across all playing positions. The reduction in sprinting in county defenders during the second half of play coincided with an increase in jogging. Similarly, soccer players and Australian Rules football players perform less sprinting and high intensity running during the second half of play (117, 147). The development of fatigue is the most obvious explanation for the reduction in high intensity activity. However, external factors such as the score in the game or phase of the season could influence the motivation level of the players and in turn the degree of effort during the latter stages of match play.

It was hypothesised that the frequency and duration of high intensity running and sprinting would be position dependant. However, playing position had no effect on the frequency, distance or duration per bout of high intensity activity in county players. The findings were similar in club level players with the exception of forward players who ran for longer duration during bouts of high intensity running than defenders and midfield players. These findings indicate that a uniform approach in the design and implementation of high intensity training content is suitable for U-18 Gaelic football players.

There was no difference in the amount of jogging or walking between playing positions. A greater amount of moderate to low intensity activity was performed by midfield players compared to defenders and forwards at both county and club level. The primary role of a midfield player in Gaelic football is to secure and advance possession from the middle area of the field. Although midfield players are typically positioned in the middle sector of the playing field, they are often required to advance forward or retreat towards their own goal to assist team mates create and prevent scoring opportunities. It is likely that a large proportion of the low-moderate intensity running performed by midfield players occurs after these phases of play when returning to their position in the central area the field.

Interestingly, club midfield players strided for longer periods during match play and subsequently covered more distance per effort than county midfield players. The limited quality in club teams means that a small percentage of players will generally influence the outcome of a game. Although it is not unusual for club teams to position their most influential player in the midfield position, great reliance is placed on these players to advance forward when their team is in possession in the opposition half of the field. County midfield players may fulfil a more tactical role during match play which may explain the different nature of striding activity between playing levels.

The fact that county defenders covered a greater distance during bouts of sprinting and high intensity running, and performed a greater amount of sprinting during the first 30 min of match play than club defenders highlights the more dynamic nature of the defensive position at county level. This may be attributed to different tactical set-ups of forward units between county and club games. Also, county forwards are more active than club forwards during periods of low intensity, and may be more proactive in positioning themselves to receive possession. Future research should examine the influence of other important factors such as game related activities, the quality of the opposition, the score line and the stage of the season on the physical demands of match play.

4.7.4 Practical Application

This study will provide coaches with an insight in to the physical demands of match play in young Gaelic football players. The information provided may be used as a framework for coaches in the design and prescription of training strategies, which will have an important implication in terms of improving the specificity of current training methods.

4.7.5 Study Limitations

1. Participating county and club teams were limited to Leinster and Dublin, respectively and may not reflect county and club players nationwide
2. The county games in this study were analysed during a preparatory competition with unlimited substitutions which may have affected the overall physical demands of the game
3. There was a considerable score difference between county teams during a small number of games during which motivation levels may have been diminished

CHAPTER V

RESEARCH STUDY 3

Physiological Responses during Match Play in U-18 Gaelic Football Players

5. Rationale

Great emphasis is now placed on the physical conditioning of young Gaelic football players. However, the lack of information relative to the demands of the game is currently a major limitation in the design and application of underage training programmes. The effect of playing position or competition level on the physiological demands of match play is also not well understood. This study will for the first time describe the physiological responses during match play relative to playing position and competition level.

5.1 Aim

To evaluate the physiological demands of match play in adolescent (U-18) Gaelic football players

5.1.1 Specific Objectives

1. To compare the physiological demands during match play in county and club level players during 15-a-side games
2. To compare the physiological demands during 15-a-side games relative to playing position in county and club level players
3. To compare the physiological demands between the first and second half of 15-a-side match play in county and club level players

5.1.2 Hypotheses

1. The relative heart rate and estimated $\dot{V}O_2$ during match play will be significantly higher in county players than club level players
2. The physiological demands during match play will be greatest in the midfield position regardless of playing level
3. There will be a significant difference in the physiological demands of match play between the first and second half of match play

5.2 Participants

Members of six U-18 Gaelic football teams (3 county; 3 club level) volunteered to participate in this study. The club level players represented the best U-18 Gaelic football players in their respective communities. All club teams participated in Division 1 of the Dublin minor football league. The county players were classified as elite in their respective county. Included in the county teams that participated in this study were the 2012 provincial and All-Ireland football champions. Players at both levels trained on average twice per week and played a competitive game most weekends. They had a minimum of 2 years playing experience. Participants were provided with a plain language statement outlining the nature and demands of the study as well as the inherent risks (Appendix B). Written informed consent was obtained from each of the participants and their parents prior to participation (Appendix B). The experimental procedures were approved by the Research Ethics Committee at DCU.

5.3 Overview of Study Design

A total of 17 official 15-a-side games were analysed in this study (9 county; 8 club level). The games were played on a standard adult pitch and consisted of two 30 min periods with a 10 min interval between periods. Data was collected during the competition phase of the season. A maximum of 10 players per game excluding goalkeepers were purposely selected to wear a portable 10-Hz GPS device (SPI Pro X II, GPSports Systems Pty. Ltd, Canberra, Australia) in the upper thoracic region and a heart rate telemetry system (Polar Team Pro, Polar Precision Performance SW 3.0, Kempele, Finland) around the chest. The devices were supported in a purpose built harness worn by the player underneath their playing kit.

Player selection was rotated in an attempt to capture data representative of different playing positions and to limit bias from individual responses. No instruction was provided to players outside their normal tactical cues. A total of 63 players (34 county; 29 club level) of the 85 players that participated in the games made a single visit to the Human Performance Laboratory in DCU to assess their maximal aerobic capacity ($\dot{V}O_2max$). Testing took place within 4 weeks of obtaining the game based measurements. Oxygen uptake during each game was estimated for each subject using the individual linear regression equation between HR and $\dot{V}O_2$ obtained during an incremental treadmill test. Individual peak HR values obtained during testing were used as a reference point to establish the relative HR response during match play.

5.4 Methods

5.4.1 Anthropometry

Height was measured to the nearest cm using a portable stadiometer (Seca 707 Balance Scales, GmbH, Hamburg, Germany). Body mass was obtained to the nearest 0.1 kg using a calibrated scale (Seca 707 Balance Scales, GmbH, Hamburg, Germany). Footwear was removed prior to both measurements. BMI was calculated as body mass (kg) divided by squared body height in metres.

Harpenden skin fold callipers (Baty International Ltd, West Sussex, UK) were used to measure double thickness subcutaneous adipose tissue on the right side of the body. The following anatomical sites were measured: triceps, pectoralis, subscapular, abdomen, midaxillary, suprailiac and thigh. Measurements were taken following the guidelines outlined by the International Society for the Advancement of Kinathropometry (172). Body density was calculated using the Jackson and Pollock equation (173) and body fat was determined using the Siri equation (185).

5.4.2 Maximal Oxygen Uptake

Maximal oxygen uptake ($\dot{V}O_2max$) was assessed on an automated treadmill (Woodway ELG55) using a ramp protocol. The protocol consisted of initial 4 x 4 min stages. The initial treadmill velocity was set at 6.0 $km \cdot h^{-1}$ and was increased by 2.0 $km \cdot h^{-1}$ at the end of each stage. Treadmill velocity remained constant after the fourth stage and the treadmill gradient was increased by 2% in the initial min after the fourth stage and at 2 min intervals thereafter until volitional exhaustion. Cardiorespiratory measurements were determined using a Sensormedics Vmax 229 metabolic system (Sensormedics Vmax 229, Sensormedics Corp., CA). $\dot{V}O_2max$ was determined by averaging the 3 highest consecutive 20 sec values.

5.4.3 Mass Flow Sensor Heated Wire Anemometer-Mode of Operation

A mass flow sensor (Sensormedics, Loma Linda, CA, USA) was used to collect breath-by-breath measurement of ventilation. The mass flow sensor is a low resistance tube with a tapered internal diameter extending from both ends of a laminar flow throat. Cold and hot stainless steel wires electrically heated to -180°C and -240°C respectively, are centered in the flow stream. These wires are elements in a servo-controller bridge circuit that maintains the resistance ratio of the two wires at a constant value. If only the temperature of the inspired gases changes, then both wires lose heat at the same rate and no current change is required to keep the bridge balanced. As air flows across the wires, the hot air loses heat more rapidly than the cold air and the current must be added to keep the bridges balanced at a 3:4 ratio. The amount of current required is proportional to the mass flow of the gas. This method ensures that the sensor measures only the heat loss from the molecular convection of the moving gas stream and not the artifact due to cooling of the gas as it passes through a breathing assembly. The mass flow meter responds to instantaneous flow rates between 0-16 $L \cdot sec^{-1}$ and integrated flow between 0-350 $L \cdot min^{-1}$, with flow resistance $<1.5\ cmH_2O \cdot L^{-1} \cdot sec^{-1}$. The mass flow sensor was outputted to the analyser module of the Vmax 229 and was sampled at a rate of 125 Hz.

5.4.4 Mass Flow Sensor Calibration

A 3 L volume syringe (Sensormedics, Loma Linda, CA, USA) was used to calibrate the mass flow sensor prior to each test. The syringe was connected to the mass flow sensor and stroked four times in order to measure inspired and expired volumes. The volumes were calculated by expressing 3 L as a fraction of each measured inspired and expired volume achieved during calibration. An average correction factor was calculated for inspired and expired volumes and used to fine tune the volume measurement.

A verification procedure was performed. This involved stroking the 3 L volume syringe four times. Inspired and expired volumes were measured using the newly calculated correction factors. In order to pass the calibration procedure, one of the four strokes had to have an average flow rate < 0.5 $L\cdot sec^{-1}$ and at least one of the four strokes had to have an average flow > 3.0 $L\cdot sec^{-1}$.

5.4.5 Gas Analysers

The Vmax 229 utilizes a rapid response infrared measurement technique. An O_2 and CO_2 analyser is integrated with the Vmax 229. A small sample of inspired air is drawn through a sample cell and exposed to an infrared light through an optical that is passed through a band pass filter and the sample cell. An infrared detector responds to the amount of infrared light that passes through the sample cell. The amount of light that passes through the sample cell varies according to the concentration of CO_2 in the sample cell. Based on measured levels of infrared light intensity, the analyser computes the PCO_2 in the gas sample. The CO_2 analyser is linearly scaled across the 0-100% range with a resolution of

0.01% CO_2 and a response time of < 130 $m \cdot s^{-1}$ (10-90%) at 500 $ml \cdot min^{-1}$ flow. The O_2 analyser is based on the high paramagnetic susceptibility of O_2. A diamagnetic glass dumbbell suspended in a magnetic field rotates in proportion to the PO_2. The analyser is linearly scaled across the 0-100% range with a resolution of 0.01% O_2 and a response time of < 130 ms (10-90%) at 500 $ml \cdot min^{-1}$ flow.

5.4.6 Calibration of CO_2 and O_2 Analysers

The gas analysers were calibrated with standard gases of known concentration (BOC gases, Dublin, Ireland). The first calibration gas contained 26.00 ± 0.02% oxygen and the balance nitrogen (N_2). The second calibration gas contained 4.00 ± 0.02% carbon dioxide, 16.00 ± 0.02% O_2, and the balance N_2. A small bore drying tube connected to the CO_2 and O_2 analysers sampled the calibration gases. The absorption and evaporative properties of the drying tube ensured that the relative humidity of the calibration gas was equilibrated to ambient conditions prior to sampling by the O_2 and CO_2 analysers. The calibration gas was sampled at a rate of 125 Hz. The response time was similar between O_2 and CO_2 analyser.

5.4.7 Ratings of Perceived Exertion

RPE was obtained using the 16-point Borg category RPE scale. Prior to the maximal exercise test participants read a standard set of perceptual scaling instructions. These instructions followed an established format used in previous investigations (186). Low and high "perceptual anchors" were established during the maximal exercise test. This involved asking participants to assign a rating of 6 (low anchor) to the lowest exercise intensity, and 20 (high anchor) to the highest exercise intensity. Participants were instructed to make their subjective assessments of perceived exertion relative to these minimum and maximum standards (perceptual anchors).

5.4.8 Game Day Procedures

Participants were fitted with a GPS device 30 min prior to start of each game. The playing number of each participant and unit number of each device were manually recorded for identification purposes. To ensure that data collection was strictly limited to match activities, the GPS system was synced with an electronic mobile device (iPhone 4GS, Apple Inc. San Francisco, USA) that was used to manually record the exact start and end time of each playing half. The exact times of all tactical or injury enforced substitutions of monitored players were also manually recorded. Data were later downloaded from each GPS unit to a personal laptop computer (Intel i7, Intel, Santa Clara, CA) where further analysis was carried out using specifically designed computer software analysis programme.

5.4.9 Heart Rate

Heart rate was continuously measured with a sampling frequency of 5 sec using a wireless team system (Polar Team Pro, Polar Precision Performance SW 3.0, Kempele, Finland). Heart rate data was stored on a receiver that was attached to an elastic strap and placed around the participant's chest. The data was transferred to a personal laptop computer for analysis. Individual peak HR's were identified in order to categorise HR data obtained during match play in to one of four zones: 0-60%, 61-70%, 71-80%, 81-90% and 91-100% HRmax. Similar zones have previously been used to evaluate the heart rate response in elite youth soccer players (160).

5.5 Data Analysis

The initial stage of analysis involved the removal of any obvious outliers and corrupted data caused by hardware error. In the second phase data was transformed to a format suitable for our analytical methods. This involved 3 steps, i) data reduction, ii) data alignment and iii) outlier removal. The GPS receivers used provided up to 20 readings per sec. The average of these readings was taken to reduce the data and generate sensed readings on a per sec basis. The data was then extracted at each 1 sec interval across three categories: player, time and heart rate. Contextual data recorded during each match allowed the program to align times recorded on the GPS devices with the actual start times for both playing halves, thereby filtering all non-game related data. Outliers were removed using the outlier algorithm previously described by Roantree *et al*., (2012) (180). Analyses of individual data files were limited to an entire first half and / or second half of play.

5.6 Statistical Analysis

Data were analysed using SPSS (IBM SPSS Statistics v21). Descriptive statistics (mean ± SD) were calculated for all data. An independent samples t-test was used to determine mean differences between competition levels. A paired samples t-test was used to determine the mean differences in physiological responses between the first and second half of play. Two way analysis of variance (ANOVA) was used to determine mean differences between playing positions (defender, midfield and forward) at club and county level. A Bonferroni post-hoc analysis was used to locate significant differences. A probability of $p \leq 0.05$ was accepted for statistical significance.

