An investigation into the variation that exists between the physical performance indicators of hurling players at different levels of participation

Andrew Murphy

A thesis submitted to the University of Limerick for the award of Master of Science (MSc.)

Department of Physical Education and Sports Sciences

University of Limerick

Supervised by: Dr. Cian O’Neill

Submitted to the University of Limerick, November 2012
Abstract

Background: There is a paucity of research profiling the anthropometric measures and physical performance indicators of hurling athletes. Such profiles are essential to optimising the physical preparation structures of hurling athletes.

Methods: A battery of tests profiling the anthropometric measures and physical performance indicators of 95 hurling athletes from three different levels of participation, senior elite (n1=34), senior sub-elite (n2=28) & junior elite (n3=33) were evaluated on two separate occasions during the season. Data was collected on all squads describing height, body mass, upper and lower extremity power, sprint performance, local muscular endurance, anaerobic endurance and aerobic endurance. Additional body composition measurements were conducted using DXA on the senior elite team.

Results: There was a significant difference (p≤0.05) between measures of body mass, lower extremity power, sprint performance and endurance between senior elite and senior sub elite squads. Significant differences were also present (p≤0.05) between measures of height, body mass, upper and lower extremity power and sprint performance in the senior elite and junior elite squads. The findings also revealed selecte anthropometric measures and physical performance indicators are subject to significant seasonal change (p≤0.05).

Conclusion: The results of this research provide normative data for the population of hurling athletes. The results also show that selected anthropometric measures and physical performance indicators illustrate a progressive improvement as level of participation increases. Such measures and indicators are subject to seasonal change but are dependent on the training programme content and initial pre-season levels.
Authors Declaration

I hereby declare that the work contained within this thesis is entirely my own work other than the counsel of my supervisor, Dr. Cian O’Neill of the Department of Physical Education and Sport Sciences, University of Limerick. This work has not been submitted for any academic award, or part thereof, at this or any other educational establishment. Where the use has been made of the work of other people, it has been fully acknowledged and referenced.

_______________________________
Andrew Murphy, November 2012
Acknowledgements

I would like to thank the following people for their help in assisting me in the completion of this thesis

First of all I would like to thank my girlfriend Annmarie without whom none of this would be possible and without such support provided by her I would have quit long ago

Dr. Cian O’Neill who was extremely supportive and understanding of my unique needs as a student in particular my working lifestyle, without this understanding completion of this project and day to day living would not have been possible. I would also like to thank Dr. Cian for continual perseverance in correcting my unique and sometimes disastrous writing style

Sincere thanks must go to Limerick G.A.A., Tipperary G.A.A., Kildangan G.A.A. and Toomevara G.A.A. whom without their co-operation testing would not have been possible

A huge shout out to all the testers that assisted in the testing process without you help and excellent knowledge base the testing would never have been possible

For the provision of the best training environment to release the stresses of college work a huge thanks must go all the weightlifters of U.L. with a particular sincere thanks to the Byrd man

Thanks must go all my fellow post grads that assisted me along the never ending journey that filled me with their superior knowledge in particular all things electronic

Words cannot some up the appreciation for the assistance, guidance and everything else provided by my mother, for this I will be forever grateful and someday I will get a real job

Oh and last but not least to the ladies and gents upstairs who provided me with guidance and much more prior to and during this journey
Table of Contents

Abstract....................................................................................................................................................... i
Authors Declaration ...................................................................................................................................... iii
Acknowledgements ....................................................................................................................................... v
List of Tables ............................................................................................................................................... vii
List of Figures ............................................................................................................................................... x

Chapter 1. Introduction.................................................................................................................................. 1
  1. 1. Introduction......................................................................................................................................... 3
  1. 2. Purpose of the Research.................................................................................................................... 4
  1. 3. Hypotheses......................................................................................................................................... 5
  1. 4. Significance of the Research............................................................................................................. 5
  1. 5. Conclusion........................................................................................................................................ 6

Chapter 2. Literature Review.......................................................................................................................... 9
  2. 1. Introduction....................................................................................................................................... 11
  2. 2. Human Performance Measurement in Field Sports ......................................................................... 12
      2. 2. 1. The Importance of Performance Measurement in Field Sports.............................................. 13
      2. 2. 2. Effective Measurement............................................................................................................. 14
  2. 3. The Sport of Hurling.......................................................................................................................... 16
      2. 3. 1. Physiological Demands of the Game ......................................................................................... 19
  2. 4. Physical Performance Indicators in Field Sports............................................................................. 20
      2. 4. 1. Muscular Power ....................................................................................................................... 20
      2. 4. 1. 1. Lower Extremity Power – Vertical Plane ............................................................................. 21
      2. 4. 1. 2. Lower Extremity Power – Horizontal Plane ....................................................................... 22
      2. 4. 1. 3. Lower Extremity Power- Reactive Strength ......................................................................... 23
      2. 4. 1. 4. Upper Extremity Power ....................................................................................................... 24
      2. 4. 2. Speed-Acceleration .................................................................................................................. 25
      2. 4. 3. Endurance.................................................................................................................................. 26
      2. 4. 4. Local Muscular Endurance ...................................................................................................... 27
      2. 4. 5. Anaerobic endurance ............................................................................................................... 27
      2. 4. 6. Aerobic Endurance .................................................................................................................. 29
  2. 5. The Physiological Profile of Hurlers ................................................................................................. 31
      2. 5. 1. Anthropometric Measures ...................................................................................................... 32
2. 5. 1. 1. Height and Body Mass ................................................................. 32
2. 5. 1. 2. Body Composition ................................................................. 32
2. 5. 2. Speed, Strength and Power ............................................................ 34
2. 5. 2. 1. Speed ................................................................................. 34
2. 5. 2. 2. Strength and Power ............................................................... 36
2. 5. 3. Endurance ............................................................................... 37
2. 5. 3. 1. Local Muscular Endurance and Anaerobic Endurance .......... 37
2. 5. 3. 2. Aerobic Power ..................................................................... 38
2. 5. 4. Physiological Overview of the Hurling Athlete ......................... 39
2. 6. Relationships between Level of Participation and Physical Performance Indicators ........................................................................ 39
2. 6. 1. Soccer ..................................................................................... 40
2. 6. 2. Rugby League .......................................................................... 43
2. 7. Seasonal Change in Field Sports ..................................................... 45
2. 7. 1. Seasonal change in Anthropometric Measures ......................... 47
2. 7. 1. 1. Seasonal Change in Body Mass ............................................... 48
2. 7. 1. 2. Seasonal Change in Body Composition ................................... 49
2. 7. 2. Seasonal Change in Speed-Acceleration ..................................... 51
2. 7. 3. Seasonal Change in Upper and Lower Extremity Power .......... 52
2. 7. 4. Seasonal Change in Aerobic Endurance ...................................... 53
2. 8. Conclusion .................................................................................. 55
Chapter 3. Methodology ........................................................................ 57
3. 1. Introduction ................................................................................ 59
3. 2. Participants ................................................................................ 59
3. 3. Key Anthropometric Measures and Physical Performance Indicators .......................................................... 62
3. 3. 1. Anthropometric Measures ......................................................... 62
3. 3. 2. Power Measures ....................................................................... 64
3. 3. 3. Speed and Acceleration ............................................................ 66
3. 3. 4. Local Muscular Endurance ....................................................... 67
3. 3. 5. Anaerobic and Aerobic Endurance ........................................... 68
3. 4. Data Analysis ............................................................................. 70
Chapter 4. Results .................................................................................. 71
4. 1. Introduction ................................................................................ 73
4. 2. Physical Performance Indicators - Senior Elite at Pre-Competition Phase .......................................................... 73
4. 3. Physical Performance Indicators – Senior Sub-Elite at Pre-Competition Phase .......................................................... 74
4. 4. Physical Performance Indicators – Junior Elite at Pre-Competition phase .............75
4. 5. Differences in Physical Performance Indicators Between Squads at Pre-Competition Phase of the Season ........................................................................................................76
   4. 5. 1. Senior Elite vs. Senior Sub-Elite at pre-competition ........................................77
   4. 5. 2. Senior Elite vs. Junior Elite at Pre-Competition Phase .....................................78
4. 6. Seasonal Change in Physical Performance Indicators from Preseason to Pre Competition..............................................................................................................................80
   4. 6. 1. Seasonal Change: Senior Elite Squad ................................................................80
   4. 6. 2. Seasonal Change: Senior Sub-Elite Squad .........................................................82
   4. 6. 3. Seasonal change: Junior Elite Squad .................................................................83
Chapter 5. Discussion ...........................................................................................................85
   5. 1. Introduction .............................................................................................................87
   5. 2. Physical Performance Indicators: Senior Elite .......................................................87
   5. 3. Physical Performance Indicators: Senior Sub-Elite ...............................................90
   5. 4. Physical Performance Indicators: Junior Elite ......................................................91
   5. 5. Senior Elite vs. Senior Sub Elite ...........................................................................92
   5. 6. Senior Elite vs. Junior Elite ...................................................................................95
   5. 7. Seasonal Change: Senior Elite .............................................................................97
   5. 8. Seasonal Change: Senior Sub-Elite ......................................................................99
   5. 9. Seasonal Change: Junior Elite .............................................................................101
   5. 10. Conclusion ..........................................................................................................102
Chapter 6. General Conclusions and Recommendations for future research ..................105
   6. 1. Introduction ..........................................................................................................107
   6. 2. Physical Performance of the Modern Day Hurling Athlete ................................107
   6. 3. Differences in Physical Performance Indicators Between Squads at Different Levels of Participation ........................................................................................................108
   6. 4. Seasonal Change in Physical Performance Indicators ........................................109
   6. 5. Limitations of the research ..................................................................................111
   6. 6. Recommendations for Future Research in this Area .........................................111
References ..........................................................................................................................113
Appendices ..........................................................................................................................125
List of Figures

Figure 2.1 Playing pitch and positions. G.A.A (2012).................................................................17
Figure 2.2 Camán. Handcraft hurleys (2012).............................................................................17
Figure 2.3 Blocking an Opponent. RTE (2012)...........................................................................18
List of Tables

Table 2.1 Anthropometric Measures of Hurlers ................................................................. 34
Table 2.2 Speed and Power Measures of Hurlers ................................................................. 36
Table 2.3 Endurance Measures of Hurlers ........................................................................... 39
Table 2.4 Sprinting Performance: German Soccer (Professional vs. Amateur) ................. 41
Table 2.5 Sprinting Performance: Serbian Soccer (Professionals Division 1 vs. amateurs Division 3) ................................................................................................................. 41
Table 2.6 Anaerobic Power: French soccer (Professional Div. 1, Div. 2 & Amateur) ........ 42
Table 2.7 Physical Performance Indicators Under 13 and Senior First Grade Rugby League Players (Gabbett 2002) ........................................................................................................ 44
Table 2.8 Phase of the Competitive Season in Field Sports .................................................. 46
Table 3.1 Descriptives of Participants .................................................................................. 60
Table 4.1 Subject Information of Senior Elite, Senior Sub-Elite & Junior Elite .................. 73
Table 4.2 Physical Performance Indicators Senior Elite at Pre-Competition Phase .......... 74
Table 4.3 Physical Performance Indicators Senior Sub-Elite at Pre-Competition Phase ..... 75
Table 4.4 Physical Performance Indicators Junior Elite at Pre-Competition Phase .......... 76
Table 4.5 Senior Elite vs. Senior Sub-Elite at Pre-Competition Phase ............................... 78
Table 4.6 Senior Elite vs. Junior Elite at Pre-Competition Phase ............................................. 79
Table 4.7 Seasonal Change : Senior Elite Squad ................................................................. 81
Table 4.8 Seasonal Change : Senior Sub-Elite Squad ........................................................... 83
Table 4.9 Seasonal Change : Junior Elite Squad ................................................................. 84
Table 5.1 Senior Elite vs. Senior Sub Elite Speed and Power Measures Pre Competition ................................................................. 93
Table 5.2 Senior Elite vs. Junior Elite Speed and Power Measures Pre Competition .......... 96
Table 5.3 Seasonal change Senior Elite: Speed and Power Measures ................................. 98
Table 5.4 Seasonal Change Senior Sub-Elite: Speed and Power Measures ....................... 100
Table 5.5 Seasonal Changes in Speed and Power Measures in Junior Elite Squad .......... 102
Chapter 1. Introduction
1.1. Introduction

Human performance measurement is the process whereby scientists examine the parameters in which high level performance occurs (Morrow et al., 2010). An ever increasing demand for high level competitive sporting performance is accompanied by the continued search for the determinants of such performances. In the field of sport and exercise science, the search continues to establish the determinants of high level sporting performance from within the various disciplines, e.g. physiology, psychology, biomechanics, etc. In field invasion sports the determinants of high level performance have been sub categorised into technical, tactical, physical and mental (Reilly, 2001). This categorisation provides a complex interaction between large numbers of variables before high level sporting performance can be attained.

The current study will focus on the category of physical performance indicators. The physical performance indicators that are integral to high level sporting performance in field sports are (1) anthropometric measures (height, weight, body composition etc.), (2) power measures (upper & lower extremity power), (3) speed measures & (4) endurance measures (local muscular, anaerobic, aerobic etc.) (Carling, Reilly & Williams, 2009). The current study will examine these performance indicators from athletes in the sport of hurling, which is one of the national games of Ireland governed by the Gaelic Athletic Association. Hurling is a field invasion sport which places high demands on skill levels and features periods of high intensity game play interspersed with periods of lower intensity work believed to be similar to soccer, rugby union and Australian Rules football (Reilly & Collins, 2008).

A significant proportion of human performance research has explored the relationship between physical performance indicators and athletes of various levels of participation. Research of this nature has focused on the differences present between (a) sub elite and elite and (b) junior and senior athletes in sports such as Australian rules football (Young et al., 2005), rugby league (Gabbett, 2002), soccer (le Gall et al., 2008), volleyball (Gabbett & Georgieff, 2007) and American football (Sierer et al., 2005). The purpose of this research has been to:
• Determine the levels of physical performance required to participate at various levels (e.g.) of sporting performance (Gabbett, 2002)
• Establish physical performance standards required for progression along the relevant player pathways (Pyne et al., 2005)
• Determine some level of rationale as to why some players do not progress to playing at a higher level in their respective sport (le Gall et al., 2008).

Another significant area of interest in sports performance measurement is the monitoring of seasonal change in physical performance indicators at various stages of the competitive season. Research of this nature has been conducted in rugby union (Argus et al., 2011), soccer (Silvestre et al., 2006), rugby league (Gabbett, 2002), Gaelic football (Reilly & Keane, 1999) and field hockey (Astorino et al., 2004). The purpose of this research is to establish normative data at the various stages of the season and to explore the improvements or decreases in physical performance which occur as a result of the competitive season.

1.2. Purpose of the Research

• To examine the physical performance indicators of the hurling athlete at senior elite, senior sub-elitete and junior elite levels.
• To investigate whether a difference exists between physical performance indicators and levels of participation (senior elite and senior sub-elite) and (senior elite and junior elite) in the sport of hurling.
• To determine what physical performance indicators differentiate between levels of participation (senior elite and senior sub-elite) and (senior elite and junior elite)
• To monitor seasonal change in physical performance indicators across the competitive season in squads of hurling athletes.
1. 3. Hypotheses

HO1 There will be no significant difference in physical performance indicators between hurling squads participating at different levels of participation (senior elite and senior sub-elite).

HO2 There will be no significant difference in physical performance indicators between hurling squads at different levels of participation (senior elite and junior elite).

HO3 There will be no significant change in physical performance indicators in the hurling athlete across the season.

1. 4. Significance of the Research

With the increasing demand for high level performance at the top level of Gaelic games, the support structures in place for inter county hurling teams have risen to mirror the levels of professional sport in many ways. Athletic development specialists are now integral members of the backroom staff of inter county hurling teams and some senior club teams. Evidence-based measurement data is a critical requirement for the aforementioned professionals to facilitate the provision of a support structure where optimal sporting performance can take place.

There is a dearth of normative data related to the physical performance indicators of hurling athletes in comparison to the other major international field sports, or even in comparison to Gaelic Football (the other indigenous team sport of Ireland) (Reilly & Collins, 2008). In the absence of such data related to the physical performance of hurling athletes, athletic development specialists working with hurling squads and individual athletes lack the meaningful information from which to compare the current physical performance of their athletes, or set goals for future performance. There is a paucity of normative data describing the physical performance required for high level sporting performance in senior elite hurling with much of the research having been conducted on athletes from outside the top tiers of hurling competitions (Brick & O’ Donoghue, 2005; Doran et al, 2003; McIntyre, 2005).
Normative data exists from only research study on the physical performance of the senior sub elite (club) hurler and to date no normative data exists on the junior athlete (under 18). The relationship that exists between physical performance and different standards of participation are essential to inform those working with developmental athletes as to the physical performance required for participation at the elite level, therefore further investigation is certainly warranted. To date minimal research (2 studies) has explored the relationship between physical performance indicators and levels of participation in the sport of hurling. One of the studies explored the differences between an “elite” squad participating in a sub-elite competition (Tier 2 inter county) and sub elite players (senior club) from the same county (Doran et al., 2003). The other study examined athletes from the same level of participation and success in that season was used to differentiate between the teams (Collins et al., 2007). No research to date has been found that examines the seasonal change in physical performance measures in the sport of hurling.

1.5. Conclusion

The current study will serve to establish a normative database of a variety of physical performance indicators of the hurling athlete at senior elite, senior sub-elite and junior elite level. This normative data can subsequently be used to further educate and inform managers, athletic development specialists and players of the levels of physical performance required for high level performance in the sport of hurling. Such data increases the knowledge base from which development pathways can be created which can lead to the attainment of higher levels of sporting performance in the future. Furthermore a clear provision of standards of physical performance will enable the consistent monitoring of the ongoing physical development of the young hurling athlete along the development pathway.

The examination of the performance data across the season provides invaluable information to athletic development specialists regarding the changes in physical performance that can be expected to occur as a result of the training interventions undertaken during the competitive season. This data can lead the process of ‘goal setting’ for players as realistic and attainable goals for future performance may be set in line with previous performance improvements. Furthermore, this data can aid the development
of periodised, structured and informed training plans to ensure high level sporting performance at the critical stages of the competitive season.
Chapter 2. Literature Review
2.1. Introduction

The measurement of human performance in field sports has been the subject of a considerable amount of research and analysis over the course of the last 20-30 years. Such research has been conducted with the purpose of profiling the physical performance of athletes in all the major field sports including soccer (Sutton et al., 2009), rugby league (Baker, 2008), Australian Rules football (Young et al., 2005) and rugby union (Smart, 2011). Another area of research that has attracted considerable interest is the exploration of the relationship between levels of sporting participation and selected physical performance indicators (Baker, 2002; Gabbett, 2002). Compared to these two widely researched areas of human performance, there is a dearth of research in existence which has monitored seasonal change in such physical performance indicators (Argus et al., 2009; Gabbett, 2005).

The sport of hurling often referred to as “the fastest field sport in the world”, has not yet been the subject of such extensive research and analysis in comparison to many of the other major field sports (Reilly & Collins, 2008). Extensive analysis of the game is limited primarily due to its minority position within global sport and also the relatively small playing population due to the size of the Irish nation, i.e. hurling is played largely within Ireland and in pockets around the world where the Irish diaspora have relocated. This is in stark contrast to the other major field sports which are played on an international basis in countries worldwide.

This systematic review of the literature explores the existing research relating to the human performance measurement in field sports and in particular reference to the sport of hurling. It explores key studies, models and terminology relating to the following areas:

- Human performance measurement in field sports
- Physical performance indicators (Speed, strength, power etc.)
- Hurling: A Basic Introduction
- The physiological profile of huriers
- The relationship between physical performance indicators and level of participation
- Seasonal variation in physical performance indicators
2. 2. Human Performance Measurement in Field Sports

Athletic development specialists, researchers and athletes are continuously searching for optimal ways of identifying the key elements that contribute to improved athletic performance (Carling, Reilly & Williams, 2009). The process of performance measurement aids athletic development specialists in the assessment of athletic ability, preparedness for sporting activity and helps to identify physical performance strengths and weaknesses (Harman, 2008). When the athlete’s strengths and weaknesses are determined, it is possible for the athletic development specialist to prescribe a specific programme to address the relevant concerns (Gore, 2000).

Successful sporting performance in field sports requires the complex interaction of individual complex skills, high levels of physical performance along with intricate team work and appropriate tactics all in response to the skill set of the opposition before optimal performance can be attained (Carling, Reilly & Williams, 2009). Researchers have attempted to establish the physical performance required for optimal sporting performance in a number of ways: (1) by exploring the relationship between successful and less successful squads and physical performance and (2) by exploring the relationship between participation level and physical performance (Reilly, 2001).

Studies attempting to determine the physical performance required for optimal sporting performance have been undertaken in a number of field sports including soccer (Sutton et al., 2009), rugby league (Gabbett, 2002), Australian Rules football (Young et al., 2005) and Gaelic football (Keane et al., 1997). The results of these studies have demonstrated that athletes of a higher standard and/or from a more successful team possess higher levels of selected physical performance indicators. This is discussed in further detail at a later stage in this chapter (Section 2.6).
2. 2. 1. The Importance of Performance Measurement in Field Sports

“The implementation of physical performance testing allows for the examination of adaptations to training, assessment of training programmes, evaluation of player qualities, talent identification, prescription of training, and prediction of performance”.

(Duthie et al., 2003)

The measurement of physical performance indicators presents valuable information to athletic development specialists, team management, medical staff and those responsible for talent development. When team management are provided with data profiling the physical performance of their squad, they can commence an objective review of their programme in conjunction with the relevant personal in the back room such as strength and conditioning coaches, Medical Team, etc. This type of testing is an essential process for athletic development specialists as it provides them with critical information that helps them to monitor changes in physical performance across the playing season, in addition to the identification of physical staleness and the prevention of overtraining (Harman, 2008). It can also assist them in making the necessary changes required to ensure optimal performance into the future. Fitness test results are important tools that may be used in goal setting with athletes, either on an individual or collective basis. Baseline physical performance measures are provided which can be used to establish the athlete’s initial goals and repeated measures allow for the monitoring of the athletes progress, “Setting appropriate training goals gives purpose and direction to the training program and promotes athletes intrinsic motivation, self-confidence and sense of responsibility” (Hatfield & Brody, 2008). In contrast, inappropriately set training goals often lead to a decrease in motivation, loss of self-confidence, loss of belief in the training programme and decrease in adherence to the training programme.

Physical performance results are utilised by medical staff during the rehabilitation process of injured players as they provide reference values which serve to guide the Medical Team throughout the rehabilitation process (Arnason et al., 2004). The results of human performance measurement identify the important physical performance indicators that are integral to the successful performance in that given sport. When these key physical performance indicators have been identified it is then possible for governing bodies of
respective sports to develop and implement coaching frameworks, systems and programmes targeting these physical performance indicators.

2.2.2. Effective Measurement

Physical performance measures must adhere to the principle of validity and specificity. To ensure the validity and specificity of the measurement procedure, the measurement must assess components of fitness, energy systems and movements relevant to the sport (Harman, 2008). The components of fitness required for optimal performance in field sports have been identified as speed, upper and lower extremity power and strength, local muscular endurance, anaerobic endurance and aerobic endurance (Carling, Reilly & Williams, 2009). Validity can be determined in several ways, face (logical) validity, criterion validity, construct validity, content validity and direct validity. Face validity is the appearance to the subjects (non-experts) that the test measures what it is reported to measure e.g. 10m sprint would have high levels of face validity as the subject can easily associate the test with an ability to measure short distance sprinting speed. In tests of athletic ability determined by maximal performance, face validity is important as it will affect the subject’s effort in performing the test. Criterion validity is the degree to which performance measures are associated with other established measures of the same performance characteristic e.g. the association between estimated VO₂max as calculated indirectly from 20MST and VO₂max as calculated directly in the laboratory setting. Direct validity is the extent of which the measures obtained during a fitness test describe the actual physical attributes (distances covered, speeds attained, etc.) of players during competitive matches.

When conducting longitudinal research to observe change over a period of time, the principle of ‘sensitivity’ must be taken into consideration (O’Donoghue, 2010). The measurements and protocols selected must be capable of detecting meaningful change in the variable rather than reporting change due to other external influences. In physical performance research, the methods selected must address and monitor the influences of other external factors that may impair the ability of the test to report truly reflective performance scores. External factors in physical performance research that may alter the performance scores are environmental factors (e.g. weather, temperature, facilities), and the
preparation of the subject (e.g. nutritional, motivational, injuries, previous training and warm up protocols used).

The preparation of the athletes during the warm up immediately prior to the testing session may also have a large influence on the reliability and sensitivity of the measurement. There has been significant research examining the effects of different warm up protocols on various physical performance indicators (Fradkin, Zazryn and Smoliga, 2010). Warm up protocols that are appropriately designed and which allow adequate recovery prior to measurement have been shown to improve leg power as monitored via different jumping tasks and endurance running performance (Bishop, 2003). A topic of great interest and debate in research is what form of stretching to perform during a warm-up protocol. The warm up conducted immediately prior to testing must be relevant and appropriate to the test that is to be undertaken. Activities performed during the warm-up protocol can greatly affect the results of physical performance measurement in particular measures of speed or power (Fradkin et al., 2010). Consistency in the warm-up protocol is integral to increasing the ability of the testing procedure to report truly reflective performance scores and increase the chance of monitoring meaningful change rather than reporting variation as a result of different warm-up protocols.

Another factor that has a significant influence on the reliability and sensitivity of physical performance measures is the level of physical exertion experienced by the subjects in the hours/days prior to testing. The preparation of the subjects in the previous 24-48 hours greatly influences the ability of the testing procedure to report scores truly reflective of the subject’s actual physical performance (Harman, 2008). During repeated measurements of physical performance, the levels of fatigue present as a result of high intensity activities such as speed training, maximum strength training or competitive sporting performance in the previous 24-48 hours may inhibit truly reflective measurement of leg power, and sprinting speed.

