A Comparison of Speed and Power Variables in u18, u21 and Senior Inter-county Hurling Players and an Investigation into the Relationship Between Speed and Power in Elite Hurlers

ABSTRACT

Background: Hurling is a very popular amateur field sport played in Ireland which requires high levels of skill and fitness to participate at the elite level. The purpose of this study was to compare the speed and power capabilities of elite u18, u21 and senior hurlers as well as investigating the relationship between these variables in this population. **Methods:** A battery of speed and power tests was carried out on thirty-five u18s, fifteen u21s and twenty senior elite hurlers during pre-season. Height and weight were measured before 10m and 20m sprint tests were carried out. A combination of countermovement jump (all squads), squat jump (seniors and u21s) and standing broad jump (minor) were used for power assessment. Speed and power were tested on separate days. **Results:** Minors (u18s) were significantly faster ($p<0.05$) than u21s for 10m speed. Seniors were significantly faster ($p<0.05$) than u21s for 20m speed. Significant differences were found between minors and the other two groups for CMJ ($p<0.01$). **Conclusion:** The results of the research provide normative data for speed and power for elite u18, u21 and senior hurlers. The results also show that hurlers at the age of eighteen have similar sprinting abilities and possibly greater power capabilities than their senior counterparts. It is also clear that the training phase being implemented has a major influence on speed and power. The significant relationship between speed and power indicates the need for continued and further emphasis on speed and power training for these athletes.

Key Words: hurling; speed; power; u18; u21; senior

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1. INTRODUCTION

1.1. Generic measurement

The measurement of human performance examines the parameters that constitute a high standard of performance (Morrow *et al* 2011). The use of measurement helps make good decisions (Morrow *et al* 2011), to allow strategic planning (Howell *et al* 2006) and to assess performance to allow improvement (Joint Commission Resources 2008) which is sought by all in one's respective activities.

1.2. Measurement in Sport

Improved performance is sought by all competitive athletes and so performance parameters as well as the relationship between parameters are continually being investigated by sport scientists. Measurement is essential in this investigation. In sport, measurement helps identify weaknesses and strengths (Baechle and Earle 2008). When a player's strengths and weaknesses are identified, a specific program can be designed to improve/maintain specific areas of performance (Gore 2000).

Measurement enables the monitoring of progress (Gore 2000). The measurement of sports performance, throughout the competitive season is important to assess improvement or disimprovement in performance at the different stages of the year. This type of research has been carried out in numerous field sports including hurling (Collins *et al* 2012c), Gaelic football (Reilly and Keane 1999), rugby league (Gabbett 2002) and soccer (Silvestre *et al* 2006). Although hurling is an amateur sport, sport scientists along with strength and conditioning coaches, sport psychologists, nutritionists and performance analysts are all members of inter-county hurling set-ups. These professionals work together to help hurlers achieve optimal performance. Measuring physical parameters such as those in this study, i.e. power and speed, provide these professionals with data to help design programs to enhance performance. It also allows the collection of normative data for hurlers of the respective age groups (u18, u21 and senior), which can be used for comparison. With this data, systematic planning of programs can be facilitated (Gore 2000).

Measurement of sports performance can be used to predict performance potential (Gore 2000). High standards of selected physical performance variables have been reported to be associated with high performance in soccer (Sutton *et al* 2009), rugby league (Gabbett 2002) and Australian Rules (Young *et al* 2005). Based on these findings, similar results are expected to be found in hurlers. Human performance measurement can also be used to identify staleness and overtraining (Harman 2008) while also offers feedback to both coach and athlete (Gore 2000), which can then be used to help set goals and programs (Baechle and Earle 2008).

1.3. Speed and Power in Sport

Field sport athletes strive to attain a high level of performance in a number of areas, namely technical, tactical, physical and mental (Reilly 2001). Speed and power are major components of the physical aspect of performance and are essential for superior performance in many sports (Jeffreys 2013).

Speed is important in sports that require a great deal of effort over a very short period of time. It is vital in team sports when a sudden change of pace and direction can bring success (Beashel 2001). Field sport athletes sprint short distances (e.g. 10-30m) during practice and in competition (Brown and Vescovi 2012).

Power is the speed at which the muscles can develop its maximum strength (Smolin and Grosvenor 2005) and is crucial for the performance of different sporting actions including agility, accelerating and jumping (Newton *et al* 1997; McBride *et al* 2002; Smolin and Grosvenor 2005). The ability to create maximal power during complex motor skills is vital in many sports (Cormie *et al* 2011). Superior athletic performance is determined by an athlete's ability to create maximal power (Baker *et al* 2001; Sleivert and Taingahue 2004). An interesting finding by Black and Roundy (1994) found that players that scored high on tests of strength, power and speed were more likely to be starters on a team and are therefore, essential attributes required by athletes.

1.4. Aim

The aim of this study is to investigate differences in speed and power in hurler of different age groups and to investigate the relationship between changes in lower body power and speed time) throughout the hurling season in u18 (minor) and u21 inter-county hurlers.

1.5. Objectives

The objectives of this study are to measure lower body power using the countermovement jump (CMJ), squat jump (SJ) and standing broad jump (BJ) and to measure sprint speed over 10m and 20m. Statistical analysis will be carried out using data obtained from the CMJ, BJ, SJ and sprint speed to establish if a relationship exists between the variables.

1.6. Rationale/Significance

Although some research has been carried out in hurling, no data has been recorded at the sub-senior elite level of competition (Doran *et al* 2003; Brick and O'Donoghue 2005; McIntyre 2005). Murphy (2012) examined the physical abilities as well as the seasonal changes in adult level hurlers. However, there has been no examination into either the physical abilities in physical performance in u18 and u21 hurlers. There is also a lack of research examining the relationship between the changes in power and speed in hurlers. The current study will establish a database of normative data for speed and power measures for inter-county u18, u21 and senior hurlers. This will be used by management and the backroom team to enhance performance in hurling as well as a marker to assess and compare performance.

This study is concerned with power measures (lower body) and speed measures which are parameters which are components of the physical aspect of the game. These parameters are essential for high level performance in field sports (Carling *et al* 2009). The purpose of this study is:

- To examine the physical performance parameters of power and speed (acceleration) of hurlers at u18, u21 and senior inter-county level
- To investigate if differences exist in power and/or speed between u18, u21 and senior inter-county hurlers
- To investigate if a relationship exists between power and speed in elite hurlers

As a result of this study, an insight into whether or not changes in power reflect in positive changes in speed variables will be revealed. If so, this will provide S&C coaches with valuable information with respect to the importance of power and power training in hurling and will impact program and training design.

1.7. Hypotheses

The following is hypothesised:

HO1: There will be no significant difference in acceleration between u18, u21 and senior intercounty hurlers

HO2: There will be no significant relationship between lower body power and speed in u18, u21 and intercounty hurlers

HO3: There will be no significant relationship between speed and lower body power in elite hurlers.

2. LITERATURE REVIEW

2.1. What is hurling?

Hurling, along with Gaelic football, camogie (ladies equivalent to hurling), ladies football, rounders and handball is one of the Gaelic Games played in Ireland regulated by the Gaelic Athletic Association (Reilly and Collins 2008; GAA 2013a). Hurling is also played in many other places around the world including Asia, North America, Australia, Canada, Europe, Britain and New York (GAA 2013a).

Hurling is an amateur sport and involves using a stick called a 'camán' (or hurl) and a ball called a sliotar (Reilly and Collins 2008). All players must wear a protective helmet (Khan *et al* 2008). It is played on a grass pitch which is 130-165m long and up to 90m wide. Goals are found at either end of the pitch, consisting of two tall goalposts and a crossbar that joins the two posts 2.5m above the ground (Reilly and Collins 2008; Cullen *et al* 2013; GAA 2013a). There are fifteen players on each team (see Fig 1.1) and a maximum of five substitutes can be used per game, although a panel usually consists of 30 players (Reilly and Collins 2008; Cullen *et al* 2013). The team consists of a goalkeeper, six defenders usually positioned in two lines of three (three in the full back line and three in the half back line), two midfielders and six attackers or forwards (three in the half forward line and three in the full forward line) (Reilly and Collins 2008). A point is scored when the sliotar goes over the crossbar between the posts. A goal (which is equivalent to three points) is scored when the sliotar goes under the crossbar between the two posts (Reilly and Collins 2008). Neither a goal nor point can be scored by throwing or handpassing the sliotar (GAA 2013c). The team that has the most points (a combination of goals and points) at the end of the match is the winner (Reilly and Collins 2008).