5.7 Results

5.7.1 Anthropometric and Physiological Measurements

Descriptive statistics for the 63 subjects are summarised in table 5.1. County players were significantly older ($p<0.001$) and heavier ($p<0.05$) than club players.

Table 5.1 Anthropometric and physiological characteristics

Variable	**Club**	**County**	**Combined**
Age	17.21 ± 0.49	17.88 ± 0.33[b]	17.57 ± 0.53
Height (m)	1.80 ± 0.06	1.83 ± 0.06	1.82 ± 0.06
Weight (kg)	72.16 ± 8.98	76.98 ± 6.84[a]	74.76 ± 8.20
BMI ($kg \cdot m^2$)	22.16 ± 2.18	23.08 ± 1.70	22.65 ± 1.97
Sum of 7 skin folds (mm)	70.56 ± 21.13	63.65 ± 11.66	66.83 ± 16.91
Body fat (%)	9.23 ± 2.92	8.38 ± 1.65	8.77 ± 2.34
$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	57.72 ± 5.73	57.93 ± 5.58	57.83 ± 5.60

Values are mean ± SD. [a]$p<0.05$ vs. club players; [b]$p<0.001$ vs. club players

Anthropometric and physiological characteristics according to position and playing level are outlined in table 5.2. County defenders and forwards players were significantly older ($p<0.01$) than their club level counterparts. County forward players were significantly taller than club forward players ($p<0.05$). Club level midfield players were significantly older ($p<0.05$) than club defenders and taller than both club defenders ($p<0.01$) and forward players ($p<0.01$). Similarly, county midfield players were significantly taller ($p<0.01$) and heavier ($p<0.05$) than county defenders. There was no significant difference in $\dot{V}O_2max$ between playing positions within or between club and county players respectively.

Table 5.2 Anthropometric and physiological characteristics by playing level and position

	Club			County		
Variable	**Defender**	**Midfield**	**Forward**	**Defender**	**Midfield**	**Forward**
Age	17.08 ± 0.49	17.75 ± 0.50[f]	17.17 ± 0.39	17.86 ± 0.36[b]	18 ± 0.00	17.85 ± 0.37[c]
Height (m)	1.79 ± 0.06[g]	1.9 ± 0.02	1.79 ± 0.04[g]	1.79 ± 0.03	1.88 ± 0.04[d]	1.84 ± 0.06[a]
Weight (kg)	69.49 ± 7.43	79.88 ± 5.01	72.49 ± 10.40	73.26 ± 5.67	81.97 ± 6.04[e]	78.28 ± 6.56
BMI ($kg\cdot m^2$)	21.76 ± 1.51	22.12 ± 1.78	22.6 ± 2.89	22.82 ± 1.54	23.26 ± 2.21	23.25 ± 1.65
Sum of 7 skin folds (mm)	65.54 ± 19.46	76.18 ± 21.49	74.13 ± 23.29	65.24 ± 11.36	61.01 ± 13.15	63.34 ± 11.86
Body fat (%)	8.52 ± 2.67	10.09 ± 3.01	9.72 ± 3.21	8.61 ± 1.6	8.02 ± 1.87	8.34 ± 1.68
$\dot{V}O_2max$ ($ml\cdot kg^{-1}\cdot min^{-1}$)	57.9 ± 4.53	58.3 ± 3.39	57.33 ± 7.6	60.03 ± 4.94	58.33 ± 4.01	55.45 ± 6.26

Values are mean ± SD. [a]$p<0.05$ vs. club forward; [b]$p<0.001$ vs. club defender; [c]$p<0.001$ vs. club forward; [d]$p<0.01$ vs. county defender; [e]$p<0.05$ vs. county defender; [f]$p<0.05$ vs. club defender; [g]$p<0.01$ vs. club midfield

5.7.2 Relative Heart Rate Response

When combined across both club and county level, the average %HRmax per game was 81%. The average %HRmax was significantly higher at county than club level during the first ($p<0.01$) and second 30 min period ($p<0.05$) and for the entire 60 min of match play ($p<0.01$) (figure 5.1). The %HRmax during county matches was significantly higher ($p<0.05$) than club level during all 10 min segments of play with the exception of the first and last 10 min periods of the second half (figure 5.2).

The %HRmax was significantly higher in the first half than the second half in both club level ($p<0.05$) and county ($p<0.001$) games, respectively (figure 5.1). The %HRmax during club level games was significantly higher in the first 10 min period of the first half than the first 10 min period of the second half ($p<0.01$) (figure 5.2). The %HRmax during county games was significantly higher during each three 10 min segments of play in the first half of play than the second half of play ($p<0.05$) (figure 5.2).

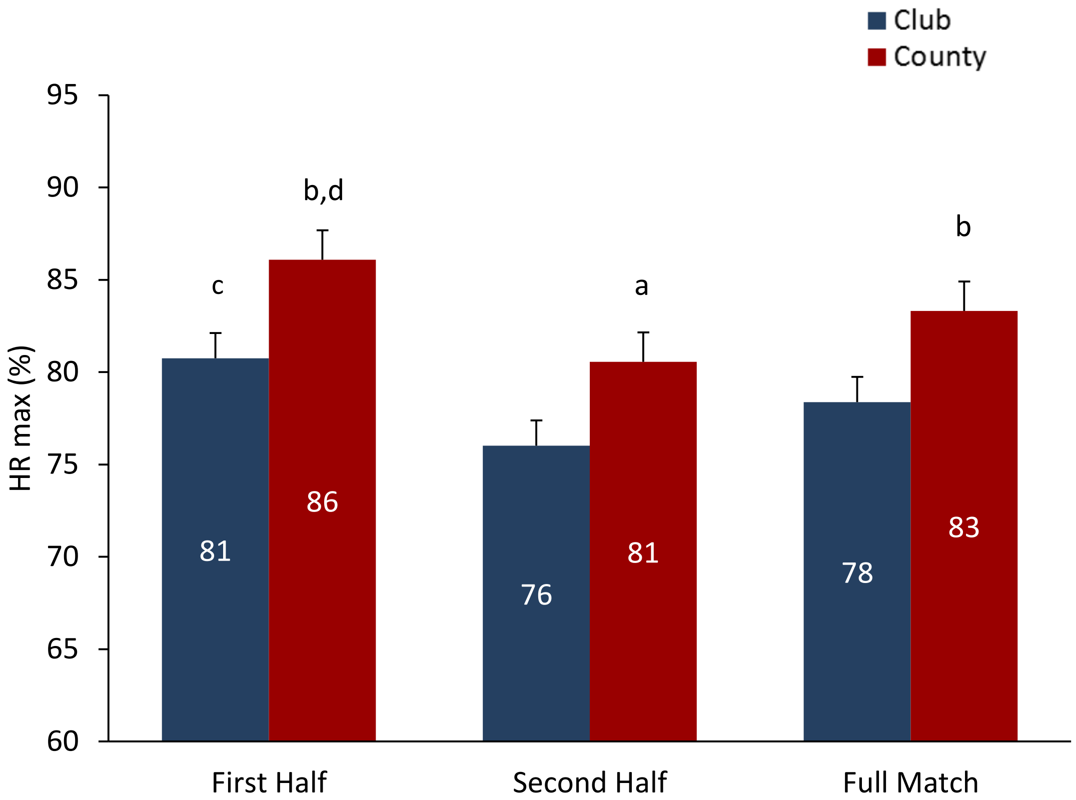

Figure 5.1 Percentage heart rate max during county and club level games. [a]$p<0.05$ vs. club game; [b]$p<0.01$ vs. club game; [c]$p<0.05$ vs. 2nd half; [d]$p<0.001$ vs. 2nd half

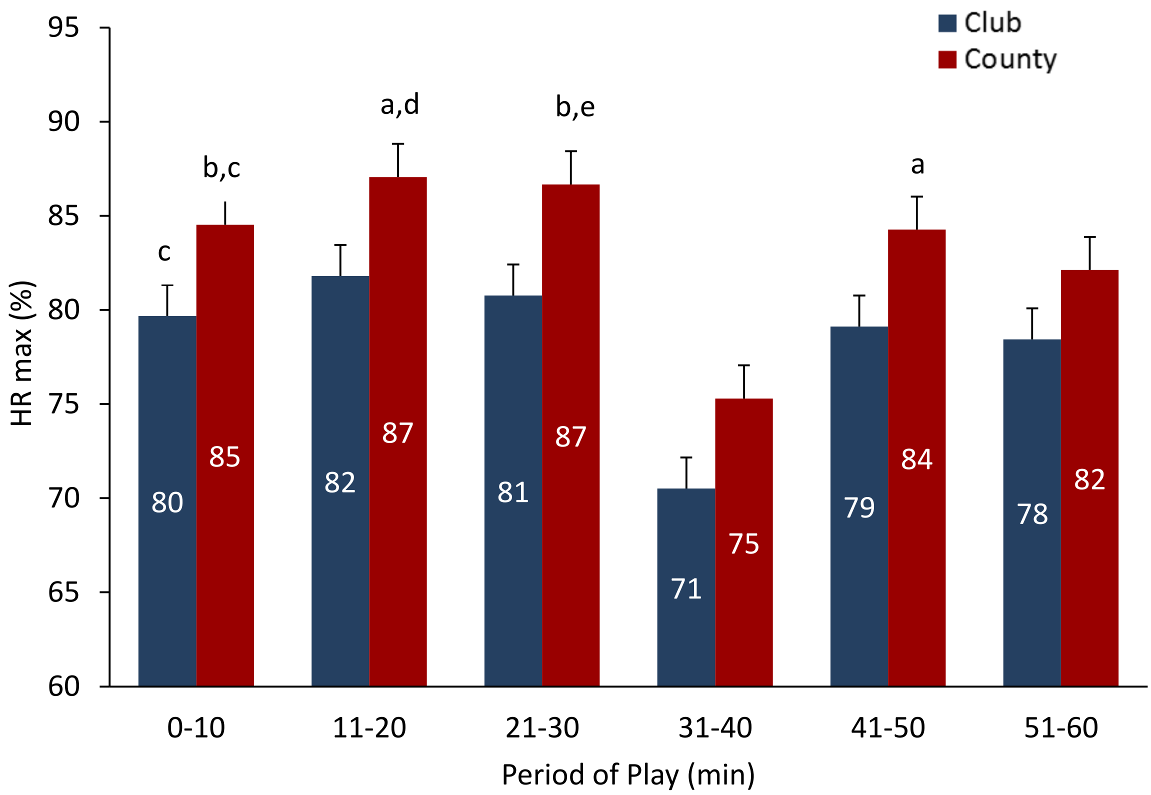

Figure 5.2 Percentage heart rate max during different 10 min game segments. [a]$p<0.05$ vs. club match; [b]$p<0.01$ vs. club match; [c]$p<0.01$ vs. 31-40 min; [d]$p<0.05$ vs. 41-50 min; [e]$p<0.01$ vs. 51-60 min

Table 5.3 summarises the %HRmax by playing level and playing position during different game segments. Playing position did not have a significant effect on the heart rate response during match play at club or county level. When averaged over each 10 min segment of the first half, the entire first half and full 60 min game, the %HRmax was significantly higher in county level midfield players than their club counterparts. The %HRmax in county level defenders was significantly greater ($p<0.05$) than club level defenders during the final 10 min segment of the second half of play and when averaged over the 60 min of play.

The %HRmax in county defenders and midfield players was significantly higher ($p<0.01$) during the first half than the second half of play. County level defenders exercised at a higher %HRmax during the first and second 10 min segments of the first half of play than the same time segments during the second half of play ($p<0.01$). Similarly, county level midfield players exercised at a significantly higher ($p<0.05$) %HRmax during the first and last 10 min segments of the first half of play than the same time segments during the second half of play.

Irrespective of playing position, %HRmax was significantly higher in club players during the first half than the second half of play ($p<0.05$), and during the first 10 min segment of the first half than the first 10 min segment of the second half ($p<0.01$). The %HRmax was also significantly higher among club forwards during the second 10 min segment of the first half than the second 10 min segment of the second half ($p<0.05$).

Table 5.3 Percentage maximal heart rate by level and position during different game segments

	Club			County		
	Defender	**Midfield**	**Forward**	**Defender**	**Midfield**	**Forward**
First Half						
0-10 min	79.79 ± 4.51[d]	79.92 ± 6.38[k]	81.57 ± 4.91[d]	83.75 ± 4.45[d]	86.75 ± 1.79[cd]	84.15 ± 4.16
11-20 min	82.92 ± 2.79	84.14 ± 3.33	85.17 ± 5.61[e]	86.05 ± 6.29[f]	89.63 ± 3.53[a]	85.75 ± 7.31
21-30 min	83.46 ± 2.42	82.86 ± 3.38	82.7 ± 6.46	85.43 ± 2.75	88.81 ± 2.15[cg]	86.57 ± 5.52
0-30 min	82.06 ± 2.56[h]	82.31 ± 3.81[h]	83.15 ± 5.33[i]	85.08 ± 3.91[j]	88.4 ± 1.96[ci]	85.49 ± 5.47
Second Half						
31-40 min	72.9 ± 6.90	67.08 ± 11.48	71.62 ± 10.47	75.57 ± 6.35	75.64 ± 7.90	75 ± 13.68
41-50 min	80.48 ± 6.16	82.42 ± 5.30	81.31 ± 4.54	83.68 ± 4.02	86.71 ± 2.74	82.06 ± 5.16
51-60 min	75.4 ± 11.55	77.08 ± 8.63	81.05 ± 5.63	83.88 ± 2.97[b]	81.81 ± 4.16	80.25 ± 5.90
31-60 min	76.26 ± 5.12	75.53 ± 6.38	77.99 ± 6.45	81.04 ± 2.91	81.36 ± 2.58	79.1 ± 7.77
Total Game	79.16 ± 2.54	79.14 ± 4.79	80.57 ± 5.80	83.61 ± 2.20[b]	84.69 ± 1.83[a]	82.3 ± 4.92

Values are mean ± SD. [a]p<0.05 vs. club midfield; [b]p<0.05 vs, club defender; [c]p<0.01 vs. club midfield; [d]p<0.01 vs. 31-40 min; [e]p<0.05 vs. 41-50 min; [f]p<0.01 vs. 41-50 min; [g]p<vs. 51-60 min; [h]p<0.05 vs. 31-60 min; [i]p<0.001 vs. 31-60 min; [j]p<0.01 vs. 31-60 min; [k]p<0.05 vs. 31-40 min

5.7.3 Relative Heart Rate Distribution

Figures 5.3-5.5 summarises the percentage of playing time in selected heart rate zones during a full game, and the first half and second half in county and club level players. During each half of play and over the full 60 min duration of the game, county players spent significantly more time than club level players at an exercise intensity between 91-100% HRmax. Club players spent a significantly greater percentage of playing time than county players at an exercise intensity between 71-80 %HRmax higher during both halves of play ($p<0.05$) and for the entire game ($p<0.01$)

A significantly greater percentage of time during county games is spent at an intensity ranging from 61-70%, 71-80% and 81-90% HRmax during the second half of play than the first half of play ($p<0.05$). The percentage of playing time spent by county players at an intensity ranging from 91-100% HRmax decreased significantly ($p<0.01$) from the first to the second half of play. Club players spent a significantly greater percentage of playing time at an intensity ranging from 61-70% HRmax, and less time at 91-100% HRmax in the second half than the first half ($p<0.05$).