It is common place in physical performance measurement to perform a battery of tests to examine a number of components of fitness during the same testing session. When measurement is carried out in a format such as this, it is important that careful planning with regard to the sequencing of the tests is arranged to reduce the possible effects of competing energy systems from previously undertaken tests during the assessment session.
A battery of physical performance measures should be carried out in the following order:

1. Non-fatiguing tests (e.g. anthropometric and other non-physical activity measures).
2. Power or strength tests (e.g. various jumps or other power activities, 1RM testing on various strength exercise).
3. Sprinting (e.g. time to sprint 10-40m).
4. Local muscular endurance (e.g. maximum push up, 1 minute sit up or other measures of local muscular endurance with high levels of fatigue).
5. Anaerobic activities fatiguing in nature (e.g. repeated sprint tests such as the 150m shuttle test).
6. Aerobic capacity tests (e.g. 20MST).

(Gore, 2000)

2. 3. The Sport of Hurling

The sport of hurling is a field sport played by two teams of fifteen players. At senior inter county level, the game consists of two 35 minute periods and at all other adult levels (over the age of 16) the game consists of two 30 minute periods separated by a 10-15 minute rest interval at half time. Hurling is traditionally played on a grass pitch with goalposts at either end of the pitch similar to rugby union with the exception that there is goal netting on the goal frame. The dimensions of the goal are 6.5 m wide with the crossbar at a height of 2.5 m. The dimensions of the playing pitch range from 130m to 145m in length and 80m to 90m in width (Fig. 2.1). The sport of hurling is contested by two teams of 15 players with the option of using up to five additional players from among the nominated substitutes. Each team is made up of one goalkeeper, six defenders, two midfielders and six attackers. There is a tradition of man-to-man marking in the sport of hurling and the traditional formations of a line of three in the full and half back line, two midfielders and two lines of three in the half and full forward line are usually adhered to.
Each player is equipped with a hurley (camàn) and a helmet (mandatory since 2010) (Fig. 2.2). A camàn is a wooden stick shaped similar to a hockey stick but wider at the bottom and can be used to strike the ball on either side unlike a hockey stick. A camàn is traditionally manufactured from the wood of an ash tree, however with advances in technology and drains on natural resources some manufactures have begun to experiment with synthetic materials.

Figure 2.2 Camàn. Handcraft hurleys (2012)

The aim of the sport of hurling is to score more points than the opposing team. One point is awarded for striking the sliotar (a small hard ball similar in size to a tennis ball composed of a leather outer layer with a padded cork core) over the cross bar. A score of three points is awarded for striking the sliotar into the goal. Players compete in a challenging contest involving frequent bouts of high-intensity activity (e.g. running and passing, striking, sprinting, tackling for possession), separated by short bouts of low-intensity activity (e.g.
Standing, walking). Playing the ball entails striking it with the camàn for distances up to 110m. The camàn is used to block the ball or to ‘hook’ an opponent attempting to strike it (Fig. 2.3). This is the primary means of tackling the opponent to retain possession. Hand passing (striking the ball with the hand), and soloing (where the athlete places the ball on their hurl whilst running) are other skills that are common place in the sport of hurling. Physical contact is permitted by tackling shoulder-to-shoulder but pushing and tripping are illegal. A player may only take four steps with the ball in their hand before being required to play the ball, while the ball may only be caught two times during a possession prior to being passed to a team mate or struck for a score. It is illegal to pick the sliotar off the ground with the hand; it must be skilfully lifted off the ground with the use of the camàn.

**Figure 2.3 Blocking an Opponent. RTE (2012)**

At the elite level (senior inter county), teams play for the All Ireland trophy (Liam McCarthy Cup). This competition is competed for by 12-14 senior inter county teams (pending on the season) and is the premier hurling competition at inter county level. The remaining inter county teams (16-18) participate in one of three other competitions which are viewed by the public as secondary competitions. There is a traditional group of team’s (approximately 10-11) that always compete in the premier competition and these counties would be regarded as Tier 1 hurling counties. Although there is a relegation/promotion system in place the teams from this Tier 1 group of counties have always participated in the premier competition. All counties outside of this Tier 1 group of teams would be regarded as Tier 2 inter county teams as they compete in the secondary competitions.
2.3.1. Physiological Demands of the Game

The physiological demands imposed on hurlers are governed by the duration of performance (two 30-35 minute halves) and a playing field that must lie between 130-145m in length and 80-90m in width. Considering these demands it would suggest that hurling requires high levels of aerobic endurance. When the game is more closely analysed, it is clear that optimal hurling performance is not reliant on aerobic metabolism alone. The speed of the ball and the distances that it can be struck (up to 100m) contribute to a high paced game where the ball may be struck from one end of the playing pitch to the other in a matter of seconds unlike most other field sports. High intensity anaerobic work such as sprinting, tackling, jumping or changing direction is an integral component of the sport of hurling. In essence, the game places physiological requirements on hurlers to perform frequent high intensity anaerobic activities with lower intensity aerobic activities being performed during the periods of rest (Reilly & Collins, 2008).

A significant amount of research has examined the physiological demands placed on players of the major field sports during competitive performance including soccer (Reilly, 2001), Australian Rules football (Gray & Jenkins, 2010), Gaelic football (Reilly and Doran, 2001) and rugby union (Duthie, Pyne & Hooper, 2005). These physiological demands have been often described in terms of work rate profiles. Previously used indices of work rate profiles include (1) total distance covered (2) distances travelled at different intensities of locomotion (defined as walking, jogging, sprinting etc.) (3) work to rest ratios (defined as ratio of high intensity activity to low intensity activities) (4) profiling of heart rates, (5) estimation of exercise intensity as a percentage of VO2max (Carling, Reilly & Williams, 2009). However, there is a paucity of research examining the work rate profiles of hurlers.

In a recent review paper entitled ‘Science and the Gaelic sports: Gaelic Football and Hurling’ (Reilly & Collins, 2008), the physiological demands of hurling were considered to resemble the demands of Gaelic Football. The researchers based their thoughts on a number of factors: (1) the similarity in positional play, (2) the size of the pitch, (3) the demands of the game and (4) the similarities in the rules. Although there may be large similarities present in both codes in terms of the demands of the game there is one factor that differentiates between the two codes and that is the distances and speed that the ball travels during normal play. In Gaelic football the ball can travel up to distances of
approximately 55m when kicked, but this rarely happens as, short hand passing and an emphasis on retaining possession and patient support play are more common place in the modern game. In contrast to this, in the sport of hurling the sliotar travels from one end of the playing pitch to the other in a matter of seconds with one strike of the camàn. Comparing the physiological demands of one of the fastest field sport in the world to a sport where slow and patient build up play is common place based on the similarity in size of the pitch, rules, perceived demands of the games and player position must be questioned. These clear differences between the two Gaelic sports demonstrate the importance of conducting comprehensive research on the sport of hurling rather than attempting to relate research from an entirely different sport.

2.4. Physical Performance Indicators in Field Sports

The physical performance indicators that are identified as being integral to high level performance in field sports are (1) muscular power (upper and lower extremity power, reactive strength, etc.), (2) speed (linear speed, acceleration, agility etc.) and (3) endurance measures (local muscular endurance, aerobic and anaerobic endurance) (Carling et al., 2009).

2.4.1. Muscular Power

Muscular power is the ability of a muscle to exert high force while contracting at a high speed (Harman & Garhammer, 2008). In all field sports, the ability of the athlete to generate power in both the upper and lower extremity is an essential pre-requisite for performance. When undertaking measurements of muscular power it is important that an in-depth analysis of the sport in question is undertaken. In the sport of hurling, players are required to express high levels of muscular power in the lower extremity during actions such as running, jumping, contesting possession or changing direction. The ability to generate power in the upper extremity is required during striking and contests of possession. The most commonly used methods of measuring muscular power in field sports are various jumps and throws performed for maximal height or distance. Other
methods have used maximal power output tests from cycle ergometer performance, maximum load lifted in weightlifting exercises or maximal power output from weight training exercises (Baechle & Earle, 2008)

2.4.1.1. Lower Extremity Power – Vertical Plane

Historically, vertical jump testing has been used extensively to assess the muscular power of the lower extremities (Gore, 2000). This test involves measuring the maximal vertical distance the athlete can elevate themselves off the ground from a standing position. Vertical jump measurement has been conducted on athletes participating in soccer (Arnason et al., 2005), rugby union (Argus et al., 2009), rugby league (Gabbett, 2002), Australian Rules football (Young et al., 2007), Gaelic football (McIntyre, 2005) and to a lesser extent in the sport of hurling (Collins et al., 2007).

There have been significant advances in the equipment and the methods used to measure vertical jump performance. Advances have been made from the original chalk test (e.g. Sargent Jump Test) to the modern era where portable force platforms and electronic devices are common place. Common methods of measuring vertical jump height include force platforms and contact mats which use the flight time (time spent in air) to calculate the vertical distance jumped (Markovic et al., 2004). Further advances have been made with the development of a new device known as the Optojump system ©. This system is a portable optical measurement system which consists of a transmitting and receiving bar. Each of these bars contains 33 to 100 L.E.D.’s pending on the model. The L.E.D.’s from the transmitting bar are synchronised with the receiving bar to detect any motion between the bars. The duration of these motions are then calculated allowing the determination of variables such as flight time or contact times which can be used in turn to calculate jump heights or other variables of interest (Microgate, 2009). The Optojump system © has been used extensively in researching lower extremity power and locomotion (Rampanini et al., 2007; Lehanse et al., 2005). This system has been found to have a high level of test-retest reliability with ICC’s ranging from .982 - .989 (Glatthorn et al., 2011.)

Factors that impact on the reliability and validity of vertical jump measurement include the presence of an arm swing, sequencing of counter movement and the equipment used
The use of the arm swing in vertical jump measurement is an area that has received a significant amount of interest. Studies have focused on the effect of arm swing in comparison to no arm swing on jump height (Markovic et al., 2004) and how the arm swing influences the jump height (Hara et al., 2006). The use of an arm swing action leads to higher results (30-54) cm than no arm swing (29-45) cm (Markovic et al., 2004). This increase is believed to be caused by an increase in lower extremity work brought about by the additional pre-loading of the lower extremity by the arm swing (Hara et al., 2006).

The sequencing of countermovement is an important factor that has been addressed in the literature in respect to performing a vertical jump test. There are two commonly used techniques in vertical jump measurement: counter movement jump where the athlete utilises the stretch shortening cycle at the bottom of the descent and the squat jump where the subject pauses for a specified time at the bottom of their descent. Hara and colleagues (2006) found that counter-movement jumps result in greater jump heights (35.3 ± 4.5 cm) than squat jumps (32.73 ± 4.2 cm) due to the ability of the subject to be able to utilize the stretch shortening cycle at the bottom of the descent. Countermovement jumps are deemed to be an indicator of the lower body’s reactive ability or reactive strength while squat jump is believed to be an indicator of the concentric strength of the lower body (Maulder & Cronin, 2006). The work of Markovic et al. (2004) found that countermovement jumps had higher levels of reliability \( r = .97 \) than 6 of the other jumping protocols examined (Sargent jump, Abalakow’s jump with arm swing and without arm swing, standing long jump and standing triple jump). This research also found that the countermovement jump possessed the best relationship with the explosive factor \( r = .87 \) among all of the other measures used.

2.4.1.2. Lower Extremity Power – Horizontal Plane

Field sports are multi-planar in that athletes are required to apply forces in more than one plane. In the sport of hurling, players are required to display high levels of muscular power in both the vertical and horizontal planes during acceleration, changes of direction and breaking a tackle. The relationship between horizontal and vertical jumping performance have been found to be quite poor suggesting that horizontal and vertical jump tests detail
different aspects of lower extremity muscular power (Maulder & Cronin, 2006). The most commonly used method of measuring lower extremity power in the horizontal plane is via the use of the standing broad jump test. This test is very practical in nature as it is time efficient, low in cost in terms of equipment and is suitable for use with large numbers of subjects (Castro-Pinero, 2010). The standing broad jump involves measuring the maximal distance the athlete can propel themselves forward from a standing position. Standing broad jump performance has been assessed in the major field sports including soccer (Reilly et al., 2007), rugby union (Duthie et al., 2003), rugby league (Gabbett et al., 2008), Gaelic football (Keane et al., 1995) and one research study on the sport of hurling (Collins et al., 2007). Research on improving the effectiveness of standing broad jump performance has mirrored vertical jump performance with examinations being conducted to examine the influence of arm swing on performance (Ashby & Heegaard, 2002; Ashby & Delp, 2006). Ashby and Heegard (2002) found subjects jumped further in the standing broad jump with arm movement (2.09 ±0.03 m) compared to no arm movement (1.72 ± 0.03 m). The use of the arm swing has been found to increase the distance travelled as a result of the increased horizontal and vertical positions and velocities at of the centre of gravity at take-off (Ashby & Delp 2006). The standing broad jump was found to be a better predictor (r=0.65) of 20m sprint performance than vertical jump assessment (r= .52) (Maulder & Cronin, 2005).

2.4.1.3. Lower Extremity Power- Reactive Strength

Reactive strength (the ability to utilize the stretch shortening cycle) in the lower extremity is an integral component of fitness for field sports athletes (Carling et al., 2009). Movement in field sports occurs with a pre-loading of the muscles prior to performing the movement e.g. running, jumping and tackling. This cyclical fashion of motion requires field sport athletes to be efficient at utilizing the stretch shortening cycle in order to maximise their movement performance. Reactive strength is commonly evaluated via the use of repeated maximal jumps and has been evaluated in both the vertical and horizontal plane (Morrow et al., 2010 & Gore, 2000). In the vertical plane, the most commonly used protocols are drop jumps and repeated vertical jumps performed unilaterally and bilaterally (Maulder & Cronin, 2005). Researchers have commonly used total jump height or jump distance to
quantify the performance (Maulder & Cronin, 2005). The most commonly used protocols for assessment in the horizontal plane are unilateral triple jump, standing triple jump and the standing five jump test (Gamble, 2009). The most widely used variable to illustrate reactive strength in the horizontal plane is total distance jumped. Repeated horizontal jump performance in comparison to single and repeated vertical jumps have been found to have the highest correlation to sprinting ability in a number of research studies (Maulder & Cronin, 2006; Nesser et al., 1996).

2. 4. 1. 4. Upper Extremity Power

Upper body power is an important component of fitness for field sports, particularly those sports that are combative in nature and where physical contact is a common occurrence. Hurling is a fast paced aggressive physical contact sport where physical contesting of possession is a primary feature of play. Upper body power has been monitored via the use of various medicine ball throws (Mayhew et al., 2005) and via the use force transducers during the performance of ballistic weight training movements at various percentages of 1RM to calculate maximal power (Watts) (Argus et al., 2011; Baker, 2008). Each method has its own respective advantages and disadvantages. The advantages of using medicine ball throwing-based exercises lie in their ease of administration with large numbers, low skill requirement and low cost of equipment requirement.

The main limitations of using force transducers to analyse upper body strength during ballistic weight training exercise are the large time constraints imposed on the evaluators and subjects. Numerous different throws have been utilised to monitor upper body power with the most common being overhead throws and variations of the seated medicine ball throw (Logan et al., 2000). The main disadvantage of using various medicine ball throws to assess upper extremity power is its ability to only measure the strength and power properties of the elbow and shoulder extensors. A systematic review of the literature failed to find any research that has profiled the upper body power of hurlers. It is essential that this significant gap in the research be filled given the combative and physical nature of the sport of hurling.
2. 4. 2. Speed-Acceleration

Speed and Acceleration are essential components of fitness for the field sport athlete as the nature of such sports requires players to accelerate and achieve high sprinting speeds during game play in the evasion and pursuit of opponents. Extensive research exploring the speed-acceleration profiles of field sport athletes has been conducted in soccer (Arnason et al., 2004), rugby union (Duthie et al., 2003), rugby league (Gabbett et al., 2008), Australian Rules football (Young et al., 2008) and to a lesser extent Gaelic football (McIntyre, 2005) and hurling (Collins et al., 2007).

Although the sport of hurling takes place on a pitch up to 90m wide and 145m long, it is the sliotar that traditionally travels these long distances. These demands require hurlers to possess high levels of speed over short distances. Environmental conditions and logistical reasons can affect the distances that can be safely and effectively monitored (Young et al., 2008). In elite Australian Rules footballers, pre-season performances of both 10m and 20m sprint times were reported to be significantly faster in players who were subsequently selected to play the first game of the season (Young et al, 2005) demonstrating the importance of sprinting performance in field sports. Short and longer sprints have respectively different biomechanical muscle activation patterns’ (e.g., the amount of forward lean) and strength requirements, consequently they have been shown to reflect independent qualities.

The time taken to sprint from a stationary start over a relatively short distance (≤10m) is considered to be a reflection of acceleration capability, whereas longer sprints (≥20m) may be considered to be more reflective of maximum speed (Young et al., 2008). Indoor testing (sports halls, multi-purpose units, etc.) increases the reliability and ability of the measure to monitor meaningful change by controlling the environmental conditions. Unfortunately this ability to control the environment places constraints on the maximal distance that be safely tested due to the limited facility dimensions.
2.4.3. Endurance

From close analysis it is clear that optimal field sport performance is reliant on high levels of local muscular and anaerobic endurance to perform repeated high intensity activities such as sprinting, tackling, jumping or changing direction. In addition high levels of aerobic endurance are required in order to sustain low intensity activities such as walking, jogging, changing position and man marking for the entire duration of the game (60-90 minutes pending on the sport and level) and also to aid in recovery from the aforementioned high intensity activities (Carling et al., 2009). The ability to perform the required skills of the individual sport during the entire game can often be the deciding factor in the results of the games (Bangsbo et al., 2008).

Considering these demands it is not surprising that profiling the endurance capacity of field sport athletes has attracted more attention than any other physical performance indicator. Extensive research exploring the endurance profiles of field sport athletes has been conducted in soccer (le Gall et al., 2010), rugby league (Gabbett et al., 2008), Australian Rules football (Wadley & LeRossignol, 1998) and to a lesser extent in Gaelic football (McIntyre, 2005) and hurling (Collins et al., 2007).

Like any other physical performance indicator it is important that the demands of the specific game are analysed closely so that the endurance capacity measurements selected are appropriate to the sport in question (Carling et al., 2009). Field based measurement of endurance capacity in field sports has been broken down into three distinct categories (Reilly, 2001): 1. Aerobic power (e.g. 20 MST, 12 minute run, 1.5 mile run). 2. Anaerobic capacity (e.g. 150m test, repeated sprints ability 7x30m) & 3. Sports specific tests (e.g. various test incorporating sports specific skills). The results obtained from the final category of tests “sports specific tests” cannot be interpreted as pure measures of aerobic power or anaerobic capacity as performance during these tests are heavily influenced by other factors such as speed, power and motor control (Reilly, 2001). It is for this purpose that the following sections 2.4.5 & 2.4.6. will focus on the first two categories of endurance capacity.
2. 4. 4. Local Muscular Endurance

Local muscular endurance (L.M.E.) is an important component of fitness for field sports, particularly those sports that abrasive tackling and physical contact are a common occurrence. Hurling is a sport where physical contesting of possession is a primary feature of play given the tradition of close man to man marking in all outfield positions. L.M.E. measurement has been conducted in all the major field sports soccer, rugby union, rugby league, Australian Rules football, Gaelic football and hurling.

L.M.E. has been measured via maximum repetition tests in various lower body, whole body and upper body exercises (sit ups, pushups, chin ups, squats with a % of 1RM etc.). The two most common measurements selected to measure L.M.E. have been maximum push up and sit up tests (Gore, 2000). L.M.E. measurements should be selected based on their ability to assess the L.M.E. required for the sport in question. Although high levels of L.M.E. endurance are required in the trunk region of hurlers the levels required are a combination of stability, rotation, flexion and extension and not just isolated flexion as in maximum sit up test performance. Physical contact during the sport of hurling predominantly involves a pushing action of the upper body due to the rules based around the tackle and as a result high levels L.M.E. are required in the extensor muscles (chest, shoulders & triceps). Maximum push up rep testing has been shown to be a valid and appropriate measure of assessing L.M.E. in the upper body pushing musculature (Baechle & Earle, 2008). Maximum push up test has also been shown to be sensitive to change following periods of local muscular conditioning in junior rugby league athletes (Gabbett et al., 2008).

2. 4. 5. Anaerobic endurance

Physiological measurements such as heart rate, blood sampling and metabolic measurements during competition have shown there is a large loading on the aerobic energy systems during competitive field sport performance, however it is during crucial times of games that there is a significant loading on the anaerobic system in particular when players are directly involved in play ( in possession, competing for possession or showing for possession (Bangsbo et al., 2008). The ability to successfully perform these repeated
bouts of anaerobic activity during the entire game can often be the deciding factor in the results of the games. Anaerobic endurance testing has been extensively performed in all the major fields sports soccer, rugby union, rugby league, Australian Rules football and to a lesser extent in the hurling and Gaelic football.

In a review of repeated sprints by Spencer et al., (2005), repeated sprints interspersed with periods of recovery (active or passive) and various cycle ergo meter sprint tests with similar periods of work and recovery were the most commonly used. In this same review the importance of selecting the mode of activity relevant to the sport in question was highlighted and thus the validity of using cycle ergo meter tests to assess anaerobic performance in athletes who are required to sprint has to be questioned. In tests examining over ground sprinting the most commonly used methods of assessing performance have been to use electronic timing gates to measure time taken to sprint the various distances (e.g. RSA 7x30m sprint with 30 secs recovery) and also distance covered during a specified work period (150m shuttle test). Data from sprint based testing has been most commonly presented in total distance covered or by presenting the percentage fatigue (time or distance) between the first sprint and the remaining sprints (Glaister, 2006).

The difficulties of using techniques such as the RSA and electronic timing gates to assess large groups of athletes is clear given the time constraints of using such a technique. During repeated sprint measurements it is important that the testing procedure involves movement patterns that are specific to the sport in question (Wragg, Maxwell & Doust, 2000). The linear nature of the tests such as the RSA and the difficulties in carrying out such testing with large groups of athlete’s limits the suitability of such tests to assess large groups of field sport athletes where acceleration, deceleration and change of directions are prevalent.

The 150 m shuttle test (a series of repeated maximal effort shuttle runs interspersed with periods of rest) is a commonly used test of anaerobic endurance in field sport athletes (Clark, 2007). This multi-directional anaerobic endurance test which requires athletes to decelerate, accelerate and change direction frequently has been reported to have high levels of direct validity (compared to high speed distances covered in field games) (Boddington et al., 2004). In a separate study also carried out by Boddington et al., (2001), the reliability of the 150m shuttle test was assessed by performing 4 repeated measures of the test on a squad of elite level South African hockey players. The results show that measures of total
distance covered from the 150m test have been reported to have higher levels of reliability as determined via ICC (R = .98) than measures of peak distance (R = .86), delta distance and fatigue index (R = .74). Total distance covered in the 150m shuttle test is a reliable measure of anaerobic endurance and is capable of detecting changes in anaerobic performance due to training. When working with large groups of hurling athletes the 150m shuttle test is an appropriate test to evaluate anaerobic endurance given its ease of administration and the demands it places on acceleration and deceleration as required in the sport of hurling.

2. 4. 6. Aerobic Endurance

In competition measurement of factors such as heart rate, distances covered, duration of efforts in field sports has revealed that there is a significant loading on the aerobic systems required to maintain performance over the 60-90 minutes of the match (Bangsbo et al., 2008). Given the large loading placed on the aerobic system it is no surprise that this is the physical performance indicator that has received the most attention in field sport athletes (Carling et al., 2009). The most commonly used measurement to describe endurance performance has been maximal oxygen uptake (VO² max). A high VO² max facilitates recovery from high intensity effort and maintains the ability to reproduce high intensity efforts over a prolonged period of time (Morrow et al., 2010). Increases in VO² max has been positively related to an increase in a number of sports performance variables present within the competitive environment such as distance covered, intensity of effort, number of sprints and possessions of the ball (Helgerud et al., 2001). In a review of field sports by Reilly, (2001 a) VO² max was the only physical performance indicator that there was a level of performance highlighted (60 ml/kg/min) that players were unlikely to perform at the highest levels of professional football without obtaining.

Commonly used methods to assess this physical performance indicator have utilised incremental exercise tests in various modes of activity e.g. treadmill running, over ground running and stationary cycling. VO² max performance has been evaluated directly via the use of various ventilatory apparatus during treadmill stationary cycling and rowing ergometer performance. This direct measurement technique is perceived as the gold standard in measuring this physical performance indicator. As stated previously the mode of exercise (Spencer, 2005) and movement patterns (Wragg, Maxwell & Doust, 2000) selected to
measure endurance performance should replicate the demands of the sport. As a result the appropriateness of utilising a treadmill or stationary cycle to assess VO$_2$ max in athletes who during competitive performance perform multi directional running has to be questioned. Given the difficulties in getting team sports athletes to attend laboratory testing at stages other than the pre-season due to time constraints (Reilly, 2001), treadmill or stationary cycling direct assessments of VO$_2$ max are not appropriate to use with large groups of field sports athletes.

For the reasons presented above there have been a number of field tests proposed as an alternative to the time consuming laboratory based assessments of aerobic endurance. Aerobic endurance has also been measured during over ground running indirectly via the use of regression equations which have been shown to produce results for estimated VO$_2$ max with high levels of criterion validity when compared to the direct measurement of VO$_2$ max (Grant et al, 1995). The most commonly used protocols for assessing estimated VO$_2$ max with over ground running in large groups have been the 20 MST (Ramsbottom, 1988), the Cooper run test (Cooper, 1968) and the 1.5 mile run (Harmann & Garhammer, 2008). The limitations of the use of the Cooper run test and the 1.5 mile run in assessing aerobic performance have been highlighted as: 1. The relatively linear nature of test compared to the multi-directional nature of field sports and, 2. The steady state running pace of both tests compared to the varying running speeds required in field sports.