Figure 1.1 Playing positions on a hurling team (GAA 2013a)

Hurling is played at club, school, college and inter-county level at both underage and senior level (Reilly and Collins 2008). Inter-county hurling is the highest standard of hurling one can play, i.e. it is the elite level of competition (Reilly and Collins 2008). An inter-county team consists of the elite club players in the respective county. Inter-county hurling involves competitions and matches between different counties. The duration of an inter-county match consists of two thirty minute halves with senior inter-county matches consisting of two thirty-five minute halves (GAA 2013c). There are provincial and All-Ireland Championship series for senior, u21 and u18 (minor) age groups in which each county enters a representative squad (i.e. 32 teams plus London and New York for senior level). Each level (age group) of competition consists of several tiers (or divisions). The senior All-Ireland championship is divided into four different tiers based on ability (see Table 1.1) (GAA 2014).

Table 1.1 Divisions of Senior Hurling All-Ireland

Level of Competition	Name of Competition
Top Tier	Liam McCarthy
Second Tier	Christy Ring
Third Tier	Nicky Rackard
Fourth Tier	Lory Meagher

The teams participating in the minor ‘A’ championship (top division) compete for the Irish Press Cup, while the teams in the u21 ‘A’ championship compete for the Cross of Cashel respectively (GAA 2013b). With regard to the top level minor competition, provincial winners of Munster and Leinster progress automatically to the semi final stage of the All-Ireland series with provincial finalists of Munster and Leinster as well as Galway and Antrim (the only top tiered GAA county teams in Connacht and Ulster respectively) comprising the quarter final pairings. The minor All-Ireland Hurling Championship final precedes the Senior All-Ireland Hurling Final on the first Sunday in

September in Croke Park. The u21 provincial and All-Ireland championships are automatic knockout competitons. The winners of Munster and Leinster along with Galway and Antrim make up the semifinalists. The All-Ireland Final takes place in Thurles on the second Saturday in September (having changed in recent years from the second Sunday). The Senior Championship format has been changed numerous times in recent years. Provincial winners gain automatic entry to the latter stages of the All-Ireland series while those eliminated at the provincial stages must compete to reach the latter stages.

2.1.1. The Game Demands of Hurling:

Hurling is the fastest field game in the world (GAA 2013a; Irish Independent 2013). The sliotar can reach speeds up to 150km/hr (Croke Park 2014). The sliotar can move quickly from end to end of the field. Speed of hand, eye, legs, hands and mind are crucial in hurling in order to react to the fast moving sliotar and movements of the opponents. It is an intermittent high intensity contact field sport which requires a high level of skill (McIntyre 2005; Duncan 2006, Reilly and Collins 2008). The skills of the game include striking, handpassing, soloing, hooking, blocking, tackling, evading opponents, shooting, jab lifting and roll lifting among many others (Reilly and Collins 2008). A wide range of fitness components are also necessary in order to excel (McIntyre 2005; Duncan 2006).

A study by Collins *et al* (2012a) monitored work-rate in hurling, using GPS on 53 elite hurlers. It was found that hurlers cover a distance of 8017 ± 1145m in a game of which 1326 ± 377m (which accounted for 5.3 + 1.4% of game time) was spent in high intensity activity (17-40km/hr). 405 ± 243m of the high intensity activity was spent sprinting maximally (22-40km/hr) (Collins *et al* 2012a). A hurler is reported to carry out an average of 71.6 + 26.7 high intensity bursts of 4.2 + 1.5s followed by a period of low intensity of 55.1 +19.0s (Collins *et al* 2011a). Repeated high intensity work and aerobic fitness are therefore vital. It is reported that more successful teams are found to have greater aerobic fitness than less successful teams (Collins 2014). Based on these findings which are summarised in table 1.2, it is clear that elite hurling requires intermittent bouts of low intensity activity with short bursts of high intensity (Collins *et al* 2012a). It is also evident from table 1.2 that hurling requires similar physical fitness levels to that of Gaelic Football and Australian Rules Football (Varley *et al* 2013).

Table 1.2 Comparison of GPS data in team sports (± SD)
(Collins *et al* 2012a, Collin *et al* 2012b, Varley *et al* 2013)

	Hurling	GF	ARF	RL	Soccer
Total Distance (m)	8017 (1145)	8815 (1287)	12620 (1872)	6276 (1950)	10274 (946)
Accelerations (no.)	71.6 (26.7)	N/A	82 (26)	71 (38)	65 (21)
High Intensity (m)	1326 (377)	1695 (503)	1322 (374)	327 (168)	517 (239)
Sprinting (m)	405 (203)	N/A	328 (164)	50 (50)	93 (77)

GF= Gaelic Football, ARF=Australian Rules Football, RL=Rugby League

From this data, the elements of physical fitness required for elite hurling include aerobic capacity, anaerobic capacity (Shephard and Astrand 2000; O'Neill 2009), speed (both sprinting and agility) (Collins *et al* 2012a), power and reaction time as well as strength, flexibility and body composition (O'Neill 2009). These are all components of physical fitness which is one of the key elements in the development of a hurler as proposed by the OTú Coaching Model (GAA 2013d) along with technical proficiency, tactical prowess, playing facts, team-play and psychological focus. All of these components of a hurler must be nurtured and developed in order to achieve one's potential.

2.2. Speed

Speed over short distances (acceleration) is a distinguishing factor between higher level and lower levels of competition (elite and non-elite) in soccer (Cometti *et al* 2001), lacrosse, field hockey (Lockie *et al* 2011), rugby league (Baker and Newton 2008; Gabbett *et al* 2010), NFL (Sierer *et al* 2008) and NCAA Football (Garstecki *et al* 2004) as well as between starters and non-starters in Australian Rules Football (Young *et al* 2004).

Acceleration has been tested using electronic timing gates (McIntyre 2005; Duncan 2006; Cullen *et al* 2013) over varying distances (0-40m) depending on the specific demands of the sport. Sprinting speed is defined as the product of stride length and stride frequency (Dawes and Lentz 2012; Murphy *et al* 2003). Stride length is defined as the distance between the contact of one foot and the contact of next foot (Hunter *et al* 2004). Stride frequency is defined as the rate at which a stride can be produced (Lockie *et al* 2012). In order to improve sprinting speed either stride frequency or stride length or both must be improved (Dintiman and Ward 2003; Lockie *et al* 2012) without the occurrence of negative interaction which is described by Hunter *et al* (2004) as the decrease in one of the factors as a result of the improvement of the other.

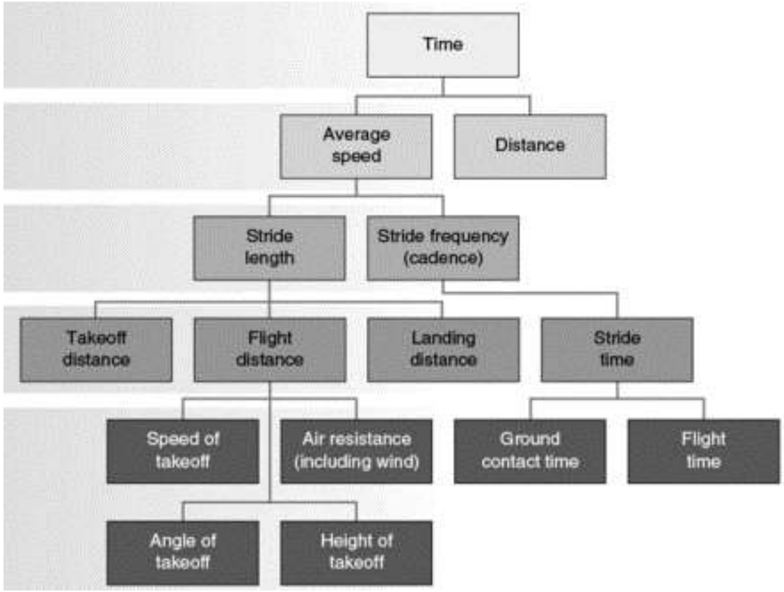

Figure 2.1 Deterministic Model for Sprinting (Human Kinetics 1999)

Stride frequency is affected by both contact time and flight time (Weyand *et al* 2000; Murphy *et al* 2003). Contact time is the time elapsed between the initial strike of the foot and the toe-off of the same foot (Lockie *et al* 2012). It is during contact time that force is generated for propulsion (Weyand *et al* 2000). Flight time is the time elapsed between toe-off of one foot and the initial strike of the opposite foot (Lockie *et al* 2012). Stride length is affected by both contact distance and flight distance (Hunter *et al* 2004). Contact distance and flight distance is the horizontal distance which the CoM travels during the respective phases (Hunter *et al* 2004). Stride length is also influenced by anthropometric characteristics (Bissas *and* Havenetidis 2008). Longer limbs have been linked with faster sprint times (Coleman and Lasky 1992; Abe *et al* 1999). The amount of force generated while in contact with the ground also affects stride length (Bissas Havenetidis 2008).