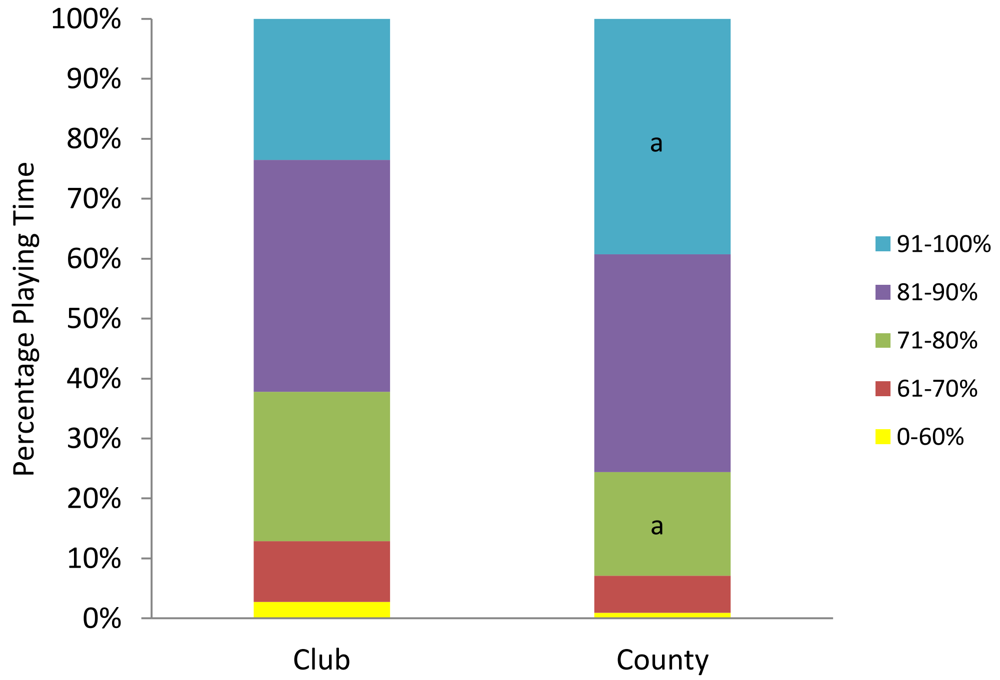

Figure 5.3 Percentage playing time in different HR zones during a full game. [a]p<0.01 vs. club game

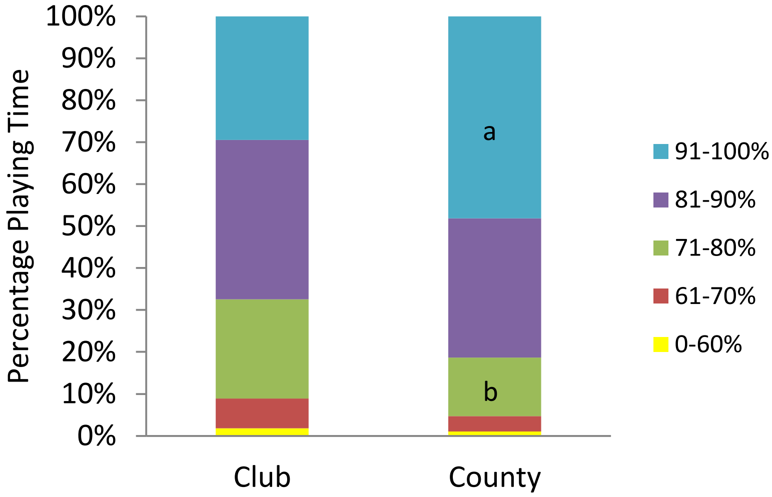

Figure 5.4 Percentage playing time in different HR zones during the first half of play. [a]p<0.01 vs. club game; [b]p<0.001 vs club game

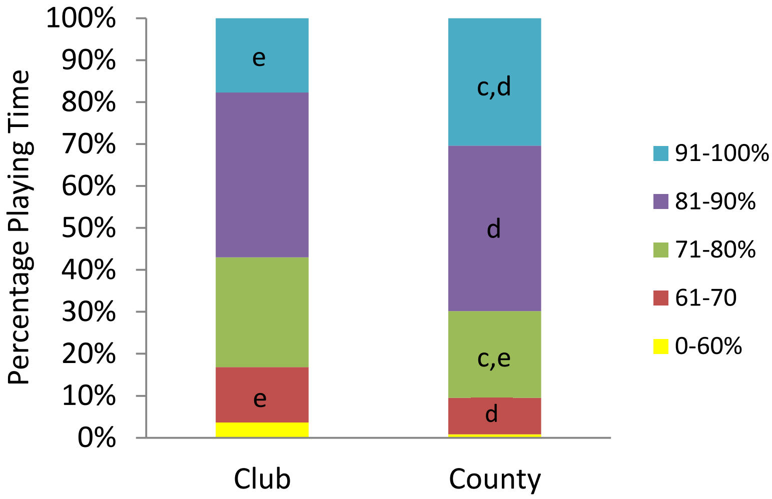

Figure 5.5 Percentage playing time in different HR zones during the second half of play. [c]p<0.05 vs. club game; [d]p<0.01 vs 1st half; [e]p<0.05 vs. 1st half

The percentage of playing time in selected HR zones by playing level and position are summarised for the entire game, and for each half of play (Table 5.4). During the first half of play county defenders spent significantly less time ($p<0.05$) than club defenders at an exercise intensity ranging from 71-80% HRmax. County defenders spent significantly more time ($p<0.05$) than their club counterpart at an exercise intensity between 91-100% HRmax during both the first and second half of play and over the entire 60 min of play. County defenders and forward players spent significantly less ($p<0.05$) time at an intensity between 71-80% than club defenders and forward players, respectively during the entire game. County midfield players spent significantly more time ($p<0.01$) than club midfield players at an intensity ranging from 91-100% HRmax during the first half of play. Conversely, during the first half of play, club midfield and forward players spent significantly more time at an intensity between 71-80% HRmax than county midfield and forward players respectively ($p<0.01$).

Irrespective of playing position, county players spent significantly less time ($p<0.05$) in the second half than the first half of play at an intensity between 91-100% HRmax. County defenders and forward players spent a significantly greater percentage of playing time in the second half at an exercise intensity between 71-80% and 81-90% HRmax ($p<0.05$). County defenders also spent a significantly greater percentage of playing time in the second half between 61-70% HRmax. County midfield players spent a significantly greater percentage of playing time in the second half at an exercise intensity ranging from 61-70% ($p<0.05$) and 81-90% HRmax ($p<0.01$).

Club midfield players spent a significantly greater percentage of playing time in the second half at an exercise intensity ranging from 71-80% HRmax ($p<0.05$). Club forward players spent significantly less playing time in the second half at an exercise intensity ranging from 91-100% HRmax ($p<0.05$).

Table 5.4 Percentage playing time in selected HR zones by level and position

	Club			County		
	Defender	**Midfield**	**Forward**	**Defender**	**Midfield**	**Forward**
Full Game						
0-60%	3.53 ± 6.98	3.65 ± 5.80	1.65 ± 2.19	0.44 ± 0.47	0.17 ± 0.25	2.11 ± 4.12
61-70%	8.96 ± 4.75	6.35 ± 6.49	10.77 ± 10.67	6.28 ± 3.60	3.72 ± 2.56	6.12 ± 4.64
71-80%	26.14 ± 5.34	18.89 ± 9.15	24.65 ± 4.61	18.79 ± 5.25[a]	13.71 ± 4.32	17.23 ± 5.95[c]
81-90%	41.35 ± 9.49	39.14 ± 13.86	36.37 ± 9.41	34.2 ± 5.51	39 ± 11.27	38.2 ± 10.28
91-100%	19.52 ± 7.28	29.99 ± 25.39	26.18 ± 13.17	39.99 ± 12.66[b]	43.33 ± 12.14	36.33 ± 13.67
First Half						
0-60%	0.63 ± 1.15	3.05 ± 3.80	2.20 ± 3.54	0.3 ± 0.63	0.03 ± 0.08	2.83 ± 7.27
61-70%	5.72 ± 5.71	4.84 ± 4.41	8.70 ± 7.93	5.2 ± 6.49	0.83 ± 0.85	4.24 ± 6.47
71-80%	23.67 ± 6.36	17.96 ± 8.08	23.75 ± 5.52	18.28 ± 9.44[a]	8.57 ± 3.16[d]	12.13 ± 4.8[e]
81-90%	44.18 ± 11.94	42.23 ± 19.6	33.35 ± 8.25	32.48 ± 6.05	32 ± 12.62	34.39 ± 10.43
91-100%	24.78 ± 7.32	31.09 ± 30.03	31.78 ± 13.41	43.61 ± 18.8[a]	58.57 ± 14.73[d]	46.41 ± 16.13
Second Half						
0-60%	6.43 ± 14.10	4.35 ± 7.75	1.10 ± 1.95	0.54 ± 0.76	0.33 ± 0.5	1.39 ± 2.31
61-70%	12.19 ± 9.42	8.24 ± 8.56	12.84 ± 13.65	9.37 ± 5.12[f]	6.67 ± 4.91[g]	8.00 ± 7.20
71-80%	28.62 ± 7.44	20.35 ± 9.69[g]	25.55 ± 5.87	21.66 ± 4.87[g]	17.93 ± 8.84	22.34 ± 10.49[g]
81-90%	38.51 ± 12.39	39.27 ± 14.10	39.38 ± 12.66	36.59 ± 5.84[g]	43.64 ± 11.56[f]	42.02 ± 10.97[f]
91-100%	14.26 ± 11.74	24.78 ± 20.41	20.58 ± 14.46[g]	31.41 ± 14.64[af]	31.28 ± 15.13[f]	26.26 ± 17.45[g]

Values are mean ± SD.[a]$p < 0.05$ vs. club defender; [b]$p < 0.01$ vs. club defender; [c]$p < 0.05$ vs club forward; [d]$p < 0.01$ vs. club midfield; [e]$p<0.01$ vs. club forward; [f]$p<0.01$ vs. 1st half; [g]$p<0.05$ vs. 1st half

5.7.4 Aerobic Demand

When combined across both club and county level, the mean %$\dot{V}O_2$max per game was 70%. There was no difference in the mean %$\dot{V}O_2$max between county and club level games (figure 5.6). The %$\dot{V}O_2$max in county players was significantly higher during each 10 min segment of the first half that the second half ($p<0.05$) (figure 5.7) and during the first half than the second half of play ($p<0.01$) (figure 5.6). There was a significant decrease in the %$\dot{V}O_2$max in club players between the first 10 min segment of the first and second half ($p<0.01$) (figure 5.7). Among club players the %$\dot{V}O_2$max was significantly higher ($p<0.01$) in the first half than the second half of play (figure 5.6).

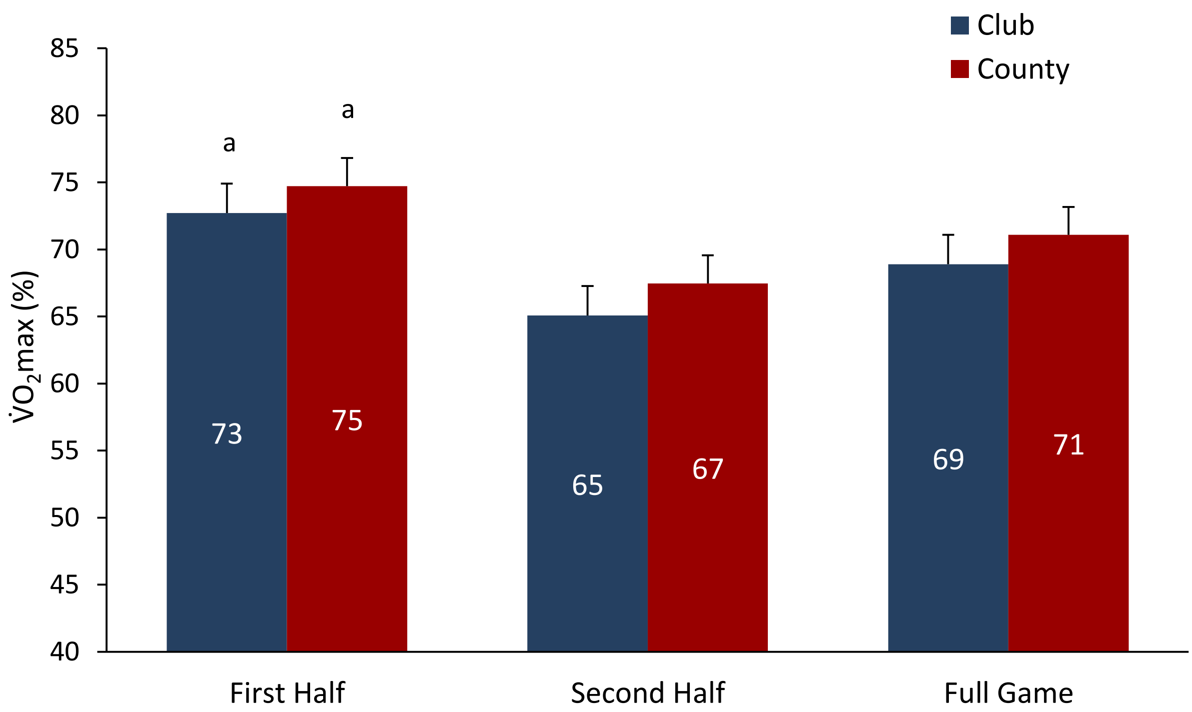

Figure 5.6 Percentage $\dot{V}O_2$max during county and club games. [a]$p<0.01$ vs. 2nd half