The 20MST is an incremental shuttle test that is performed between two cones 20m apart and be easily administered with large groups of athletes. The test requires the participants to run between the two cones placing demands on deceleration, acceleration, change of direction and running at varying speeds. The pace of the running is controlled by a series of beeps emitted from a compact disc (C.D.) The series of beeps on the C.D. (20-m Shuttle Run test CD, Australian Sports commission) get progressively closer which signal a requirement for an elevated sprinting speed. The decrease in time between the series of beeps co-incides with the measurement system of the testing with each respective beep corresponding to a level and number of shuttles performed. The participants attempt to maintain the speed of running with synchronisation of the beeps from the C.D. for as long as possible. When the participant is no longer able to run in synchronisation with the beeps the level and number of shuttles they have completed is recorded and used in conjunction with conversion tables to calculate the estimated VO$_2$ max (Ramsbottom, 1988). The ability of the 20MST to estimate VO$_2$ max was first validated by Leger et al, (1982) compared to
direct measurement and has been validated on athletes of various fields sports on numerous occasions since (Grant et al. 1995, McNaughton et al., 1998 & Wilkinson et al., 1999) with correlations of R= 0.82-0.93.

The reliability and sensitivity to change of the 20MST national level soccer players was examined by Aziz, MYH and Tyeh, (2005). The reliability results of this research show the 20 MST to be able to produce reliable results with a co-efficient of variation of 2.2% for two measurements within a two week period. The results presented by Aziz & colleagues (2005) also show that the 20MST is capable of detecting change in aerobic performance following a period of conditioning. Given the reliability, validity and ability of the 20 MST to detect change in aerobic endurance performance, this multi-directional, multi paced shuttle running test is an appropriate measurement technique to assess the aerobic performance of hurling athletes.

2.5. The Physiological Profile of Hurlers

An extensive review of the literature identified four studies that profiled the physical performance of hurlers. Two of the four studies evaluated the physical performance of Tier 2 inter county hurlers (Brick & O’Donoghue, 2005; McIntyre, 2005), one study examined the physical performance of Tier 1 inter county hurlers (Collins et al., 2003) while one of the studies examined club level players from a Tier 2 county in comparison to inter county players from the same Tier 2 county (Doran et al., 2003). The physical performance measurement conducted from this narrow range of studies examined physical parameters such as basic anthropometry, lower body power, upper body strength, sprinting speed and measures evaluating various aspects of endurance performance. This review of the literature failed to report any research that has profiled all of the important components of physical performance integral the sport of hurling. The results from these key studies are presented in Tables below (Tables 2.1 to 2.3).
2. 5. 1. Anthropometric Measures

The 4 key studies profiling the physical performance of hurling athletes have all evaluated anthropometric measures (height, body mass & body composition) in an attempt to explore the determinants of successful performance. Anthropometric measures have been examined as height, body mass and additional lean mass are believed to be advantageous during physical exchanges that are prevalent during the sport of hurling.

2. 5. 1. 1. Height and Body Mass

Collins et al. (2007) N= (41) reported height and body mass of (1.79 ±0.06m, 80 ± 6.9 kg) and (1.83 ±0.06m, 81.2 ± 8kg) for two Tier 1 inter county hurling teams. McIntyre (2005) in a comparison of field sports athletes reported height and body mass for Tier 2 inter county hurlers N= (29) of (1.77 ±0.06m and 83kg ±9kg). The ranges in these studies demonstrate the relatively heterogeneous stature of inter county hurlers participating at Tier 1 and Tier 2 levels of performance. Similar anthropometric measures for inter county Gaelic football athletes have been published with reported values for standing height ranging from 1.79 ± 0.06m (McIntyre, 2005) to 1.81 ±0.08m (Watson, 1995) and body mass ranging from 79.2 ± 8.2kg (Doran, Donnelly & Reilly, 2003) to 86.5 ± 8.6kg (Brick & O’Donoghue, 2005). English premiership outfield soccer players have reported values for standing height ranging from 1.78 ± 0.05cm to 1.84 ± 0.06cm and body mass 78.0 ± 5.8kg to 86.0 ± 7.3kg depending on position (Sutton et al., 2009). Premiership Australian Rules players have reported values of 1.87± 0.08m and 88.0 ± 8.9kg for height and body mass respectively (Young et al., 2005). Inter county hurlers are similar in height and body mass to athletes of inter county Gaelic Football, English premiership soccer and smaller and lighter than premiership Australian rules players.

2. 5. 1. 2. Body Composition

Body composition is an area that has received a significant amount interest in field sports including soccer (Sutton et al., 2009), rugby union (Duthie et al., 2003), rugby league
(Gabbett, 2005), Australian Rules football (Gray, 2010), and to a lesser extent in Gaelic football and hurling (Reilly, 2001). Percentage body fat (BF%) has been estimated in a number of studies on inter county hurlers through the use of skin fold measurements, with values ranging from $12.4 \pm 2.1\% \ N= \ (41)$ (Collins et al., 2007) to $18.4 \pm 3 \% \ N= \ 29$ (McIntyre, 2005). The wide range of values presented on estimated %BF can be explained by a number of factors: (1) the difficulties and degree of error between evaluators as associated with comparing skin fold measurements from different studies and (2) the difference in standard of the squads between the studies (one of the research studies evaluated Tier 1 athletes and three of the research studies evaluated Tier 2 athletes). The squads possessing the larger estimated percentage %BF scores were from a Tier 2 squad and in contrast to the squads that reported the lower values who were from a Tier 1 squad.

Two of the previous research studies Brick & O'Donoghue (2005) and McIntyre (2005) made direct comparisons between inter county hurling athletes and inter county Gaelic Football athletes. These studies reported estimated %BF scores of $13.4 \pm 3\%$ and $12.9 \pm 4.3\%$ for the respective inter county Gaelic football squads in comparison to $18.4 \pm 3.0 \%$ and $15.8 \pm 5.3 \%$ for their respective inter county hurling squads. In both studies, the researchers made comparisons between Tier 1 inter county Gaelic football squads and Tier 2 inter county hurling squads. The failure of the researchers to recruit squads from the same level of performance (Tier 1 inter county) prevents an appropriate comparison between the body composition of hurlers and Gaelic footballers. The professional support structures afforded to Tier 1 Gaelic football squads are not present in the preparation of Tier 2 senior inter county hurling squads leading to disparities in preparation which may have influenced body composition levels. Ostojic, (2004) reported values for BF% via the sum of seven skinfolds in Serbian professional footballers of between $9.6 \pm 2.5$ and $11.5 \pm 2.1 \%$ pending on stage of the season. This range of values presented for the body composition of elite soccer player is lower than the reported values of senior inter county hurling athletes in the existing research. These differences can be attributed to the full time professional status of premiership soccer players and the amateur status of the senior inter county hurling athlete.
Table 2.1 Anthropometric Measures of Hurlers

<table>
<thead>
<tr>
<th>Study</th>
<th>Level</th>
<th>Height (m)</th>
<th>Mass (kg)</th>
<th>% BF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Collins et al., 2007</strong></td>
<td>SIC</td>
<td>1.79 ± (0.06)</td>
<td>80.0 ± (6.9)</td>
<td>13.0 ± (1.4) *</td>
</tr>
<tr>
<td>Tier 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SIC</td>
<td>1.83 ± (0.06)</td>
<td>81.2 ± (8.0)</td>
<td>12.4 ± (2.1) *</td>
</tr>
<tr>
<td>Tier 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Doran et al., 2003</strong></td>
<td>SIC</td>
<td>1.74 ± (0.05)</td>
<td>73.4 ± (7.7)</td>
<td>13.1 ± (1.4) *</td>
</tr>
<tr>
<td>Tier 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SC</td>
<td>1.77 ± (0.05)</td>
<td>73.8 ± (8.2)</td>
<td>14.1 ± (3.1) *</td>
</tr>
<tr>
<td>Tier 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>McIntyre, 2005</strong></td>
<td>SIC</td>
<td>1.77 ± (0.06)</td>
<td>83.0 ± (9.0)</td>
<td>18.4 ± (3.0) *</td>
</tr>
<tr>
<td>Tier 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Brick &amp; O’Donoghue, 2005</strong></td>
<td>SIC</td>
<td>1.78 ± (0.06)</td>
<td>83.35 ± (8.57)</td>
<td>15.8 ± (5.3) **</td>
</tr>
<tr>
<td>Tier 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Denotes estimated from skinfolds using sum of four skinfolds (Durnin and Womersley, 1974)
** Denotes estimated from skinfolds using three site (Chest, abdomen and thigh)

SIC= Senior inter county
SC= Senior Club

2.5.2. Speed, Strength and Power

Given the demands of the sport of hurling with its fast paced end to end deliveries, short distance sprints and abrasive tackling, speed, acceleration, strength and power are attributes required for optimal performance. Like most other attributes of team sport physical performance discussed to date, there is a paucity of research exploring the speed, strength and power attributes of hurlers. Only 1 of the 4 key studies profiling the physical performance of hurlers evaluated upper extremity strength and of the 3 studies that evaluated lower extremity power, different methodologies were used in all of the studies making it very difficult to make comparisons between the respective squads.

2.5.2.1. Speed

The time to sprint 10m was examined by Collins et al. (2007) with two different inter county hurling squads with results of 1.75 ± 0.03s and 1.77 ± 0.04s for each squad.
Donnelly, Doran & Reilly (2003) also investigated 10m sprint performance of inter county hurlers (N= 7) and reported mean values of 1.78 ± 0.08s. Caution should be used when interpreting the data from Doran, Donnelly & Reilly (2003) given the low subject N= (7) numbers less than 50% of a starting team (15). The reported values of 1.75-1.77s for 10m sprint performance (not taking results from Doran, Donnelly & Reilly, 2003) are still slower than reported values of 1.73 ± 0.08 (s) for English premiership footballers (Dunbar & Treasure, 2005) and Australian Rules football players. (M=1.70 sec’s, SD= 0.2) (Young et al., 2008). The differences present in sprint performance between amateur hurlers and professional soccer and Australian rules players can be attributed to the differences in preparation and the support structures in which these athletes train. Hurlers are amateur athletes and do not have the same time to dedicate to training and recovery as the professional athletes which can explain the differences present in sprinting performance.
### Table 2.2 Speed and Power Measures of Hurlers

<table>
<thead>
<tr>
<th>Study</th>
<th>Level</th>
<th>C.M.J (cm)</th>
<th>S.B.J. (m)</th>
<th>10m (sec's)</th>
<th>30m (sec's)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collins et al., 2007</td>
<td>SIC Tier 1</td>
<td>47.14 ±(3.24) *</td>
<td>2.47±(.15)</td>
<td>1.75± (0.03)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SIC Tier 1</td>
<td>47.29 ±(6.29) *</td>
<td>2.54 ±(0.2)</td>
<td>1.77 ±(0.04)</td>
<td></td>
</tr>
<tr>
<td>Doran et al., 2003</td>
<td>SIC Tier 2</td>
<td>40.8± (4.5) **</td>
<td>1.78± (0.08)</td>
<td>4.43±(0.17)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SC Tier 2</td>
<td>33.0±(2.7) **</td>
<td>1.94± (0.12)</td>
<td>4.72±( 0.35)</td>
<td></td>
</tr>
<tr>
<td>McIntyre 2005</td>
<td>SIC Tier 2</td>
<td>2.29 ±( 0.1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brick &amp; O’Donoghue, 2005</td>
<td>SIC Tier 2</td>
<td>56.6±(4.0) ***</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Denotes vertical jump performance as assessed using Newtest © contact jump mat
** Denotes vertical jump performance as assessed using Eleiko © contact jump mat
*** Denotes vertical jump performance as assessed using Takei © dynamometer

### 2. 5. 2.2. Strength and Power

C.M.J performance has been evaluated by Collins et al. (2007) in two separate Tier 1 inter county squads via the use of a contact mat (Newtest ©) with results of 47.14 ± 3.24cm and 47.29 ± 6.29cm respectively. This testing procedure was also utilised by Doran, Donnelly and Reilly (2003) albeit with a different contact mat (Eleiko ©) with members of Tier 2 inter county hurling squad resulting in vertical jump heights of 40.8 ± 4.5cm. The differences in performance may be again attributed to the difference in standard of squads selected for the two studies and also to the use of different testing equipment. Collins et al. (2007) examined broad jump (BJ) in two Tier 1 inter-county hurling squads and the results were 2.54±0.2m and 2.47 ± 0.15m respectively. These results presented are higher than Tier 1 inter county Gaelic footballers 2.44 ± 0.2m (Keane, Reilly & Borrie, 1997). This difference in BJ performance may be attributed to the advances made in the physical preparation of Gaelic games athletes and their support structures from when the research of Keane et al. (1997) took place. Investigations examining the upper body strength and power are less prevalent. Limited research has taken place on profiling the upper body
strength and power properties of hurlers. 1RM bench press performance of Tier 2 hurlers was evaluated by McIntyre (2005) and Brick and O’Donoghue (2005) with results of 69.7 ± 12.35kg and 63.2 ± 15kg respectively. These reported results are lower than values presented for Tier 2 inter county Gaelic Footballers 73.7 ± 12kg (McIntyre, 2005). Such differences between hurlers and Gaelic footballers may be attributed to the differences in level of participation and the differences in the demands of the game in particular the ‘tackle’. In the sport of hurling there is a tradition of tackling using the camáín whereas in the sport of Gaelic football tackling is reliant on upper body strength. This difference in the tackle area would require superior levels of upper body strength in athletes participating in Gaelic football than those participating in the sport of hurling.

2.5.3. Endurance

The high intensity intermittent nature of hurling played over two 30-35 minute periods places a large demand on the endurance capacities of the players. Both the aerobic and anaerobic endurance capacities must be sufficiently developed to maintain performance for the whole duration of the game. Research profiling the aerobic endurance of hurling athletes has been carried out extensively (4 out of 4 key studies), while there is a paucity of literature examining the local muscular and anaerobic endurance (1 out of 4 key studies).

2.5.3.1. Local Muscular Endurance and Anaerobic Endurance

High levels of local muscular endurance (LME) and anaerobic endurance are required to sustain the high intensity physical demands of the sport of hurling over the duration of the game 60-70 mins. Given these requirements for successful performance in the sport it is surprising that to date only one study has examined the local muscular endurance and anaerobic endurance performance of inter county hurlers. McIntyre (2005) evaluated LME via a maximum push up and sit up test in a Tier 2 inter county hurling squad, a Tier 1 inter county Gaelic footballers and semi-professional soccer players in the League of Ireland. LME performance (push up and sit up test) of the hurling squad (M= 42.8 reps, S.D. = 10 and M= 42 reps, S.D. =9) were both significantly lower than values for the Gaelic
footballers (M=46.8 reps, S.D. =10 and M = 47 reps, S.D. = 11) and soccer players (M=59.1 reps, S.D. =15 and M= 64 reps, S.D. = 11).

McIntyre (2005) also compared the anaerobic endurance capacities (150m test) of a Tier 2 inter county hurling squad (M= 667m, S.D. =44), a Tier 1 inter county Gaelic football squad (M=774 m, S.D. = 25) and a League of Ireland semi-professional soccer team (M= 817m, S.D. = 79). The differences present in aerobic and anaerobic endurance performance can be attributed to the amateur status of the hurling squad in comparison to the semi-professional nature of the soccer squad and the differences in level of performance between the hurling squad (Tier 2) and the Gaelic football squad (Tier 1).

2.5.3.2. Aerobic Power

Aerobic power is the performance characteristic that has received the most attention in research into the sport of hurling. The most common measurement used to describe endurance performance has been maximal oxygen uptake (VO² max) with the most widely used protocol selected being an estimated value derived from a multi stage fitness test (20MST) rather than direct measurement in the laboratory. An investigation by Collins et al. (2007) exploring the aerobic power of two Tier 1 inter county hurling squads found values of estimated VO2max of 58.04 ± 2.64 ml/kg/min and 55.59 ± 2.61 ml/kg/min respectively. Aerobic performance has been evaluated in Tier 2 inter county hurling squads by Doran, Donnelly & Reilly (2003) who found similar values of 58.9 ± 4.8 ml/kg/min to one of the squads from Collins et al. (2007). Brick & O’Donoghue (2005) found lower levels of aerobic endurance 53.2 ± 4 ml/kg/min in a separate squad of Tier 2 inter county hurling athletes.

The range of reported values of estimated VO² max for inter county hurlers are similar to values reported for Tier 1 inter county Gaelic football squads 57.0 ± 3.9 ml/kg/min (Brick & O’Donoghue 2005) and 57.1 ± 4.6 ml/kg/min (Young & Murphy, 1994) and lower than reported values for English premiership soccer players 62.6 ± 3.8 ml/kg/min (Clark et al, 2003) and premiership Australian Rules football players (61.6 ± 3.5 ml/kg/min) The differences present can again be attributed to the differences present in support structures and training environments and circumstances of amateurs and professional athletes.
Table 2.3 Endurance Measures of Hurlers.

<table>
<thead>
<tr>
<th>Study</th>
<th>Level</th>
<th>Push up (reps)</th>
<th>Sit-up (reps)</th>
<th>150m (m)</th>
<th>VO² max (ml/kg/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collins et al., 2007</td>
<td>SIC Tier 1</td>
<td></td>
<td></td>
<td></td>
<td>58.04 ± (2.64) #</td>
</tr>
<tr>
<td>Doran et al., 2003</td>
<td>SIC Tier 2</td>
<td></td>
<td></td>
<td></td>
<td>58.9 ± (4.8) *</td>
</tr>
<tr>
<td>McIntyre 2005</td>
<td>SC Tier 2</td>
<td>42.8 ± (10)</td>
<td>42 ± (9)</td>
<td>667 ± (44)</td>
<td>47.4 ± (7.0) #</td>
</tr>
<tr>
<td>Brick &amp; O’Donoghue, 2005</td>
<td>SIC Tier 2</td>
<td></td>
<td></td>
<td></td>
<td>53.2 ± (4.0) #</td>
</tr>
</tbody>
</table>

*Denotes assessed via incremental graded treadmill test.
#Denotes assessed via 20MST

2. 5. 4. Physiological Overview of the Hurling Athlete

The content above illustrates the physical performance of the hurling athlete and outlines the differences present in relation to athletes from other codes. The lack of research exploring all the relevant components of fitness from one hurling squad creates major difficulties when attempting to create a human performance profile for the hurling athlete. The inability of the research to facilitate the development of such a profile necessitates the undertaking of further investigations to address this gap in the literature.

2. 6. Relationships between Level of Participation and Physical Performance Indicators

A substantial amount of research has been undertaken examining the relationships between respective participation levels and measures of anthropometric and physical performance.
Research of this nature has been widely performed in rugby league (Baker, 2002; Gabbett, 2002) and soccer (Commetti et al., 2000; Le Gall et al., 2008). Similar investigations have been carried out in rugby union (Quarrie et al, 1995) and to a lesser extent in the sports of Gaelic football (Keane et al., 1997) and hurling (Doran et al., 2003). A considerable amount of the research has documented that selected anthropometric and physical performance measures improve as the level of participation increases.

The identification of the differences in anthropometric and physiological qualities between squads of elite and sub elite athletes provides an insight into the levels of physical performance that are required for sporting performance at each respective level, in addition to determining factors that may limit progression to performing at a higher level (Reilly, 1999). This information proves invaluable to athletic development specialists and those charged with developing long term player development pathways as it clearly identifies the anthropometric and physiological requirements for performance at the various levels within the sport. Furthermore, programmes and structures can subsequently be devised to enable the athletes to reach these required levels of physical performance (Duthie et al., 2003).

2. 6. 1. Soccer

A significant amount of research has examined the physical performance of soccer players at different levels of participation (Arnason et al., 2004; Commetti et al., 2001). Arnason et al. (2004) explored the physical performance characteristics of 306 players from 17 teams in the two highest divisions (Elite Division & Division 1) in professional soccer in Iceland. Elite division players were significantly taller (181.7 ± 0.5cm vs. 179.6 ± 0.5 cm: p<0.05). Players from the elite division also had lower %BF as estimated via 6-site skin folds (8.99 ± 0.5% vs. 11.2±0.5%), and superior estimated VO₂max 63.2 ± 0.4 ml/kg/min vs. 61.9 ± 0.7ml/kg/min compared to their division one counterparts. Within the respective divisions, there was a significant relationship found between average jump height as monitored via countermovement jump (P=0.009) and standing broad jump (P = 0.012) on a contact mat (PE, Tape Switch Corp., Farmingdale, NY) and team success as determined by final placing in the league table (p<0.05). Kollath and Quade (1993) evaluated the sprinting abilities of 20 professional soccer players in the national first division and 19 top
class amateurs from Germany. The results of the study showed the professional players were significantly faster than the amateurs at all distances tested.

Table 2.4 Sprinting Performance: German Soccer (Professional vs. Amateur)

<table>
<thead>
<tr>
<th>Distance</th>
<th>5m (sec's)</th>
<th>10m (sec's)</th>
<th>20m (sec's)</th>
<th>30m (sec's)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profess n=20</td>
<td>1.03 ± (0.08)</td>
<td>1.79 ± (0.09)</td>
<td>3.03 ± (0.11)</td>
<td>4.19 ± (0.14)</td>
</tr>
<tr>
<td>Amateur n=19</td>
<td>1.07 ± (0.07)</td>
<td>1.88 ± (0.10)</td>
<td>3.15 ± (0.12)</td>
<td>4.33 ± (0.16)</td>
</tr>
</tbody>
</table>

Adapted from (Kollath & Quade, 1993)

Ostojic, (2003) examined the relationship between level of playing performance and measures of physical performance in two separate squads: Squad 1 (n=30) were professionals playing in the first division and Squad 2 (n=30) were amateurs playing in the third division. The professional players had significantly higher estimated VO² max values, compared with the amateur players (52.9 ±9.1 vs. 45.1 ±5.5 ml/kg/min; p ≤ 0.01). The professional players also had significantly superior leg power than the amateur players as evaluated via vertical jump performance (49.9 ±7.5cm vs. 43.9 ±6.9cm, p ≤ 0.01).

Table 2.5 Sprinting Performance: Serbian Soccer (Professionals Division 1 vs. amateurs Division 3)

<table>
<thead>
<tr>
<th>VO² max (ml/kg/min)</th>
<th>Vertical jump (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Div 1 n = 30</td>
<td>52.9 ±9.1</td>
</tr>
<tr>
<td>Div 3 n = 30</td>
<td>45.1 ±5.5</td>
</tr>
</tbody>
</table>

Adapted from (Ostojic, 2003)
Table 2.6 below illustrates the findings of Commetti et al. (2001) who evaluated the anaerobic strength power of French soccer players playing in the first division, second division and an amateur squad. The first division soccer players were significantly faster (M=1.804 sec’s, S.D. = 0.063) than second division players (M=1.818 sec’s, S.D. = 0.058) and the amateur soccer players (M=1.859 sec’s, S.D. =0.075) in time to sprint 10m: p≤0.05. The higher level athletes were also faster over 30m but this difference failed to reach significance (p<0.05). In contrast to much of the other research, Commetti et al. (2001) failed to find a relationship between level of participation and squat jump and countermovement jump as measured using a Boscos © jump mat (Ergojump, Globus Italia). Although the first division athletes had superior levels of leg power than second division athletes, the amateur athletes had superior levels of leg power than either of the two professional teams. The failure of either of the vertical jump tests to differentiate between the professionals and the amateurs could possibly indicate that lower extremity power in the vertical plane is not a pre-requisite to playing at the professional level in soccer.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Div. 1 (Pro) n= 29</th>
<th>Div2 (Pro) n= 34</th>
<th>Amateur n= 32</th>
</tr>
</thead>
<tbody>
<tr>
<td>10m sprint (sec's)</td>
<td>1.804 ± (0.063)</td>
<td>1.818 ±(0.058)</td>
<td>1.859 ± (0.075)</td>
</tr>
<tr>
<td>30m sprint (sec's)</td>
<td>4.223 ± (0.192)</td>
<td>4.249 ± (0.147)</td>
<td>4.294 ± (0.141)</td>
</tr>
<tr>
<td>Squat jump (cm)</td>
<td>38.48 ± (3.8)</td>
<td>33.86 ± (7.47)</td>
<td>39.83 ± (5.15)</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>41.56 ± (4.18)</td>
<td>39.71 ± (5.17)</td>
<td>43.93 ± (5.65)</td>
</tr>
</tbody>
</table>

Adapted from (Commetti et al, 2001)

Some of the research indicates that soccer players playing at a higher level have superior leg power than players at a lower level as monitored via the use of various jump tests (Arnason
et al., 2004; Ostojic, 2003), but not all studies have confirmed this finding (Cometti et al., 2001; Wisloff et al., 1998). Arnason & colleagues (2004) suggest that soccer players at a higher level are taller and heavier than players from a lower level. Again there exists a body of research that conflicts with these findings which have found no relationship between height and weight and level of playing performance (Commetti et al., 2001; Ostojic, 2003). In light of the presented data the main physical performance characteristics that differentiate between elite and sub elite soccer players are measures of speed and aerobic endurance (Commetti et al., 2001; Kollath & Quade, 1993; Ostojic, 2003).

2.6.2. Rugby League

Research of a similar nature has also been conducted in the sport of rugby league (Baker, 2002; Gabbett et al, 2009). Investigations have examined the differences between elite level athletes and sub-elite level athletes at both senior and junior levels (Baker, 2001; Gabbett, 2002; Gabbett, et al., 2009). Furthermore, research has been conducted to examine the differences between athletes at different stages of development i.e. senior and junior levels of participation (Gabbett, 2002). This research has shown that in the sport of rugby league as the level of participation increases, there is also a progressive increase in measures of speed, power and endurance (Baker, 2002; Gabbett et al, 2002 a).