Research is inconclusive to whether stride length (Armstrong *et al* 1984; Gajer *et al* 1999) or stride frequency (Mero *et al* 1981; Mero *et al* 1992; Lockie *et al* 2011) is the most important factor in determining sprint speed. Stride length may be improved through increased strength and power of the leg muscles as greater forces can be produced, improving propulsion and therefore increasing flight distance (Klinzing 1984; De Villarreal *et al* 2008; Brechue *et al* 2010). However, Faccioni (1994) and Brown and Vescovi (2012) has shown that stride length will reach a plateau whereas stride frequency may still improve by decreased contact time through the improved ability of the stretch-shortening cycle.

2.2.1. The importance of speed in hurling

Sprinting speed over short distances, which is referred to as acceleration (Murphy et al 2003) is very important for field based sports such rugby (Gabbett *et al* 2010), soccer (Rebelo *et al* 2010; Lopez-Segovia *et al* 2011), AFL (Young *et al* 2011) as well as Gaelic Football (McIntyre 2005, Cullen *et al* 2013) and hurling (McIntyre 2005).

Table 2.1 Age (yrs) and sprint times(s) for various sports and distances (± SD)

Study	Sport	n	Age	10m	20m	30m	40m
Cullen *et al* 2013	GF	265	17(0.7)		3.22(0.15)		
Gabbett 2013	NRL	24	23.6(3.8)	1.77(0.09)			5.23(0.16)
	NRL Youth	11	19.0(0.2)	1.81(0.1)			5.34(0.25)
Lopez-Segovia *et al* 2011	Soccer (u21)	14	20.1(0.4)	1.92(0.06)	3.22(0.09)	4.43(0.14)	
Young *et al* 2011	AFL	23	22.3(2.1)	1.73(0.06)			
Cometti *et al* 2001	Soccer Div 1 (France)	29	26.1 (4.3)	1.8 (0.06)		4.2 (0.19)	
Rebelo *et al* 2010	SL (Pro)	22	25.0 (4)	1.81 (0.08)	3.01 (0.08)		5.33 (0.12)
Gabbett *et al* 2010	RL (Pro)	58	23.8 (3.8)	1.73 (0.07)			5.25 (0.17)
Gabbett *et al* 2005	RL (Pre-season)	52	>18	1.83 (0.04)	3.12 (0.06)		5.61 (0.13)

GF=Gaelic Football, NRL=National Rugby League, Pro=Professional, RL=Rugby League, SL=Soccer League

In a hurling match, speed is vital when trying to get free from an opponent (McIntyre 2005; Reilly and Collins 2008), trying to gain possession (McIntyre 2005), when chasing an opponent and also in support play, before a strike is executed, before jumping to contest a high ball and when breaking through tackles (McIntyre 2005). Speed has been reported in a number of studies as seen in Table 2.

Table 2.2 Sprint times (s) and distances in hurling studies (± SD)

Study	Competitive Level	n	Age	10m	15m	20m	30m
McIntyre 2005	SIC	30	24(5)		2.48(0.1)		
Collins *et al* 2012	Competitive Hurlers (March)	23	23(3)	1.78(0.04)		3.03(0.06)	
Collins *et al* 2007	Wexford SIC	18	27.2(2.7)	1.75(0.03)		3.02(0.07)	
Collins *et al* 2007	Dublin SIC	23	23(3.4)	1.77(0.04)		3.03(0.07)	
Doran *et al* 2003	SIC Div 2			1.78(0.08)			4.43(0.17)

SIC=Senior Inter-County Team

From Table 2.1 and 2.2, it is clear that the sprint times over 10m of hurlers is similar to that of other intermittent field sports such as rugby (Gabbett *et al* 2010), soccer (Cometti *et al* 2001) and AFL (Young *et al* 2011). However, AFL and rugby league had slightly faster sprint times. This may be due to the professional nature and thus training opportunities that these players have in comparison to the amateur hurlers. On the other hand, the 10- and 20m sprint times of the hurlers are faster than that of youth soccer (Lopez) and rugby players during the pre-season (Gabbett *et al* 2005) which may be due to greater resistance and power training by the hurlers as well as different training phases (rugby league players were tested pre-season).

Similar 20m sprint times are reported for the hurlers and professional soccer league SA which may be expected due to the similar speed requirements for both sports. Similar scores were reported for hurlers and u21 soccer players over 30m. The superiority of the hurlers over the u21 soccer players at 10- and 20m but similarity over 30m reflects the fact that sprints in hurling are of short duration (10-20m). As distance increases, performance decreases. Professional soccer league players produced greater 30m times than the hurlers due to the demand of longer sprints in the sport of soccer as players must accelerate these distances when making a break away from the opposition of attempting to support a team mate.

It is found that the sprints occur around the key moments in field games (Reinzi *et al* 2000; Meir *et al* 2001), including hurling (Collins *et al* 2011b). In a study carried out by Rienzi *et al* (2000) on soccer players during international games, it was found that 5% of match time is spent in high intensity activity. Similar finding were reported by Reilly 1996, with 7% of match time spent striding and with a mere 2% sprinting in possession of the ball. Although this seems like a small proportion of match time, these burst of high intensity occurred at the crucial moments of the game as players tried to create space to collect a pass, make a pass or score a goal and determined the outcome of the games. This was also found by Meir *et al* 2001 in professional rugby league. It is reported that a hurler spends 3% of match time sprinting and 2% of match time sprinting at maximum speed (Young 2008) or 5.3 + 1.4% of match time doing high intensity activity (defined as speeds of 17-40km/hr) (Collins *et al* 2012c). It must be noted that the sliotar is in actual play for a mere 41% of total match time (Collins *et al* 2010). As is the case in soccer and rugby league, these sprints are of vital importance to the crucial moments of the game and therefore, speed is imperative in hurling.

2.2.2. Speed and Acceleration in Hurling

A study carried out by O'Donoghue *et al* (2004) revealed that on average, a hurler sprints for a duration of 4.2 + 1.5s and these sprints occurred 71.6 + 26.7 times in a match. It must be considered that this data was obtained based on analysis of sub elite hurlers. According to a study by Collins *et al* (2012c), using GPS monitoring of 53 elite hurlers, it was found that hurlers cover an accumulative distance of 405m (±243m) sprinting (22-40km/hr). The short duration of these sprints was also found by Young 2008, who found that 70% of sprints during a hurling match took less than 10 steps. This is similar to findings in rugby union (Deutsch *et al* 1998), soccer (Bangsbo *et al* 1991), field hockey (Spencer *et al* 2004) and ARF (Dawson *et al* 2004) which have found that a sprint performed in a match rarely lasted more than 3s. From the above findings, it is clear that acceleration is more relevant to hurling as opposed to maximum speed.

2.3. Power

Power is defined as the product of force and velocity (Dawes and Lentz 2012). To improve power, one or both of the variables must be improved (without the disimprovement of the other) (Randell *et al* 2010). Lower body power is vital for field sports and has been shown to be a distinguishing factor between starters and non-starters in American football Division 1AA (Barker *et al* 1993), elite and junior rugby union (Hansen *et al* 2011), senior and collegiate rugby league (Baker 2001), divisional teams in American Collegiate Football (Fry and Kraemer 1991).