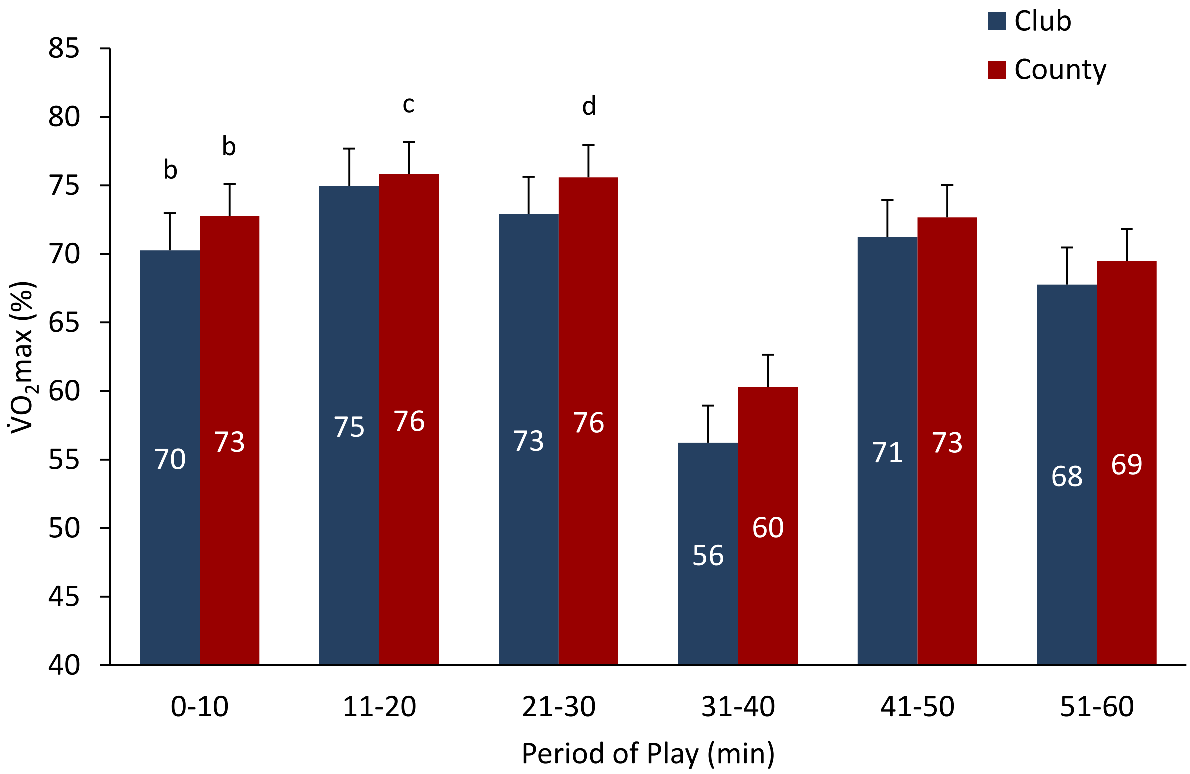

Figure 5.7 Percentage %$\dot{V}O_2$max during different 10 min game segments. [b]$p<0.001$ vs. 31-40 min; [c]$p<0.05$ vs.41-50 min; [d]$p<0.01$ vs. 51-60 min

Table 5.5 summarises the %$\dot{V}O_2$max by playing level and playing position during different game segments. %$\dot{V}O_2$max was significantly higher ($p<0.05$) in county midfield players than county forwards during the second 10 segment of the second half. Compared to club midfield players, the %$\dot{V}O_2$max was significantly higher ($p<0.05$) during the first 10 min segment and the entire first half of play in county midfield players. The %$\dot{V}O_2$max for county defenders was significantly higher during the first ($p<0.01$) and second ($p<0.05$) 10 min segments of the first half than during the same periods in the second half of play.

Table 5.5 Percentage $\dot{V}O_2$ max by level and position during different game segments

	Club			County		
	Defender	Midfield	Forward	Defender	Midfield	Forward
First Half						
0-10 min	66.59 ± 6.33	70.01 ± 10.14	69.74 ± 4.83	71.26 ± 6.72[c]	78.96 ± 5.34[a]	71.09 ± 7.23
11-20 min	72.31 ± 5.30	76.07 ± 5.43	74.62 ± 7.51	73.74 ± 7.87[d]	83.18 ± 6.48	72.62 ± 12.72
21-30 min	71.92 ± 5.77	74.78 ± 6.29	71.18 ± 8.40	73.63 ± 5.79	82.03 ± 5.19	74.23 ± 9.61
0-30 min	70.27 ± 5.25	73.62 ± 6.82	71.85 ± 6.51	72.87 ± 5.69	81.39 ± 5.1[a]	72.65 ± 9.58
Second Half						
31-40 min	55.68 ± 14.52	54.61 ± 17.86	55.16 ± 11.01	61.74 ± 9.28	61.65 ± 13.51	63.64 ± 10.00
41-50 min	68.28 ± 10.50	72.98 ± 7.70	69.48 ± 4.92	71.76 ± 8.09	79.2 ± 8.52[b]	67.61 ± 8.61
51-60 min	64.28 ± 12.31	65.53 ± 10.41	69.41 ± 5.65	72.2 ± 6.88	71.57 ± 10.19	65.43 ± 10.60
31-60 min	62.34 ± 10.36	64.37 ± 9.55	64.68 ± 6.37	68.57 ± 6.8	70.8 ± 7.42	63.98 ± 10.70
Total Game	68.3 ± 11.10	69.42 ± 8.05	68.27 ± 6.09	71.12 ± 5.83	75.91 ± 6.20	68.31 ± 8.68

Values are mean ± SD. [a]$p < 0.05$ vs. club midfield; [b]$p < 0.05$ vs. county forward; [c]$p < 0.01$ vs. 31-40 min; [d]$p < 0.05$ vs.41-50 min

5.8 Discussion

5.8.1 Percentage Heart Rate Max

The present study evaluated the physiological response during match play in county and club level U-18 Gaelic football players. Heart rate is generally considered a valid indicator of exercise intensity and has been widely employed in the study of field-based team sports (148, 160, 181). No previous study has evaluated the physiological demands of match play in young Gaelic football players. The %HRmax attained during match play in U-18 Gaelic football players was similar to values reported in elite youth soccer players (148, 153, 154, 156) and club and county adult players (3, 19).

Elite youth soccer players exercise at a higher absolute HR than their sub-elite counterparts during both the first and second half of play (148). As expected, county players performed at a higher %HRmax than club level U-18 players. It is likely that the greater %HRmax values in county players is a reflection of the greater distance covered and bouts of sprinting activity performed at this level during the course of an entire 60 min game.

The hypothesis that there would be a reduction in the physiological demands of match play between the first and second half of match play was accepted. There was a similar reduction in the mean %HRmax between the first and second 30 min period of match play in both county and club players. Similar findings have been reported among youth players in other field based sports (153, 154). It is expected that young, relatively inexperienced players will fatigue over the course of a game due to a decrease in muscle glycogen and accumulation of blood lactate and other metabolites. In contrast, studies in elite adult Gaelic football players found no difference in the relative or absolute HR response during the first and second half of play (3, 19). The difference may be attributed to the greater training age or more economical movement of elite senior players.

There was a 9% reduction in %HRmax in club and county players between the first 10 min segment of the first half and the same playing period during the second half of play. The increased frequency of walking and duration of jogging between the first and second half of play may help explain the reduced %HRmax during the initial 10 min period of the second half in young Gaelic football players. Research in adult soccer players found that a reduction in muscle and core temperature during the half time was associated with a reduced capacity to perform sprinting activity at the onset of the second half (157). The benefits of an appropriate warm up are well documented (22). A brief sport specific warm up in advance of the second half of play may help raise muscle and core temperature and minimise any reduction in high intensity activity.

To date, no study has evaluated the HR response during match play relative to playing position among county or club level Gaelic football players. It was hypothesised that the physiological demand during match play would be greatest in the midfield position. However, the hypothesis was rejected due to the fact the mean %HRmax during match play was similar across playing position at both club and county level. This finding would suggest that technical competencies and tactical understanding of the game should be the prime consideration in the positioning of players because there seems to be no difference in the physiological demands between playing positions at both county and club level.

The fact that county defenders and midfield players exercised at a higher %HRmax than their club level counterparts indicates that the ability to sustain high intensity exercise may be a discriminating factor between club and county players in the midfield and defensive positions.

5.8.2 Relative Heart Rate Distribution

HR response during match play is commonly evaluated relative to time spent at various intensities. Adult county players spent the majority of playing time (42.5%) at a heart rate of 161-180 bpm, which based on peak HR values obtained during match play equates to 80-89% HRmax. Interestingly only 10.5% of playing time was spent at an exercise intensity >181 bpm or >90% HR max (3). In contrast, county players in the present study spent 36% and 39% of total playing time at an intensity between 81-90% and 91-100% HRmax, respectively. Youth soccer players also spend the majority of playing time exercising at >81% HRmax (160).

County players spend a greater percentage of playing time than club players exercising between 91%-100% during the entire game. However, both county and club players spent less time exercising between 91-100% HRmax during the second half of play. Interestingly, playing position had no effect on the percentage of total playing time spent in the specified heart rate zones in both club and county players. These findings are in agreement with recent studies in elite youth soccer players (160, 161). For the most part, there was no difference between playing positions between county and club players.

5.8.3 Percentage $\dot{V}O_2max$

Oxygen consumption is essential to support the production of ATP required to sustain the metabolic demands of physical activity. Maximal oxygen uptake ($\dot{V}O_2max$) refers to the highest volume of oxygen an individual can consume to produce chemical energy at a cellular level during exercise (22). A high rate of aerobic energy expenditure may reduce the metabolic disturbances from anaerobic metabolism and enhance the ability to resist fatigue during intermittent activity (100, 103).

The direct assessment of $\dot{V}O_2$ is inhibited by the need for portable metabolic devices unsuitable for the nature of field based sports. However, it is possible to estimate $\dot{V}O_2$ during match play based on the HR-$\dot{V}O_2$ relation obtained during an incremental exercise test (142). In this study the HR-$\dot{V}O_2$ relation obtained during an incremental laboratory based treadmill test was used to estimate $\dot{V}O_2$ during match play in both club and county level Gaelic football players. The mean Pearson's product-moment correlation coefficient was 0.98 indicating excellent linearity in the data.

The mean %$\dot{V}O_2max$ attained during match play was 70% which is in agreement with studies in adult Gaelic football players, youth and adult soccer players (19, 144, 148). This suggests that the physiological workload during Gaelic football is comparable in young and adult players. There was no difference in the %$\dot{V}O_2max$ during match play between club and county players. Elite youth soccer players have been found to exercise at a higher %$\dot{V}O_2max$ than non-elite players in the same age group (148).

County and club level players both exercised at a higher %$\dot{V}O_2$max during the first half than the second half of play. It was hypothesised based on studies in youth soccer (148) that midfield players would experience the highest physiological strain during match play. However, playing position had little or no effect on %$\dot{V}O_2$max during match play in county or club players. County midfield players did however exercise at a higher %$\dot{V}O_2$max than their club counterpart during the first half of play. This highlights the increased demand of elite level competition in the midfield playing position among U-18 Gaelic football players.

Future research should examine the influence of other important factors on the physiological demands of match play such as game related activities, the quality of the opposition, the score line and the stage of the season.

5.8.4 Practical Application

An understanding of the physiological demands of match play is necessary in order to devise sport specific training strategies. Coaches may use this information to replicate the intensity of match play during small sided games or technical/training drills. The present study demonstrates that playing level influences the intensity of match play in young Gaelic football players and training should be adapted accordingly. The large reduction in playing intensity in the second period of play compared to the first period emphasises the need for coaches to be aware that the need to alter their tactical approach to account for individual and team fatigue.

5.8.5 Study Limitations

1. Oxygen uptake was estimated and not directly measured during the individual games
2. Participating county and club teams were limited to Leinster and Dublin, respectively and may not reflect county and club players nationwide
3. The county games were part of preparatory competition with unlimited substitutions which may have affected the physiological demand of match play
4. There was a considerable score difference between county teams during a small number of games during which motivation levels may have been diminished
5. The effect of game related activities on the physiological response during match play was not considered

CHAPTER VI

GENERAL DISCUSSION, CONCLUSION & RECOMMENDATIONS

The GAA is a sporting and cultural organisation responsible for the organisation and promotion of Gaelic games. It is the largest sporting organisation in Ireland and has a presence on five continents. Gaelic football is the most popular sport in Ireland (1). Annual minor level competitions are organised between club and county players between 16-18 years. The All-Ireland minor football final acts as a curtain raiser to the senior final which attracts crowds of up to 82,000 spectators to Croke Park.

In many instances Gaelic football coaches are influenced by their observations of adult level teams, both in both Gaelic games and other team based field sports. There is anecdotal evidence that important factors such as age, experience and training status are often ignored when evaluating fitness characteristics in underage players. This often results in young players being assigned unrealistic fitness targets unsuitable to their stage of development. Given the absence of any scientific information describing the fitness characteristics, physiological demands and movements patterns of contemporary Gaelic football, the specificity of current training strategies is questionable. This gap in the literature has yielded generic training methods with little consideration of positional requirements or level of competition.

The amateur status of the GAA may help explain the lack of research in Gaelic games compared to that in other team based field sports. Furthermore, the study of sport science remains a relatively new addition to the curriculum of many third level institutions in

Ireland. The series of studies undertaken as part of this PhD thesis describes the anthropometric, physical fitness and game related demands in minor (U-18) level Gaelic football players. The first study established norm-referenced percentile scores for selected anthropometric and fitness indices across playing positions. The second and third studies compared player movement patterns and the physiological response during match play between county and club level players.

No previous studies have described the physical fitness characteristics or evaluated the physical and physiological demands of match play in U-18 Gaelic football players. The similar fitness characteristics between playing positions in U-18 Gaelic footballers indicate that the speed, power and endurance are important components of fitness in Gaelic football regardless of playing position. For the most part, playing position had no effect on the physical or physiological demands of match play in county and club level games. Although challenging given the lack of specialisation at underage level, a broader category of playing positions should be considered in future studies.