Gabbett (2002) explored the relationships between level of playing performance and physical performance measures of rugby league athletes from the same sub elite rugby league club in Australia. The breakdown of players was as follows: under 13 (n= 27), under 14 (n= 17), under 15 (n= 23), under 16 (n= 21), under 19 (n= 22), second grade senior (n= 29) and first grade senior (n=20). Each grouping of players was then broken down further into forwards and backs. Measures of leg power (C.M.J.), sprint performance (10m, 20m and 40m) and aerobic endurance (20MST) were undertaken on all players and the results from the Under 13 squad and senior first grade squad are illustrated in table 2.7 below. Leg power (CMJ), 10m, 20m and 40m speed and aerobic endurance (Est. VO² max) increased steadily at all groupings as level of performance increased from under 13 athletes to senior first grade athletes.
Table 2.7 Physical Performance Indicators Under 13 and Senior First Grade Rugby League Players (Gabbett 2002)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Under 13</th>
<th></th>
<th></th>
<th></th>
<th>Senior first grade</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Forwards</strong></td>
<td><strong>Backs</strong></td>
<td><strong>Forwards</strong></td>
<td><strong>Backs</strong></td>
<td><strong>Forwards</strong></td>
<td><strong>Backs</strong></td>
<td><strong>Forwards</strong></td>
<td><strong>Backs</strong></td>
</tr>
<tr>
<td>C.M.J. (cm)</td>
<td>28.2 (21.7 to 34.7)</td>
<td>30.8 (28.2 to 33.4)</td>
<td>48.7 (42.1 to 55.3)</td>
<td>50.9 (47.5 to 54.3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 m(s)</td>
<td>2.60 (2.53 to 2.67)</td>
<td>2.46 (2.38 to 2.54)</td>
<td>2.05 (1.97 to 2.13)</td>
<td>1.98 (1.93 to 2.03)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 m(s)</td>
<td>4.24 (4.14 to 4.34)</td>
<td>4.04 (3.92 to 4.16)</td>
<td>3.38 (3.28 to 3.48)</td>
<td>3.28 (3.21 to 3.35)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 m(s)</td>
<td>7.50 (7.29 to 7.71)</td>
<td>7.11 (6.87 to 7.35)</td>
<td>5.86 (5.76 to 5.96)</td>
<td>5.69 (5.58 to 5.80)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VO²max (ml/kg/min)</td>
<td>32.1 (29.6 to 34.6)</td>
<td>36.2 (33.8 to 38.6)</td>
<td>50.0 (47.6 to 52.4)</td>
<td>50.1 (47.4 to 52.8)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All data are illustrated as means (95 % Confidence intervals)

Adapted from (Gabbett, 2002)

Gabbett et al., (2009) explored the differences between junior rugby league athletes that participated at the elite level (n=28) and the sub elite level (n=36). The results of this study found no significant difference (p≤0.05) between elite and sub elite junior rugby league players in measures of height (178±5.9cm vs.176.0±6.0cm respectively), body mass (elite77.5±10kg vs. sub-elite 74.3±13.4kg) and sum of seven skin fold thickness (elite 67.1±14.9cm vs. sub elite 75.1±31.0cm). Although the presented values for body mass and skin fold thickness failed to reach levels of significance (p≤0.05) it is clear that the elite players were heavier and had lower levels of %BF as estimated via the use of the sum of seven site skin fold thickness. The elite players had significantly superior levels of speed over 10m and 20m (1.81 ±0.08s & 3.11±0.12s) than sub elite (1.94± 0.11s &3.25± 0.18s: p≤0.05). Elite players also had significantly superior vertical jump performance (51.6±7.7cm) than the sub elite players (46.9± 6.8cm: p≤0.05). Elite players also had significantly superior aerobic endurance performance (48.2±4.6 ml/kg/min) than sub elite (43±5.4 ml/kg/min: p≤0.05) as evaluated via estimated VO² max using the 20MST

Baker, (2001) explored the differences in anthropometric measures and measures of upper body strength and power between 22 professional National Rugby League (NRL) and 27 state and city league, college-aged (SRL) rugby league players from the same Australian
based club. The results of the study found no significant difference in height or body mass between the professionals and non-professionals but found significant differences in all measures of upper body strength and power. Maximum strength as determined by 1RM bench press performance was significantly greater in the professionals (144 ± 10kg vs. 111±8kg) compared to the non-professionals. In addition to this, maximum power as determined during bench throws with loads of 40,50,60,70 and 80kg was significantly higher (p<.05) for professionals than amateurs at all loads as monitored via the use of a portable force transducer (PPS ©). In a similar study of Australian rugby league players, Baker (2002) examined the upper and lower body strength and power of 95 athletes from four different levels of participation (elite professional \( n_1 = 25 \) college aged \( n_2 = 20 \) high school \( n_3 = 25 \) and junior high school \( n_4 = 20 \) ). Upper body strength as measured via the 1RM bench press performance increased as level of playing performance increased professional (144±10kg), college (111±8kg), high school (98±7kg) and junior high school (85±6kg). Upper and lower extremity power as measured via bench press throws with 20kg and squat jumps with 20kg were also significantly different between all levels of playing performance (p<.05) with an increase in maximum power as level of playing performance increased. These results demonstrate that in the sport of rugby league, as level of participation increases there is also a progressive increase in measures of speed, upper and lower body strength and power and endurance.

2. 7. Seasonal Change in Field Sports

In field sports, the competitive season is broken down into distinct phases with training volumes and intensities manipulated according to competitive games. The common phases have been described as the following:
Table 2.8 Phase of the Competitive Season in Field Sports

<table>
<thead>
<tr>
<th>Phase of season</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Off Season</td>
<td><em>Period between the end of the past season and prior to the beginning of the new season, where typically no collective team training takes place</em></td>
</tr>
<tr>
<td>2. Pre-season</td>
<td><em>Period where competitive games are limited or non-existent and training loads are highest</em></td>
</tr>
<tr>
<td>3. Pre-competition</td>
<td><em>Period prior to the competitive phase of the season, which in some sports contains the secondary competitions.</em></td>
</tr>
<tr>
<td>4. Competition</td>
<td><em>Period that involves the primary focused competitions or competitive games)</em>.</td>
</tr>
</tbody>
</table>

Monitoring the effects of the various phases of the season and the resulting changes in training schedules on physical performance has attracted a significant amount of interest. This interest has been due to the ability of the data to describe the effects of seasonal change which enable manipulation of training volumes, frequencies and intensities in the current season and also in future seasons to counteract any negative findings that may occur. Much of the research in the major field sports has concentrated on examining the changes that occur from the beginning of the pre-season to the end of pre-season or between the beginning of the season and end of the season. Literature examining the differences in physical performance between stages of the season other than pre-season and the pre-competitive phase of the season as highlighted above have been less abundant (Reilly, 1999). Such a paucity of research in this field is due to the difficulty in repeated testing during the season due to the challenges associated with managing the teams/players schedules and reluctance of sporting teams to test during various stages of the season when competitive games are frequent.
Similar to most of the other areas of sports performance, research the sport of soccer has attracted a significant amount of interest compared to the other major field sports. There is a dearth of research examining seasonal change in the sport of hurling which can be attributed to the previously mentioned reasons in section 2.1. Further difficulties in examining seasonal change in hurlers can be explained by the multitude of (county, club, school, colleges, university and age grade) teams that these players represent further limiting availability and suitability for testing at multiple stages throughout the season. Although players in other sports are part of multiple teams, there is generally minimal overlap in terms of the competitive season in the different teams. This is not the case in the sport of hurling where the competitive season of club and inter county usually overlap leading to limited access to players during the competitive season.

Previous research has revealed a trend towards an increase in selected physical performance indicators from the beginning of the season to the latter stages of the season (Aziz et al., 2006; Kalapotharakos et al., 2011). Authors have reasoned that pre-season training loads are sufficient to raise physical performance and that lower in-season training loads and high intensity competitive game play are sufficient to continually raise physical performance levels (Ostojic, 2004). There also exists a body of research that has shown selected physical performance indicators are maintained after initial improvements in the pre-season period (Aziz et al., 2006) and some may even disimprove during the latter stages of the season (Kraemer et al., 2004).

2. 7. 1. Seasonal change in Anthropometric Measures

Unlike many of the physical performance indicators which involve maximal physical exertion, anthropometric measures (body mass and % body fat) have been extensively researched at all stages throughout the competitive season from the beginning of pre-season to the end of the competitive season (Gabbett, 2005 a; Reilly 1999). The existence of such data can be attributed to the non-invasive and non-fatiguing nature of these protocols compared to many of the other physical performance measurements where maximal exertions are required. Research that has monitored changes in body composition variables throughout the competitive season has revealed a trend towards a decrease in
%BF however conflicting results exists on how these measures change over the competitive season (Clark et al., 2008; Ostojic, 2004).

2. 7. 1. 1. Seasonal Change in Body Mass

Aziz and colleagues (2006) found a non-significant decrease in body mass (M=70.6 kg, SD=10.3) at the beginning of pre-season to (M=69.7 kg, SD=10.1) at the pre-competitive stage of the season in professional soccer players playing in the Singaporean first division. Similar findings were reported in English premiership footballers over a period of three consecutive seasons (Clark et al., 2008). In two of the three seasons there was a decrease in body mass from pre-season to mid-season and a further reduction to the end of the season although none of the changes reached statistical significance (p<0.05).

Gabbett (2005a) found similar results with a reported a significant decrease in body mass from beginning of pre-season (M=84.2 kg) to (M=82.0 kg) to pre-competition phase of the season in Australian senior sub elite rugby league players (p≤0.05). Following the pre-competition phase, these new lower levels of body mass were not maintained and body mass returned to previously elevated levels during mid-season 84.5 (79.0-90.1) kg and significantly higher levels than pre-season at the end of season 86.2 (80.7-91.7) kg. Gabbett (2005b) also found a decrease in body mass in elite junior rugby league players from 83.3 (72.9-94.3) kg at the beginning of pre-season to 79.9 (74.1-85.8) kg at the pre-competitive phase of the season; however this change failed to reach statistical significance (p≤0.05). These reduced levels of body mass were maintained through the mid-season and the end of season.

There have also been a number of studies that have reported no statistically significant change in body mass from pre-season to the later stages of the season. The body mass of elite level rugby league athletes participating in the professional super league in England remained significantly unchanged from (95.28 ± 11.33 kg) at the end of pre-season compared to (95.55 ± 11.99 kg) at the mid-season point and (95.05 ± 11.81 kg) at the end of the competitive season (Harley et al., 2011). Kalapotharakos and colleagues (2011) reported similar findings with no significant difference in body mass between the beginning of pre-season, end of pre-season and mid-season (74.2 ± 6.5 kg vs. 74.6 ± 6.5 kg vs. 74.2 ± 6.6 kg) in elite soccer players playing in the first division of the Greek national league.
In contrast Ostojic (2004) found no significant change in body mass from the start of pre-season \((M=77.8, \text{ S.D.}=6.3 \text{ kg})\) to the start of the competitive season \((M=78.0, \text{ S.D.}=6.1 \text{ kg})\) and at mid-season \((M=76.8, \text{ S.D.}=6.1 \text{ kg})\) in professional male soccer players from the 1st National league in Serbia \((p<0.05)\). Ostojic (2004) also found a significant decrease in body mass in the same cohort of players from mid-season \((M=76.8, \text{ S.D.}=6.1 \text{ kg})\) to end of season \((M=74.8, \text{ S.D.}=6.0 \text{ kg})\). Similar finding were also reported by Keane and Reilly (1999) who evaluated Tier 1 inter county Gaelic footballers at 6 time points during the season and found no significant change in body mass from \(86.0 \pm 5.3 \text{ kg}\) at the beginning of pre-season to \(85.7 \pm 5.3 \text{ kg}\) at the end of the pre-season \((p<0.05)\). The only significant changes \((p<0.05)\) reported in body mass occurred at Time 5 (an unspecified stage, mid-season) and also Time 6 (final stages of the competitive season) where body mass decreased to \(82.9 \pm 5.7 \text{ kg}\) and \(82.7 \pm 5.0 \text{ kg}\) respectively.

There also exists a body of research that has shown body mass to increase during the competitive season. Elite junior Asian soccer player playing at the professional level reported no significant change in body mass from beginning of pre-season \((M=67.2, \text{ S.D.}=7.5 \text{ kg})\) to the end of pre-season \((M=66.2, \text{ S.D.}=7.3 \text{ kg})\), but significant increases were reported from the end of pre-season \((M=66.2, \text{ S.D.}=7.3 \text{ kg})\) to the middle of the competitive season \((M=68.0, \text{ S.D.}=7.9 \text{ kg})\) (Mukherjee and Chia, 2010). The authors attributed the increases in body mass to the growth and development that is occurring during the maturation process of these junior athletes.

The results presented above demonstrate that body mass is subject to seasonal change but the literature also demonstrates the conflicting findings that have been found. The conflicting findings can be attributed to the different training regimes, competition formats and nutritional practices that vary hugely within and between squads and in particular between sports. The results also demonstrate the impact that maturation in youth athletes may have on body mass as observed over a season log period.

### 2.7.1.2. Seasonal Change in Body Composition

Literature examining seasonal changes in body composition has revealed a trend of decreasing percentage body fat (%BF) from the beginning of pre-season to the end of pre-season and pre-competition stages of the season. Ostojic (2004) found a significant decrease in %BF from \(10.5 \pm 2.5\%\) at the beginning of pre-season to \(8.7 \pm 1.8\%\) prior to
the start of the competitive season in Serbian professional soccer players. Similar results were also reported by Caldwell and Peters (2009) who found a non-significant decrease in %BF from 11.5 ±2.1% at pre pre-season to 10.9 ±2.4% to post pre-season in players participating in the English Nationwide Conference.

The above trend was continued in the research by Kalapotharakos and colleagues (2011) who found estimated % BF via 3 site skin fold (Jackson & Pollack, 1985) significantly decreased from 10.5 ± 2.5% at the start of pre-season to 8.7 ± 1.8% at the pre-competitive stage of the season (p<0.001). The % BF remained at a significantly lower level of 8.3 ± 1.44% during the mid-season compared to the pre-season average scores (p<0.001). In one of the few papers that examined seasonal change in elite youth athletes, Mukherjee and Chia (2010) found a significant decrease in %BF from 13.2 ± 2.8% at the beginning of pre-season to 11.2 ± 2.2% at the early stage of the competitive phase in elite youth Japanese soccer players (p<0.05). There was subsequently a significant increase in %BF at the end of the mid-season point where % BF reached 12.4 ± 2%. Gabbett (2005a) also found a reduction in % BF in elite youth rugby league players as measured via the sum of 7 skinfolds from beginning of pre-season (M=93.9mm) to the end of pre-season (M= 85.2 mm). In contrast to the findings of Mukherjee and Chia (2010), these lower levels of % BF remained statistically lower than the initial pre-season values at mid-season and end of season testing points.

The % BF as determined via DXA in elite level rugby league athletes participating in the professional super league in England remained significantly unchanged from 15.21 ± 3.55% at the end of pre-season compared to 15.47 ± 3.66 % at the mid-season point but significantly increased to 16.24 ± 3.79% at the end of the competitive season (Harley et al., 2011). The increase in %BF towards the end of the season were attributed to a reduction in training time as result of the increased competition schedule in addition to players missing training due to injury.

The results of the studies shown above demonstrate that there is a trend towards a decrease in % BF from beginning of pre-season to the early stages of the season where periods of conditioning and training volumes are highest. The in-season period where training volumes reduce and competitive game play increases results in either maintenance of these new lower levels or an increase to elevated levels which are lower than pre-season values for % BF.
2. 7. 2. Seasonal Change in Speed-Acceleration

The existing research has revealed a pattern towards an improvement in speed and acceleration from the beginning of the pre-season period to the end of the pre-season and throughout the rest of the competitive season (Caldwell & Peters, 2009). There also exists a body of research that conflict with these findings, i.e. failing to show speed-acceleration improvements throughout the competitive season (Kramer et al, 2004). The authors have reasoned that the failure of the speed-acceleration scores to improve may have been due to the difficulties associated with recovering from competitive game play whilst simultaneously attempting to improve speed.

In the sport of soccer 10m sprinting speed in semi-professional players in the Nationwide Conference in England has been shown to improve from pre-preseason (M=2.49 sec’s, S.D.= .10) to post pre-season (M=2.43 sec’s, S.D.=.10) (Caldwell & Peters, 2009). Aziz et al., (2006) also reported increases in 5m and 10m sprinting performance from beginning of pre-season (M= 1.04 sec’s, S.D.= .06 and M=3.04 sec’s, S.D.=.10) to the beginning of the competitive season (M= 1.03 sec’s, S.D.= .06 and M=3.01 sec’s, S.D.=.10 ) in professional players in the top Singapore league. Increases in speed over 50m were also reported by Ostojic (2004) in professional male soccer players from the 1st National league in Serbia from pre-season (M= 7.5 sec’s, S.D. =0.6) to start of season (M=7.3 sec’s, S.D. =0.6). These new enhanced levels of sprinting performance as determined via 50m timed sprint were improved up at the mid-season testing point (M=7.2 sec’s, S.D.= 0.5). Reilly and Keane (1999), reported similar increases in 50m sprint performance from beginning of pre-season (M= 7.43 sec’s, S.D. =0.2) to the end of the pre-season (M=7.19 sec’s, S.D. = 0.2) in Tier 1Gaelic footballer players. There was then a further improvement in 50m sprint performance during the remainder of the season with the lowest levels reported prior to the most important competitive game of the season reported as (M=6.56 sec’s, S.D. =0.2).

These reported increases in short distance speed from the beginning of pre-season to the pre-competition phase were not found at all distances measured in senior sub elite rugby league players (Gabbett, 2005 a). Sprint times over 10m significantly increased from the beginning of pre-season (M=1.83 sec’s) to the pre-competition phase(M=1.85 sec’s; p≤0.05. 10m sprint performance significantly decreased at mid-season point (M=1.80 sec’s) compared to initial values at pre-season and at the pre-competitive phase of the season In
the same study Gabbett (2005 a) found conflicting results for 40m sprint performance. 40m sprint performance remained statistically unchanged from the beginning of pre-season (M=5.61 sec’s) to the pre-competitive phase of the season (M= 5.61 sec’s) and on to the midseason point (M=5.62 sec’s). Gabbett (2005b) also found inconsistent changes in sprint performance in elite Australian junior rugby league players from the beginning of pre-season to the pre-competitive phase and the mid-season point. A statistically significant increases in 10m time occurred from the beginning of pre-season (M=1.82 sec’s) to the start of pre-competitive phase of the season (M=1.85 sec’s); p≤0.05. At the midseason point there was then a reduction in 10m sprint performance (M=1.82 sec’s) compared to the pre-competitive phase (M=1.85 sec’s), however unlike with the senior sub elite rugby league players this new level was not significantly lower than pre-season values (Gabbett, 2005 a).

The results of the studies presented here demonstrate that there is a trend towards an increase in short distance sprinting speed from the beginning of the season to later stages of the season. The literature also outlines the differences present in sprinting speed that may occur as a result of the different training regimes, competition structures and recovery from these stresses.

2. 7. 3. Seasonal Change in Upper and Lower Extremity Power

Research evaluating seasonal change in field sport athletes has revealed a trend towards increased levels of upper and lower extremity power from the beginning of pre-season to later stages of the season (Aziz et al., 2006). Leg power as measured via countermovement jump using arm swing with a dynamometer (Takei) has been shown to improve from pre-season (M=54 cm, S.D. = 3.2) to the end of pre-season (M=56 cm, S.D. =3.7) in Nationwide Conference soccer players (Caldwell & Peters, 2009). Increases in leg power from pre-season (M=55 cm, S.D.=5) to end of pre-season (M=59 cm, S.D.=5) as measured using a counter movement jump with the yardstick device have also been documented in soccer players participating in the first division of the Singapore professional league(Aziz et al., 2006) .
C.M.J. performance has also been shown to improve in senior sub-elite rugby league players from pre-season (M=55.4 cm) to pre-competition (M=58.6 cm) (Gabbett, 2005 a). Similar increases in countermovement jump performance from pre-season (M=54.8 cm) to pre-competition (M=58.2 cm) have also been reported in junior elite rugby league players (Gabbett, 2005 b). In contrast, Casajus (2001) reported no significant changes (p<0.05) in lower body power as measured via a number of different protocols (counter movement jump hands on hip, squat jump and countermovement jump with arm swing) from the beginning of pre-season to the midpoint of the competitive phase of the season in professional soccer players playing in the premier league in Spain. Baker (2001) reported similar findings of no significant change (p≤0.05) in upper extremity power as evaluated via bench throws in Australian professional rugby league players.

The authors have concluded that upper and lower extremity power can continually improve throughout the competitive season provided that there is an appropriate balance between soccer specific practice, a balanced strength and conditioning programme and recovery from the stresses of competitive game play (Kramer et al., 2004; Silvestre et al., 2006).

2. 7. 4. Seasonal Change in Aerobic Endurance

Similar to many other aspects of sports performance research, monitoring seasonal change in aerobic endurance capacity as measured via estimated VO² max has attracted significantly more interest than any of the other physical performance indicators. There has been a common trend towards increasing aerobic endurance performance from the beginning of the pre-season period through to the end of the pre-season or immediately prior to the pre-competitive phase of the season (Aziz et al., 2006; Caldwell & Peters, 2009). The authors have concluded that the increases in aerobic performance have been as a result of the content of the pre-season and pre-competitive periods which contain large amount of focused conditioning work, non-competitive game play and sport-specific skill practice.

Estimated VO² max increased in nationwide conference soccer players from pre-season (M=56 ml/kg/min, S.D. = 1.2) to end of pre-season (M=58 ml/kg/min, S.D= 1.6)
(Caldwell & Peters, 2009). In senior sub elite rugby league players Gabbett (2005b) reported an increase in VO\textsuperscript{2} max from the beginning of pre-season (M=42.0 ml/kg/min) to the end of pre-season (M= 48.5ml/kg/min). Gabbett (2005 a) also reported similar increases in VO\textsuperscript{2} max in junior elite rugby league players from the beginning of pre-season (M= 43.7 ml/kg/min) to the end of pre-season (M=50.6 ml/kg/min).

Keane and Reilly (1999) tracked the physical performance of Tier 1 senior inter county Gaelic footballers from beginning of pre-season to the competition period on 6 separate testing sessions. The authors found a trend towards an increase in estimated VO\textsuperscript{2} max from Time 1 at the beginning of the season (M=52.8 ml/kg/min, S.D.=2.1) to Time 4 (unspecified stage mid-season) M= 53.3 ml/kg/min, S.D.= 3.2) but this increase failed to reach statistical significance (p≤.05). Due to restricted time commitments the VO\textsuperscript{2} max testing was not conducted during the final two testing sessions that were deemed to reflect the aerobic capacity of the players during the important competitive phase of the season. With limited details describing the time and stages of the season of testing sessions 2-4 and the failure of testing sessions 5 & 6 to evaluate the VO\textsuperscript{2} max performance of the players the ability of this research to be applied to a wider cohort of players is severely limited.

There also exists a body of research that has evaluated aerobic endurance performance during the competitive period of the season (Clark et al., 2008; Kalapotharakos et al., 2011). Clark and colleagues (2008) evaluated English premiership footballers and found a trend towards increased aerobic endurance performance as determined by VO\textsuperscript{2} max via an incremental treadmill test from the beginning of pre-season to the midpoint of the season in two consecutive seasons, however these increases failed to reach statistical significance (p<0.05). Similar findings were also reported in professional soccer players in the First division of the Singapore league (Aziz et al., 2006). The results of this research showed a significant increase in VO\textsuperscript{2} max performance as estimated from the 20MST from pre-season (M=52.7 ml/kg/min, S.D. =3.4) to post pre-season (M=55.7 ml/kg/min, S.D. =3.1). These new elevated levels of aerobic endurance performance remained elevated at the mid-season and the end of the season. Similar findings were reported by Kalapotharakos and colleagues (2011) who demonstrated a significant increase in estimated VO\textsuperscript{2} max from pre-season (M=58.1 ml/kg/min, S.D. =3.11) to post pre-season (M=60.8 ml/kg/min, S.D.=2.66) in elite soccer players playing in first division of the Greek national league (p<0.002). Kalapotharakos and colleagues (2011) also found that increased levels of estimated VO\textsuperscript{2} max remain elevated during at the mid-season point (M=61.2 ml/kg/min,
S.D. = 2.3). The authors have concluded that in-season training and match schedules are sufficient to maintain but not significantly improve the aerobic endurance performance of the players.

2.8. Conclusion

This systematic review of the literature has found that human performance research has been extensively carried out in many of the major field sports and but to a lesser extent in the sport of hurling. Normative data that describes the anthropometric and physical performance measures scores of soccer, rugby league, rugby union and Australian rules players have been widely researched and published in peer reviewed journals. In contrast athletes from the sport of hurling have not been subject to such widespread analysis. The current review of the literature only found four research articles that contained normative data of various hurling populations. Of the four papers that were examined there was huge variance in the population samples chosen with one paper examining a Tier 1 inter county squad, and the rest examining the physical performance of Tier 2 inter county and club hurling squads.

This systematic review of the literature found evidence of the profiling of ~120 hurling athletes. This is in huge contrast to all the other major field sports where published profiling data exists on thousands and thousands of players. Unfortunately huge variance exists in what components of fitness each of the players were profiled in with regard to the components of fitness examined in such studies and also huge variation exists in with regard to the methods used to profile these components of fitness. Although all relevant components of fitness have been investigated by the four presented research papers, no single paper has examined all the important components of fitness for hurling successful hurling performance. There also exists a dearth of research examining the relationship between level of playing performance and measures of anthropometric and physical performance. This review of the literature found only 1 paper in existence that examined this important area of human performance research. The review of the literature failed to find any work relating to youth hurling (under the age of 18).
It is clear that there is gap in the literature relating to performance profiling of hurling athletes. Future research must attempt to aid in the development of normative data for hurling athletes and must assess all important components of fitness from the same population. Further research must be undertaken to examine the differences present between hurling squads at the different levels of performance and also at the different levels of development (< 18 years of age).
Chapter 3. Methodology
3. 1. Introduction

The testing of the participants in the current investigation consisted of anthropometric measures in addition to selected physical performance indicators related to the game of hurling (upper and lower extremity power, sprinting speed, local muscular endurance, anaerobic and aerobic endurance). All testing sessions took place in the University of Limerick PESS Building. A team of evaluators, which consisted of qualified sport scientists led by the Principal Investigator, was utilised to carry out the measurements on the selected squads. Ethical approval (EHSREC 09-99) was attained from the University of Limerick Education and Health Science Research Ethics Committee (EHSREC) prior to the commencement of testing.