Table 2.3. Summary of lower body power tests for various sports (in cm) (±SD)

Study	Sport	N	Age	CMJ	SJ	SBJ
Brechue *et al* 2010	NFL	61	20.1(1.4)			252.2(22.9)
Cometti *et al* 2001	Division1 French Soccer	29	26.1(4.3)	41.56(4.18)	38.48(3.8)	
Cullen *et al* 2013	Gaelic Football	265	17(0.7)	43.32(5.08)		198.2(20.7)
Lopez-Segovia *et al* 2011	Soccer (u21)	14	20.1(0.4)	38.34(4.44)		
Cormack et al 2008	AFL	15	23.3(3.8)	48.8		

Table 2.4. Summary of lower body power tests in hurling studies (in cm) (±SD)

Study	Competitive Level	n	Age	CMJ	SBJ
Collins *et al* 2012	Competitive Hurlers (March)	23	23(3)	45.7(6.3)	240(20)
Collins *et al* 2007	Wexford SIC	18	27.2(2.7)	47.14(3.24)	247(15)
Collins *et al* 2007	Dublin SIC	23	23(3.4)	47.29(6.29)	254(20)
Doran *et al* 2003	SIC Div 2			40.8(4.5)	

It is evident in Table 2.3 and 2.4, from relevant studies, hurlers have greater CMJ heights than other sports including soccer and Gaelic football. This may be due to the greater jumping that occurs in hurling as opposed to soccer. The players tested in the study by Cullen *et al* 2013 were secondary school players and so the standard of playing may not equate to that of the hurlers tested. AFL players reported higher CMJ which is expected due to the large demand for jumping the sport (Tanner and *Gore 2013*). NFL, another intermittent field sport, has similar SBJ scores to that of the Dublin and Wexford senior teams. The lower score achieved by the players in the study by Collins *et al* 2012 may be due to the timing of testing (pre-season) where the main focus would not be on speed and power.

Research has shown that leg power is essential for acceleration (De Villarreal *et al* 2008; Brechue *et al* 2010; Chelly *et al* 2010).Athletes with greater power have been shown to have greater stride length (Triplett *et al* 2012). Stride length is largely determined by the force applied to the ground during the take-off for each stride. If force applied to the ground increases, a consequent increase in flight distance is also observed which results in a greater stride length (Triplett *et al* 2012). The greater force generated (power) also allows a greater knee lift which results in a longer stride length (Harris *et al* 2008), which from the sprint speed equation (speed = stride length x stride frequency) (Behrens and Simonson 2011) should lead to faster athletes (without concurrent decrease in stride frequency), with greater acceleration.

The greater muscular force (power) produced against the surface also results in an increase in jump abililty (Hoffman 2012) which is sought after in many field sports. Lower body power is essential for jump height to compete for aerial possession and crucial during physical exchanges such as breaking the tackle or competing for possession on the ground (Baker and Newton 2008; Cullen *et al* 2013). During jumping, the countermovement (eccentric part of the movement) results in the stretching of the muscle due to its elastic component. Muscle spindles within the muscle also stretch and send signals to the central nervous system. This in turn causes a signal to be sent to the muscle spindles resulting in the contraction of the muscle. When followed immediately with a concentric action, there is an increase in the acceleration of the body involved in the movement (Haff and Nimphius 2012). By improving the proficiency and performance of the SSC, improvements in jumping ability will be observed.

Power can be improved by different methods of training including resistance training to improve maximal force production, plyometric exercises to improve the ability to use the stretch shortening cycle as well as high speed activities such as sprinting and agility which are game specific (Dawes and Lentz 2012).

2.3.1. Relationship between Power and Speed

Several studies report the relationships between sprint times for varying distances with jumping tests (as a measure of lower body power) in soccer (Comfort et al 2014; Wisloff *et al* 2004). Studies examining the relationship between lower body power and acceleration in rugby players (Baker and Newton 2008), Gaelic footballers (Cullen *et al* 2013) and athletes following plyometric training programs have all found statistical significance (Rimmer *et al* 2000; De Villareal *et al* 2012). A study carried out by Brick and O'Donoghue (2005) compared the fitness characteristics of soccer, rugby union, Gaelic football and hurling players playing at the elite level, in which 40m sprint times and vertical jump height among other variables were tested. However, the relationship between them was not examined. It must also be noted that the sprint distance used in this study (40m) was not reflective of the average sprint distances covered by hurlers during a game with the vast majority requiring less than 10 strides (Young 2008). As well as this, the hurlers used were from Ulster which would not be one of the strongest hurling areas as Antrim is the only team from Ulster that compete in the Liam McCarthy Cup and compete in the Division 1B league. The other Ulster counties that do play hurling compete in the lower divisions of the respective competitions. Gaelic Football is the predominant sport in this province. Therefore, this study will be the first to provide insight into the relationship between speed and power in hurlers.

2.3.2. Lower body power tests

In field sports, a widely used test to assess muscular power involves jumps for maximum height and distance (in the horizontal and vertical planes) (Gore 2000). Other tests include the 30s wingate anaerobic test and 6s bicycle test (Gore 2000).
CMJ is a common power test used to assess stretch shortening capacity in the vertical plane. It has been used in studies for soccer (Cometti *et al* 2001; Lopez-Segovia *et al* 2011), hurling (Collins *et al* 2012), ARF (*Cormack et al* 2008). Different variations of the CMJ including unloaded CMJ (Hoffman *et al* 2007) loaded CMJ (Young *et al* 2004), VJ (Keogh 1999) as well as CMJ performed using a Smith machine (Marques *et al* 2011) have all been previously used in the assessment in of lower body power. SJ has been used as a measure of the concentric contraction ability and has been tested in several studies (Cronin *et al* 2003) of soccer (Cometti *et al* 2001). DJ has been used in many studies (Young *et al* 2002) which allows the testers to obtain reactive strength index (the ability of the athlete to produce force under high eccentric load). This has been used in many studies including the study of 20 active field sport players (Lockie 2012), Other lower body power tests in the horizontal plane include single-leg vertical jump (Hopper *et al* 2002) and repeated vertical jumps (Tkac *et al* 1997),

SBJ has been used to assess horizontal power in NFL (Brechue *et al* 2010), Gaelic Football (Cullen *et al* 2013) and soccer (Cometti *et al* 2001). Other tests that have been used to assess lower body power in the horizontal plane include single hop for distance (Bolga and Kestula 1997; Clark *et al* 2002) and triple hop for distance (Bolga and Kestula 1997; Clark *et al* 2002) and 5BT (Lockie *et al* 2012).

2.3.2.1. Lower body power tests in the vertical plane

Vertical jump testing has been used to assess lower body muscular power. A vertical jump test involves propelling oneself off the ground as high as possible (in the vertical plane) from a stationary position (Baechle and Earle 2008). Vertical jump testing has been carried out on soccer players (Brechue *et al* 2010; Chelly *et al* 2010), Gaelic

Football (Cullen *et al* 2013), rugby league (Gabbett *et al* 2005), field sport athletes (Lockie *et al* 2011;2012).

There are a number of methods to test vertical jump (VJ) including the chalk test (Baechle and Earle 2008), Vertex, VJ using a Smith machine and force plate, force plates, vertical jump mats and Optojump. In the chalk and vertex test height reached is measured. However, there are a number of disadvantages to tests carried out with these pieces of equipment. Co-ordination of the subject ability to jump and hit the mark or vane at the highest point influences the results. As well as this, subjects are liable to jump forward as opposed to straight up in an attempt to reach the vane/wall (Gore 2000). Testing using the Smith machine results in greater control during the jump and horizontal and lateral displacement is minimised. However, a lot of space is required and it is an expensive piece of equipment. As well as this there is no comparative scores available (Gore 2000). When testing using the vertical jump mat, Optojump and force plates height is calculated based on recorded flight time (calculated from time of take-off to time of landing). This reduces any error that may be caused due to co-ordination. It is assumed however, that the take-off and landing points are the same. Therefore, any deviations in the horizontal or lateral directions may introduce error. Subjects are instructed to jump with minimal deviation from take-off position on landing (Gore 2000).

A number of factors must be taken into account when testing vertical jump height including the use of arm swing (Harman *et al* 1990) and whether the jump is a countermovement jump or a squat jump, the angle at the knee at the starting position (Komi and Bosco 1978; Cordova and Armstrong 1996) and also the equipment used. If arm swing is used, greater height can be achieved 30-54cm (Markovic *et al* 2004) as opposed to no arm swing (29-45cm). However, jumping with no arm movement (by placing hands on hips), the motor skill aspect of the jump is eliminated (Gore 2000). Jumping without arm swing is preferable for testing leg power (Gore 2000).