The standard battery of field based fitness tests administered in study 1 was designed to assess the key fitness components of Gaelic football. The normative data outlined in this study should be used by coaches as a reference point in the assessment of U-18 Gaelic football players. The periodical assessment of players is recommended in order to identify areas of weakness and monitor progress over time. The study findings indicate that the development of muscular power, running speed and aerobic fitness in young Gaelic football is important regardless of playing position. There is little need for position specific programmes in the development of these qualities given the changeable nature of playing position at this level.

The limitation of this study was that the testing surface was not standardised. Given the cost of transport and the limited availability of players during school hours, it was not practical or possible for the participating schools to travel to a single central location. In order to control external influences on test performance, coaches should aim to assess players in a standardised setting and under identical conditions. It is also recommended that testing take place throughout the season to measure changes in fitness. Due to the fatiguing nature of the overall battery of tests administered in study 1, and in order to avoid interfering with their game day preparation, it was decided that participating schools would be tested within two weeks of wining/exiting the championship.

The movement patterns and physiological demands of match play in U-18 Gaelic football games may closely resemble that in young soccer players of a similar age and playing level. The results indicate that county games involve a higher physical and physiological demand than club games. This information may be used by coaches to assist in the progression of players from club to county level. Practice sessions should be designed to replicate the intensity of match play exhibited during county level games. Developing a greater technical ability and tactical understanding of the game in club level players may also aid the progression of players at U-18 level.

Irrespective of playing level, the second half of match play was characterised by a decline in distance covered, frequency of high intensity activity and %HRmax. This pattern was particularly evident during the first 10 min period of the second half, highlighting the potential negative impact of the half time period on the intensity of match play. It is recommended that players perform a reduced version of a typical pre-game warm up prior to the second half of play. Coaches should also avoid prolonged static periods of inactivity during practice sessions, which may affect training intensity.

The limitation of study 2 and 3 is that data was collected during a preparatory competition with unlimited substitutions, which may have affected the movement profile and subsequent physiological demand of match play. Ideally players should be monitored during championship fixtures. Coaches are however, reluctant to make their players available for research purposes given the importance of such fixtures. It is not possible to directly measure $\dot{V}O_2$ during match play without a portable metabolic device, the use of which are not permitted within the rules of the game. Estimating $\dot{V}O_2$ based on heart rate data was therefore the most practical method of quantifying the physiological response during match play.

There has been a recent marked increase in the use of telemetry systems and GPS units to monitor the physical and physiological demands during team sports involving intermittent activity. Despite the abundance of data in this area across different sports, the influences of many other important factors are not well understood. Future research in Gaelic games should consider the effect of team possession, skill execution and the score line on the movement patterns and physiological demands of match play.

In summary, this is the first series of studies to examine the physical fitness characteristics, movement patterns and physiological demands during match play in U-18 Gaelic football players. The information provided will greatly assist coaches and players in their preparation. A unique feature of this research was the use of GPS technology to track player movements, and the estimation of $\dot{V}O_2$ from heart rate. Research in Gaelic games has for long periods been neglected. However, this series of studies should provide a foundation for future research.

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APPENDIX A

Table A Percentage heart rate max during county and club games

	Club	County	Combined
First Half			
0-10 min	79.68 ± 3.56[a]	84.53 ± 2.26[a]	82.25 ± 3.78
11-20 min	81.80 ± 5.25	87.06 ± 3.07[b]	84.59 ± 4.91
21-30 min	80.76 ± 4.86	86.66 ± 1.63[c]	83.88 ± 4.57
0-30 min	80.75 ± 4.05[e]	86.08 ± 1.68[d]	83.57 ± 4.02
Second Half			
31-40 min	70.51 ± 5.99	75.29 ± 7.41	73.04 ± 7.01
41-50 min	79.12 ± 5.14	84.26 ± 2.34	81.84 ± 4.62
51-60 min	78.44 ± 7.20	82.12 ± 2.22	80.39 ± 5.36
31-60 min	76.02 ± 4.29	80.56 ± 2.73	78.42 ± 4.15
Total Game	78.38 ± 3.32	83.32 ± 1.83	80.99 ± 3.60

Values are mean ± SD. [a]p<0.01 vs. 31-40 min; [b]p<0.05 vs. 41-50 min; [c]p<0.01 51-60 min; [d]p< 0.001 vs. 31-60 min; [e]p<0.05 vs. 31-60 min

Table B Percentage of playing time in selected heart rate zones

	Club	County	Combined
First Half			
0-60%	1.79 ± 2.07	1.01 ± 2.27	1.38 ± 2.15
61-70%	6.92 ± 5.61	3.72 ± 2.61	5.22 ± 4.46
71-80%	23.16 ± 3.35	13.94 ± 3.80[c]	18.28 ± 5.89
81-90%	37.24 ± 7.53	33.15 ± 7.13	35.07 ± 7.40
91-100%	28.86 ± 11.42	48.11 ± 9.57[b]	39.05 ± 14.18
Second Half			
0-60%	3.62 ± 4.72	0.79 ± 0.69	2.12 ± 3.48
61-70%	13.00 ± 9.75[e]	8.67 ± 3.43[d]	10.71 ± 7.24
71-80%	25.88 ± 5.33	20.61 ± 4.64[ae]	23.09 ± 5.52
81-90%	38.76 ± 8.21	39.36 ± 7.45[d]	39.08 ± 7.57
91-100%	17.51 ± 11.02[e]	30.28 ± 11.43[ad]	24.27 ± 12.71
Full Game			
0-60%	2.71 ± 2.32	0.90 ± 1.26	1.75 ± 2.00
61-70%	9.96 ± 7.24	6.20 ± 2.40	7.97 ± 5.44
71-80%	24.52 ± 3.90	17.28 ± 3.03[b]	20.69 ± 5.01
81-90%	38.00 ± 6.47	36.26 ± 6.94	37.08 ± 6.57
91-100%	23.18 ± 10.05	39.20 ± 9.34[b]	31.66 ± 12.48

Values are mean ± SD.[a]p<0.05 vs. club level players; [b]p<0.01 vs. club level players; [c]p<0.001 vs. club level players; [d]p<0.01 vs. 1st half; [e]p<0.05 vs. 1st half

Table C Percentage $\dot{V}O_2$ max during county and club level games

	Club	**County**	**Combined**
First Half			
0-10 min	70.25 ± 1.25[a]	72.76 ± 4.42[a]	71.58 ± 3.48
11-20 min	74.96 ± 3.15	75.81 ± 4.95[b]	75.41 ± 4.10
21-30 min	72.91 ± 3.93	75.58 ± 2.52[c]	74.33 ± 3.44
0-30 min	72.71 ± 2.32[a]	74.72 ± 3.27[d]	73.77 ± 2.96
Second Half			
31-40 min	56.22 ± 9.32	60.28 ± 11.31	58.37 ± 10.31
41-50 min	71.23 ± 7.04	72.66 ± 5.26	71.99 ± 6.00
51-60 min	67.75 ± 9.50	69.47 ± 6.53	68.66 ± 7.85
31-60 min	65.07 ± 5.97	67.47 ± 6.21	66.34 ± 6.03
Full Game	68.89 ± 3.47	71.09 ± 4.52	70.06 ± 4.09

Values are mean ± SD. [a]p<0.01 vs. 31-60 min; [b]p<0.05 vs. 41-50 min; [c]p<0.01 vs. 51-60 min; [d]p<0.01 vs. 31-60 min

Table D Distance (m) covered during county and club level games

	Club	County	Combined
First Half			
0-10 min	919.41 ± 56.91[f]	1066.41 ± 80.81[ad]	997.23 ± 101.99
11-20 min	999.04 ± 44.09[g]	1056.55 ± 81.27	1029.43 ± 70.88
21-30 min	935.61 ± 75.65	1010.07 ± 57.64[b]	975.03 ± 75.05
0-30 min	2854.06 ± 118.79[e]	3132.92 ± 128.05[ce]	3001.69 ±186.97
Second Half			
31-40 min	737.68 ± 158.09	847.27 ± 109.69	795.7 ± 141.88
41-50 min	863.49 ± 150.60	1013.84 ± 113.57[b]	943.09 ± 149.51
51-60 min	876.85 ± 148.78	1010.02 ± 151.74	947.35 ± 160.90
31-60 min	2478.03 ± 365.87	2871.13 ± 307.72[b]	2686.14 ± 383.16
Total Game	5332.09 ± 398.01	6004.05 ± 354.74[a]	5687.83 ± 501.74

Values are mean ± SD. [a]p<0.01 vs. club level players; [b]p<0.05 vs. club level players; [c]p<0.001 vs. club level players; [d]p<0.001 vs. 31-40 min; [e]p<0.05 vs. 31-60 min; [f]p<0.05 vs. 31-40 min; [g]p<0.05 vs. 41-50 min

APPENDIX B

Dublin City University
RESEARCH ETHICS COMMITTEE

APPLICATION FOR APPROVAL OF A PROJECT INVOLVING **HUMAN PARTICIPANTS**

Application No. *(office use only)* DCUREC/2009/ ☐☐☐

Period of Approval *(office use only)* ....../....../...... to ....../....../....

This application form is to be used by researchers seeking ethics approval for individual projects and studies. The **signed original and an electronic copy** of your completed application must be submitted to the DCU Research Ethics Committee.

NB - The hard copy must be signed by the PI. The electronic copy should consist of <u>one file only</u>, which incorporates all supplementary documentation. The completed application must be proofread and spellchecked before submission to the REC. All sections of the application form should be completed. Applications which do not adhere to these requirements will not be accepted for review and will be returned directly to the applicant.

Applications must be completed on the form; answers in the form of attachments will not be accepted, except where indicated. No handwritten applications will be accepted. **Research must <u>not</u> commence until written approval has been received from the Research Ethics Committee.**

PROJECT TITLE **Assessment of fitness levels in senior level post-primary school Gaelic football players**

PRINCIPAL INVESTIGATOR(S) **Prof. Niall Moyna**

Please confirm that **<u>all</u>** supplementary information is included in your application (in both signed original and electronic copy). If questionnaire or interview questions are submitted in draft form, a copy of the final documentation must be submitted for final approval when available.

	INCLUDED		NOT APPLICABLE
Bibliography	☐		☒
Recruitment advertisement	☒		☐
Plain language statement/Information Statement	☒		☐
Informed Consent form	☒		☐
Evidence of external approvals related to the research	☐		☒
Questionnaire	☒ draft	☐ final	☐
Interview Schedule	☐ draft	☐ final	☒
Debriefing material	☐		☒
Other	☐		☒

Please note:

1. Any amendments to the original approved proposal must receive prior REC approval.
2. As a condition of approval investigators are required to document and report immediately to the Secretary of the Research Ethics Committee any adverse events, any issues which might negatively impact on the conduct of the research and/or any complaint from a participant relating to their participation in the study

1. ADMINISTRATIVE DETAILS

THIS PROJECT IS:
(tick as many as apply)

☐ Research Project
☐ Practical Class
☒ Student Research Project
(please give details)
☒ Research Masters
☐ Taught Masters
☐ PhD
☒ Undergraduate

☐ Funded Consultancy
☐ Clinical Trial
☐ Other - *Please Describe:*

Project Start Date: January 14, 2009 **Project End date:** Dec 31, 2009

1.1 INVESTIGATOR CONTACT DETAILS *(see Guidelines)*

PRINCIPAL INVESTIGATOR(S):

TITLE	*SURNAME*	*FIRST NAME*	*PHONE*	*FAX*	*EMAIL*
Prof.	Moyna	Niall	7008802	7008888	niall.moyna@dcu.ie

OTHER INVESTIGATORS:

TITLE	*SURNAME*	*FIRST NAME*	*PHONE*	*FAX*	*EMAIL*
Mr	Cullen	Bryan	0879720738		bryan.cullen2@gmail.com
Mr.	Travers	Hugh Stephen	0876200025		hugh.travers2@mail.dcu.ie
Mr.	Kelly	David	0851618207		david.kelly59@mail.dcu.ie
Mr.	Cullivan	Raymond	0877767296		raymond.cullivan2@mail.dcu.ie
Mr.	Cregg	Cathal	0877633021		cathal.cregg2@mail.dcu.ie

FACULTY/DEPARTMENT/SCHOOL/ CENTRE: School of Health and Human Performance

1.2 WILL THE RESEARCH BE UNDERTAKEN ON-SITE AT DUBLIN CITY UNIVERSITY?

☒ YES ☐ NO The research will be undertaken in post primary schools

1.3 IS THIS PROTOCOL BEING SUBMITTED TO ANOTHER ETHICS COMMITTEE, OR HAS IT BEEN PREVIOUSLY SUBMITTED TO AN ETHICS COMMITTEE?*)*

☐ YES ☒ NO

DECLARATION BY INVESTIGATORS

The information contained herein is, to the best of my knowledge and belief, accurate. I have read the University's current research ethics guidelines, and accept responsibility for the conduct of the procedures set out in the attached application in accordance with the guidelines, the University's policy on Conflict of Interest and any other condition laid down by the Dublin City University Research Ethics Committee or its Sub-Committees. I have attempted to identify all risks related to the research that may arise in conducting this research and acknowledge my obligations and the rights of the participants.

If there any affiliation or financial interest for researcher(s) in this research or its outcomes or any other circumstances which might represent a perceived, potential or actual conflict of interest this should be declared in accordance with Dublin City University policy on Conflicts of Interest.

I and my co-investigators or supporting staff have the appropriate qualifications, experience and facilities to conduct the research set out in the attached application and to deal with any emergencies and contingencies related to the research that may arise.

Signature(s):

Principal investigator(s): ______________________________ ______________________________

Print name(s) in block letters: *Niall Moyna* Date: _______

2. PROJECT OUTLINE

2.1 LAY DESCRIPTION *(see Guidelines)*

Gaelic football is the national sport of Ireland. It is played in a large number of post primary schools. In addition to technical and tactical skills, an appropriate level of physical fitness is required to play the game. There is currently no information available on the fitness levels of post primary school Gaelic football players. The purpose of this study is to 1) measure height, weight, body fat, speed, agility, power, aerobic endurance and flexibility in senior level post-primary school Gaelic football players using non-laboratory based tests, and 2) develop normative data that can be used to optimize training and performance. A team of 5 researchers will make a single visit (2.5 h) to each school to collect the data.