3. 2. Participants

Participants (N=95) from three different levels of performance (senior elite \(n_1=34\), senior sub-elite \(n_2=28\) & junior elite \(n_3=33\) from the sport of hurling in the Munster region were recruited for the study. A convenience sampling approach was used in selection of the participants. The participants were selected from squads which the investigator or the investigators supervisor had previously worked with or were currently working with. This method of sampling was utilised as it increased the accessibility to the players after the pre-season period. This method of sampling also lead to an increased understanding of the training undertaken by the participants as all training was disclosed to the investigator. Direct contact was made with the management teams of the chosen squads explaining the benefits that would be derived from the planned testing and the requirements and time commitments involved in the research study. Following agreement from the respective management teams, subject information sheets (see appendix C) and informed consent documents (see appendix D) were distributed to all participants. Parental information sheets (see appendix B) and parental informed consent sheets (see appendix A) were also distributed to the junior elite squad. The three squads reported to the University of Limerick for testing at the very start of their respective pre-season training phase and 10 weeks later during the pre-competition stage of the season (during their secondary competition) of the season. All testing sessions were conducted at the same time of the day.
as the initial testing sessions to control the effect of external influences on the performance scores such as work, college or other commitments. Requests were made to the players and management teams to avoid strenuous activity of any type in the 24 hours prior to testing.

Prior to each testing session, all participants completed a PARQ health questionnaire (see appendix E) and were instructed to inform the principal investigator if any particular test was contraindicated for their current health and/or physical fitness status. Notably, a number of players were unable to participate in certain tests due to injuries sustained throughout the season. In addition to this, there were a number of players in each respective squad that were dropped following the pre-season testing and as result were not present during the pre-competitive testing. Similar to this there were also a number of players that were present during the second testing session but missed the initial testing as they were only called in to the squad at a later stage in the season. This is common practice in team sport where players will transition in and out of a squad due to a loss of form, injury or falling out of favour with the management team.

Table 3.1 Descriptives of Participants

<table>
<thead>
<tr>
<th>Squad</th>
<th>n</th>
<th>Age (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senior Elite</td>
<td>34</td>
<td>24.9 ± (2.5)</td>
</tr>
<tr>
<td>Senior Sub- Elite</td>
<td>28</td>
<td>26.9 ± (4.4)</td>
</tr>
<tr>
<td>Junior Elite</td>
<td>33</td>
<td>17.2 ± (0.3)</td>
</tr>
</tbody>
</table>
Figure 3.2 Training undertaken by the respective squads between pre-season and pre-competition

<table>
<thead>
<tr>
<th>Squad</th>
<th>Pitch based</th>
<th>Non pitch based</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S&amp;C programme</td>
<td>S &amp; C programme</td>
</tr>
<tr>
<td>Senior Elite</td>
<td>Training emphasised the development of speed via the use of a specialised speed coach. Emphasis was also placed on developed anaerobic and aerobic endurance via an interval pitch based running programme</td>
<td>The training programme targeted hypertrophy with high volume upper and lower body resistance training exercises. The repetitions and sets performed were in the ranges of 2-4 sets of 8-15 reps</td>
</tr>
<tr>
<td>Senior Sub-Elite</td>
<td>Training emphasised the development of anaerobic and aerobic endurance via an interval pitch based running programme was also placed on developed anaerobic and aerobic endurance via an interval pitch based running programme</td>
<td>The training targeted L.M.E. and further develop of the anaerobic and aerobic endurance via high volume muscular conditioning circuits, Common exercises present included various bodyweight exercise and medicine ball throws</td>
</tr>
<tr>
<td>Junior Elite</td>
<td>Training emphasised the development of anaerobic and aerobic endurance via an interval pitch based running programme was also placed on developed anaerobic and aerobic endurance via an interval pitch based running programme</td>
<td>The training focused on the development of strength and power via a whole body resistance training programme. The repetitions and sets performed were in the ranges of 2-4 sets of 2-6 reps</td>
</tr>
</tbody>
</table>
3.3. Key Anthropometric Measures and Physical Performance Indicators

The key variables evaluated are contained below in Table 3.2. The variables measured are broken down into the following categories (Anthropometric, power, speed and endurance). As a result of using a number of evaluators to carry out the measurement process the importance of clear, stringent and consistent protocols was paramount. The protocols utilised during the measurement are outlined in the following sections 3.3.1.to 3.3.4.

**Figure 3.1 Anthropometric Measures and Physical Performance Indicators**

<table>
<thead>
<tr>
<th>Category</th>
<th>Variable</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anthropometric</strong></td>
<td>Height</td>
<td>Metre (m)</td>
</tr>
<tr>
<td></td>
<td>Body mass</td>
<td>Kilogram (kg)</td>
</tr>
<tr>
<td></td>
<td>Lean Tissue Mass (LTM)*</td>
<td>Kilogram (kg)</td>
</tr>
<tr>
<td></td>
<td>% Body fat (%BF) *</td>
<td>Percentage (%)</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>Countermovement Jump</td>
<td>Centimetre (cm)</td>
</tr>
<tr>
<td></td>
<td>Broad Jump</td>
<td>Metre (m)</td>
</tr>
<tr>
<td></td>
<td>Kneeling Medicine Ball Throw</td>
<td>Metre (m)</td>
</tr>
<tr>
<td></td>
<td>Triple Bound</td>
<td>Metre (m)</td>
</tr>
<tr>
<td><strong>Speed</strong></td>
<td>10m standing sprint</td>
<td>Seconds (s)</td>
</tr>
<tr>
<td></td>
<td>30m standing sprint **</td>
<td>Seconds (s)</td>
</tr>
<tr>
<td><strong>Local Muscular Endurance</strong></td>
<td>Push ups</td>
<td>Repetitions (reps)</td>
</tr>
<tr>
<td><strong>Anaerobic Endurance</strong></td>
<td>150m shuttle run</td>
<td>Metre (m)</td>
</tr>
<tr>
<td><strong>Aerobic Endurance</strong></td>
<td>20MST</td>
<td>ml/kg/min</td>
</tr>
</tbody>
</table>

* Denotes measured only in the senior elite squad

** Denotes measured only in the senior elite and senior sub-elite squad
3. 3. 1. Anthropometric Measures

Height

Height was measured using a stadiometer (Seca, Birmingham, United Kingdom). Participants were measured barefoot and in shorts and a t-shirt. Participants were required to stand with their head, shoulders, gluteals and heels against the upright of the stadiometer with arms hanging by their side palm facing inwards. The top of the ear canal should be level with the cheek bone and the participants are instructed to look straight ahead. Participants were instructed to inhale deeply; upon inhalation the evaluator lowered the top piece of the stadiometer down to the highest point of the participants head. The evaluator recorded the height of the participant to the nearest 0.1cm. This process was repeated on two more occasions and the average of the three scores was calculated.

Body Mass

Body Mass was measured using a calibrated digital scales (Seca, Birmingham, United Kingdom). Participants were barefoot and in shorts and a t-shirt. Participants were instructed to stand still on the scales with their mass evenly distributed between both feet. When the digital scale settled and the mass was recorded, the participant stepped off the scale. The body mass was measured to the nearest 0.1kg. The process was then repeated on two more occasions and the average of these three scores was calculated.

Body Composition

Body composition of the senior elite players was analysed using a Lunar iDXA scanner (GE Healthcare, Chalfont St Giles, Bucks., UK). The whole body scanner was used in conjunction with VERSION 11.0 software for post scan analysis. Dual Energy X-ray Absorptiometry (D.X.A.) machines such as the above are used to measure lean and fat tissue mass by passing two x-ray beams of different attenuation through the body (Heyward, 2001). Whole body scans were performed on the participants in order to determine their lean tissue mass and % body fat. Participants were positioned according to the manufacturer’s guidelines on the bed of the scanner. Participants were instructed to remain still for the duration of the scan which ranged between 6 and 12 minutes, pending on the participant and the thickness of the scan required.
3. 3. 2. Power Measures

Power measures focused on evaluating both lower and upper extremity power. Leg power was evaluated in both the horizontal and vertical planes to analyse the ability of the leg musculature to apply force quickly in all planes of movement as is required in all field sports. Countermovement jump was chosen to measure explosive lower extremity power in the vertical plane. Standing broad jump was selected to measure explosive power in the horizontal plane. Both of these tests measure the acyclical nature of muscle force production, however many of the forces applied in field games are cyclical in nature henceforth placing a requirement on a test to examine cyclical leg power. Standing triple bound was selected to reflect this game-specific requirement as it incorporates the important components of repeated efforts in a cyclical fashion. With regard to upper extremity power, the kneeling medicine ball throw test was selected to measure this aspect of explosive performance. A standardised testing protocol was developed for all power measurements to minimise inter- and intra-evaluator error and was strictly adhered to. These protocols contained standardised techniques for warm up, the performance of all the measures in addition to strict criteria for the evaluator to monitor.

Countermovement Jump

Countermovement jump was measured using the Optojump system ©. The Optojump system © uses the flight time of the jump in order to calculate the height of the jump. This system is a portable optical measurement system which consists of a transmitting and receiving bar. Each of these bars contains 33 to 100 l.e.d.’s pending on the model. The l.e.d.’s from the transmitting bar are synchronised with the receiving bar to detect the duration of any motion between the bars. The Optojump system has been validated and found to be reliable for the measurement of jump height (Bosquet et al., 2009; Glathorn et al., 2010).

Participants stood in a shoulder width stance with hands on hips inside a 50x50cm square. They descended into a partial squat of self-selected depth and upon reaching the bottom of the squat they jumped for maximum height while keeping their hands on hips throughout. Participants were instructed to land inside a 50x50cm square with excessive bending of the
knees upon landing not permitted. Participants were allowed 2 practice trials upon completion of the practice trials testing began. Each participant performed three trials and the highest score achieved was the score recorded. Each participant had a resting period of 1.5-2 minutes between attempts. Countermovement Jump was measured to the nearest 0.01cm.

Standing Broad Jump

Standing Broad Jump was measured using a standing broad jump graded mat (Versa Flex Mat), and measured to the nearest 0.01 m. Participants were instructed to stand with the toes of their feet behind the start line (0 cm) of the mat adopting a shoulder width stance with their hands in the air. They were then instructed to initiate the jump by swinging their arms down and descending into a partial squat of self-selected depth. Once in this partial squat position they were instructed to jump horizontally as far as they could whilst swinging their arms forward to assist their forward movement. Participants were required to land on both feet and to maintain their foot position as it made contact with the surface of the mat. A measurement was then taken from the start line to the back heel where they landed. If one of the participants’ feet landed in front of the other the measurement was taken from the heel of the foot that was closest to the starting line. Participants were permitted two practice trials before official testing commenced. Once testing began, participants were allowed three attempts and the best score from the three attempts was selected. Each participant had a resting period of 2 minutes between attempts.

Standing Triple Bound

Standing Triple Bound was measured via the use of a tape measure. Two evaluators were required for the measurement protocol on this test. One evaluator was placed at the start line to ensure correct starting position and the other evaluator was situated in the area of anticipated landing on the third jump approx. 6-7m (depending on the estimated jumping ability of the respective participant) from the start line. Participants were instructed to stand with the toes of their feet behind the start line (0 cm) adopting a shoulder width stance with their hands in the air. They were then instructed to initiate the jump by swinging their arms down and descending into a partial squat of self-selected depth. Once in this partial squat position they were instructed to jump horizontally as far as they could whilst swinging their arms forward to assist their forward movement. Participants were
required to land on both feet prior to repeating this jumping motion on two further occasions. Participants were instructed to minimise ground contact time during the landing and subsequent take-off of the repeated jumps. The measurement was taken from the toe placed at the start line to the back of the heel on the third landing. If one of the participants’ feet landed in front of the other the measurement was taken from the heel of the foot that was closest to the starting line. Participants were given two practice trials each before testing began which consisted of three measured attempts. Each participant had a resting period of 1.5-2 minutes between attempts. The best score of the three jumps was selected. Standing Triple Bound was measured to the nearest 0.01 (m).

Kneeling Medicine Ball Throw

Kneeling Medicine Ball Throw was selected to measure upper body power. The participants were placed in a kneeling position to minimise the contribution of the lower extremities to the measurement. Participants were instructed to kneel on a gymnastics mat while holding the 5kg medicine ball in a chest pass position. Participant’s feet were fixed in a plantar flexed position to further minimise the contribution of the lower body. They were instructed to sit back onto their heels and then extend forward in a forceful manner throwing the ball for maximum distance while landing safely on their hands with elbows flexed and shoulders extended in deep push position to minimise impact on the upper extremities. The score was taken as the distance from the starting line to centre point of the ball upon landing. The medicine ball was covered in chalk to aid with measurements. When the medicine ball landed it left a circular chalk mark on the ground, from which the centre point of the circle was used to determine the measurement. All participants were given two practice trials each before testing began. Participants completed three trials each with a resting period of between 1.5- 2 minutes between attempts. The Kneeling Medicine Ball Throw was measured to the nearest 0.01 (m).

3. 3. 3. Speed and Acceleration

Sprint testing was undertaken to evaluate the participant’s speed and acceleration as these are both important physical performance characteristic of hurling athletes (Reilly & Collins, 2008). 10m sprint time was selected as a measure of acceleration; while 20m sprint time
was selected as measure of sprinting speed. Prior to speed testing, participants underwent a 5 minute warm up period to prepare themselves for maximal sprinting. This warm up included dynamic stretching, sprinting drills and sub maximal sprints. Upon completion, each participant performed 2 practice trials each. They were instructed to sprint at around 80-90% on the first practice trial and 90+% on the subsequent practice trial.

Speed was measured by monitoring 10m and 20m sprint times using Microgate © brand dual beam light gates. The speed gates were set at 0m, 10m and 30m with the start line positioned 0.5m behind the 0m line to prevent the gates being triggered prematurely by an arm action. Participants were positioned in a standing start stance with the preferred leg on the starting line. They were not permitted to rock forward and back to gain momentum on the start line nor were participants allowed to use a track start position. There was no starting signal given to the participants and they were informed that they could begin the trial in their own time. Participants were instructed to sprint as fast as possible through the three sets of gates and encouraged not to decelerate until they had passed through the final gate. Each participant performed two trials each and were given 3-4 minutes rest between trials. They were advised to keep active at very low intensity between trials in order to minimise injury. 10m and 20m sprint times were measured to the nearest 0.01 second.

3. 3. 4. Local Muscular Endurance

High levels of local muscular endurance are required in hurling athletes due to the physicality of the game of hurling. These athletes engage in physical contact with opposition players when attempting to gain possession in the air or on the ground. Physical contact occurs when players are in possession and are travelling with the ball. Through the sixty or seventy minutes of the game (depending on the level of play) these physical contests place a large demand on upper body local muscular endurance. A large amount of the physical contests require the athletes to push the opposition players away in order to gain possession, which results in local muscular endurance fatigue in the pushing muscles shoulders, chest and triceps. The maximum repetition push up test was selected to monitor the local muscular endurance performance of these pushing muscles.

Push up Test
The push up test was selected to monitor the strength endurance of the upper body musculature of the participants. Participants began the test in the top position of the push up with hands and elbows fully extended and positioned directly beneath their shoulders. The participants were instructed to maintain a neutral position with ankle, knee, hip, shoulder and head all in a straight line. Testing began when the participants descended into a push up position lowering the chest and shoulders. The bottom of the position push up was reached when the elbows were at the same height as the shoulders creating a 90° angle between the upper arm and lower arm. After reaching the bottom of the push up position the participant then extended their arms to return to the original starting position. Each participant was required to complete the maximum number of push ups they were capable of. The evaluators counted each repetition for the participants and were in direct communication with the participant throughout. Only full push ups (where the lower arm made a 90° angle with the upper arm) were counted. Testing was complete when the participants were no longer able to perform any more repetitions with the required demands on depth or on the maintenance of the neutral position. Push up test was measure in whole repetitions performed (reps).

3.3.5. Anaerobic and Aerobic Endurance

The sport of hurling places demands on the players to perform a variety of physical motor skills including jogging, sprinting, changing direction, jumping and contesting physical challenges. These physical demands, in addition to the technical requirements of the game, place a significant amount of stress on both the anaerobic and aerobic energy systems. The anaerobic energy system is stressed during intense periods of play through the sixty or seventy minutes of the game. The aerobic system is stressed as the athletes are required to perform various different lower intensity tasks, in addition to facilitating recovery from high intensity periods of activity over a sixty or seventy minute period.

150m Test

A repeated sprint test was used to assess the anaerobic capacity of the participants. The 150m shuttle test also known as the 5m multiple shuttle test has been found to be a valid and reliable measure of anaerobic fitness (Boddington et al., 2001, 2004). Six lines (labelled
1 to 6) were placed at 5m intervals. Participants were each assigned a lane and an evaluator. Participants were required to sprint from the start line (line 1) to line 2 and back to the start line, then to line 3, back to the start line, and so on. Participants were instructed to sprint as far as they could in this fashion for 30s. A whistle signalled the start of each shuttle run, with six runs in total, each separated by 30s of recovery. During the recovery the participants were required to make their way back to the start line in order to be ready for the next run. Total sprint distance for each 30s sprint was recorded to the nearest 5m and the distance of the six sprints were summed together to provide a final score. The score on each run was recorded as the last cone that the participant passed. If participants did not sprint all the way to the cones they were given a warning. If a player received three warnings they were docked 5m from their score.

20 MST.

The test procedures that were carried out were in accordance with Ramsbottom et al. (1988) using sounds from a compact disc (C.D.)(20-m Shuttle Run test CD, Australian Sports Commission). The 20 MST was carried out following a 30 minute break after completion of the 150m shuttle testing procedure. Participants were instructed to perform their own warm up lasting 5-10 minutes including jogging, dynamic stretching and change of direction drills. Two lines 20m apart were marked on an indoor surface with cones. When the C.D. started the participants were required to run back and forth between the two lines in time with a beep from the C.D. The participants were required to cross the line each time the beep sounded not before or after. Each time the participant crossed the line in time with the beep this was recorded as an shuttle completed. As the C.D. progressed the beeps get progressively closer together requiring a faster speed of running. If a participant failed to cross the line in time with the beep they received a warning and if a participant received two warnings in a row their testing was terminated. Testing was also terminated when the participants could no longer keep up with pace and voluntarily drop out. Participants completed the test in groups of 10-12 participants depending on the number of players present for testing. The number of completed shuttles was recorded. The number of shuttles completed is given in the format 10:1 where 10 represents the level and 1 represents the number of shuttles completed at this level. All levels do not contain the same number of shuttles therefore for analysis purposes all scores were converted to estimated VO₂max using the accompanying conversion tables (Australian Sports Commission).
3. 4. Data Analysis

Data analysis was carried out on SPSS version 16.0. All data were analysed to assess for normality using a Shapiro Wilks test in addition to analysing the distribution of the histogram of the data set. For normally distributed data sets in the test retest analysis (i.e. when examining the changes in the senior elite squad from Time 1 to Time 2) a paired sample t-test was used. For non-normally distributed data sets a Wilcoxon signed rank test was used. To analyse between subject group differences i.e. examining the relationship between senior elite, senior sub-elite and junior elite squads, variances between data sets were analysed to ensure equality of variance. If data sets were normally distributed and equal variances an independent sample t test was used. For non-normally distributed data sets or data sets with unequal variances a Mann- Whitney U-test was used. Further information on statistical methods and analysis are contained in Chapter 4.
Chapter 4. Results
4. 1. Introduction

Participants (N=95) from three different levels of performance senior elite (senior inter county) \((n_1=34)\), senior sub-elite (senior club) \((n_2=28)\) & junior elite (minor inter county) \((n_3=33)\) from the sport of hurling were recruited for the current study. Table 4.1 outlines the subject information of each respective squad.

Table 4.1 Subject Information of Senior Elite, Senior Sub-Elite & Junior Elite

<table>
<thead>
<tr>
<th>Squad</th>
<th>n</th>
<th>Age (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senior Elite</td>
<td>34</td>
<td>24.9 ± (2.5)</td>
</tr>
<tr>
<td>Senior Sub- Elite</td>
<td>28</td>
<td>26.9 ± (4.4)</td>
</tr>
<tr>
<td>Junior Elite</td>
<td>33</td>
<td>17.2 ± (0.3)</td>
</tr>
</tbody>
</table>

4. 2. Physical Performance Indicators - Senior Elite at Pre-Competition Phase

Table 4.2 contains the 13 measures (5 anthropometric and 8 physical performance indicators) at the pre-competition phase of season in the Senior Elite squad. The Shapiro Wilks test was utilised to determine normality of the measures with the result that 11/13 were deemed normal – the exceptions were the 10m speed and 150 shuttle run test
Table 4.2 Physical Performance Indicators Senior Elite at Pre-Competition Phase

<table>
<thead>
<tr>
<th>Test</th>
<th>(Units)</th>
<th>Mean ± (S.D.)</th>
<th>Median ± (S.D.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HT</td>
<td>(m)</td>
<td>1.83 ± (.04)</td>
<td>1.83 ± (.04)</td>
</tr>
<tr>
<td>BM</td>
<td>(kg)</td>
<td>85.3 ± (6.7)</td>
<td>85.2 ± (6.7)</td>
</tr>
<tr>
<td>LTM</td>
<td>(kg)</td>
<td>68.21 ± (4.91)</td>
<td>67.00 ± (4.91)</td>
</tr>
<tr>
<td>%BF</td>
<td>(%)</td>
<td>16.66 ± (3.24)</td>
<td>15.90 ± (3.24)</td>
</tr>
<tr>
<td>BMI</td>
<td>(kg/m²)</td>
<td>25.4 ± (1.5 )</td>
<td>25.3 ± (1.5 )</td>
</tr>
<tr>
<td>SBJ</td>
<td>(m)</td>
<td>2.28 ± (.14)</td>
<td>2.30 ± (.14)</td>
</tr>
<tr>
<td>TB</td>
<td>(m)</td>
<td>7.56 ± (.41)</td>
<td>7.68± (.41)</td>
</tr>
<tr>
<td>CMJ</td>
<td>(cm)</td>
<td>35.61 ± (3.77)</td>
<td>36.4 ± (3.77)</td>
</tr>
<tr>
<td>KMBT</td>
<td>(m)</td>
<td>6.56 ± (.41)</td>
<td>6.58 ± (.41)</td>
</tr>
<tr>
<td>10M</td>
<td>(s)</td>
<td>1.73 ± (.06)</td>
<td>1.72 ± (.06)*</td>
</tr>
<tr>
<td>PU</td>
<td>(reps)</td>
<td>51.3 ± (13.3)</td>
<td>49 ± (13.3)</td>
</tr>
<tr>
<td>150m</td>
<td>(m)</td>
<td>715 ± (29)</td>
<td>712 ± (29)*</td>
</tr>
<tr>
<td>20MST</td>
<td>(ml/kg/min)</td>
<td>56.5± (3.2)</td>
<td>56.6± (2.9)</td>
</tr>
</tbody>
</table>

*denotes non-normally distributed data as determined as determined via Shapiro wilks p≤0.05

4.3. Physical Performance Indicators – Senior Sub-Elite at Pre-Competition Phase

Table 4.3 contains the 11 measures (3 anthropometric measures and 8 physical performance indicators) at the pre-competition phase of season in the Senior Sub-Elite squad. The Shapiro Wilks test was utilised to determine normality of the measures with the result that all of the 11 were deemed normally distributed.
Table 4.3 Physical Performance Indicators Senior Sub-Elite at Pre-Competition Phase

<table>
<thead>
<tr>
<th>Test</th>
<th>(Units)</th>
<th>Mean ±(S.D.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HT</td>
<td>(m)</td>
<td>1.79 ± (.04)</td>
</tr>
<tr>
<td>BM</td>
<td>(kg)</td>
<td>82.9 ± (8.9)</td>
</tr>
<tr>
<td>BMI</td>
<td>(kg/m²)</td>
<td>25.6 ± (2)</td>
</tr>
<tr>
<td>SBJ</td>
<td>(m)</td>
<td>2.1 ± (.15)</td>
</tr>
<tr>
<td>TB</td>
<td>(m)</td>
<td>35.17 ± (4.51)</td>
</tr>
<tr>
<td>CMJ</td>
<td>(cm)</td>
<td>6.96 ± (.51)</td>
</tr>
<tr>
<td>KMBT</td>
<td>(m)</td>
<td>6.44 ± (.74)</td>
</tr>
<tr>
<td>10M</td>
<td>(s)</td>
<td>1.80 ± (.065)</td>
</tr>
<tr>
<td>PU</td>
<td>(reps)</td>
<td>39.6 ± (11.1)</td>
</tr>
<tr>
<td>150m</td>
<td>(m)</td>
<td>691 ± (27)</td>
</tr>
<tr>
<td>20MST</td>
<td>(ml/kg/min)</td>
<td>51.2 ± (3.9)</td>
</tr>
</tbody>
</table>

4. 4. Physical Performance Indicators – Junior Elite at Pre-Competition phase

Table 4.4 contains the 11 measures (physical performance indicators) at the pre-competition phase of season in the J.E. squad. The Shapiro Wilks test was utilised to determine normality of the measures with the outcome that 9/11 were deemed normal - the exceptions being 10m sprint and the 150m shuttle run test.
Table 4.4 Physical Performance Indicators Junior Elite at Pre-Competition Phase