CMJ is a jump with a standing start position. It involves activating the stretch-shortening cycle. This involves the stretching of the muscles and tendons during the eccentric phase of the jump, thereby increasing potential energy and this results in more force being generated during the contraction of the muscle (concentric phase) which is desirable (Chelly *et al* 2010). SJ, on the other hand, involves a pause at the bottom of the descent before jumping (Baechle and Earle 2008). SJ is a measure of concentric contraction ability only (Ingebrigsten and Jeffreys 2012). The countermovement is a better representation of the jumping that occurs in the sport of hurling as it make use of the stretch shortening cycle which is used in field sports in actions such as accelerating, decelerating, jumping as well as turning and tackling

(Reilly 2007). Hara *et al* 2006 found that countermovement jump resulted in greater heights (35.3 + 4.5cm) than squat jumps (32.7 +4.2cm). The lower squat jump heights are attributed to the fact that subjects are not accustomed to performing this type of jump, muscles are not capable of achieving high levels of force before the concentric contraction nor does it make use of the SSC which improves jump height (Bobbert *et al* 1996). CMJ has a high level of reliability of r=0.97 (Markovic *et al* 2004). Maulder and Cronin (2001) found that vertical jump and 20m sprint performance has a correlation of r=0.52.

2.3.2.2. Lower body power test in the horizontal plane

In hurling muscular power is required in both the horizontal direction (for acceleration, speed, agility) and vertical direction (jumping, catching) and therefore, different tests are required.

The standing broad jump has been used to lower body power (and SSC capacity) in the horizontal plane in numerous studies including soccer (Brechue *et al* 2010) and Gaelic Football (Cullen *et al* 2013). Standing broad jump involves jumping maximum distance in the horizontal plane which involves a countermovement. The use of arm movement is again a factor that must be taken into consideration. It has been found that jumps with arm movement resulted in greater distances (2.09 + 0.03m) in comparison to no arm movement (1.72 +0.03m). Maulder and Cronin 2001 found that broad jump and 20m sprint performance has a correlation of r=0.65 and is therefore more indicative of 20m sprint performance than vertical jump.

3. METHODS

3.1. Experimental Approach

Tests of lower body power and speed (acceleration) were measured in inter-county hurlers participating at two different age groups (u18 and u21). Test scores were analysed to determine if differences in speed and power existed between the groups and also to investigate the correlation between speed and power in hurlers. All testing took place in the University of Limerick PESS Building. A team of final year sport science students studying in the University of Limerick, under the supervision of a qualified sport scientist, carried out the tests on the two squads. Ethical approval (was attained from the University of Limerick Education and Health Science Research Ethics Committee (EHSREC) before testing began.

3.2. Participants

70 participants, including thirty-five u18s, fifteen u21 and twenty inter-county hurlers preparing for the first division ('A') Munster and All-Ireland championship were recruited for this study. All players were members of the same county. The subjects were selected from the squads which the supervisor were currently working with which helped with accessibility to the players. Subject information sheets and informed consent forms were given to all athletes. Information sheets and consent forms were given to the parents of subjects under the age of 18. Subjects were free to withdraw from the study at any stage. Testing was carried out after a 5minute warm up at the beginning of a pre-season training session.

3.3. Testing

Tests were chosen to measure lower body power, sprint speed, acceleration and sprint variables including ground contact time, stride frequency and stride length.

3.3.1. Sprint Testing

A 10 minute warm-up including dynamic stretching and sprinting drills was completed before sprint testing was carried out. Each participant performed 2 practice trials each before the test. Wireless double beam electronic timing gates (MicroDual) were positioned at the starting line and a distance 10m and 20m from the start line.The start line was positioned 0.5m behind the line to prevent early triggering of the gates due to arm motion. Preffered leg was placed on the starting line and a standing start was adopted. The participant began the trial at their own discretion. Subjects were instructed to sprint as fast as possible through the finishing gate. Each participant performed 3 trial with a 3 minute resting period between trials. Sprint times were recorded to the nearest millisecond.The best of the three trials was selected for analysis.

3.3.2. Lower body power testing

Lower body power measures were recorded in both the horizontal and vertical planes as power in both direction is important in hurling. Countermovement jump (CMJ) and drop jump were used to measure explosive leg power in the vertical direction. Standing broad jump was used to measure explosive leg power in the horizontal direction.

3.3.2.1. CMJ and SJ

Countermovement jump height and squat jump were measured to the nearest centimetre using a JustJump mat. The jump mat consists of a rubber rectangular mat with a lead connected to a handheld monitor.

Countermovement jump height was calculated by the mat (Height = 1/8 ($g*t^2$)) (Pond 2003) based on time elapsed between last contact with the mat during the upward phase and first contact with the mat during the downward phase. Jump height is displayed immediately on a handheld digital device. Before the CMJ, participants stood upright with both feet on the mat. For both jumps, subjects were instructed to keep their hands on their hips throughout the jump.

For the CMJ, participants were instructed to flex their lower limbs and jump as high as possible in one continuous motion (no pause at the bottom between eccentric and concentric phases) and land as close to the starting position as possible on the mat with both feet in contact with the mat. Subjects were not instructed on depth or speed of the jump.

For the SJ, participants were instructed to flex their limbs to a 90^o angle and pause which is the starting position. Participants were then instructed to jump as high as possible.

Each participant carried out one practice jump. Three trials were then carried out with 2-3 minutes recovery between each. The best score from the 3 trials was chosen for analysis. The Just Jump mat is highly reliable and valid for measuring CMJ height (Pond 2003; Markovic *et al* 2004). An inter-class correlation of 0.926-0.942 for between-trial measures exists. It also has a validity correlation of 0.815-0.9 (Pond 2003).

3.3.2.2. Standing Broad Jump

Standing broad jump was measured using a solid floor and a measuring tape to the nearest centimetre. Participants were instructed to begin with their toes behind a fixed starting line which was marked on the ground by electrical tape. With arms in the arm, participants were instructed to squat down to a desired level bringing arms down before propelling themselves horizontally (using forward arm swing) as far as possible landing on both feet. The distance between starting point and the heel of the foot closest to the line was recorded. Each participant performed one practice jump. Three jumps were then performed with 1 minute recovery between each. The best of the three jumps was recorded and used for analysis.

3.4. Statistical Analyses

Data analysis was carried on SPSS version 21.0. All data was tested for normality using a Shapiro Wilks test in addition to analysing skewness and kurtosis.
For normally distributed data, between group differences i.e. examining the relationship between u18, u21 and seniors were analysed using a one-way ANOVA (one-way analysis of variance) test and Tukey's Post hoc test. Following tests for normality, linearity and homoscedasticity, a Pearson correlation was calculated to establish the relationship between speed and power measures in u18s, u21s and seniors. A probability $p<0.05$ was accepted for statistical significance.

4. RESULTS

4.1. Descriptive Statistics

The purpose of this study was to determine the difference in speed and power variables between u18 (minor), u21 and senior inter-county hurlers. Another purpose was to determine the relationship between different speed and power variables for hurlers. Table 1 shows the mean and standard deviation for age, height and weight of the individual age groups.

Table 4.1 Descriptive Statistics

Group	Age (years)	Mass (kg)	Height (m)
Minor	17.5 ± .8	76.90 ± 6.84	181.70 ± 5.02
u21	20 ± 1.3	80.47 ± 7.40	181.43 ± 6.82
Senior	24.7 ± 2.7	83.00 ± 4.85	182.13 ± 4.67

4.2. Comparison of variables across the age groups

Tables 4.2. displays the mean scores and standard deviations for each variable for each of the age groups.

Table 4.2 Mean scores ± SD for 10m, 20m, CMJ, SJ and SBJ for all three age groups

	n♦	10m (s)	20m (s)	CMJ (cm)	SJ (cm)	SBJ (m)
Minor	**35**	1.77 ± 0.07*	3.04 ± 0.10	52.80 ± 6.30†‡		2.26 ± 0.19
u21	**15**	1.84 ± 0.10	3.13 ± 0.16[t]	43.46 ± 6.35	36.94 ± 5.42	
Senior	**20**	1.79 ± 0.06	3.03 ± 0.09	47.48 ± 4.90	40.51 ± 5.47	

*p<0.05 versus u21, [t] p<0.05 versus Senior, †p<0.01 versus u21, ‡p<0.01 versus Senior

♦some players did not participate in all testing due to testing on different days and due to injury and availability

One way ANOVA was conducted for all the variables across the groups of the players and the results revealed there was a significant difference in both 10m ($F_{(2,53)}$ = 3.553, p= 0.036) and 20m ($F_{(2,53)}$ = 3.408, p= 0.041) across the 3 age groups Tukey HSD revealed that the significant difference in 10m sprint times (p=0.027) existed between the minor and u21 age group while the difference in 20m sprint times (p=0.045) existed between the u21 and senior age group.