2.2 AIMS OF AND JUSTIFICATION FOR THE RESEARCH *(see Guidelines)*

Gaelic football is the most popular sport in post primary schools. The winners of the division 1 provincial post-primary, school competitions compete annually for the National title (Hogan cup). Optimal performance in Gaelic football requires that players develop the appropriate fitness attributes that allow them to cope with the physical demands of the game while maintaining technique and skill levels. Players are required to undertake multiple short duration, intermittent bouts of high intensity exercise interspersed with short duration recovery periods. In addition they must possess the strength and flexibility attributes that allow them to obtain and maintain possession of the ball, optimally execute skills and tackle opponents. There is currently relatively little information available to coaches regarding the optimal fitness level for post primary school Gaelic football players. In addition, there is a lack of normative data to assist coaches in evaluating test results. The primary aim of this study is to assess indices of fitness in post-primary schools Gaelic football players and to develop normative data.

2.3 PROPOSED METHOD *(see Guidelines)*

A team of researchers will visit each of the participation schools on one occasion. During the visit the following fitness parameters will be assessed; height, weight, body fat, speed, agility, power, aerobic endurance and flexibility. Subjects will refrain from strenuous physical activity for 24 hours before the test. The total time required to collect the data will be approx 2.5 hours.

Height – height will be measured to the nearest centimetre using a stadiometer (Seca Model 220, GMBH Hamburg. Germany)

Weight - weight will be measured to nearest kg using a medical scale (Seca Ltd, Hamburg, Germany)

Skin folds – Harpenden skinfold callipers (Baty International, England) will be used to measure double thickness subcutaneous adipose tissue on the right side of the body. The following anatomical sites will be measured; pectorialis, abdominal, thigh, subscapular, suprailiac and mid-axillary. A minimum of two measurements will be taken at each site. If the measurements vary by more than 2mm a third measurement will be taken. Body density will be calculated using the Jackson and Pollock (Body Density = 1.0994921-0.00009929*sum squared-0.0001392*age) equation and body density will be converted to percent body fat by the Siri equation (Percent Fat = [(495/Body Density)-450]*100). (x).

Standing Jump for Distance: The subject will jump in a horizontal direction for maximal distance

Counter Movement Jump (CMJ): The CMJ will be performed on a force platform. Subjects will flex the lower limb joints and then jump vertically as high as possible.

Vertical Jump: For this test the subject is in a standing position facing sideways to a wall on which a measuring tape has been attached. The person jumps reaching as high as possible with their arms and fingers fully extended. The subject gets three trials with 15sec rest between each effort.

Forward speed: Subjects will sprint in a forward direction for 20m. Performance will be measured using electronic timing gates positioned at 5m intervals. Each subject will perform 3 trials and the best score will be recorded.

Backward speed: Subjects will sprint in a backward direction for 20m. Performance will be measured using electronic timing gates positioned at 5m intervals. Each subject will perform 3 trials and the best score will be recorded.

Agility: Subjects will complete a predetermined course in the fastest possible time. Performance will be measures using electronic timing gates. Each subject will perform 3 trials and the best score will be recorded.

Hamstring Flexibility: Hamstring flexibility will be measured using a sit and reach test (Item 5111, Takei Physical Fitness Test, Takei Scientific Instruments Co., Ltd, Tokyo 142, Japan). Subjects will sit on a flat surface with their shoes removed and heels placed against the edge of the measuring box. They will be instructed to hyper-extend their knees and to flex their trunk as far as possible. The instructor's hands will press against the knees to prevent flexing. Subjects will remain in the final position for 3 sec. Each subject will perform 3 trials and measurements will be recorded to the nearest cm.

Analysing Data: Percentile scores will be generated using SPSS. Mean differences between playing positions (defence, mid field and attack) will be determined using a one way ANOVA. P

2.4 PARTICIPANT PROFILE *(see Guidelines)*

Inclusion criteria

- Male ≥ 16 years
- Member of a post-primary school senior football team competing in the 'A' (Division 1) competition.

Exclusion Criteria

- Clinical conditions that may preclude them from exercise
- Injury, which would affect their performance in the tests, or which may be aggravated by performing the tests.

2.5 MEANS BY WHICH PARTICIPANTS ARE TO BE RECRUITED *(see Guidelines)*

A letter will be sent to school principles informing them of the study. A researcher will visit interested schools to explain the details of the study. The aim and rationale of the study, the tests involved, the time commitment and the potential benefits will be explained to the coaches and players. Players will be given the opportunity to ask questions. If they wish to participate in the study they will have to provide a written informed consent.

2.6 PLEASE EXPLAIN WHEN, HOW, WHERE, AND TO WHOM RESULTS WILL BE DISSEMINATED, INCLUDING WHETHER PARTICIPANTS WILL BE PROVIDED WITH ANY INFORMATION AS TO THE FINDINGS OR OUTCOMES OF THE PROJECT?

Subjects will be provided with a report, which will summarise the relevant results from their participation in the research project. The results will form the basis for an undergraduate thesis and may be presented at scientific meetings and published in scientific journals.

2.7 OTHER APPROVALS REQUIRED *Has permission to gain access to another location, organisation etc. been obtained? Copies of letters of approval to be provided when available.*

☐ YES ☐ NO ☒ NOT APPLICABLE

(If YES, please specify from whom and attach a copy. If NO, please explain when this will be obtained.)

2.8 HAS A SIMILAR PROPOSAL BEEN PREVIOUSLY APPROVED BY THE REC?

☐ YES ☒ NO

(If YES, please state both the REC Application Number and Project Title)

3. RISK AND RISK MANAGEMENT

3.1 ARE THE RISKS TO SUBJECTS AND/OR RESEARCHERS ASSOCIATED WITH YOUR PROJECT GREATER THAN THOSE ENCOUNTERED IN EVERYDAY LIFE?

☐ YES ☒ NO *If YES, this proposal will be subject to full REC review*
If NO, this proposal may be processed by expedited administrative review

3.2 DOES THE RESEARCH INVOLVE:

	YES	NO
• Use of a questionnaire? (attach copy)?	☐	☒
• interviews (attach interview questions)?	☐	☒
• observation of participants without their knowledge?	☐	☒
• participant observation (provide details in section 2)?	☐	☒
• audio- or video-taping interviewees or events?	☐	☒
• access to personal and/or confidential data (including student, patient or client data) without the participant's specific consent?	☐	☒
• administration of any stimuli, tasks, investigations or procedures which may be experienced by participants as physically or mentally painful, stressful or unpleasant during or after the research process?	☒	☐
• performance of any acts which might diminish the self-esteem of participants or cause them to experience embarrassment, regret or depression?	☐	☒
• investigation of participants involved in illegal activities?	☐	☒
• procedures that involve deception of participants?	☐	☒
• administration of any substance or agent?	☐	☒
• use of non-treatment of placebo control conditions?	☐	☒
• collection of body tissues or fluid samples?	☐	☒
• collection and/or testing of DNA samples?	☐	☒
• participation in a clinical trial?	☐	☒
• administration of ionising radiation to participants?	☐	☒

3.3 POTENTIAL RISKS TO PARTICIPANTS AND RISK MANAGEMENT PROCEDURES *(see Guidelines)*

You may experience some muscle soreness in your legs or nausea following some of the exercise tests. Exercise carries with it a very small risk of abnormal heart rhythms, heart attack or death. The likelihood of theses risks in healthy young adults who have no known heart disease is very low. The nature and risks involved in the study will be fully explained and subjects will be given the opportunity to ask questions.

3.4 ARE THERE LIKELY TO BE ANY BENEFITS (DIRECT OR INDIRECT) TO PARTICIPANTS FROM THIS RESEARCH?

☒ YES ☐ NO

3.5 ARE THERE ANY SPECIFIC RISKS TO RESEARCHERS? *(e.g. risk of infection or where research is undertaken at an off-campus location)*

☐ YES ☒ NO *(If YES, please describe.)*

3.6 ADVERSE/UNEXPECTED OUTCOMES *(see Guidelines)*

Due to the nature of the study we do not envisage any major adverse events or unexpected outcomes. Members of the research team will be trained in first aid.

3.7 MONITORING *(see Guidelines)*

The research team will have weekly meetings to update on all aspects of the study. A post-graduate student with experience in field based testing will oversee all aspects of the testing. All research will be familiar with the testing procedures prior to data collection. A number of practice sessions will be undertaking to ensure proficiency and reliability in the data collection procedure.

3.8 SUPPORT FOR PARTICIPANTS *(see Guidelines)*

It is anticipated that no additional support will be needed.

3.9 DO YOU PROPOSE TO OFFER PAYMENTS OR INCENTIVES TO PARTICIPANTS?

☐ YES ☒ NO *(If YES, please provide further details.)*

4. INVESTIGATORS' QUALIFICATIONS, EXPERIENCE AND SKILLS *(Approx. 200 words – see Guidelines)*

Prof. Niall Moyna is an exercise physiologist and has extensive experience with exercise testing in healthy and disease populations.

Mr. Bryan Cullen is a postgraduate student and has extensive experience in laboratory and field based exercise testing.

David Kelly, Cathal Cregg, Raymond Cullivan and Stephen Travers are final year students in BSc. Sport Science and Health. They are familiar with laboratory and field based exercise protocols that will be used in the present study.

5. CONFIDENTIALITY/ANONYMITY

5.1 WILL THE IDENTITY OF THE PARTICIPANTS BE PROTECTED?

☒ YES ☐ NO *(If NO, please explain)*

IF YOU ANSWERED YES TO 5.1, PLEASE ANSWER THE FOLLOWING QUESTIONS:

5.2 HOW WILL THE ANONYMITY OF THE PARTICIPANTS BE RESPECTED? *(See Guidelines)*

Confidentiality is an important issue during data collection. Participant's identity, or other personal information, will not be revealed or published. Subjects will be assigned an ID number under which all personal information will be stored in a secure file and saved in password protected file in a computer at DCU. The researchers and principal investigator will have access to the data.

5.3 LEGAL LIMITATIONS TO DATA CONFIDENTIALITY: *(Have you included appropriate information in the plain language statement and consent form? See Guidelines)*

☒ YES ☐ NO *(If NO, please advise how participants will be advised.)*

6 DATA/SAMPLE STORAGE, SECURITY AND DISPOSAL *(see Guidelines)*

6.1 HOW WILL THE DATA/SAMPLES BE STORED? *(The REC recommends on campus)*

Stored at DCU ☒
Stored at another site ☐ **(***Please explain where and for what purpose)*

6.2 WHO WILL HAVE ACCESS TO DATA/SAMPLES?

Access by named researchers only ☒
☐
Access by people other than named researcher(s) ☐ **(***Please explain who and for what purpose)*

Other : ☐ **(***Please explain)*

6.3 IF DATA/SAMPLES ARE TO BE DISPOSED OF, PLEASE EXPLAIN HOW, WHEN AND BY WHOM THIS WILL BE DONE?

Data will be stored for 5 years following the completion of the project. The principal investigator will be responsible for security of the data. The data will be kept in a secure area and access to the data will only be attainable by the named researchers. Aside from the named researchers, no others will have access to the raw data.

7. FUNDING

7.1 HOW IS THIS WORK BEING FUNDED?
School of Health and Human Performance

7.2 PROJECT GRANT NUMBER (If relevant and/or known)

7.3 DOES THE PROJECT REQUIRE APPROVAL BEFORE CONSIDERATION FOR FUNDING BY A GRANTING BODY?

☐ YES ☐ NO

7.4 HOW WILL PARTICIPANTS BE INFORMED OF THE SOURCE OF THE FUNDING?

7.5 DO ANY OF THE RESEARCHERS, SUPERVISORS OR FUNDERS OF THIS PROJECT HAVE A PERSONAL, FINANCIAL OR COMMERCIAL INTEREST IN ITS OUTCOME THAT MIGHT COMPROMISE THE INDEPENDENCE AND INTEGRITY OF THE RESEARCH, OR BIAS THE CONDUCT OR RESULTS OF THE RESEARCH, OR UNDULY DELAY OR OTHERWISE AFFECT THEIR PUBLICATION?

☐ YES ☐ NO *(If Yes, please specify how this conflict of interest will be addressed.)*

8. PLAIN LANGUAGE STATEMENT *(Approx. 400 words – see Guidelines)*

Project Title: Assessment of fitness levels in senior level post-primary school Gaelic football players

The principle investigator is: Prof. Niall M. Moyna, (Tel: 7008802 Fax 7008888)

EMAIL: niall.moyna@dcu.ie

I. Players who compete in elite Gaelic football competitions in post primary school need to attain fitness levels that will allow them to cope with the physical demands of the game while maintaining their skill levels. The demands of the game require speed, strength, flexibility, agility, power and endurance. This study will measure each of these fitness attributes in Division 1 post primary schools Gaelic football players.

II. A team of researchers from Dublin City University (DCU) will visit your school. During the visit the following fitness attributes will be assessed: height, weight, body fat, speed, agility, power, endurance, and flexibility. You will refrain from strenuous physical activity for 24 hours before the tests. The total time required to collect the data will be approx 2.5 hours.

III. You may experience some muscle soreness in your legs or nausea following some of the exercise tests. Exercise carries with it a very small risk o abnormal heart rhythms, heart attack or death. The likelihood of theses risks in healthy young adults who have no known heart disease is very low

IV. You will receive a report summarizing the results of your tests undertaken during the study. No other benefits have been promised.

V. Your identity and other personal information will not be revealed, published or used in further studies. You will be assigned an ID number under which all personal information will be stored in a secure file and saved in a password protected file in a computer at DCU. The principal investigator, and collaborators listed on this ethics application will have access to the data. You need to be aware that confidentiality of information provided can only be protected within the limitations of the law. It is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions.

VI. The original documentation will be stored for a maximum of 5 years. Thereafter the documentation will be shredded.

VII. Involvement in this study is completely voluntary. You may withdraw from the Research Study at any point.

VIII. If you have concerns about this study and wish to contact an independent person, please contact: The Secretary, Dublin City University Research Ethics Committee, c/o Office of the Vice-President for Research, Dublin City University, Dublin 9. Tel 01-7008000

9. INFORMED CONSENT FORM *(Approx. 300 words – see Guidelines)*

Informed Consent

Dublin City University

Project Title Assessment of fitness levels in senior level post-primary school Gaelic football players

Principle Investigator: Prof. Niall M. Moyna

Introduction to this study

Players who compete in elite Gaelic football competitions in post primary school need to attain fitness levels that will allow them to cope with the physical demands of the game while maintaining their skill levels. The demands of the game require speed, strength, flexibility, agility, power and endurance. This study will measure each of these fitness attributes in Division 1 post primary schools Gaelic football players.