<table>
<thead>
<tr>
<th>Test</th>
<th>(Units)</th>
<th>Mean ±(S.D.)</th>
<th>Median±(S.D.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HT</td>
<td>(m)</td>
<td>1.78 ±(.06)</td>
<td>1.78 ±(.06)</td>
</tr>
<tr>
<td>BM</td>
<td>(kg)</td>
<td>78.8 ±(10.5)</td>
<td>79.4 ±(10.5)</td>
</tr>
<tr>
<td>BMI</td>
<td>(kg/m²)</td>
<td>24.6 ±(2.6)</td>
<td>23.9 ±(2.6)</td>
</tr>
<tr>
<td>SBJ</td>
<td>(m)</td>
<td>2.02 ±(.13)</td>
<td>2.01 ±(.13)</td>
</tr>
<tr>
<td>TB</td>
<td>(m)</td>
<td>34.44 ±(4.76)</td>
<td>7.05 ±(3.8)</td>
</tr>
<tr>
<td>CMJ</td>
<td>(cm)</td>
<td>7.06 ±(3.8)</td>
<td>34.00 ±(4.76)</td>
</tr>
<tr>
<td>KMBT</td>
<td>(m)</td>
<td>5.22 ±(4.9)</td>
<td>5.29 ±(4.9)</td>
</tr>
<tr>
<td>10M</td>
<td>(s)</td>
<td>1.81 ±(.06)</td>
<td>1.79 ±(.06) *</td>
</tr>
<tr>
<td>PU</td>
<td>(reps)</td>
<td>50.1 ±(11.2)</td>
<td>49.8 ±(11.2)</td>
</tr>
<tr>
<td>150m</td>
<td>(m)</td>
<td>726 ±(36)</td>
<td>732 ±(36) *</td>
</tr>
<tr>
<td>20MST</td>
<td>(ml/kg/min)</td>
<td>55.1 ±(2.8)</td>
<td>54.0 ±(2.8)</td>
</tr>
</tbody>
</table>

*denotes non- normally distributed data as determined as determined via Shapiro wilks p≤0.05

4.5. Differences in Physical Performance Indicators Between Squads at Pre-Competition Phase of the Season

The Shapiro Wilks test was utilised to determine normality of the measures with a significance level set at p≤0.05. All pairs of data sets were also analysed using Levenes test to ensure equal variances between the data sets. Between-group differences were analysed using Independent sample t-tests in cases where data sets were normally distributed and pairs had equal variances, while Mann Whitney U-tests were conducted on non-normal data or data sets that had unequal variances as assessed using Levene’s test, with a significance level set at p≤ 0.05.
4. 5. 1. Senior Elite vs. Senior Sub-Elite at pre-competition

Table 4.5. Illustrates the physical performance indicators of the senior elite and senior sub-elite squads at the pre-competitive phase of the season. Three of the twelve measures (TB, 10m & 150m) were analysed non-parametrically via the use of the Mann Whitney U-Test. All nine other measures were analysed via the use of an independent sample t-test. Eight of the twelve measures (67%) demonstrated significant differences between the Senior Elite and Senior Sub-elite squads. Senior elite players were heavier than senior sub-elite players but were of similar height and BMI. Four of the six measures (66%) of speed and power (10m sprint, 30m sprint, standing broad jump and triple jump) were superior in the senior elite squad compared to the senior sub-elite squad. All three measures of endurance performance (pushup test, anaerobic endurance as assessed via 150m shuttle running and aerobic endurance as assessed via estimated VO2max) were superior in the elite squad compared to the sub-elite squad.
<table>
<thead>
<tr>
<th>Test</th>
<th>Senior Elite</th>
<th></th>
<th>Senior Sub- Elite</th>
<th></th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± (S.D.)</td>
<td>Median ± (S.D.)</td>
<td>Mean ± (S.D.)</td>
<td>Median ± (S.D.)</td>
<td>(p≤0.5)</td>
</tr>
<tr>
<td>HT (m)</td>
<td>1.83 ± (.04)</td>
<td>1.83 ± (.04)</td>
<td>1.79 ± (.04)</td>
<td>1.79 ± (.04)</td>
<td>.084</td>
</tr>
<tr>
<td>BM (kg)</td>
<td>85.3 ± (6.7)</td>
<td>85.2 ± (6.7)</td>
<td>82.9 ± (8.9)</td>
<td>83.4 ± (8.9)</td>
<td>.009 †</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>25.4 ± (1.5)</td>
<td>25.3 ± (1.5)</td>
<td>25.6 ± (2)</td>
<td>25.6 ± (2)</td>
<td>.895</td>
</tr>
<tr>
<td>SBJ (m)</td>
<td>2.28 ± (.14)</td>
<td>2.30 ± (.14)</td>
<td>2.1 ± (.15)</td>
<td>2.09 ± (.15)</td>
<td>.003 †</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>35.61 ± (3.77)</td>
<td>36.4 ± (3.77)</td>
<td>35.17 ± (4.51)</td>
<td>35.2 ± (4.51)</td>
<td>.654</td>
</tr>
<tr>
<td>TB (m)</td>
<td>7.56 ± (.41)#</td>
<td>7.68 ± (.41)#</td>
<td>6.96 ± (.51)#</td>
<td>6.87 ± (.51)#</td>
<td>.000 †</td>
</tr>
<tr>
<td>MB (m)</td>
<td>6.56 ± (.41)</td>
<td>6.58 ± (.41)</td>
<td>6.44 ± (.74)</td>
<td>6.40 ± (.74)</td>
<td>.234</td>
</tr>
<tr>
<td>10m (s)</td>
<td>1.73 ± (.06) *</td>
<td>1.72 ± (.06)*</td>
<td>1.80 ± (.065)</td>
<td>1.81 ± (.065)</td>
<td>.000 †</td>
</tr>
<tr>
<td>30m (s)</td>
<td>4.23 ± (.11)</td>
<td>4.23 ± (.11)</td>
<td>4.28 ± (.11)</td>
<td>4.29 ± (.11)</td>
<td>.000 †</td>
</tr>
<tr>
<td>PU (reps)</td>
<td>51.3 ± (13.3)</td>
<td>49 ± (13.3)</td>
<td>39.6 ± (11.1)</td>
<td>40.5 ± (11.1)</td>
<td>.000 †</td>
</tr>
<tr>
<td>150m (m)</td>
<td>715±(29)**#</td>
<td>712 ± (29)**#</td>
<td>691 ± (27)**#</td>
<td>692 ± (27)**#</td>
<td>.000 †</td>
</tr>
<tr>
<td>20MST (ml/kg/min)</td>
<td>56.5 ± (3.2)</td>
<td>56.6 ± (29)</td>
<td>51.2 ± (3.9)</td>
<td>51.1 ± (3.9)</td>
<td>.000 †</td>
</tr>
</tbody>
</table>

† Significantly different between senior elite and senior sub elite p≤ 0.05
* Denotes non- normally distributed data as determined via Shapiro wilks p≤0.05
# Denotes data sets of unequal variance as determined via Levene’s test p≤0.05

### 4. 5. 2. Senior Elite vs. Junior Elite at Pre-Competition Phase

Table 4.6 presents the physical performance indicators of the senior elite and junior elite squads. Only two of the eleven measures (10m & 150m) were analysed non parametrically via the use of the Mann Whitney U-Test. All eight remaining measures were analysed via...
the use of an independent sample t-test. Six of the eleven measures (55%) reported significant differences between senior elite and junior elite players. Senior elite players were heavier and taller than junior elite players but there were no significant differences in B.M.I.

Four of the five measures (80%) of speed and power demonstrated significant differences, with the countermovement vertical jump (CMJ) the only exception. In contrast, there were no significant differences in any of the three measures of endurance (Push Ups, 150’s Shuttle Runs and the 20MST).

Table 4.6 Senior Elite vs. Junior Elite at Pre-Competition Phase

<table>
<thead>
<tr>
<th>Test</th>
<th>Senior Elite</th>
<th>Junior Elite</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Unit)</td>
<td>Mean ± (S.D.)</td>
<td>Median± (S.D.)</td>
<td>Mean ± (S.D.)</td>
</tr>
<tr>
<td>HT (m)</td>
<td>1.83 ± (.04)</td>
<td>1.83 ± (.04)</td>
<td>1.78 ± (.06)</td>
</tr>
<tr>
<td>BM (kg)</td>
<td>85.3 ± (6.7) #</td>
<td>85.2 ± (6.7)#</td>
<td>78.8 ± (10.5)#</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>25.4 ± (1.5)</td>
<td>25.3 ± (1.5)</td>
<td>24.6 ± (2.6)</td>
</tr>
<tr>
<td>SBJ (m)</td>
<td>2.28± (.14)</td>
<td>2.30 ± (.14)</td>
<td>2.02 ± (.13)</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>35.61± (3.77)</td>
<td>36.4 ± (3.77)</td>
<td>34.44± (4.76)</td>
</tr>
<tr>
<td>TB (m)</td>
<td>7.56 ± (.41)</td>
<td>7.68± (.41)</td>
<td>7.06 ± (.38)</td>
</tr>
<tr>
<td>MB (m)</td>
<td>6.56 ± (.41)</td>
<td>6.58± (.41)</td>
<td>5.22 ± (.49)</td>
</tr>
<tr>
<td>10m (s)</td>
<td>1.73 ± (.06) *#</td>
<td>1.72 ± (.06)*#</td>
<td>1.81 ± (.06)*#</td>
</tr>
<tr>
<td>PU (reps)</td>
<td>51.3± (13.3)</td>
<td>49 ± (13.3)</td>
<td>50.1 ± (11.2)</td>
</tr>
<tr>
<td>150m (m)</td>
<td>715± (29)*#</td>
<td>712 ± (29)*#</td>
<td>726 ± (36)*#</td>
</tr>
<tr>
<td>20MST (ml/kg/min)</td>
<td>56.5± (3.2)</td>
<td>56.6± (29)</td>
<td>55.1 ± (2.8)</td>
</tr>
</tbody>
</table>

† Significantly different between senior elite and junior elite p≤ 0.05
*Denotes non- normally distributed data as determined via Shapiro wilks p≤0.05
# Denotes data sets of unequal variance as determined via Levene's test p≤0.05
4.6. Seasonal Change in Physical Performance Indicators from Preseason to Pre Competition

The Shapiro Wilks test was utilised to determine normality of the physical performance indicators with a significance level set at $p \leq 0.05$. Seasonal changes were analysed using paired sample t-tests in cases where data were normally distributed, while Wilcoxon signed rank-tests were conducted on non-normally distributed data sets with a significance level set at $p \leq 0.05$.

4.6.1. Seasonal Change: Senior Elite Squad

Table 4.7 illustrates the change in physical performance indicators of the senior elite squad from pre-season to the pre-competition phase of the season (10 weeks). A Wilcoxon signed ranked test was used to analyse two of the thirteen measures (10m & 150m). The remaining eleven measures were analysed via the use of a paired sample t-test. Seven of the thirteen measures (54%) demonstrated significant change from the pre-season training phase to the pre-competition phase of the season. There was a significant increase in lean tissue mass and a significant decrease in %BF. Only 1/4 of the power measures demonstrated a significant increase (Triple Bound - TB) while both measures of speed (10m and 30m) demonstrated significant improvements. Both aerobic and anaerobic endurance performance increased significantly across the intervention period.
### Table 4.7 Seasonal Change: Senior Elite Squad

<table>
<thead>
<tr>
<th>Test</th>
<th>Senior Elite Pre Season</th>
<th>Senior Elite Pre Competition</th>
<th>Sig (p ≤ 0.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(Unit)</strong></td>
<td>Mean ± (S.D.)</td>
<td>Median± (S.D.)</td>
<td>Mean ± (S.D.)</td>
</tr>
<tr>
<td>BM (kg)</td>
<td>85.4 ± (6.6)*</td>
<td>84.5 ± (6.6)*</td>
<td>85.3 ± (6.7)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>25.5 ± (1.6)</td>
<td>25.3 ± (1.6)</td>
<td>25.4 ± (1.5)</td>
</tr>
<tr>
<td>LTM (kg)</td>
<td>66.35 ± (4.94)</td>
<td>66.25 ± (4.94)</td>
<td>68.21± (4.91)</td>
</tr>
<tr>
<td>% BF (%)</td>
<td>17.93 ± (3.71)</td>
<td>17.10 ± (3.71)</td>
<td>16.66 (3.24)</td>
</tr>
<tr>
<td>SBJ (m)</td>
<td>2.25 ± (.15)</td>
<td>2.27 ± (.15)</td>
<td>2.28 ± (.14)</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>35.54 ± (3.97)</td>
<td>36.00 ± (3.97)</td>
<td>35.61± (3.77)</td>
</tr>
<tr>
<td>TB (m)</td>
<td>7.34 ± (.39)</td>
<td>7.36 ± (.39)</td>
<td>7.56 ± (41)</td>
</tr>
<tr>
<td>MB (m)</td>
<td>6.78 ± (.39)</td>
<td>6.76 ± (.39)</td>
<td>6.56 ± (41)</td>
</tr>
<tr>
<td>10m (s)</td>
<td>1.75 ± (.04)</td>
<td>1.74 ± (.04)</td>
<td>1.73 ± (.06)*</td>
</tr>
<tr>
<td>30m (s)</td>
<td>4.26 ± (.11)</td>
<td>4.26 ± (.11)</td>
<td>4.23 ± (.11)</td>
</tr>
<tr>
<td>PU (reps)</td>
<td>48.5 ± (9.0)</td>
<td>49 ± (9.0)</td>
<td>51.3± (13.3)</td>
</tr>
<tr>
<td>150m (m)</td>
<td>703 ± (22)</td>
<td>700 ± (22)</td>
<td>715± (29)*</td>
</tr>
<tr>
<td>20MST (ml/kg/min)</td>
<td>53.5 ± (2.6)</td>
<td>53.4 ± (2.6)</td>
<td>56.5 ± (3.2)</td>
</tr>
</tbody>
</table>

†Significantly different between pre-season and pre-competition p ≤ 0.05

*Denotes non-normally distributed data as determined via Shapiro Wilks p ≤ 0.05
4. 6. 2. Seasonal Change: Senior Sub-Elite Squad

Table 4.8 contains the analysis of the change in physical performance indicators of the senior sub-elite squad from beginning of the pre-season to the pre-competitive phase of the season (10 weeks). Only one of the eleven measures (BM) was analysed non-parametrically via the use of a Wilcoxon signed ranked test. All ten other measures were analysed via the use of a paired sample t-test. Six of the eleven measures (55%) reported significant changes from beginning of pre-season to the pre-competition phase of the season. Upper extremity power increased significantly from the beginning of pre-season to the pre-competition phase of the season. None of the three measures of lower body power increased but 10m and 30m sprint performance increased significantly from the beginning of pre-season to the pre-competition phase of the season. All three measures of endurance (Push Ups, 150’s Shuttle Runs and the 20MST) increased significantly across the season.
### Table 4.8 Seasonal Change: Senior Sub-Elite Squad

<table>
<thead>
<tr>
<th>Test (Unit)</th>
<th>Senior Sub</th>
<th>Elite Pre Season</th>
<th>Senior Sub Elite Pre Competition</th>
<th>Sig (p≤0.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BM (kg)</td>
<td>82.9 ± (9.5) *</td>
<td>82.6 ± (9.5) *</td>
<td>82.9 ± (8.9)</td>
<td>.855</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>25.6 ± (2)</td>
<td>25.7 ± (2)</td>
<td>25.6 ± (2)</td>
<td>.864</td>
</tr>
<tr>
<td>SBJ (m)</td>
<td>2.10 ± (.16)</td>
<td>2.11 ± (.16)</td>
<td>2.1 ± (.15)</td>
<td>.898</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>35.43 ± (4.8)</td>
<td>34.55 ± (4.8)</td>
<td>35.17 ± (4.51)</td>
<td>.542</td>
</tr>
<tr>
<td>TB (m)</td>
<td>6.92 ± (.48)</td>
<td>6.90 ± (.48)</td>
<td>6.96 ± (.51)</td>
<td>.492</td>
</tr>
<tr>
<td>MB (m)</td>
<td>6.09 ± (.78)</td>
<td>6.02 ± (.78)</td>
<td>6.44 ± (.74)</td>
<td>.000 †</td>
</tr>
<tr>
<td>10m (s)</td>
<td>1.82 ± (.04)</td>
<td>1.84 ± (.04)</td>
<td>1.80 ± (.065)</td>
<td>.013 †</td>
</tr>
<tr>
<td>30m (s)</td>
<td>4.33 ± (.13)</td>
<td>4.35 ± (.13)</td>
<td>4.28 ± (.11)</td>
<td>.025 †</td>
</tr>
<tr>
<td>PU (reps)</td>
<td>32.7 ± (12.5)</td>
<td>30.5 ± (12.5)</td>
<td>39.6 ± (11.1)</td>
<td>.000 †</td>
</tr>
<tr>
<td>150m (m)</td>
<td>669 ± (29)</td>
<td>670 ± (29)</td>
<td>691 ± (27)</td>
<td>.000 †</td>
</tr>
<tr>
<td>20MST (ml/kg/min)</td>
<td>47.7 ± (3.9)</td>
<td>47.1 ± (3.9)</td>
<td>51.2 ± (3.9)</td>
<td>.000 †</td>
</tr>
</tbody>
</table>

†Significantly different between pre-season and pre-competition p≤ 0.05

* Denotes non-normally distributed data as determined via Shapiro Wilks p≤0.05

### 4.6.3. Seasonal change: Junior Elite Squad

Table 4.9 illustrates the analysis of the variation in physical performance indicators of the junior elite squad from the beginning of pre-season training to the period pre-competition (10 weeks). Three of the measures (TB, 10M & 150m) were analysed non parametrically via
the use of a Wilcoxon signed ranked test. All remaining measures were analysed via a paired sample t-test. There was a significant change in 8 of the 10 measures (80%) across this 10 week training period. There was a significant increase in body mass and a resulting significant increase in B.M.I. from beginning of pre-season to the pre-competitive phase of the season. There was a significant increase in all 4 power measures. Sprinting speed did not significantly improve. All three measures (100%) of endurance performance (Push Ups, 150’s Shuttle Runs and the 20MST) increased significantly.

Table 4.9 Seasonal Change: Junior Elite Squad

<table>
<thead>
<tr>
<th>Test (Unit)</th>
<th>Junior Elite Pre Season</th>
<th>Junior Elite Pre Competition</th>
<th>Sig (p≤0.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HT (m)</td>
<td>75.4 ± (9.2)</td>
<td>76.8 ± (9.2)</td>
<td>78.8 ± (10.5)</td>
</tr>
<tr>
<td>BM (kg)</td>
<td>23.6 ± (2.4)</td>
<td>23.1 ± (2.4)</td>
<td>24.6 ± (2.6)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>1.97 ± (.16)</td>
<td>1.97 ± (.16)</td>
<td>2.02 ± (.13)</td>
</tr>
<tr>
<td>SBJ (m)</td>
<td>32.9 ± (4.0)</td>
<td>32.9 ± (4.0)</td>
<td>34.44 ± (4.76)</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>6.93 ± (.56)*</td>
<td>7.07 ± (.56)*</td>
<td>7.06 ± (.38)</td>
</tr>
<tr>
<td>TB (m)</td>
<td>5.03 ± (.55)</td>
<td>4.92 ± (.55)</td>
<td>5.22 ± (.49)</td>
</tr>
<tr>
<td>MB (m)</td>
<td>1.83 ± (.06)</td>
<td>1.79 ± (.06)</td>
<td>1.81 ± (.06) *</td>
</tr>
<tr>
<td>10m (s)</td>
<td>43.5 ± (8.1)</td>
<td>42.5 ± (8.1)</td>
<td>50.1 ± (11.2)</td>
</tr>
<tr>
<td>PU (reps)</td>
<td>703 ± (20)</td>
<td>705 ± (20)</td>
<td>726 ± (36) *</td>
</tr>
<tr>
<td>150m (m)</td>
<td>52.2 ± (3.5)</td>
<td>51.9 ± (3.5)</td>
<td>55.1 ± (2.8)</td>
</tr>
<tr>
<td>20MST (ml/kg/min)</td>
<td>75.4 ± (9.2)</td>
<td>76.8 ± (9.2)</td>
<td>78.8 ± (10.5)</td>
</tr>
</tbody>
</table>

†Significantly different between pre-season and pre-competition p≤ 0.05
* Denotes non-normally distributed data as determined via Shapiro Wilks p≤0.05
Chapter 5. Discussion.
5.1. Introduction

The aims of the current study were to:

1. Examine the physical performance indicators of the modern day hurling athlete at senior elite, senior sub elite and junior elite level.
2. Explore the relationship between the level of participation (senior elite versus senior sub-elite) & (senior elite versus junior elite) and selected physical performance indicators
3. Investigate the seasonal change in performance indicators from the beginning of pre-season to the pre-competition phase of the season.

5.2. Physical Performance Indicators: Senior Elite

Senior elite level hurling athletes are taller (M= 1.83m, SD =.04) and heavier (M=85.3kg, SD = 6.7) than previously reported range of values for inter county hurling athletes (Collins et al., 2007; Doran, Donnelly & Reilly, 2003; McIntyre, 2005). The results presented also illustrate that the sampled squad of senior inter county hurling athletes are similar in height and weight to reported values for outfield English premiership soccer players (M=1.82m, SD= 0.07) and (M=83.2kg, SD=7.5) (Sutton, Scott, Wallace & Reilly, 2009), which is not surprising as these are two sports that are heavily reliant on technical skills for successful performance. In contrast to this professional rugby union players from New Zealand are taller (M= 1.86m, SD=0.06) and heavier (M=102.3kg, SD=10.3) (Argus et al., 2009) than the current squad of elite hurling athletes due to the nature of the game of rugby where additional height and weight are perceived to be an advantage as physical contact is so prevalent.

Body composition scores (LTM and FTM) measured by DXA, demonstrate that selected inter county hurling athletes have higher values of % BF than the Tier 1 senior inter county hurling athletes from the work of Collins et al. (2007). However, caution must be expressed when comparing such results as the latter study utilised skin fold measurements to estimate %body fat which has a tendency to under estimate % body fat (Ball, Alten & Swan, 2004). The % body fat levels (M=16.66 %, SD = 3.24) are higher than values reported for premiership soccer players measured using DXA (M=10.07 %, SD =2.24)
(Company & Ball, 2010). The large differences present in % body fat are unsurprising considering the professional full time training status and the professional support structure of the premiership soccer players in comparison to the amateur status of the inter county hurling athlete.

The senior inter county hurling athletes also demonstrated superior 10m sprint performance ($M=1.73$ sec’s, $SD = .06$) and 30m sprint performance ($M= 4.23$ sec’s, $SD = .11$) compared to the range of values from the previous research on senior inter county hurling athletes ($10m = 1.75$- $1.78$ sec’s) (Collins et al., 2007, Doran, Donnelly & Reilly, 2003) and ($30m = 4.43$ sec’s, $SD = 0.17$) (Doran, Donnelly and Reilly, 2003). The 10m sprint time of the sampled senior inter county hurling athletes is similar to reported values for English premiership footballers ($M=1.73$ sec’s, $SD =0.08$) (Dunbar & Treasure, 2005) and slower than Australian Rules football players ($M=1.70$ sec’s, $SD =0.2$) (Young et al., 2008).

Given the superior levels of sprinting speed of the senior elite squad in the current study in comparison to athletes reported in the wider literature from a similar level of performance, it is surprising that their lower extremity power measures are inferior. Countermovement jump performance ($M=35.61$ cm, $SD=3.77$) was lower than values reported by Collins & colleagues (2007) for two different Tier 1 inter county hurling squads ($M=47.14$ cm, $SD=3.24 & M=47.29$ cm, $SD= 6.29$ respectively). The current research evaluated CMJ performance via the use of the Optojump © whereas Collins & colleagues (2007) utilised a contact mat from Newtest©. However recent research has shown that the Optojump system © can be used interchangeably with a contact mat system (Bosquet, Berryman & Dupuy, 2011) similar to the one used by Collins & colleagues (2007). The standing broad jump performance of the current senior elite squad ($M= 2.28$ m, $SD= .14$) was inferior to measures previously reported for two different senior inter county hurling squads ($M=2.47$ m, $SD= 0.15 & M= 2.54$m, $SD=0.2$) (Collins et al., 2007). Such differences in countermovement jump (~12cm) and broad jump performance (~20cm) are surprising considering the advances that have been made in the physical preparation of senior inter county hurling athletes in the last number of years.

The local muscular endurance performance as determined via push up test ($M=51.3$ reps, $SD =13.3$) and anaerobic endurance performance as determined via 150m test ($M=715$ m, $SD =29$) of the current Tier 1 senior inter county hurling athletes exceeds the
performances previously reported for Tier 2 senior inter county hurling athletes (M=42.8 reps, SD =10) and (M=667 m, SD= 44) (McIntyre, 2005). The differences here can be attributed to the difference in level of performance of the two squads. The squad analysed by McIntyre (2005) participated in the Tier 2 hurling competition and as a result the support structures and training afforded to them may be at an inferior level.