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One way ANOVA conducted on the CMJ height also revealed there was a significant difference in CMJ height across the 3 age groups ($F_{(2,60)}$ = 13.110, p<0.001) which was shown to exist between the minor and u21 age group (p<0.01) as well as between the minor and senior group (p<0.009) following the application of Tukey HSD to the data. One way ANOVA revealed that there was no significant difference in squat jump height across the 2 age groups ($F_{(1,35)}$ = 3.904, p=0.056).

From Table 4.2, it is evident that the minors had the fastest 10m time(1.77s), slightly faster than the seniors (1.79s)and significantly greater than the u21s (1.84s) (p<0.05).It is clear that the seniors had the fastest 20m (3.03s), slightly faster than the u18s (3.04s) and significantly faster than the u21s (3.13) (p<0.05).

Results show that the minors achieved greater CMJ height than both the u21s and seniors. Statistical significance between the (a) minor and u21s and (b) minor and seniors was p<0.01. There was no significance between u21s and seniors for CMJ height. Seniors had a greater squat jump height than the u21s as is evident from Table 4.2. However, no statistical significant existed.

4.3. Correlations Statistics

The correlation analysis results between the speed and power variables are presented in Table 4.3. A Pearson's correlation coefficient (r) was calculated to measure the relationship between the variables.

Table 4.3 Correlations between variables

	10m	20m	CMJ	SJ	SBJ
10m	1	0.936**	0.698**	-0.575**	-0.344
20m	0.936**	1	-0.69**	-0.662**	-0.387

**p<0.001

The x,y scatterplot and best fit line are displayed for each relationship in Fig 4.1.

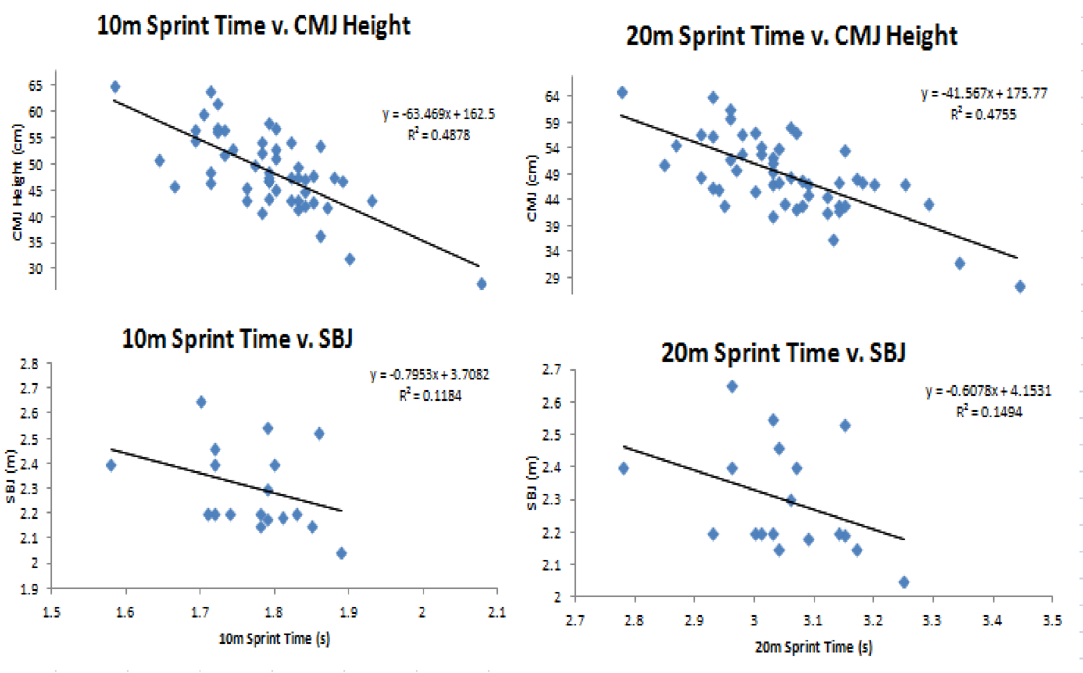

Figure 4.1 Relationship between sprint times and power variables (CMJ and SJ)

The strongest negative correlations were found between both 10m sprint time and CMJ (r= - 0.698) and 20m sprint time and CMJ (r= -0.69). Strong negative correlations were also found between 10m sprint time and SJ (r= -0.575) as well as 20m sprint time and SJ (r = -0.662). Moderate negative correlations were found between 10m sprint time and SBJ (r= -.344) and 20m sprint time and SBJ (r= -387). However, these correlations were non-significant (p=0.162, p=0.113 respectively).

5. DISCUSSION

5.1. 10m and 20m Sprint Times

10m sprint times for minors (1.77 ± 0.07s) were significantly faster than u21s (1.84 ± 0.10s)(p<0.05). There was no significant difference between the minors and seniors (1.79 ± 0.06s) or the u21s and seniors. 20m sprint times for seniors (3.03 ± 0.09s) were significantly faster than u21s (3.13 ± 0.16s). There was no significant difference between u18s (3.04 ± 0.10s) and seniors or u18s and u21s.

Marchant and Austin 1996 reported similar findings in AFL where there was no significant difference between elite senior and u18 players in sprint times. This shows that 18 year olds can achieve similar sprinting performance levels of that of a senior player. This may be due to the 18 year olds reaching the end of physical maturation which occurs during adolescence.

Limb lengths, strength/power and technique and training and body composition can all impact sprinting performance (Brechue *et al* 2010). Longer limbs are associated with greater sprint times (Anderson *et al* 1991; Abe *et al* 1999). Height (and thus limb length) is not a contributing factor as all players are of similar height with mean values (SD) ranging from 1.81(0.07) to 1.82(0.04).

Strength/power levels may be contributing factors to the differences between groups. As the minors and seniors had undertaken several weeks of pre-season training (involving primarily strength training and in recent weeks plyometric/power training) , strength and power levels (and consequently concentric abilities required for initial acceleration (0-10m) as well as SSC function for speed) would be expected to be greater for minors and seniors (Ingebrigsten and Jeffreys 2012) in comparison to the u21s who had just finished off-season. Therefore, the difference in strength and power levels may explain the unexpected trend in sprint times. It may be expected that seniors would have faster times than the other two groups due to greater strength/power levels (and therefore greater force production) as a result of greater experience and years of resistance and power training (Fleck and Kraemer 2014). it is clear from Table 4.1 that seniors have a greater body mass (83.0 ± 4.85kg) than both u21s (80.47 ± 4.85kg) and minors (76.9 ± 6.84kg) and this additional mass (due to greater amounts of body fat or muscle mass or a combination or both) requires greater energy to move which may help explain the unexpected findings (Kang 2008). This would suggest that u21s should have similar times to both seniors and minors. However, due to current training status, they may have greater body fat (as opposed to muscles mass which assists in force generation) than the other two groups which is not beneficial for sprinting and requires the use of energy to transport. However, body composition cannot be assumed based on body mass scores.

10- and 20m sprint times for the minors and seniors were similar to those reported by Collins *et al* 2007 for the Wexford (1.75 + 0.03s; 3.02 ± 0.07s) and Dublin (1.77 + 0.04s; 3.03 ± 0.07s) senior inter-county squads who competed in the Liam McCarthy Cup that year. Testing was carried out during the championship period at which players are expected to be at their fastest. This must be taken into account when considering the testing was carried out pre-season in this study. Similar sprint times were found for senior inter- county Division 2 hurling team (10m: 1.78 + 0.08s) (Doran *et al* 2003) and competitive hurlers during pre-season (March) (1.78 + 0.04; 3.03 ± 0.06s) (Collins *et al* 2012c). These results of Collins *et al* 2012c are most comparable to those in this study as testing was undertaken at the same stage of the competitive year. Therefore the elite competitive hurlers tested by Collin et al 2012c would have been at similar stages in their training compared with the hurlers in this study (i.e. end of pre-season).

10m sprint times of the seniors and minors were similar to that of the starters in a club AFL team (1.73 ± 0.06s) (Young *et al* 2004). AFL is a sport requiring high levels of speed and time motion analysis has revealed that the game is getting faster (Gray and Jenkins 2010). AFL is a professional sports compared to hurling which is amateur. AFL players have greater training opportunities and so are likely to have greater muscle mass which would allows greater force development and thus faster sprint times.