Participants Requirements

A team of researchers from DCU will measure my height, weight, body fat, speed, agility, power, endurance, and flexibility. I will refrain from strenuous physical activity for 24 hours before the fitness evaluation.

Potential risks to participants from involvement in the Research Study

You may experience some muscle soreness in your legs or nausea following some of the exercise tests. Exercise carries with it a very small risk o abnormal heart rhythms, heart attack or death. The likelihood of theses risks in healthy young asymptomatic adults who have no known heart disease is very low.

Benefits (direct or indirect) to participants from involvement in the Research Study

I will receive a report summarizing the results of the tests I undertook during the study. No other benefits have been promised to me.

Participant – please complete the following (tick Yes or No for each question)

Have you read or had read to you the Plain Language Statement? Yes ☐ No ☐

Do you understand the information provided? Yes ☐ No ☐

Have you had an opportunity to ask questions and discuss this study? Yes ☐ No ☐

Have you received satisfactory answers to all your questions? Yes ☐ No ☐

Advice as to arrangements to be made to protect confidentiality of data, including that confidentiality of information provided is subject to legal limitations.

My identity and other personal information will not be revealed, published or used in further studies. I will be assigned an ID number under which all personal information will be stored in a secure file and saved in a password protected file in a computer at DCU. The principal investigators and undergraduate and graduate students listed on the application will have access to the data. Data will be shredded after five years by Prof. Moyna.

Confidentiality is insured, but I must be aware that confidentiality of information provided can only be protected within the limitations of the law. It is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions.

If I am in a dependent relationship with any of the researchers my involvement in the project will not affect ongoing assessment/grades/management or treatment of health at DCU.

Signature:

I have read and understood the information in this form. The researchers have answered my questions and concerns, and I have a copy of this consent form. Therefore, I consent to take part in this research project entitled fitness levels in post primary school Gaelic football players.

Participant's Signature: ______________________________________

Name in Block Capitals ___________________________________

Witness: ___________________________________

Date: ___________________________________

DUBLIN CITY UNIVERSITY

ASSENT FORM FOR CHILDREN

Study Title: Assessment of fitness levels in senior level post-primary school Gaelic football players

1. My school mentor manager teacher has talked to me about being part of a research study.
2. I have been told that if I take part in the study that I will have to have to undergo a standard battery of fitness assessments.
3. I will not take any food or beverages except water for 3 hours before testing.
4. I will not do any strenuous exercise for 24 hours before testing.
5. I will have my height, weight and body composition assessed.
6. I will undergo tests of flexibility, muscular power, speed and aerobic fitness.
7. I may feel tired or be out of breath during testing and my legs may feel tired
8. If I wish, I can stop doing the tests at any time.
9. If I wish, I may choose not to take part in any of the tests.
10. I know that the people in DCU, my school mentor and my parents/guardian will not be upset with me if I decide not to take part in this study, or if I wish to stop taking part in the study.

SIGNED: ____ DATE: __________
(Participant's name)

SIGNED: ____ DATE: __________
(Witness name)

2nd December 2009

Dear Principal,

The School of Health and Human Performance in Dublin City University is undertaking a National study to assess indices of fitness in senior level post-primary schools Gaelic football players, and to develop normative data that can be used to optimize training and performance in competition.

It is envisaged that a team of researchers will visit your school on one occasion. During this visit the following fitness parameters will be assessed; height, weight, body fat, speed, agility, power, aerobic endurance and flexibility. The total time required to collect the data will be approx 2.5 hours.

We are seeking your permission to contact the coach/manager of the Senior football team.

If you would like more information, please feel free to contact my office on 01-7008802.

I will contact your office in the near future.

Kindest regards,

____________________________ ____________________________

Niall M. Moyna, PhD., FACSM. **Bryan Cullen, BSc**

Dublin City University

RESEARCH ETHICS COMMITTEE

APPLICATION FOR APPROVAL OF A PROJECT INVOLVING **HUMAN PARTICIPANTS**

Application No. *(office use only)* DCUREC/2012/☐☐☐

Period of Approval *(office use only)* ....../....../...... to ....../....../....

This application form is to be used by researchers seeking ethics approval for individual projects and studies. The **signed original and an electronic copy** of your completed application must be submitted to the DCU Research Ethics Committee.
Note: If your research requires approval from the Biosafety Committee, this approval should be in place prior to REC submission. Please attach the approval from the BSC to this submission.

NB - The hard copy must be signed by the PI. The electronic copy should consist of <u>one file only</u>, which incorporates all supplementary documentation. The completed application must be proofread and spellchecked before submission to the REC. All sections of the application form should be completed. Applications which do not adhere to these requirements will not be accepted for review and will be returned directly to the applicant.

Applications must be completed on the form; answers in the form of attachments will not be accepted, except where indicated. No handwritten applications will be accepted. **Research must <u>not</u> commence until written approval has been received from the Research Ethics Committee.**

PROJECT TITLE Assessment of Physiological Responses and Activity Patterns in Adolescents during Gaelic Football

PRINCIPAL INVESTIGATOR(S) Prof. Niall M. Moyna

Please confirm that **<u>all</u>** supplementary information is included in your application (in both signed original and electronic copy). If questionnaire or interview questions are submitted in draft form, a copy of the final documentation must be submitted for final approval when available.

	INCLUDED		**NOT APPLICABLE**
Bibliography	☒		☐
Recruitment advertisement	☐		☒
Plain language statement/Information Statement	☒		☐
Informed Consent form	☒		☒
Evidence of external approvals related to the research	☐		☒
Questionnaire	☐ draft	☐ final	☒
Interview Schedule	☐ draft	☐ final	☒
Debriefing material	☐		☒
Other	☐		☒

Please note:

3. Any amendments to the original approved proposal must receive prior REC approval.
4. As a condition of approval investigators are required to document and report immediately to the Secretary of the Research Ethics Committee any adverse events, any issues which might negatively impact on the conduct of the research and/or any complaint from a participant relating to their participation in the study

1. ADMINISTRATIVE DETAILS

THIS PROJECT IS: *(tick as many as apply)*	☒	Research Project	☐	Funded Consultancy
	☐	Practical Class	☐	Clinical Trial
	☐	Student Research Project *(please give details)*	☐	Other - *Please Describe:*

☐	ResearchMasters	☐	Taught Masters
☒	PhD	☐	Undergraduate

Project Start Date: **March, 2012** **Project End date:** **May 31, 2014**

1.1 INVESTIGATOR CONTACT DETAILS

PRINCIPAL INVESTIGATOR(S):

TITLE	*SURNAME*	*FIRST NAME*	*PHONE*	*FAX*	*EMAIL*
Prof	Moyna	Niall	01 7008802	01 7008888	niall.moyna@dcu.ie

OTHER INVESTIGATORS:

TITLE	*SURNAME*	*FIRST NAME*	*PHONE*	*FAX*	*EMAIL*
Mr.	Cullen	Bryan	086 2319399	01 7008888	bryan.cullen2@gmail.com
Mr.	McCaffrey	Noel	087 2797597	01 7008888	noel.mccaffrey@dcu.ie

FACULTY/DEPARTMENT/SCHOOL/CENTRE: School of Health and Human Performance

1.2 WILL THE RESEARCH BE UNDERTAKEN ON-SITE AT DUBLIN CITY UNIVERSITY

☐ YES ☒ NO The collection of fitness data will be undertaken in the Human Performance Laboratory at Dublin City University. Physiological and physiological data will be obtained at different venues during Ulster and Leinster minor league fixtures.

1.3 IS THIS PROTOCOL BEING SUBMITTED TO ANOTHER ETHICS COMMITTEE, OR HAS IT BEEN PREVIOUSLY SUBMITTED TO AN ETHICS COMMITTEE?)

☐ YES ☒ NO

DECLARATION BY INVESTIGATORS

The information contained herein is, to the best of my knowledge and belief, accurate. I have read the University's current research ethics guidelines, and accept responsibility for the conduct of the procedures set out in the attached application in accordance with the guidelines, the University's policy on Conflict of Interest and any other condition laid down by the Dublin City University Research Ethics Committee or its Sub-Committees. I have attempted to identify all risks related to the research that may arise in conducting this research and acknowledge my obligations and the rights of the participants.

If there any affiliation or financial interest for researcher(s) in this research or its outcomes or any other circumstances which might represent a perceived, potential or actual conflict of interest this should be declared in accordance with Dublin City University policy on Conflicts of Interest.

I and my co-investigators or supporting staff have the appropriate qualifications, experience and facilities to conduct the research set out in the attached application and to deal with any emergencies and contingencies related to the research that may arise.

Signature(s):

Principal investigator(s): Niall Moyna *Feb 10, 2012*

2. PROJECT OUTLINE

5. LAY DESCRIPTION

Gaelic football is one of the most popular sports in Ireland. In recent is has evolved into an intense skilful game with high physical and mental demands being placed on the players. There is presently no information available to coaches regarding the activity profiles and physiological responses of adolescent players during competitive fixtures. Such information would greatly assist coaches in developing training programmes that are specific to the needs of the game at this level. The purpose of this study is to i) measure selected physiological responses in adolescent players during competitive games ii) identify their activity patterns and iii) compare activity profiles and physiological demands across different playing positions.

2.2 AIMS OF AND JUSTIFICATION FOR THE RESEARCH

Despite the popularity of Gaelic football, sport scientists have made little contribution to our understanding of the demands placed on players during games. Gaelic football has evolved into an intense and skilful game with high physical and mental demands being placed on the players. There is a need for up to date research to aid coaches in the preparation of players particularly at underage level. There is presently no information available to coaches regarding the activity profiles of the activity profiles and physiological responses of adolescent players during competitive fixtures. A greater understanding of the activity profile and physiological demands placed on players will aid coaches in the development of training programmes that are specific to the needs of the game.

The aims of this study are to i) calculate the heart rate response, estimated oxygen uptake and blood lactate levels in adolescent players during competitive games ii) identify the activity pattern of adolescent players during competitive games iii) compare activity profiles and physiological demands across positions.

2.3 PROPOSED METHOD

Study Overview

Participants will make a single visit to the Human Performance Laboratory in DCU and subsequently wear a global positioning satellite (GPS) tracking device and heart rate monitor for the duration of 3 official county minor league fixtures. During the visit to DCU, i) a blood sample will be taken ii) body composition and blood pressure will be assessed, and iii) pulmonary function and aerobic fitness (VO_2max) will be measured. Heart rate data will be used to determine the absolute and relative oxygen uptake and the GPS device, which also contains an accelerometer will be used to determine the distance covered and activity characteristics of each player. A very small blood sample will be taken from the earlobe before, at half time and after each game to assess measure lactic acids levels.

VISIT TO DCU: The laboratory visit will be approximately 1 hour in duration. Participants will be asked not to undertake any strenuous physical activity for 24 hours before the visit to DCU. During the visit, a blood sample will be drawn to check for anaemia and acute infection. Body composition and blood pressure will be assessed, and pulmonary function and aerobic fitness (VO_2max) will be measured.

FOOTBALL GAMES: Participants will wear a GPS tracking device and heart rate monitor for the duration of 2-3 county minor league fixtures. Each game will be videotaped.

GPS Tracking. The GPS tracking unit is a device that uses the Global Positioning System to determine the precise location of a player. The tri-axial accelerometer in the unit is used to calculate running velocities. The recorded location and running velocities are stored within the tracking unit. The GPS device will be placed in a pouch attached to a harness type vest

Heart Rate Determination: A transmitter will be attached to an elastic strap and placed around the chest. The strap length will be adjusted to fit comfortably and the buckle locked. The grooved electrode area on the back of the transmitter will be moistened. Heart rate will be recorded and stored on the GPS device. The data will be subsequently transferred from the receiver to a PC for analysis.

Cardiorespiratory fitness: A standard treadmill protocol with open circuit spirometry will be used to measure VO_2max. During this assessment subjects will be fitted with a mouthpiece or facemask. Exercising heart rate will be continually measured throughout the test using a heart rate monitor.

Body composition: Height, weight, waist and hip circumferences will also be measured using standard procedures. Skinfold callipers will be used to measure double thickness subcutaneous adipose tissue on the right side of the body.

Blood sampling and assays: The initial blood sample to check for anaemia and acute infection will be obtained using standard venipuncture. An individual trained in phlebotomy will draw the blood sample. The amount of blood taken will be 3 ml.

2.4 PARTICIPANT PROFILE

County level (U-18) - Gaelic football players will be recruited to take part in the study.

Inclusion criteria:

- Member of an county minor panel
- Aged 16-18 years
- Clinically stable and in good health

Exclusion criteria:

Potential participants will be excluded if:

- They have not informed consent
- Current smoker
- Clinical conditions that may preclude them from exercise. This information will be obtained from a questionnaire that will be completed by the participants (appendix 2)

2.5 MEANS BY WHICH PARTICIPANTS ARE TO BE RECRUITED

A letter providing a brief summary of the research project will be sent to the manager of each team completing in the Ulster and Leinster county minor football league's. Bryan Cullen (PhD student) will make a follow up phone call to each manager and will arrange to give a presentation to each of the teams that agree to participate. The purpose of the study will be outlined and a brief summary of what is involved will be explained to all potential participants. They will be provided with an informed consent to be signed by a parent/guardian. In addition, they will sign an assent form and complete a Physical Activity Readiness Questionnaire.

2.6 PLEASE EXPLAIN WHEN, HOW, WHERE, AND TO WHOM RESULTS WILL BE DISSEMINATED, INCLUDING WHETHER PARTICIPANTS WILL BE PROVIDED WITH ANY INFORMATION AS TO THE FINDINGS OR OUTCOMES OF THE PROJECT?

The results obtained will form the basis for a postgraduate thesis and will be presented at scientific meeting and published in scientific journals. The identity of the individual participants will remain anonymous. Information, as a group, will only be presented. Participants will be provided with a report which will detail their results from participating in the study.