The aerobic endurance performance of the senior inter county athletes (M=56.5 ml/kg/min, SD =3.2),as measured via the 20MST,correlates with the range of values reported in the existing research on Tier 1 inter county hurling athletes(M=55.59 ml/kg/min, SD =2.61) - 58.04 ± (2.64) ml/kg/min)from Collins et al., (2007). The findings of the current study illustrate that the aerobic endurance levels of the modern day senior inter county hurling athlete are similar to values reported for Tier 1 inter county Gaelic football squads (M=57.0 ml/kg/min, SD=3.9) (Brick &O'Donoghue 2005) and (M=57.1 ml/kg/min, SD= 4.6 ) (Young & Murphy, 1994) but lower than reported values for English first division soccer players (M=62.6 ml/kg/min, SD= 3.8) (Mercer et al., 2003) and Australian Rules football players (M=61.6 ml/kg/min, SD= 3.5) (Pyne et al., 2005)

The differences between selected physical performance indicators of the modern day inter county hurler and the data from hurlers from the existing research can be explained by a consistently developing level of professionalism with regard to the sports science support structures which help to create conditions for an increase in performance in more recent years. Although the lower extremity power levels of the current cohort are inferior to the existing research the current cohort of players had not transitioned into the stage of the season where power would have been the focus of the conditioning programme. The modern day hurler demonstrates greater levels of selected physical performance indicators than their counterparts from several years ago but yet they still lag behind professional soccer, rugby union, rugby league and Australian Rules football teams. These differences can be attributed to the full time training status of both of these other sports and the professional structures and support systems which they operate within.
5.3. Physical Performance Indicators: Senior Sub-Elite

The extensive review of the literature, as presented in Chapter 2, found only one previous research study that examined the physical performance indicators of players at a similar level of performance (i.e., senior club hurling athletes), with a relatively small cohort (N=14) therefore all comparisons made are quite limited. The sub-elite hurling athletes that participated in the current study are taller (M=1.79m, SD =.04 vs. M=1.77 m, SD =.05) and heavier (M=82.9 kg, SD =8.9 vs. M=73.8 kg, SD =8.2) than athletes of a similar level from the work of Donnelly, Doran and Reilly (2003). The current senior elite squad are also faster over 10m (M=1.80sec’s, SD=.06 vs. M=1.94sec’s, SD=0.12) and 30m (M=4.28sec’s, SD =.11 vs. M= 4.72 sec’s, SD =0.35) respectively. The aerobic performance of the senior elite squad (M=51.2 ml/kg/min, SD =3.9) as assessed by estimated 20MST, is inferior to that reported in the literature as estimated via an incremental treadmill test (M=53.8 ml/kg/min, SD =4.0). This difference in aerobic endurance performance can be explained by the different methodologies used as the 20MST has been shown to underestimate aerobic endurance performance by up to 4.5ml/kg/min compared to treadmill based running tests (Grant et al., 1995). Other existing differences in physical performance indicators maybe explained by the difference in the standard of the hurling squads selected. The current sub elite squad were from a Tier 1 county and the squad from the work of Donnelly, Doran & Reilly (2003) were from a Tier 2 county. The support structures and training environments provided to the Tier 2 club players would be inferior to the Tier 1 squad that was measured. Unfortunately there is no existing data on senior sub elite hurling athletes from which to compare the anaerobic performance, local muscular endurance, reactive strength or upper extremity power.

Interestingly, there is data published on similar measures from the related game of Gaelic football which allows for a worthwhile comparison due to increased subject numbers (n= 40) and sampling of sub elite athletes from a tier 1 population. The senior sub elite hurlers from the current research are taller (M=1.79 m, SD =.04 vs. M=1.75 m, SD =.06) and heavier (M=82.9 kg, SD =8.9 vs. M=76.5 kg, SD=6.7) compared to senior club Gaelic footballers (Keane, Reilly &Barrie, 1997). Leg power of senior sub elite hurlers as measured via standing broad jump (M=2.1 m, SD =.15) is inferior to the existing research on senior club Gaelic footballers (M=2.28m, SD =.10). The aerobic performance of the current senior elite hurling squad as assessed using estimated VO² max from the 20MST is similar
(M=51.2 ml/kg/min, SD=3.9 vs. M=51.4 ml/kg/min, SD=5.8) when compared to senior club Gaelic footballers. The findings suggest that the modern day senior club hurler is taller and heavier than Gaelic footballer of the same level which is surprising as in a review of “Science and the Gaelic games” by Reilly, (2001) it stated Gaelic footballers were taller and heavier to assist in physical contact during the tackle; whereas hurlers are more reliant on the skilful use of the hurl. The similarities in aerobic endurance performance between the two squads maybe as a result of a common weekly schedule (2 training session and 1 match) which is a widespread traditional format for preparing athletes at the sub elite level. These possible similarities may place a ceiling on the levels of aerobic endurance performance that can be attained on such schedules. The differences in lower extremity power between Gaelic footballers and hurlers have been previously attributed to the prevalence of overhead catching where Gaelic footballers are required to jump high in the air whereas hurlers rely on the skilful use of the camán in overhead contests for possession (McIntyre, 2005).

5.4. Physical Performance Indicators: Junior Elite

There is no reported literature that focuses on the physical performance indicators of junior elite hurling athletes. Comparisons between the physical performance indicators of the junior elite squad from the current study and existing research from age matched squads from different sports reveal some interesting similarities but also some differences. The junior elite hurling squad are of similar height (M=1.78 m, SD=0.06 vs. M=1.77 m, SD =0.06) but heavier (M=78.8 kg, SD =10.5 vs. M=70.6 kg, SD =8.1) than age matched elite professional soccer players from a Scottish premier league club (McMillan et al., 2005). The present squad are also faster over 10m timed sprints (Med=1.79sec’s, SD =0.06 vs. M=1.96 sec’s, SD =0.06) but have inferior leg power (M=34.44 cm, SD =4.76 vs. M=53.4 cm, SD =4.2 cm) as assessed via the use of CMJ when compared to this same age matched squad of soccer players. The superior levels of sprinting speed in the hurling athletes despite the substantially lower levels (~19cm) of CMJ are very surprising. As previously highlighted overhead contests for possession in the sport of hurling are competed for with the skilful use of the camán, this is in contrast to the sport of soccer where players compete for possession with the use of the head requiring high levels of vertical jump performance.
The junior elite hurling athletes are shorter (M=1.78 m, SD =0.06 vs. M=1.83 m, SD =0.06) and of similar mass (M=78.8 kg, SD =10.5 vs. M=79.8 kg, SD =8.3) in comparison to elite provincial junior under 18 Australian Rules players (Young & Pryor, 2007). These age matched Australian Rules football players possessed superior aerobic endurance (M=57.3 ml/kg/min, SD =3.5) than the present squad of junior elite hurlers (M=55.1 ml/kg/min, SD =2.8). Elite junior South African rugby union players examined by Durandt & colleagues (2003) are of similar height (M=1.79 m, SD =0.06 vs. M=1.77 m, SD =0.06) but heavier (M=84.9 kg, SD =8.3 vs. M=78.8 kg, SD =10.5) and slower over 10m sprints (M=1.9sec’s, SD =0.1 vs. Med= 1.79sec’s, SD =0.06) than the current squad of junior elite hurlers (Durandt et al., 2003). The larger mass of the rugby players is a requirement for the high impact collisions of the game and other demands of the game that additional body mass would be an advantage. The larger mass and the associated difficulties in overcoming the additional mass during sprinting activities in addition to the different demands of the games in particular the requirement for high levels of sprinting speed in all positions in the sport of hurling can explain the superior levels of sprinting speed present in the hurling athletes.

5.5. Senior Elite vs. Senior Sub Elite

The senior elite squad were taller than the senior sub elite squad (M=1.83 m, SD =0.04 vs. M=1.79 m, SD =0.04) however this difference failed to reach statistical significance as analysed via an independent sample t-test p≤.05 (two tailed). An independent sample t-test revealed a statistically significant difference in body mass at the pre-competition phase of the season in senior elite hurlers (M=85.3 kg, SD =6.7) compared to their senior sub-elite counterparts (M=82.9 kg, SD =8.9), p≤.05 (two tailed). Senior elite level athletes have also been found to be heavier than senior sub elite athletes in the sports of rugby league (Gabbett, 2002), rugby union (Argus, Gill & Keogh, 2012) and Gaelic Football (Keane et al., 1997). Elite players are heavier than sub elite players in field invasion sports due to the added advantage of the additional body mass (ideally LTM) in physical contact situations.

There was a significant difference in 4 of the 6 (66%) measures of upper and lower extremity power between the senior elite and senior sub elite squads as illustrated below in Table 5.1.
Table 5.1 Senior Elite vs. Senior Sub Elite Speed and Power Measures Pre Competition

<table>
<thead>
<tr>
<th>Test (Unit)</th>
<th>Senior Elite Pre Competition</th>
<th>Senior Sub Elite Pre Competition</th>
<th>Sig (p≤0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± (S.D.)</td>
<td>Median± (S.D.)</td>
<td>Mean ± (S.D.)</td>
</tr>
<tr>
<td>SBJ (m)</td>
<td>2.28± (.14)</td>
<td>2.30 ± (.14)</td>
<td>2.10 ± (.15)</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>35.61 ± (3.77)</td>
<td>36.4 ± (3.77)</td>
<td>35.17 ± (4.51)</td>
</tr>
<tr>
<td>TB (m)</td>
<td>7.56 ± (.41)#</td>
<td>7.68± (.41)#</td>
<td>6.96 ± (.51)#</td>
</tr>
<tr>
<td>MB (m)</td>
<td>6.56 ± (.41)</td>
<td>6.58 ± (.41)</td>
<td>6.44 ± (.74)</td>
</tr>
<tr>
<td>10m (s)</td>
<td>1.73 ± (.06)*</td>
<td>1.72± (.06)*</td>
<td>1.80 ± (.065)</td>
</tr>
<tr>
<td>30m (s)</td>
<td>4.23 ± (.11)</td>
<td>4.23 ± (.11)</td>
<td>4.28 ± (.11)</td>
</tr>
</tbody>
</table>

† Significantly different between senior elite and senior sub elite p≤ 0.05
*Denotes non- normally distributed data as determined via Shapiro wilks p≤0.05
# Denotes data sets of unequal variance as determined via Levene’s test p≤0.05

The standing broad jump performance of the senior elite team (M=2.28, SD =.14) was significantly higher than the senior sub-elite team (M= 2.1m, SD = .15) p≤.05 (two tailed). A Mann-Whitney U-test revealed significantly higher levels of triple bound performance in senior elite players in comparison to senior sub-elite hurlers (M=7.68 m, SD =.41 vs. M=6.87 m, SD =.51: p≤.05 two tailed). Lower extremity power measures have been shown to differentiate between elite and sub elite players in the sports of Gaelic Football (Keane et al., 1997), rugby league (Baker, 2002) and soccer (Ostojic, 2003), therefore it is surprising that an independent sample t-test revealed no statistically significant difference in CMJ between senior elite (M=35.61cm, SD =3.77) and senior sub-elite hurlers (M= 35.17cm, SD = 4.51), p≤.05 (two tailed). The lack of difference in CMJ between the two squads may suggest that lower extremity power required for performance in the sport of hurling may be movement plane specific. This suggestion is further enhanced by the differences present in both horizontal plane measures of lower extremity power (SBJ and TB). In many of the other field sports such as Gaelic Football, Australian Rules and soccer, aerial contests are reliant on vertical jumping ability for contesting possession, whereas in the sport of hurling...
the players are predominantly reliant on the skilful use of the camán when competing for overhead possession.

Senior elite players had significantly faster 10m sprint times (Med= 1.72 sec’s, SD = .06) than the senior sub elite players (Med =1.81 SD =.06 sec’s) p≤.05 (two tailed). Significant differences were also present in 30m sprint performance times between senior elite and senior sub-elite players (M=4.23sec’s, SD = .11 vs. M= 4.28 sec’s, SD =.11) as illustrated via an independent sample t-test p≤.05 (two tailed). This difference is consistent with the existing literature that has examined short distance sprinting ability and levels of playing performance in the other major field invasion sports (Commetti et al., 2001; Doran, Donnelly & Reilly, 2003; Kollath & Quade, 1993). The differences present in short distance sprinting performance have been attributed to the faster pace of sport at the elite level than the sub-elite level (Reilly, 2009).

A positive relationship between level of playing performance and levels of anaerobic endurance has been found previously in soccer players (Ostojic, 2003) and rugby union players (Argus, Gill & Keogh, 2012). This trend also occurs in the current study where a Mann Whitney U-Test revealed statistically significantly higher levels of anaerobic endurance in senior elite players (M=715m, SD =29) compared to senior sub-elite (M= 691m, SD = 27), p≤.05 (two tailed). The higher levels of training intensity, volumes and professionalism of the training support structures afforded to the elite level athletes leads to an increased level of anaerobic endurance in the elite athletes. Aerobic performance as assessed via 20MST illustrated significantly higher levels of aerobic endurance in senior elite (M=56.5 (ml/kg/min), SD =3.2) compared to senior sub-elite (M= 51.2ml/kg/min, SD = 3.9), p≤.05 (two tailed). There is a large body of literature that substantiates such findings between aerobic endurance and level of playing performance in soccer (Ostojic, 2003), rugby league (Gabbett, 2009), rugby union (Argus, Gill & Keogh, 2012) and Gaelic football (Keane et al., 1997).

The differences between senior elite and sub-elite athletes have been largely attributed to training-related differences such as higher training frequencies (Reilly et al., 2000), higher volumes (Gabbett, 2005), higher work rates in training sessions (Keane et al., 1997) and the greater level of support structures afforded to the elite athletes, including supervised strength and conditioning programmes. To optimise the chances of progressing from senior sub-elite level to senior elite level in the game of hurling, physical preparation
programmes should concentrate on developing lean body mass, lower body power in the horizontal plane, speed, anaerobic capacity and aerobic endurance.

5.6. Senior Elite vs. Junior Elite

There was a statistically significant difference in body mass between senior elite and junior elite hurlers ($M=85.3$ kg, $SD=6.7$ vs. $M=78.8$ kg, $SD=10.5$), $p\leq.05$ (two tailed). The senior elite squad were also significantly taller than the junior elite squad ($M=1.83$ m, $SD=.04$ vs. $M=1.78$ m, $SD=.06$). The differences present between the two squads can be attributed to the different maturation levels of the two squads as the senior elite squad ($M=24.9$ years, $SD=(2.5)$ were older than the junior elite squad ($M=17.2$ years, $SD=(0.3)$). The differences in age between the two squads may have resulted in further opportunities for the senior players to develop additional body mass through rigorous exercise and nutritional support. Differences in height and mass between senior elite and junior elite have also been found in a number of studies relating to other field invasion sports including the sports of rugby league (Gabbett, 2002) and rugby union (Argus, Gill & Keogh, 2012).

The senior elite squad achieved significantly higher scores in 4 of the 5 measures of speed and power as illustrated in the Table 5.2 below. These differences are consistent with much of the literature from a variety of other sports where the senior players possessed superior levels of upper and lower extremity power (Argus, Gill & Keogh, 2012; Baker, 2002; Gabbett, 2009). Interestingly, in the current study there was no difference in CMJ between the senior elite players and junior elite players. In addition there was no significant difference in CMJ between the senior elite players and senior sub elite players as illustrated in Section 5.3.1 This is in contrast to the existing research that has found senior elite players to possess superior CMJ abilities than junior elite players (Baker 2002 a, Gabbett, 2002b). These results suggest that a higher level of lower extremity power in the vertical plane is not a pre-requisite for performance at the elite level of hurling. A Mann Whitney U-Test revealed that senior elite players were significantly faster over 10m ($Med=1.72$ sec’s, $SD=.06$) compared to junior elite ($Med=1.79$ sec’s, $SD=.06$), $p\leq.05$ (two tailed). There was no 30m sprint testing performed on the junior elite squad due to difficulties experienced in operating the timing gates during both testing sessions (pre-season and pre-
competition) and as a result comparison on this physical performance indicator are not possible.

### Table 5.2 Senior Elite vs. Junior Elite Speed and Power Measures Pre Competition

<table>
<thead>
<tr>
<th>Test</th>
<th>Senior Elite Pre Competition</th>
<th>Junior Elite Pre Competition</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± (S.D.)</td>
<td>Median ± (S.D.)</td>
<td>Mean ± (S.D.)</td>
</tr>
<tr>
<td>SBJ (m)</td>
<td>2.28 ± (.14)</td>
<td>2.30 ± (.14)</td>
<td>2.02 ± (.13)</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>35.61 ± (3.77)</td>
<td>36.4 ± (3.77)</td>
<td>34.44 ± (4.76)</td>
</tr>
<tr>
<td>TB (m)</td>
<td>7.56 ± (.41)</td>
<td>7.68 ± (.41)</td>
<td>7.06 ± (.38)</td>
</tr>
<tr>
<td>MB (m)</td>
<td>6.56 ± (.41)</td>
<td>6.58 ± (.41)</td>
<td>5.22 ± (.49)</td>
</tr>
<tr>
<td>10m (s)</td>
<td>1.73 ± (.06) *#</td>
<td>1.72 ± (.06)*#</td>
<td>1.81 ± (.06)*#</td>
</tr>
</tbody>
</table>

† Significantly different between senior elite and junior elite p≤ 0.05
* Denotes non-normally distributed data as determined via Shapiro wilks p≤0.05
# Denotes data sets of unequal variance as determined via Levene's test p≤0.05

There was no sig. difference in local muscular endurance between the senior elite (M= 51.3 reps, SD= 13.3) and junior elite squads (M=50.1 SD= 11.2). Although there were differences present in anaerobic and aerobic endurance between the two squads these differences failed to reach statistical significance. The inability of measures of endurance to differentiate between senior elite and junior elite performance is in contrast to the existing literature that reports an increase in endurance scores as level of performance increases from junior elite to senior elite. Moreover, aerobic endurance performance as assessed by estimated VO2max from a 20MST has been found to have a positive relationship with level of playing performance in soccer (Ostojic, 2003), Australian Rules Football (Pyne et al, 2005) and rugby league (Gabbett, 2009). The inability of measures of endurance to differentiate between these senior elite and junior elite hurling athletes suggests that the endurance capacities of junior players have been developed to the level required to perform at senior elite levels of hurling, however the differences present in measures of speed and power clearly illustrate the lack of targeted development of these physical performance indicators. Although the junior elite squad were part of a structured strength and conditioning
programme this was the first year in which they were exposed to such an environment. To ensure an optimal hurling career progression from junior elite level to senior elite level, physical preparation programmes at the junior elite level should focus on developing all components of fitness with additional emphasis on the development of speed and power.

5. 7. Seasonal Change: Senior Elite

There was no significant change in body mass from the pre-season to the pre-competition phase. Paired sample t-tests revealed a statistically significant increase in lean tissue mass (LTM) from (M=66.35kg, SD = 4.94) to (M= 68.21kg, SD = 4.91) and a significant decrease in %BF (M= 17.93%, SD =3.71) to (M=16.66%, SD =3.24), p ≤.05 (two tailed) from the pre-season to the pre-competition phase of the season. The inability of B.M.I to detect changes in body composition demonstrates the importance of directly assessing body composition via DXA in trained athletes. The decrease in body fat and increase in lean tissue can be attributed to a number of factors: (1)an increase in training volume and intensity - players were in their off season for a number of months and volumes of structured training and competition games were non-existent in comparison to pre-season and pre-competition phases of the season and (2) the content of the training programme included large amounts of physical conditioning and the structured resistance training programme in conjunction with nutrition and supplementary support.

Only one of the four power measures (25%) increased from the beginning of pre-season to the pre-competition phase (Table 5.3). A paired sample t-test revealed a statistically significant increase in triple bound scores across the training period (M= 7.34m, SD =.39) to (M=7.56m, SD =.41), p ≤.05 (two tailed). The lack of increase in lower and upper body extremity power may be attributed to the training programme which consisted of high volume resistance training with a focus on hypertrophy. However, the 10m and 30m sprint times improved significantly from pre-season (M=1.75 sec’s, SD =.04) and (M= 4.26 sec’s, SD =.11) to the pre-competition phase of the season (M=1.73 sec’s, SD =.06) and (M=4.23 sec’s, SD =.11), p ≤.05 (two tailed). The increase in sprinting speed despite 2 of the 3 measures of lower extremity power failing to improve can be explained by the integral role played by the specialised speed coach during the pitch based strength and conditioning
programme which focused on improving sprinting technique and short distance sprinting speed.

Table 5.3 Seasonal change Senior Elite: Speed and Power Measures

<table>
<thead>
<tr>
<th>Test (Unit)</th>
<th>Senior Elite Pre Season</th>
<th>Senior Elite Pre Competition</th>
<th>Sig (p≤0.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± (S.D.)</td>
<td>Median± (S.D.)</td>
<td>Mean ± (S.D.)</td>
</tr>
<tr>
<td>SBJ (m)</td>
<td>2.25 ± (.15)</td>
<td>2.27 ± (.15)</td>
<td>2.28± (.14)</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>35.54 ± (3.97)</td>
<td>36.00 ± (3.97)</td>
<td>35.61± (3.77)</td>
</tr>
<tr>
<td>TB (m)</td>
<td>7.34 ± (.39)</td>
<td>7.36 ± (.39)</td>
<td>7.56 ± (.41)</td>
</tr>
<tr>
<td>MB (m)</td>
<td>6.78 ± (.39)</td>
<td>6.76 ± (.39)</td>
<td>6.56 ± (.41)</td>
</tr>
<tr>
<td>10m (s)</td>
<td>1.75 ± (.04)*</td>
<td>1.74 ± (.04)*</td>
<td>1.73 ± (.06)</td>
</tr>
<tr>
<td>30m (s)</td>
<td>4.26 ± (.11)</td>
<td>4.26 ± (.11)</td>
<td>4.23 ± (.11)</td>
</tr>
</tbody>
</table>

†Significantly different between pre-season and pre-competition p≤ 0.05

*Denotes non- normally distributed data as determined via Shapiro wilks p≤0.05

There was no significant increase in push up test performance from beginning of pre-season (M= 48.5 reps, SD =9) to Pre-competition phase (M=51.3 reps, SD =13.3), p ≥.05 (two tailed). Despite the content of the gym based strength and conditioning programme (high volume resistance training) the athlete’s existing high levels of local muscular endurance may explain the minimal increases in push up test performance.

A Wilcoxon Signed Rank Test revealed a statistically significant increase in the 150m Test from pre-season (M= 703, SD = 22) to the pre-competition phase of the season (M= 715, SD = 29). There was a statistically significant increase in estimated Vo2max score from beginning of pre-season (M= 53.45ml/kg/min, SD =2.64) to pre-competition phase (M=56.54 ml/kg/min, SD =3.23), p ≤.05 (two tailed). The high intensity intermittent nature of the hurling training sessions in addition to the high volume muscular conditioning resistance training programme is capable of stimulating an increase in both anaerobic and aerobic endurance.
5. 8. **Seasonal Change: Senior Sub-Elite**

There was no significant change in body mass from the beginning of pre-season to pre-competition phase as evident from the paired sample t-test results. This lack of change in body mass was also evident in the senior elite squad however upon further examination via the use of the lean tissue and body fat analysis carried out via DXA changes in body composition were highlighted. This inability of mass or resulting BMI measurement to monitor body composition changes in athletes demonstrates the importance of using direct methods of assessing body composition such as DXA as carried on the senior elite squad when profiling the anthropometric measures of athletes.

There were no significant differences in any of the measures of lower extremity power from the pre-season to the pre competition phase as illustrated in Table 5.4 below, although there was a significant increase in sprinting speed. The lack of meaningful change in lower extremity power may be attributed to the absence of a structured strength and power programme to develop these physical performance qualities. In contrast, 10m and 30m sprint times improved significantly from pre-season (M= 1.82 sec’s, SD =.04) and (M= 4.33sec’s, SD =.13) to the pre-competition phase of the season (M=1.80sec’s, SD =.06) and (M=4.28sec’s, SD =.11), p ≤.05 (two tailed). This increase in sprinting speed can be attributed to the initially low levels of sprinting speed present in the sub elite athletes, which was improved upon as a result of the short distance sprint training programme that took place during the training period A paired sample t-test revealed a statistically significant increase in KMBT performance from the beginning of pre-season (M= 6.09m, SD =.78) to Pre-competition phase (M=6.44m, SD =.74), p ≤05, (two tailed). During the training programme as presented in chapter 3. High volume muscular conditioning circuits were common place of which medicine ball throws were a commonly used exercise. The frequent practice of this motor pattern and improved task mastery can explain the improvement in medicine ball throw performance.
### Table 5.4 Seasonal Change Senior Sub-Elite: Speed and Power Measures

<table>
<thead>
<tr>
<th>Test (Unit)</th>
<th>Senior Sub Elite Pre Season</th>
<th>Senior Sub Elite Pre Competition</th>
<th>Sig (p ≤ 0.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBJ (m)</td>
<td>2.10 ± (.16)</td>
<td>2.11 ± (.16)</td>
<td>2.10 ± (.15)</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>35.43 ± (4.8)</td>
<td>34.55 ± (4.8)</td>
<td>35.17 ± (4.51)</td>
</tr>
<tr>
<td>TB (m)</td>
<td>6.92 ± (.48)</td>
<td>6.90 ± (.48)</td>
<td>6.96 ± (.51)</td>
</tr>
<tr>
<td>MB (m)</td>
<td>6.09 ± (.78)</td>
<td>6.02 ± (.78)</td>
<td>6.44 ± (.74)</td>
</tr>
<tr>
<td>10m (s)</td>
<td>1.82 ± (.04)</td>
<td>1.84 ± (.04)</td>
<td>1.80 ± (.065)</td>
</tr>
<tr>
<td>30m (s)</td>
<td>4.33 ± (.13)</td>
<td>4.35 ± (.13)</td>
<td>4.28 ± (.11)</td>
</tr>
</tbody>
</table>

†Significantly different between pre-season and pre-competition p ≤ 0.05

Levels of local muscular, anaerobic and aerobic endurance performance increased from the beginning of pre-season to the pre-competition phase. A paired sample t-test revealed a statistically significant increase in push up score performance from beginning of pre-season (M = 33 reps, SD =12) to the pre-competition phase (M = 40 reps, SD =11), p ≤05, (two tailed). The training programme consisted of high volume muscular conditioning circuits and in addition to this, local muscular endurance activities during normal pitch based training were common place. There was a significant increase in both anaerobic (150m test) (M=669m, SD =29) and aerobic endurance (VO2max) (M= 47.69 ml/kg/min, SD =3.96) from beginning of pre-season to the pre-competition phase (M=692m, SD =27) and (M=51ml/kg/min, SD =3.96) p ≤05, (two tailed). Such increases may be attributed to the content of the physical training programme- which consisted of high intensity circuit based exercise and field based interval training.
5. 9. Seasonal Change: Junior-Elite

There was a significant increase in body mass from the beginning of pre-season (M=75.4kg, SD=9.2) to the pre-competition phase (M= 78.8kg, SD = 10.5), p ≤.05 (two tailed). Throughout the pre-season and the pre-competition phase of the season the junior elite squad underwent a supervised strength and conditioning programme incorporating full body weight training exercises, plyometric activities and bodyweight resistance exercises in conjunction with nutritional support. The increase in body mass may be attributed to the development in lean tissue that is experienced through whole body resistance training.