While National Rugby League (1.77 ± 0.09s) (Gabbett 2013) reported similar 10m times to the minor and senior hurlers, the hurlers had faster times than those reported for u21 level soccer for both 10- and 20m (1.92 ± 0.06; 3.22 ± 0.09s) (Lopez-Segovia *et al* 2010), pre-season rugby league (1.83 ± 0.04s; 3.12 ± 0.06s) (Gabbett *et al* 2005) and Youth (mean age 19.0) rugby league (1.81 ± 0.1s)(Gabbett 2013). Rugby League is a high collision sport, with long periods of low activity interspersed with high intensity sprints/bursts. Sprints occur around crucial moments in rugby league games (Gabbett 2002). However, as the match is 80 minutes (Gabbett 2002) as opposed to 60/70 minutes of an inter-county hurling match, more emphasis in training may be on aerobic fitness in rugby league and this may affect sprinting performance due to the greater expression of type I muscle fibres (Thayer *et al* 2000) and the counteraction of the stimulus response achieved through resistance training (Putman *et al* 2004). The amount of time spent undertaking low intensity activity in comparison to high intensity activity in both soccer and rugby also strengthen this possibility. From GPS studies, it is found that in rugby league 5950m (±1845m) out of 6276m(±1950m) are spent at low intensity with only 4± 4 sprints throughout a match. Similarly, in soccer (a 90minute game) 9757(±859m) out of a total of 10274m(±946m) are covered at low intensity with 7 ± 5 sprints occurring (Varley 2013). This is also supported by a superior aerobic capacity of soccer players in comparison to hurlers (McIntyre 2005).

Minors and seniors were slightly slower over 20m than those reported by Rebelo *et al* 2010 for Professional Soccer League in South Africa (3.01 ± 0.8s). This may be due to the better technique, greater resistance and power training carried out by the professional soccer team (additional training hours) as opposed to the amateur hurling teams. The time of competitive season in which testing took place may also contribute to these findings.

All age groups in this study achieved faster times than u18 Gaelic Footballers (3.22 ± 0.15s) (Cullen et al 2013). The quality of players tested may also contribute to the difference as the football players were secondary school players in comparison to elite inter-county players. Also, the athletes in the study by Cullen *et al* 2013 were smaller (178.11 ± 6.27cm) and lighter (72.09 ± 8.68kg). The findings by Abe *et al* 1999 which demonstrated taller athletes with longer limbs have greater sprinting performance may apply in this case. Also, the u18 Gaelic footballers' lower body weights may indicate lower muscle mass compared to the u21s (and thus reduced force generating abilities).

5.2. Countermovement Jump and Squat Jump

CMJ heights achieved by the minors (52.80 ± 6.30cm) were significantly greater ($p<0.01$) than both u21s (43.46 ± 6.35cm) and seniors (47.48 ± 4.90cm). No statistical significance existed between the groups for squat jump height. However, seniors did exhibit a greater SJ height (40.51 ± 5.47cm) than their u21 counterparts (36.94 ± 5.42cm).

Several weeks of pre-season training carried out by the minors in comparison to no resistance training by the u21s may be the underlying reason for this significant difference. Increased strength and power levels (and thus improved SSC and ability to produce force) which are expected for both minors and seniors resulted in greater CMJ height (Tricoli *et al* 2005) in comparison to the u21s. Additional body mass of the u21s and seniors (see Table 1) in comparison to the minors may also have affected CMJ height as the heavier athletes have additional mass to move against gravity (Kang 2008). Although the seniors had greater body mass than the u21s, they produced greater CMJ heights than their counterparts as a result of expected greater power levels due to resistance training (Fleck and Kraemer 2014). The improvements in strength and power allows better rate of force development during the CMJ (Hoffman 2014). Another factor that may contribute to the greater CMJ in comparison to the seniors is the direct supervision provided for resistance training session for the minors. Direct supervision has been shown to result in greater increases in performance (Coutts *et al* 2004). Also, with supervision technique can be monitored and trained more effectively which may have been the case for the hurlers in this study.

The senior CMJ scores were similar to the Wexford (47.14 ± 3.24cm) and Dublin (47.29 ± 6.29cm) senior teams reported by Collins et al 2007. CMJ height was greater than that of 23 competitive hurlers tested pre-season (45.7 ± 6.3cm) *(Collins et al 2012)* and much greater than that of a Division 2 inter-county team tested by Doran *et al* 2003 (40.8 ± 4.5cm). This is not surprising as the physical fitness levels of Division 1 hurlers, as the level of performance would suggest, is expected to be of a higher standard than that of Division 2 hurlers.

The u21s obtained similar CMJ scores to those playing Gaelic football (43.32 ± 5.08cm) (Cullen *et al* 2013). Gaelic football is a sport which involves high catching of the ball and thus jumping is vital (Reilly and Collins 2008). However, senior hurlers achieved greater heights compared to the Gaelic footballers. This may be due to the resistance training carried out by the seniors during the pre-season. It is unknown what amount of resistance and/or power training the Gaelic footballers in this study had carried out. Also, the players tested by Cullen *et al* 2013 were post-primary school players (competing at 'A' level) who were two weeks post championship knockout. The ability of the players as well as the fact that these teams were eliminated from competition may have influenced the testing as motivation, training and nutritional levels may have varied from those players in-season. Minors obtained greater CMJ height than all of the above mentioned sports which may have been influenced by the relatively lighter mass as well as the resistance and possibly greater power/jumping training which would increase the SSC function already undertaken by this team as their championship occurs two months prior to the seniors. No previous SJ data has been reported with regard to GAA (hurling and football).

In comparison to other intermittent field sports, all age group scores were greater than Division 1 French Soccer (41.56 ± 4.18cm) (Cometti *et al* 2001). Cometti *et al* 2001 tested CMJ using a Bosco jump mat and a two minute resting period (an additional minute compared with this study) was given between three trial jumps, of which the best was recorded. According to Reilly and Thomas 1976, soccer players only jump 15.5 times on average during a soccer game and therefore, it is not a primary component of the game. In hurling, players are required to jump to contest high balls frequently from passes, frees and puck outs. The minors achieved a greater CMJ than fifteen elite AFL players (48.8cm) (Cormack *et al* 2008) measured using a portable force plate. AFL players performed one trial following three submaximal trials (Cormack *et al* 2008). The lower AFL CMJ scores in comparison to the minor hurlers is surprising due to the large demand on high fielding and jumping in the game of AFL (Tanner and Gore 2013) as well as greater training opportunities due to their professional status. However, the AFL had greater CMJ (48.8cm) than the u21s and seniors which is expected as although hurlers must jump frequently and while high catching is an important skill, aerial possession is often contested with the hurl (Reilly and Collins 2001) as this allows the player an extended reach to contact the ball i.e. bat or simply try to stop the ball. The greater CMJ achieved by the minors in comparison to the AFL players may be due to their lower body mass and perhaps specific training of this exercise. It seems from the literature that VJ is a more common power test used for AFL players as this simulates match jumping and therefore, the AFL players would be more accustomed to the VJ as opposed to the CMJ. With respect to SJ height, seniors were greater than u21 soccer players (38.34 ± 4.44cm) (Lopez-Segovia *et al* 2011) while the u21s were lower. These differences may have occurred due to subject lack of resistance training by the u21s.

5.3. Standing Broad Jump

SBJ was tested for the minor players as a measure of horizontal power. SBJ scores for the minors (2.26m) were much lower than that reported in previous hurling studies by Collins *et al* 2012 on competitive hurlers (2.40 ± 0.2m), and senior inter-county teams (2.47 ± 0.15m; 2.54 ± 0.20m respectively)(Collins *et al* 2007). This may be due to inexperience at performing the standing broad jump as well as errors that may occur in technique due to this inexperience and competency which may affect SBJ scores. The senior teams in this study may have performed more power training than the minors in this study. Also, the power training undertaken by the seniors in these studies may have involved more plyometrics and especially more specific horizontal power training exercises in comparison to the minors.