2.7 OTHER APPROVALS REQUIRED *Has permission to gain access to another location, organisation etc. been obtained? Copies of letters of approval to be provided when available.*

☐ YES ☐ NO ☒ NOT APPLICABLE

Permission will be obtained from school principles (Appendix 1)

2.8 HAS A SIMILAR PROPOSAL BEEN PREVIOUSLY APPROVED BY THE REC

☒ YES ☐ NO

Assessment of Physiological Responses and Activity Patterns in Children During Gaelic Football (2006)

3. RISK AND RISK MANAGEMENT

3.1 ARE THE RISKS TO SUBJECTS AND/OR RESEARCHERS ASSOCIATED WITH YOUR PROJECT GREATER THAN THOSE ENCOUNTERED IN EVERYDAY LIFE?

☒ YES ☐ NO

If YES, this proposal will be subject to full REC review

If NO, this proposal may be processed by expedited administrative review

3.2 DOES THE RESEARCH INVOLVE

	YES	NO
• use of a questionnaire? (attach copy)?	☒	☐
• interviews (attach interview questions)?	☐	☒
• observation of participants without their knowledge?	☐	☒
• participant observation (provide details in section 2)?	☐	☒
• audio- or video-taping interviewees or events?	☒	☐
• access to personal and/or confidential data (including student, patient or client data) without the participant's specific consent?	☐	☒
• administration of any stimuli, tasks, investigations or procedures which may be experienced by participants as physically or mentally painful, stressful or unpleasant during or after the research process?	☒	☐
• performance of any acts which might diminish the self-esteem of participants or cause them to experience embarrassment, regret or depression?	☐	☒
• investigation of participants involved in illegal activities?	☐	☒
• procedures that involve deception of participants?	☐	☒
• administration of any substance or agent?	☐	☒
• use of non-treatment of placebo control conditions?	☐	☒
• collection of body tissues or fluid samples?	☒	☐
• collection and/or testing of DNA samples?	☐	☒
• participation in a clinical trial?	☐	☒
• administration of ionising radiation to participants?	☐	☒

3.3 POTENTIAL RISKS TO PARTICIPANTS AND RISK MANAGEMENT PROCEDURES *(see Guidelines)*

1. Exercise testing is associated with a very small risk of abnormal heart rhythms, heart attack or death. However, the likelihood of a cardiac event in a healthy asymptomatic healthy teenager is extremely rare.
2. Drawing blood is associated with slight pain and discomfort and can cause bruising where the needle is inserted. An individual trained in phlebotomy will draw the blood samples. A safe volume of approximately 3 ml of blood will be drawn.

3.4 ARE THERE LIKELY TO BE ANY BENEFITS (DIRECT OR INDIRECT) TO PARTICIPANTS FROM THIS RESEARCH?

☒ YES ☐ NO

Participants will receive a copy of their results, detailing information on their body composition, lung function and fitness levels.

3.5 ARE THERE ANY SPECIFIC RISKS TO RESEARCHERS? *(e.g. risk of infection or where research is undertaken at an off-campus location)*

☒ YES ☐ NO

Risk is associated with working with blood and handling needles. The research team has been immunized for hepatitis B.

3.6 ADVERSE/UNEXPECTED OUTCOMES

The School of Health and Human Performance has established an emergency protocol for adverse events. In the unlikely event of a major adverse outcome, an ambulance will be called and the participant will be sent immediately to Beaumont Hospital. Any minor adverse outcomes will be dealt with by the study physician who will then refer the participant, if required, to the VHI- Swift Care clinic in Swords for further attention.

3.7 MONITORING

The research team will have meetings on a weekly basis to update on all aspects of the study. All researchers involved in the study will be familiar with testing procedures and the safety statement prior to commencing data collection. A number of practice sessions will be undertaken by all the research team to ensure proficiency and reliability in performing the data collection procedures.

3.8 SUPPORT FOR PARTICIPANTS

This study does not require additional support for participants

3.9 DO YOU PROPOSE TO OFFER PAYMENTS OR INCENTIVES TO PARTICIPANTS?

☐ YES ☒ NO *(If YES, please provide further details.)*

4. INVESTIGATORS' QUALIFICATIONS, EXPERIENCE AND SKILLS

Prof. Niall M. Moyna is an exercise physiologist and has extensive experience in exercise related research.

Dr. Noel McCaffrey is a physician with extensive experience in exercise related research.

Bryan Cullen is a PhD student in exercise physiology. He has a BSc Sport Science and Health, DCU and has extensive experience of the laboratory and field based assessments to be used in the proposed study.

5. CONFIDENTIALITY/ANONYMITY

5.1 WILL THE IDENTITY OF THE PARTICIPANTS BE PROTECTED?

☒ YES ☐ NO *(If NO, please explain)*

IF YOU ANSWERED YES TO 5.1, PLEASE ANSWER THE FOLLOWING QUESTIONS:

5.2 HOW WILL THE ANONYMITY OF THE PARTICIPANTS BE RESPECTED?

Participant confidentiality is an important issue during data collection. Participant's identity and other personal information will not be revealed, published or used in other studies. Participants will be assigned an ID number under which all personal information will be stored in a secure locked cabinet in the School of Health and Human Performance at DCU. Electronic date will be stored on a password- protected computer in DCU. The principal investigator and named collaborators listed on this ethics application will be able to access the data.

5.3 LEGAL LIMITATIONS TO DATA CONFIDENTIALITY: *(Have you included appropriate information in the plain language statement and consent form? See Guidelines)*

☒ YES ☐ NO *(If NO, please advise how participants will be advised.)*

6 DATA/SAMPLE STORAGE, SECURITY AND DISPOSAL

6.1 HOW WILL THE DATA/SAMPLES BE STORED? *(REC recommends on campus)*

Stored at DCU ☒
Stored at another site ☐ **(***Please explain))*

6.2 WHO WILL HAVE ACCESS TO DATA/SAMPLES?

Access by named researchers only ☒
Access by people other than named researcher(s) ☐ **(***Please explain)*

6.3 IF DATA/SAMPLES ARE TO BE DISPOSED OF, PLEASE EXPLAIN HOW, WHEN AND BY WHOM THIS WILL BE DONE?

The raw data will be stored in a secure locked cabinet in the School of Health and Human Performance at DCU. Electronic date will saved in a password- protected in a computer at DCU. Data will be kept for a minimum of 5 years following from the date of the publication of the research. The principal investigator will be responsible for the security of the data. Only the other investigators listed on this ethics application form will have access to the data. The data will be shredded by the principal investigator after 5 years.

7. FUNDING

7.1 HOW IS THIS WORK BEING FUNDED?

A Grant has been submitted to the GAA

7.2 PROJECT GRANT NUMBER (If relevant and/or known)

7.3 DOES THE PROJECT REQUIRE APPROVAL BEFORE CONSIDERATION FOR FUNDING BY A GRANTING BODY?

☐ YES ☒ NO

7.5 HOW WILL PARTICIPANTS BE INFORMED OF THE SOURCE OF THE FUNDING?

Informed consent

7.5 DO ANY OF THE RESEARCHERS, SUPERVISORS OR FUNDERS OF THIS PROJECT HAVE A PERSONAL, FINANCIAL OR COMMERCIAL INTEREST IN ITS OUTCOME THAT MIGHT COMPROMISE THE INDEPENDENCE AND INTEGRITY OF THE RESEARCH, OR BIAS THE CONDUCT OR RESULTS OF THE RESEARCH, OR UNDULY DELAY OR OTHERWISE AFFECT THEIR PUBLICATION?

☐ YES ☒ NO

8. PLAIN LANGUAGE STATEMENT

DUBLIN CITY UNIVERSITY

Plain Language Statement

Project Title:	Assessment of Physiological Responses and Activity Patterns in Adolescents during Gaelic Football
Principal investigator	Professor Niall M. Moyna (Tel: 01-7008802; Fax 01-7008888) Centre for Preventive Medicine School of Health and Human Performance
Email:	niall.moyna@dcu.ie

I. Introduction to the Research Study

Gaelic football is one of the most popular sports in Ireland. In recent is has evolved into an intense skilful game with high physical and mental demands being placed on the players. There is presently no information available to coaches regarding the activity profiles and physiological responses of adolescent players during competitive fixtures. Such information would greatly assist coaches in developing training programmes that are specific to the needs of the game at this level. The purpose of this study is to i) measure selected physiological responses in adolescent players during competitive games ii) identify their activity patterns and iii) compare activity profiles and physiological demands across different playing positions.

II. Involvement in the Research Study will require

- That your son will visit to the Human Performance Laboratory in DCU and subsequently wear a global positioning satellite (GPS) tracking device and heart rate monitor during 3 official county minor league fixtures.

- During the visit to DCU he will have a small blood sample taken from a vein in his arm to make sure that he has adequate levels of red blood cells to carry oxygen. He will then have his height and weight measured and skinfolds taken to measure his percent body fat and lean muscle mass. Finally, his blood pressure and lung function will be assessed, and he will have his cardiovascular fitness levels measured while running on a treadmill.

- Before each game he will be fitted with a heart rate monitor and GPS tracing device. The GPS device will be placed in a pouch and worn in a custom designed harness (Figure 1). A very small blood sample will be taken from the fingertip or earlobe before the game, at half time and after each game (Figure 2 and Figure 3)


Figure 1

Figure 2


Figure 3

III. Potential risks from involvement in the Research Study

- Your child may experience some muscle soreness in his/her legs or nausea following exercise.
- Exercise carries with it a very small risk of injury, abnormal heart rhythms, heart attack or death. The likelihood of these risks in healthy young adolescents is very low.
- Drawing blood may cause a slight pain where the needle is inserted and can leave a bruise. A person trained to take blood will be used to decrease these risks. The amount of blood drawn is not harmful.

IV. Benefits from involvement in the Research Study

Your child will receive a report summarizing the results of his/her tests undertaken during the study. No other benefits have been promised.

V. Arrangements to protect confidentiality of data

Your child's identity and other personal information will not be revealed, published or used in further studies. Your child will be assigned an ID number under which all personal information will be stored and saved in a password protected file in a computer at DCU. The principal investigator, and collaborators listed on this ethics application will have access to the data. You need to be aware that confidentiality of information provided can only be protected within the limitations of the law. It is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions.

VI. Advice as to whether or not data is to be destroyed after a minimum period

The original documentation will be stored for a maximum of 5 years. Thereafter the documentation will be shredded.

VII. Involvement in the Research Study is voluntary

Involvement in this study is completely voluntary. Your child may withdraw from the Research Study at any point. There will be no penalty for withdrawing before all stages of the Research Study have been completed.

If participants have concerns about this study and wish to contact an independent person, please contact: The Secretary, Dublin City University Research Ethics Committee, c/o Office of the Vice-President for Research, Dublin City University, Dublin 9. Tel 01-7008000

9. INFORMED CONSENT FORM

DUBLIN CITY UNIVERSITY

Informed Consent Form

Research Study Title

Assessment of Physiological Responses and Activity Patterns in Adolescents during Gaelic Football

Principle Investigator

Prof. Niall M. Moyna, School of Health and Human Performance, DCU

II. Purpose of the research

To measure selected physiological responses, distance covered and activity patterns in adolescent players during competitive county minor league games

III. Confirmation of particular requirements as highlighted in the Plain Language Statement

Participant – please complete the following (Circle Yes or No for each question)

I have read the Plain Language Statement (or had it read to me)	Yes ☐	No ☐
I understand the information provided	Yes ☐	No ☐
I have had an opportunity to ask questions and discuss this study	Yes ☐	No ☐
I have received satisfactory answers to all my questions	Yes ☐	No ☐

IV. Confirmation that involvement in the Research Study is voluntary

Your child may withdraw from the Research Study at any point.

V. Advice as to arrangements to be made to protect confidentiality of data, including that confidentiality of information provided is subject to legal limitations

Your child's and other personal information will not be revealed, published or used in further studies. Your child will be assigned an ID number under which all personal information will be stored in a secure locked cabinet and saved in a password protected file in a computer at DCU. The named investigators will have access to the data. Data will be shredded after 5 years by Prof. Moyna.

Confidentiality is insured, but you must be aware that confidentiality of information provided can only be protected within the limitations of the law. It is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions.

VI. Any other relevant information

If your child is in a dependent relationship with any of the researchers their involvement in the project will not affect ongoing assessment/grades/management or treatment of health at DCU.

VII. Signature:

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to allow my child take part in this research project

Participants Signature: ______________________________

Name in Block Capitals: ______________________________

Witness: ______________________________

Date: ______________________________

DUBLIN CITY UNIVERSITY

ASSENT FORM FOR CHILDREN

Study Title: Assessment of Physiological Responses and Activity Patterns in Adolescents during Gaelic Football

1. My county minor manager teacher has talked to me about being part of a research study.
2. I have been told that if I take part in the study that I will have to have to visit DCU once and that I will have to wear a heart rate monitor and GPS tracking device during 3 minor league games
3. I will not take any food or beverages except water for 4 hours before my visit to DCU.
4. I will not do any strenuous exercise for 24 hours before my visit to DCU.
5. When I arrive in DCU I will have about a teaspoon of blood taken from a vein in my arm. Drawing blood may cause a slight pain where the needle is inserted and may leave a bruise on my arm that will clear up in a few days.
6. I will have my lung function, blood pressure and percent body fat measured and then I will run on treadmill to see how fit I am. During the test I will wear a nose clip on my nose and a mouthpiece in my mouth.
7. Before, during and at half time of each game, I will have a very small sample of blood taken from the top of my finger or from my ear lobe to measure lactic acid levels.
8. I may feel tired or be out of breath when I am running on the treadmill and my legs may feel tired
9. If I wish, I can stop doing the tests at any time.
10. If I wish, I may choose not to take part in any of the tests.
11. I know that the people in DCU, my county managerand my parents/guardian will not be upset with me if I decide not to take part in this study, or if I wish to stop taking part in the study.

SIGNED: ____ DATE: __________
(Participant's name)

SIGNED: ____ DATE: __________
(Witness' name)

APPENDIX C

Physical Activity Readiness Questionnaire

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

Yes / No Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

Yes/ No Do you feel pain in your chest when you do physical activity?

Yes / No In the past month, have you had chest pain when you were not doing physical activity?

Yes / No Do you lose your balance because of dizziness or do you ever lose consciousness?

Yes / No Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?

Yes / No Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?

Yes / No Do you know of any other reason why you should not do physical activity?

Yes to One or More Questions: -

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

No to All Questions: -

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME: ____________________

SIGNATURE: ____________________

DATE: ____________________

SIGNATURE OF PARENT: ____________________

WITNESS: ____________________