There was a significant increase in all 4 measures of lower and upper extremity power from the beginning of the pre-season to the pre-competition stage of the season as illustrated in Table 5.5 below. The increases in upper and lower extremity power can be attributed to the supervised strength and conditioning programme which focused on developing whole body strength and power in addition to the pitch based training which incorporated plyometric activities in addition to the normal skills based training. Despite a significant increase in all 4 power measures a Wilcoxon signed rank test revealed no significant change in sprinting performance from pre-season (Med= 1.79 sec’s, SD=.06)to the pre-competition phase of the season (Med=1.79sec’s, SD=.06). The failure of sprinting speed to improve despite the increases in all 3 measures of lower body power illustrates the importance of performing sprint specific training rather than relying on a transfer of training ability from other training means. This finding is further supported by the increase in sprinting speed by both the senior elite and senior sub-elite squads in the absence of an accompanying increase in lower extremity power.
Table 5.5 Seasonal Changes in Speed and Power Measures in Junior Elite Squad

<table>
<thead>
<tr>
<th>Test (Unit)</th>
<th>Junior Elite Pre Season</th>
<th>Junior Elite Pre Competition</th>
<th>Sig (p≤0.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBJ (m)</td>
<td>Mean ± (S.D.)</td>
<td>Median ± (S.D.)</td>
<td>Mean ± (S.D.)</td>
</tr>
<tr>
<td></td>
<td>1.97 ± (.16)</td>
<td>1.97 ± (.16)</td>
<td>2.02 ± (.13)</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>Mean ± (S.D.)</td>
<td>Median ± (S.D.)</td>
<td>Mean ± (S.D.)</td>
</tr>
<tr>
<td></td>
<td>32.9 ± (4.0)</td>
<td>32.9 ± (4.0)</td>
<td>34.44 ± (4.76)</td>
</tr>
<tr>
<td>TB (m)</td>
<td>Mean ± (S.D.)</td>
<td>Median ± (S.D.)</td>
<td>Mean ± (S.D.)</td>
</tr>
<tr>
<td></td>
<td>6.93 ± (.56)</td>
<td>7.07 ± (.56)</td>
<td>7.36 ± (.38)</td>
</tr>
<tr>
<td>MB (m)</td>
<td>Mean ± (S.D.)</td>
<td>Median ± (S.D.)</td>
<td>Mean ± (S.D.)</td>
</tr>
<tr>
<td></td>
<td>5.03 ± (.55)</td>
<td>4.92 ± (.55)</td>
<td>5.22 ± (.49)</td>
</tr>
<tr>
<td>10m (s)</td>
<td>Mean ± (S.D.)</td>
<td>Median ± (S.D.)</td>
<td>Mean ± (S.D.)</td>
</tr>
<tr>
<td></td>
<td>1.83 ± (.06)</td>
<td>1.79 ± (.06)</td>
<td>1.81 ± (.06)</td>
</tr>
</tbody>
</table>

†Significantly different between pre-season and pre-competition p≤ 0.05

Both anaerobic and aerobic endurance performance significantly increased from the beginning of pre-season 150m (M= 703, SD = 20 to M= 726, SD = 36). and 20MST (M= 52.2 ml/kg/min, SD =3.5 to M=55.1 ml/kg/min, SD =), p ≤.05 (two tailed). The resistance training programme was conducted using pairing of upper body and lower body exercises (an upper body exercise performed directly after a lower body exercise), which developed strength and power also while stimulating the anaerobic and aerobic energy systems as players rest periods were kept quite low less than 90 secs. This programme, in addition to the pitch based strength and conditioning activities which consisted of intermittent skills conditioning and interval runs, stimulated the increases in aerobic and anaerobic endurance performance.

5. 10. Conclusion

Comparisons between the modern day hurler (e.g. the cohorts in the current study), existing data on the hurlers and players from other codes reveal some interesting similarities and differences. Data on the modern day senior elite hurler illustrate that they are taller, heavier, and faster and possessed superior local muscular and anaerobic endurance than senior elite players from previous studies (2003, 2005 & 2007). The current
sample had lower levels of leg power and similar levels of aerobic endurance performance to the related cohorts from the existing literature. The physical performance of senior elite hurlers is still inferior to the levels of physical performance present in professional soccer, rugby union, rugby league and Australian Rules football due to the full time professional status of the other codes. When compared to the limited research that examined senior sub-elite players, the players in the current study were taller, heavier, and faster and possessed superior leg power but interestingly had inferior levels of aerobic endurance. The current junior elite hurling squad are of similar height, heavier and faster than age matched elite soccer players, but possess inferior levels of leg power and aerobic endurance (McMillan et al., 2005).

Similar to the existing research on the other major field sports, levels of selected anthropometric and physical performance indicators increased as level of playing standard increased (sub-elite to elite & junior elite to senior elite). Measures of body mass, speed, upper and lower extremity power, local muscular, aerobic and anaerobic endurance increased as playing standard increased (sub elite to elite). As the level of playing standard increased (junior elite to senior elite), there was also an increase in height, body mass, speed and upper and lower extremity power measures.

Based on the findings of the current study, it is evident that physical performance indicators are subject to seasonal change in the modern day hurling athlete. Anaerobic and aerobic endurance were the only physical performance indicators that demonstrated significant changes across the respective seasons in all playing squads. This finding highlights the emphasis placed on endurance performance in the physical preparation programmes of hurling athletes. Although other physical performance indicators underwent seasonal change these changes were dependent on the performance of specific training to target the relevant components of fitness.

To optimise the physical performance of hurling athletes (irrespective of level of playing standard) the physical preparation programme should encompass a holistic approach in order to ensure all areas of physical performance are targeted with a structured and periodised plan.
Chapter 6. General Conclusions and Recommendations for future research
6. 1. Introduction

A battery of tests was created to evaluate the various anthropometric measures and physical performance indicators that are integral to performance in the sport of hurling. The physical performance indicators of 95 hurling athletes from three different levels of performance senior elite (n₁=34), senior sub- elite (n₂=28) & junior elite (n₃=33) were evaluated on two separate occasions during the season. Comparisons between players at the different levels of performance revealed differences between these players on a number of physical performance indicators. Data also revealed that seasonal changes in physical performance occurred and were dependent on the preparations of each respective squad.

6. 2. Physical Performance of the Modern Day Hurling Athlete

Comparisons between the modern day hurler described in the current study, existing data on hurlers and players from other codes reveal some interesting similarities and differences. The modern day senior elite hurler is taller, heavier, faster and possesses superior local muscular and anaerobic endurance than senior elite players from the past (2003-2007). However, the current cohort had lower levels of leg power and similar levels of aerobic endurance performance to the related cohorts from the existing literature. Interestingly, the physical performance of senior elite hurlers are still inferior to the levels of physical performance present in professional soccer (Reilly, Bangsbo & Franks, 2000), rugby union (Duthie, Pyne & Hooper, 2003), rugby league (Gabbett, 2005) and Australian Rules football (Pyne et al., 2005). These differences here can be attributed to the full time professional status of the players from the other codes which have implications in terms of training intensity, frequency, volume and opportunities to recover from such training loads.

When compared to the limited data available on senior sub-elite players, the current sample were taller, heavier, faster and possessed superior leg power but had inferior levels of aerobic endurance (Doran, Donnelly & Reilly, 2003). The superior performance of the current squad compared to the existing research can be attributed to the differences in standard of the respective squads (Tier1 & Tier 2). The superior aerobic endurance performance of the sub elite hurlers in the existing research may be as a result of using
different means to measure aerobic endurance (20MST vs. Incremental treadmill test). The modern day senior sub-elite hurler is taller and heavier, possesses similar levels aerobic performance and inferior levels of lower body power compared to the existing research on Gaelic footballers from the same level (Keane et al., 1997; McIntyre, 2005).

The systematic review of the literature failed to report any existing data profiling the anthropometric and physical performance of junior hurling squads which restricted the comparison of the squad to age matched population from other sports. The paucity of such profiles of anthropometric measures and physical performance indicators in junior hurling squads illustrates a significant area that warrants further investigation. The current day junior elite hurling squad are of similar height, heavier, faster and possess inferior levels of leg power and aerobic endurance to age matched elite soccer players (McMillan et al., 2005). They are of similar mass, shorter and possess inferior levels of aerobic endurance when compared to Australian Rules players of the same age (Young & Pryor, 2007). The current cohort are similar in height, mass and 10m sprint performance to Under 18 elite Australian rugby league players but have inferior levels of aerobic endurance than the current cohort (Gabbett, 2005).

6.3 Differences in Physical Performance Indicators Between Squads at Different Levels of Participation

Eight of the twelve measures (67%) demonstrated significant differences between the Senior Elite and Senior Sub-elite squads. Senior elite players were heavier than senior sub-elite players but were of similar height. However given that there were no direct measurements of body composition undertaken on the sub-elite athletes it is not possible to conclude if this additional mass consisted of LTM or additional body fat. Four of the six measures (67%) of speed and power (10m sprint, 30m sprint, S.B.J. and T.B.) were superior in the senior elite squad compared to the senior sub-elite squad. All three measures of endurance performance (push up test, anaerobic endurance and aerobic endurance) were superior in the elite squad compared to the sub-elite squad. To enhance the possibilities of players progressing from senior sub elite to senior elite, the physical preparation programme should focus on developing speed, power and endurance.
Six of the eleven measures (55%) reported significant differences between senior elite and junior elite players. Senior elite players were heavier and taller than the junior elite players. However similar to the comparisons between the senior elite and senior sub-elite squads the lack of body composition measurement prevents further explorations of the differences in body mass. Four of the five measures (80%) of speed and power demonstrated significant differences, with the (CMJ) the only exception. In contrast, there were no significant differences in any of the three measures of endurance (L.M.E., Aerobic and Anaerobic). In light of these findings junior elite physical preparation programmes should concentrate on increasing speed and power to enhance the chances of these players graduating to perform at senior elite level.

The data presented in the current study on the sport of hurling are in agreement with much of the existing research on the other major field sports as levels of select anthropometric measures and physical performance indicators increased as level of playing standard increased from (sub elite to elite) and from (junior elite to senior elite). However in contrast to much of the research there was no significant difference in endurance performance (L.M.E., Aerobic and Anaerobic) between the senior elite and junior elite squads suggesting that the endurance capacity of junior elite players in the sport of hurling is developed to the levels required to perform at the senior elite level.

6. 4. Seasonal Change in Physical Performance Indicators

Physical performance indicators have been shown to be sensitive to seasonal change in a number of major international field sports (Duthie, Pyne & Hooper, 2003; Gabbett, 2005; Stolen et al., 2005). The physical performance indicators that undergo seasonal change have been shown to be dependent on the type of training performed (Hoff, 2005) and provision of adequate recovery in the programme (Kramer et al., 2005).

In the current study, seven of the thirteen physical performance indicators (56%) demonstrated a significant change from pre-season to the pre-competition phase of the season in the senior elite squad. There was a significant increase in LTM and a significant
decrease in %BF which can be attributed to the high volume muscular conditioning programme in addition to the professional nutritional support. Only one of the four measures of power (TB) increased, this is not surprising as the squad were performing a high volume hypertrophy programme focused on increasing lean tissue mass. Both measures of speed (10m & 30m) significantly improved as a result of the speed training programme supervised by the specialist speed coach. Anaerobic and aerobic endurance performance significantly increased due to a combination of the pitch based interval running programme and the high intensity intermittent nature of the skills training.

Six of the eleven (55%) physical performance indicators reported significant changes in the senior sub-elite squad from beginning of pre-season to the pre-competition phase of the season. KMBT increased significantly of the season; however none of the three measures of lower body power increased. Given the content of the training programme as illustrated in Chapter 3, these changes/ lack of changes can be attributed to the high volume muscular conditioning circuits where medicine ball throws were commonly placed exercises. Despite the lack of increase in any measures of lower body power there was a significant increase in 10m and 30m sprint performance. This increase is surprising and may be attributed to the initially low sprinting performance of the senior sub-elite squad. All three measures of endurance (L.M.E., Aerobic and Anaerobic) increased significantly across the season.

In the Junior Elite squad, 8 of the 10 (80%) physical performance indicators demonstrated significant increases between the pre-season and pre-competition values. There was a significant increase in body mass and also a significant increase in all 4 measures of power (CMJ, BJ, and TB. & KMBT). Upon analysing the content of the training programme for this squad, it is apparent that these increases in physical performance and body mass can be attributed to the gym and pitch based conditioning programme which targeted the development of whole body strength and power. In addition to this the strength and conditioning structures provided to the players was their first experience of such training modalities, which therefore meant they had greater scope to improve as their initial levels of lower body power were lower than the senior elite team. Despite a significant increase in all 4 power measures there was no significant change in sprinting performance. The failure of sprinting speed to improve despite the increases in all 3 measures of lower body power illustrates the importance of performing sprint specific training rather than relying on a transfer of training ability from other related training means i.e. lower extremity power. All three measures (100%) of endurance performance (Push Ups, 150m and the
20MST) increased significantly as a result of the exposure to a structured strength and conditioning programme which contained a field based high intensity interval running programme.

To optimise the physical performance of hurling athletes (irrespective of level of playing standard), the physical preparation programme should encompass a holistic approach in order to ensure all areas of physical performance are targeted with a structured and periodised training plan.

6. 5. Limitations of the research

During and after the research process the following limitations of the project became apparent

- Due to technical difficulties (one faulty speed gate) it was not possible to perform 30m sprint testing on the junior elite team during either the pre-season testing or the pre-competition.
- The convenience sampling method of selection is not truly representative of each respective population. However this is common place in similar research in other sports.
- There was no body composition analysis carried out on the senior sub-elite or junior elite hurling squads.
- This research does not profile the athletes during the main competition phase of the season as each teams respective competition schedule did not allow time for testing to take place.

6. 6. Recommendations for Future Research in this Area

Following an extensive review of the literature and having profiled close to 100 athletes (N = 95) from the sport of hurling during this investigation, the following are recommendation based on this experience
• It is important that the future profiling of physical performance indicators of athletes from the sport of hurling clearly outline the phase of the season that the profiling takes place, as this research has shown that physical performance indicators are subject to seasonal change. In the past this has not been clearly illustrated to the reader.

• Future research examining the differences present between hurling squads at the various levels of participation should include the direct measurement of body composition so differences in body mass as found in the current research can be explored further.

• Future research should focus on profiling the anthropometric measures and physical performance indicators of the junior hurling athlete (<18 yrs.) as a priority. There is still a dearth of research that examines this population of hurling athletes. This research is essential to provide appropriate structures and development programmes to look after this vital cohort of players as the junior athletes are the next generation of senior elite athletes.

• During this investigation it became clear that the planning and organisation of squad testing during the competition phase of the season was significantly more challenging than at the earlier stages of the season (e.g. pre-season) due to time constraints and other related matters (e.g. reluctance from team management due to the apparent ‘sacrificing of a pitch session). When examining seasonal change in hurling athletes future research should focus on educating the management/coaches of the respective squads as to the importance of assessing physical performance indicators throughout the whole season.
References


Gabbett, T.J. (2002). Physiological characteristics of junior and senior rugby league players. British Journal of Sports Medicine, 36 (3) 334-339

Gabbett, T.J. (2005 a) ‘Changes in physiological and anthropometric characteristics of rugby league players during a competitive season’, Journal of strength & conditioning research 19, (2), 400-408

Gabbett, T.J. (2005 b) Physiological and anthropometric characteristics of junior rugby league players over a competitive season, Journal of strength & conditioning research 19, (2), 764-771


Handcraft hurleys (2012). Camàn. [Image], Retrieved from http://www.handcrafthurleys.com/media/catalog/product/cache/1/image/9df78eab33525d08d6c5fb8d27136e95/h/e/heff-hurl_2.jpg


119


Rampinini, E., Bishop, D., Marcora, S.M, Ferrari Bravo, D., Sassi, F.M. & Impellizzeri (2007). Validity of simple field test as indicators of match related physical performance in top level professional soccer player. *International journal of sports medicine, 28*(3); 228-235


Appendices
Appendix A

Parental informed consent form
An Investigation Into The Variation That Exists Between The Physical Attributes Of Hurling Players At Different Levels Of Participation

Written Informed Parental Consent Form for Subjects

- I have read and understood the subject information sheet
- I understand what the project is about, and what the results will be used for
- My child and I have completed the pre-test questionnaire and have honestly answered NO to all questions
- I am fully aware of all of the procedures involving my child, and of any risks and benefits associated with the study
- I know that my child’s participation is voluntary and that my child can withdraw from the project at any stage without giving any reason
- I understand that the results of the research may be published but that personal details will not be revealed
- I am aware that the results will be kept confidential
- I understand that any questions I have concerning the research study before and after my consent will be answered by contacting:

Student researcher: Andrew Murphy  
PESS Building, University of Limerick  
Email: andrew.murphy@ul.ie

Principal Investigator: Dr. Cian O’Neill  
PESS Building, University of Limerick  
Tel: (061) 202871  
Email: cian.oneill@ul.ie

Voluntary Participation:

Participation in this study is completely voluntary. If your child decides not to participate there will not be any negative consequences. Please be aware that if your child decides to participate, they may stop participating at any time.

By signing this form I am attesting that I have read and understand the information above and I freely give permission for my child to participate.
Parental/ Guardian Name .................................

Parental/ Guardian Signature .................................

Date ....................................................

By signing this form I am attesting that I have read and understand the information above and I freely give my assent to participate.

Subjects Name ...........................................

Subjects Signature ...........................................

Date ....................................................

Evaluators Signature ...........................................

If you have any concerns about this study and wish to contact someone independent you may contact:

Chairman Education and Health Sciences Research Ethics Committee
EHS Faculty Office
University of Limerick
Tel (061) 234101
Email: ehsresearchethics@ul.ie
Appendix B

Parental information sheet
UNIVERSITY of LIMERICK

O I L S C O I L L U I M N I G H

Parental Information Sheet

An Investigation Into The Variation That Exists Between The Physical Attributes Of Hurling Players At Different Levels Of Participation

Dear Parent/Guardian

My name is Andrew Murphy and I am an MSc research student from the University of Limerick. I am currently undertaking a research masters under the supervision of Dr. Cian O’Neill. My research will examine the physical performance at different levels of playing performance in the sport of hurling.

As a member of the Limerick minor squad 2011 your son has been invited to participate in this research study. This project aims to investigate the variation that exists between the physical attributes of hurling players at different levels of participation.

What is the study about?
This study examines the differences in physical performance that are present between a senior inter county squad, minor inter county hurling squad and senior club squad from the sport of hurling.

What will the testing involve?
All participants will undertake a battery of physical performance tests that include measures of flexibility, leg power, upper body power, speed, agility, local muscular endurance, aerobic and anaerobic endurance. This series of testing should take approx three and a half hours. Participants will be required to attend another 2 testing sessions over the duration of the season. These testing dates will be at the discretion of the management team relative to the training schedule.

What are the benefits?
The main benefit of this investigation for the participant is the opportunity to work with the same professional support structure that is central to the physical monitoring of a senior inter county hurling squad. Participants will also receive a detailed report on all aspects of their physical fitness at three different stages across the season. Individual feedback will be available if requested.
What are the risks?
The risks are no greater than the risks that are present during normal training sessions. All tests will involve physical activity movement patterns that are central to your son’s normal training schedule.

What if I do not want to permit my child to take part or if I change my mind during the study?
You can simply refuse permission for your child to participate in the study. It is not compulsory to take part in this project, as participation is on a voluntary basis. If at any stage you want to withdraw permission for your child to participate you are free to do so.

What happens at the end of the study and what happens to the information?
At the end of the study all information will be stored in an encoded and secure format and in no way will it be possible to link the results to the participants. The results and data collected may be used anonymously in the preparation of scientific reports for presentation at scientific congress or for publication.

What if something goes wrong?
All testing measures used in this study are used extensively at U.L. All researchers are qualified sport scientists and are competent with the equipment. Strict exclusion criteria and safety measures will be implemented at all times. If the participant shows any signs of distress at any stage during the research, the procedure will be terminated immediately. However as the testing procedures involved will be activities that are part of the normal training programme we don’t expect any problems with the testing procedure.

What if I have more questions or do not understand something?
If you have more questions or do not understand something you can contact:

Student researcher: Andrew Murphy
PESS Building, University of Limerick
Email: andrew.murphy@ul.ie

Principal Investigator: Dr. Cian O’Neill
PESS Building, University of Limerick
Tel: (061) 202871
Email: cian.oneill@ul.ie

If you have any concerns about this study and wish to contact someone independent you may contact:

Chairman Education and Health Sciences Research Ethics Committee
EHS Faculty Office
University of Limerick
Tel (061) 234101
Email: ehsresearchethics@ul.ie
Appendix C

Subject information sheet
Subject Information Sheet

An Investigation Into The Variation That Exists Between The Physical Attributes Of Hurling Players At Different Levels Of Participation

You are invited to participate in this research study. This study aims to investigate the variation that exists between the physical attributes of hurling players at different levels of participation.

What is the study about?

This study examines the differences in physical performance that are present between a senior inter county squad, minor inter county squad and senior club squad from the sport of hurling and the differences that are present across the season also.

What will I have to do?

You are invited to participate in this study on a voluntary basis. You will be required to undertake a battery of tests that include measures of flexibility, leg power, upper body
power, speed, agility, local muscular endurance, aerobic and anaerobic endurance. This series of testing should take approx 3 and a half hours. You will be required to attend another 2 testing sessions over the duration of the season. These testing dates will be at the discretion of your management team relative to the training schedule.

**What are the benefits?**

The main benefit of this investigation for you is that you will get the opportunity to work with the same professional support structure that is central to the physical monitoring of the Tipperary senior inter county hurling squad. You will also receive a detailed report on all aspects of your physical fitness at three different stages across the season.

**What are the risks?**

The risks are no greater than the risks that are present during your normal training sessions. All tests will involve physical activity movement patterns that will be central to your normal training schedule

**What if I do not want to take part or if I change my mind during the study?**

You can simply refuse to participate in the study. It is not compulsory to take part in this project, as participation is on a voluntary basis. There are no repercussions for individuals who do not want to participate in the study. If at any stage you wish to withdraw you are free to do so.

**What happens at the end of the study and what happens to the information?**

Following data analysis all information will be stored in an encoded and secure format and in no way will it be possible to link the results to you. The results and data collected may be used anonymously in the preparation of scientific reports for presentation at scientific congress or for publication.

**What if something goes wrong?**
All testing measures used in this study are used extensively at U.L. and in sports performance measurement all over the world. All evaluators are qualified sport scientists and are competent with the equipment and safety guidelines for use of equipment have been established. Strict exclusion criteria and safety measures will be implemented at all times. If you show any signs of distress at any stage during the research, the procedure will be terminated immediately. However as the testing procedures involved will be activities that are part of the squads normal training schedules there is not expected to be any problems with the testing procedure.

What if I have more questions or do not understand something?

If you have more questions or do not understand something you can contact:

**Student researcher:**

Andrew Murphy

PESS Building, University of Limerick

Email: andrew.murphy@ul.ie

**Principal Investigator:**

Dr. Cian O’Neill

PESS Department, University of Limerick

Tel: (061) 202871

Email: cian.oneill@ul.ie
Appendix D

Subject informed consent
An Investigation Into The Variation That Exists Between The Physical Attributes Of Hurling Players At Different Levels Of Participation

Written Informed Consent Form for Subjects

- I have read and understood the subject information sheet.
- I understand what the project is about, and what the results will be used for.
- I have completed the pre-test questionnaire and have honestly answered NO to all questions.
- I am fully aware of all of the procedures involving myself, and of any risks and benefits associated with the study.
- I know that my participation is voluntary and that I can withdraw from the project at any stage without giving any reason.
- I understand that the results of the research may be published but that my personal details will not be revealed.
- I am aware that my results will be kept confidential.
- I understand that any questions I have concerning the research study before and after my consent will be answered by contacting;
Student researcher:

Andrew Murphy

PESS Building, University of Limerick

Email: andrew.murphy@ul.ie

Principal Investigator:

Dr. Cian O’Neill

PESS Department, University of Limerick

Tel: (061) 202871

Email: cian.oneill@ul.ie

Voluntary Participation:

Participation in this study is completely voluntary. If you decide not to participate there will not be any negative consequences. Please be aware that if you decide to participate, you may stop participating at any time.

By signing this form I am attesting that I have read and understand the information above and I freely give my consent to participate

Subjects Name  ........................................

Subjects Signature  .................................

Date  ...........................................

Evaluators Signature  .................................
Appendix E

Pre Test Questionnaire
Department of Physical Education & Sport Sciences

PRE-TEST QUESTIONNAIRE

NAME …………………………………. Ref. No.
………………………..
Date of Birth …………………………… Age:
………………………..
Test procedure …………………………..

As you are to be a subject in this laboratory/project, would you please complete the following questionnaire. Your cooperation in this is greatly appreciated.

Please tick appropriate box
YES

NO

Has the test procedure been fully explained to you? □

Any information contained herein will be treated as confidential

1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor? □ □

2. Do you feel pain in your chest when you do physical activity? □ □

3. In the past month, have you had chest pain when you were not doing physical activity? □ □

4. Do you lose your balance because of dizziness or do you ever lose consciousness? □ □
5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?
   □ No □ Yes

6. Is your doctor currently prescribing drugs for your blood pressure or heart condition?
   □ No □ Yes

7. Do you know of any other reasons why you should not undergo physical activity? This might include severe asthma, diabetes, a recent sports injury, or serious illness.
   □ No □ Yes

8. Have you any blood disorders or infectious diseases that may prevent you from providing blood for experimental procedures?
   □ No □ Yes

- If you have answered NO to all questions then you can be reasonably sure that you can take part in the physical activity requirement of the test procedure.

I ………………………………. declare that the above information is correct at the time of completing this questionnaire Date ……/……/…….

Please Note: If your health changes so that you can then answer YES to any of the above questions, tell the experimenter/laboratory supervisor. Consult with your doctor regarding the level of physical activity you can conduct.

- If you have answered YES to one or more questions:
  Talk with your doctor in person discussing with him/her those questions you answered yes.
  Ask your doctor if you are able to conduct the physical activity requirements.

Doctor’s signature …………………………………………… Date ……/……/……

Signature of Experimenter………………………………… Date ……/……/……