Nonetheless, minors scores (2.26 ± 0.19m) were greater than those of Gaelic Footballers (198.2 ± 20.7m) (Cullen *et al* 2013). The mean age of the players in this study was 16.96 years and so it is quite possible that the SBJ during testing was the first time they completed it. Therefore, lower scores attained by the footballers may be due to inexperience of performing the test as well as having shorter limbs (shorter in height), lower muscle mass and playing at a lower standard of competition. The time of competitive season and playing level may have influenced results .The SBJ of NFL players (252.2 ± 22.9m) (Brechue *et al* 2010) were much greater than the minors. This may be due to experience, technical proficiency as well as greater power abilities as NFL is a professional sport requiring high levels of speed and power and additional training time due to the professionalism of the sport.

5.4. Relationship between Speed and Power

The relationship between sprint and power measures was analysed using Pearson correlations. The coefficient of determination (r^2) and common variance (r^2 x 100) (Thomas and Nelson 1990) were also calculated. A common variance of less than 50% has been suggested to indicate that the variables in question may be significantly affected by other factors (Chaouachi et al 2009) or hold unique characteristics (Thomas and Nelson 1990). The following Pearson's r correlation classifications were used.

Table 5.1 Pearson correlation classification (Connolly 2007)

r	Correlation
0-0.3	Weak
0.3-0.6	Moderate
> 0.6	Strong

Firstly, there was a strong significant correlation (r=0.936, p<0.01) between 10m and 20m sprint times with a common variance of 87.6%. This is similar to that found by Young *et al* 2008 (r=0.94) in AFL players. These findings show that similar speed attributes are needed for both 10m and 20m which are related to acceleration (Young *et al* 2008). This shows that 10m speed is vital for and influences 20m speed. Therefore, by improving one's 10m sprint time, 20m sprint time may also increase which is important when devising an acceleration/speed program.

There were significantly strong correlations between 10m and CMJ (r=-0.698), 10m and SJ (r=-0.575), 20m and CMJ (r=-0.69) as well as 20m and SJ (r=-0.662) as is evident in Table 5.1, with common variances of 48.7%, 33.1%, 47.6% and 43.8% respectively. It appears from Table 5.1 and common variances that CMJ is a better predictor of sprinting performance over both 10m and 20m for the hurlers. Cronin and Hansen 2005 found quite similar significant results (r=-0.62) between 10m and CMJ with a common variance of 38.4%. Young 2011 also found a significant relationship between CMJ and 10m (r=-0.43). However, it was a moderate correlation in comparison to the strong correlation for the hurlers in this study. In contrast to our findings, Lopez-Segovia *et al* (2011) found no significant correlation between 10m and CMJ height. However,a significant moderate correlation was found between 20m sprint times and CMJ (r= -0.54). Young *et al* (1996) found similar correlations for 20m and CMJ in 18 football players (r=-0.66), while Hori et al 2008 reported an almost identical correlation between 20m and CMJ in semi professional AFL players (r=-0.69) (p<0.01). A strong significant relationship was also found in rugby league players between sprinting speed and CMJ (Baker and Nance 1999; Atkins 2004).

There was also a strong relationship between sprint times and SJ. Squat jump, however, doesn't make use of the stretch-shortening cycle which is used during sprinting (Amussen and Bonde-Peterson 1974). Rather, it measures concentric contraction abilities only (Ingebrigsten and Jeffreys 2012). Therefore, if only one test of power was to be used, the CMJ would be a better option for its specificity to the movements involved in hurling and sprinting. There was no significant relationship between sprint times and SBJ. In contrast to this, Cullen et al 2013 found that SBJ was significantly correlated with 20m (r=-0.456, p<0.01). However, their correlation was moderate with a common variance of only 20.7%. The findings of the current study are similar to that found by Bissas and Havenetidis 2008. It is suggested the lack of correlation between SBJ and sprint times is due to the fact that the ankles and hips are the primary joints that contribute to jump length, with knee muscles only contributing 3-9% during propulsion (Robertson and Fleming 1987). Taking the above relationships into account, it is important to note with correlation analysis that correlation does not mean causation and any relationships should be considered with this consideration in mind.

From the results, it is minors and seniors had the fastest sprint times. This is expected to transfer to playing performance on the field where acceleration is imperative in getting away from an opponent when in possession of the sliotar in order to pass or score, when chasing an opponent, making opportune runs to support a team mate and to get to the ball first before opponents. Therefore, results in the sprint tests are a very important indicator of performance.

It is also clear that the minors are more powerful, as indicated by the CMJ followed by the seniors and then u21s. This means that the minor athletes will be have a greater ability to jump to catch a high ball, compete for aerial possession as well as during physical exchanges e.g. breaking tackles, than their senior and u21s counterparts. This call also be said for the seniors with respect to the u21s, as seniors are shown to be more powerful than the u21s in both CMJ and SJ. The strong relationship between speed and power show that power is strongly associated with speed. Therefore, the more powerful a player is, the faster he is likely to be. However, other characteristics also contribute to speed (as is indicated by the correlation values).

5.5. Limitations

There are several limitations to this study.

First of all, testing was not carried out at exactly the same time of the competitive season for the three teams, with minors and seniors being tested near the end of pre-season and the u21s tested at the end of their off-season/beginning of pre-season. The possible implications of this have been discussed above.

Lower body power has been shown to have a strong relationship with sprinting in this study. However, the tests of power used in this study were primarily in the vertical direction (CMJ and SJ) and are acyclic in nature. SBJ, which is a measure of horizontal power, was only measured in the minor age group. Due to the fact that sprinting is a cyclic horizontal movement, perhaps a horizontal power test should be used for all teams to further assess lower body power. A unilateral test would also be more sport specific.

The players involved in this study were panel members of one u18,u21 or senior inter-county hurling team. The senior team had great success the previous year in the provincial championship as well as reaching the latter stages of the All-Ireland Championship series. While the u21 team was not successful in the provincial championship, the minor team had similar success to their senior counterparts. Based on these results, these players are participating at the highest level. Obviously due to the nature of the age, it is likely that there were numerous changes in personnel to the teams. A larger sample size, including players from the other high quality hurling teams in Ireland would give a better representation of the physiological requirements for hurling at the top level.

The number of players that performed each test varied due to availability and/or injury as testing took place on different days. Ideally, all players should perform all the tests and on the same day to prevent differences due to nutrition, fatigue, motivation and timing of testing.

Testing took place indoor in a sports hall and players wore runners. As matches take place on grass pitches and players wear football boots, testing outside wearing boots (with weather permitting) should be carried out.

5.6. Practical Applications

This is the first study to provide normative data on the sprint and power abilities of elite level u18, u21 hurlers and to compare them with senior players. These scores can act as a benchmark for all other inter-county hurling teams of this level. It will allow coaches to compare their athletes with those in this study and help set performance goals.

The data obtained in these pre-season tests will also aid the sport scientists and strength and conditioning coaches involved with these teams develop specific training programs to improve speed and power as the competitive season approaches.

The positive relationship found between sprint times and power support similar findings in the literature, illustrating the more powerful athletes are those that are the fastest. Therefore, the strong relationships highlight the importance of power training to improve speed. Greater CMJ height and SJ height have an association with 10- and 20m sprint times. Therefore, CMJ and SJ should be incorporated into training as improvements in these are expected to have a positive effect on sprint times.

5.7. Future Research

As a result of the next phase of training, sprint and power scores as well as on-field performance is expected to improve and therefore, further sprint and power testing should be carried out throughout the season to allow a database of sprint and power norms to be formulated for inter-county hurlers to aid coaches as well as to monitor success and adherence of the training programs implemented. These results will also help the S&C coaches involved with the current teams to develop specific training programs to develop the players and enhance on-field performance.

Hurling is a sport that involves agility and ball skills and therefore further research should be carried out testing these variables between the age groups as well as testing speed incorporating the ball (e.g. sprinting while soloing, sprinting involving a jab lift etc.) along with the speed and power measures.

Many sprints that occur in matches occur following a period of walking, jogging or striding (Young 2008). Therefore, an assessment of maximum speed achieved following these starting situations should be analysed. This may be achieved through the use of GPS and time-motion analysis.

Testing should be carried on a greater number of elite players from different counties throughout the county. Testing should be carried out on a single day per team, on a grass pitch and at teams should be undertaking identical phases of training at the time of testing. The inclusion of unilateral power testing should also be considered to replicate match like movements.

The use of GPS in hurling which is ever increasing will allow further study to be carried out into the physiological demands of the sport of hurling from underage level to senior level during matches which will allow the creation of more specific strength and conditioning training programs as well as field based sessions (as well as on field monitoring of players to allow substitutions to be made and to aid in the prevention of injuries).

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